Lower Colorado River Multi-Species Conservation Program

Balancing Resource Use and Conservation

Feasibility Study Using Native Seeds in Restoration, California-Arizona-Nevada – 2007 Annual Report

U.S. DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

April 2008

Lower Colorado River Multi-Species Conservation Program Steering Committee Members

Federal Participant Group

Bureau of Reclamation
U.S. Fish and Wildlife Service
National Park Service
Bureau of Land Management
Bureau of Indian Affairs
Western Area Power Administration

Arizona Participant Group

Arizona Department of Water Resources
Arizona Electric Power Cooperative, Inc.
Arizona Game and Fish Department
Arizona Power Authority
Central Arizona Water Conservation District
Cibola Valley Irrigation and Drainage District
City of Bullhead City
City of Lake Havasu City
City of Mesa
City of Somerton
City of Yuma
Electrical District No. 3, Pinal County, Arizona
Golden Shores Water Conservation District
Mohave County Water Authority
Mohave Valley Irrigation and Drainage District
Mohave Water Conservation District
North Gila Valley Irrigation and Drainage District
Town of Fredonia
Town of Thatcher
Town of Wickenburg
Salt River Project Agricultural Improvement and Power District
Unit "B" Irrigation and Drainage District
Wellton-Mohawk Irrigation and Drainage District
Yuma County Water Users' Association
Yuma Irrigation District
Yuma Mesa Irrigation and Drainage District

Other Interested Parties Participant Group

QuadState County Government Coalition
Desert Wildlife Unlimited

California Participant Group

California Department of Fish and Game
City of Needles
Coachella Valley Water District
Colorado River Board of California
Bard Water District
Imperial Irrigation District
Los Angeles Department of Water and Power
Palo Verde Irrigation District
San Diego County Water Authority
Southern California Edison Company
Southern California Public Power Authority
The Metropolitan Water District of Southern California

Nevada Participant Group

Colorado River Commission of Nevada
Nevada Department of Wildlife
Southern Nevada Water Authority
Colorado River Commission Power Users
Basic Water Company

Native American Participant Group

Hualapai Tribe
Colorado River Indian Tribes
The Cocopah Indian Tribe

Conservation Participant Group

Ducks Unlimited
Lower Colorado River RC&D Area, Inc.

Lower Colorado River
Multi-Species Conservation Program

Feasibility Study Using Native Seeds in Restoration, California-Arizona-Nevada – 2007 Annual Report

Prepared by:

GeoSystems Analysis, Inc.
2015 N. Forbes Blvd, Suite 105
Tucson, Arizona 85745

Lower Colorado River
Multi-Species Conservation Program
Bureau of Reclamation
Lower Colorado Region
Boulder City, Nevada

http://www.lcrmscp.gov

April 2008

TABLE OF CONTENTS

TABLES iii
FIGURES iv
APPENDICES vii
EXECUTIVE SUMMARY 8
1.0 INTRODUCTION 12
2.0 TASK 1: LCR SEED AVAILABILITY AND SALICACEAE GERMINATION STUDY 14
2.1 Technical Approach 14
2.1.1 Seed Availability and Collection Techniques 14
2.1.2 Seed Treatment and Storage Trials 16
2.1.3 Baccharis spp. Salinity Trials 17
2.1.4 Data Analysis 17
2.2 Seed Availability and Germination Study Results 18
2.2.1 Seed Availability and Seed Collection 18
2.2.2 Storage Trials for Salicaceae Species 22
3.0 TASKS 2, 3, AND 4: SMALL-SCALE GREENHOUSE POT STUDIES 24
3.1 Technical Approach 24
3.1.1 Riparian Year-old Seed 7-Gallon Pot Trials 25
3.1.2 Mesquite Bosque 7-Gallon Pot Trials 26
3.1.3 Emory's Baccharis and Sweetscent Trials 27
3.1.4 Soil Collection and Pot Preparation 29
3.1.5 Greenhouse Layout and Irrigation 30
3.1.6 Bermudagrass Control 30
3.1.7 Vegetation Data Collection and Analysis 31
3.2 Greenhouse Study Results 32
3.2.1 Riparian Year-old 7-Gallon Pots 33
3.2.2 Mesquite Bosque 7-Gallon Pots 33
3.2.3 Emory's baccharis and Sweetscent 7-Gallon Pots 35
3.2.3.1 Cleaned Emory's Baccharis 35
3.2.3.2 Un-cleaned Emory's Baccharis and Sweetscent 35
4.0 TASK 5: SMALL-SCALE FIELD STUDIES AT CIBOLA NATIONAL WILDLIFE REFUGE 37
4.1 Technical Approach 37
4.1.1 Small-scale Field Study Variables 37
4.1.2 Site Characterization 39
4.1.3 Plot Design and Implementation 41
4.1.4 Seed Collection, Preparation and Application 42
4.1.5 Vegetation Monitoring 44
4.2 Small-scale Field Study Results 46
4.2.1 Early-time (germination period) Sprinkler Irrigation Treatment Effects 46
4.2.2 Seed Cleaning and Application Method (Seed Treatment) 47
4.2.3 Surface Irrigation Method 48
4.2.4 Plot Position 48
4.2.5 Seeding Rate 48
4.2.6 Small-scale Field Study Vegetation Summary 49

4.2.7 2007 Site Characterization Data 49
5.0 CONCLUSIONS 53
6.0 RECOMMENDATIONS 56
7.0 ACKNOWLEDGMENTS 57
8.0 REFERENCES 58
TABLES 59
FIGURES 80

TABLES

Table 1. Seed storage treatments for Fremont cottonwood, Goodding's willow, and coyote willow germination trials. 60
Table 2. Seed source information for Fremont cottonwood, Goodding's willow, and coyote willow germination trials. 60
Table 3. Schedule for Fremont cottonwood, Goodding's willow, and coyote willow germination trials..... 61
Table 4. Seed collection sites utilized during calendar year 2007. 61
Table 5. Summer 2007 riparian species cohort 7-gallon pot study specifications..... 64
Table 6. Summer 2007 mesquite bosque species cohort 7-gallon pot study specifications. 64
Table 7. Summer 2007 Emory's baccharis 7-gallon pot study specifications. 65
Table 8. Summer 2007 un-cleaned Emory's baccharis and sweetscent cohort 7-gallon pot study specifications..... 66
Table 9. Irrigation schedule for 2007 7-gallon pot studies. 66
Table 10. ANOVA linear modeling results for riparian tree cohort 7-gallon pot study mid-season canopy cover data. 67
Table 11. ANOVA linear modeling results for riparian tree cohort 7-gallon pot study results (end-of-season data)..... 68
Table 12. ANOVA linear modeling results for mesquite bosque cohort 7-gallon pot study mid-season canopy cover data..... 69
Table 13. ANOVA linear modeling results for mesquite bosque cohort 7-gallon pot study results (end-of-season data)..... 70
Table 14. ANOVA linear modeling results for Emory's baccharis 7-gallon pot study results (mid-season crown cover and end-of-season harvest data). 71
Table 15. ANOVA linear modeling results for Emory's baccharis and sweetscent cohort 7-gallon pot study results (mid-season crown cover and end-of-season harvest data) 72
Table 16. Non-seeded species observed and relative abundance in 7-gallon pot studies..... 73
Table 17. Summer 2007 riparian cohort small-scale field study specifications. 74
Table 18. Seed weight calibrations obtained for riparian cohort small-scale field studies..... 74
Table 19. Non-target species observed in riparian cohort small-scale field study plots..... 75
Table 20. Sociologic relevé classifications used for small-scale test plot study quadrat estimation of cover. 75
Table 21. ANOVA linear modeling results for target riparian species in the small-scale field study (Task 5). 76
Table 22. ANOVA linear modeling results for non-target riparian species in the small-scale test plot study (Task 5). 77
Table 23. Irrigation schedule and applied water (AW) for first three weeks of irrigation. 78
Table 24. Surface irrigation schedule for June 7, 2007 through October 12, 2007. 79

FIGURES

Figure 1. Incubator viability for frozen Fremont cottonwood seed germination trials. Yellow or green data symbols indicate “supplemental seed” analysis. 81
Figure 2. Incubator viability for frozen Goodding’s willow seed germination trials. Yellow or green data symbols indicate “supplemental seed” analysis. 81
Figure 3. Incubator viability for frozen coyote willow seed germination trials. Yellow or green data symbols indicate “supplemental seed” analysis. 82
Figure 4. Soil germination rates for cleaned versus un-cleaned Fremont cottonwood seed (frozen, ambient oxygen) germination trials. Yellow or green data symbols indicate “supplemental seed” analysis. 82
Figure 5. Soil germination rates for ambient versus oxygen-removal treatment for Fremont cottonwood seed (frozen, cleaned) germination trials. Green data symbols indicate “supplemental seed” analysis. 83
Figure 6. Soil germination rates for cleaned versus un-cleaned Goodding's willow seed (frozen, ambient oxygen) germination trials. Yellow or green data symbols indicate “supplemental seed” analysis. 83
Figure 7. Soil germination rates for ambient versus oxygen-removal treatment for Goodding's willow seed (frozen, cleaned) germination trials. Green data symbols indicate “supplemental seed” analysis. 84
Figure 8. Soil germination rates for cleaned versus un-cleaned coyote willow seed (frozen, ambient oxygen) germination trials. Yellow or green data symbols indicate “supplemental seed” analysis. 84
Figure 9. Soil germination rates for ambient versus oxygen-removal treatment for coyote willow seed (frozen, cleaned) germination trials. Green data symbols indicate “supplemental seed” analysis. 85
Figure 10. Greenhouse layout for 2007 small-scale greenhouse Task 2-Task 4 studies. 86
Figure 11. Average crown cover of Fremont cottonwood (POFR), Goodding’s willow (SAGO), and coyote willow (SAEX) vs. seed cleaning, Biosol® addition, and storage duration in year-old seed 7-gallon pot trials. 87
Figure 12. Average stem count of Fremont cottonwood (POFR), Goodding’s willow (SAGO), and coyote willow (SAEX) vs. seed cleaning, Biosol® addition, and storage duration in year-old seed 7-gallon pot trials. 87
Figure 13. Average above-ground dry biomass of Fremont cottonwood (POFR), Goodding’s willow (SAGO), and coyote willow (SAEX) vs. seed cleaning, Biosol® addition, and storage duration in year-old seed 7-gallon pot trials. 88
Figure 14. Average maximum height of Fremont cottonwood (POFR), Goodding’s willow (SAGO), and coyote willow (SAEX) vs. seed cleaning, Biosol® addition, and storage duration in year-old seed 7-gallon pot trials. 88
Figure 15. Average stem count of screwbean mesquite (PRPU), honey mesquite (PRGL), and quailbush (ATLE) vs. soil type and seeding rate in 7-gallon pot trials. 89
Figure 16. . Average above-ground dry biomass of screwbean mesquite (PRPU), honey mesquite (PRGL), and quailbush (ATLE) vs. soil type and seeding rate in 7-gallon pot trials. .. 89
Figure 17. Average maximum height of screwbean mesquite (PRPU), honey mesquite (PRGL), and quailbush (ATLE) vs. soil type and seeding rate in 7-gallon pot trials. 90
Figure 18. Average crown cover of screwbean mesquite (PRPU), honey mesquite (PRGL), and quailbush (ATLE) vs. soil type and seeding rate in 7-gallon pot trials. 90

Figure 19. Average crown cover of Emory's baccharis (BAEM) vs. soil type and seeding rate in 7-gallon pot trials. 91
Figure 20. Average stem count of Emory's baccharis (BAEM) vs. soil type and seeding rate in 7-gallon pot trials. 91
Figure 21. Average above-ground dry biomass of Emory's baccharis (BAEM) vs. soil type and seeding rate in 7-gallon pot trials. 92
Figure 22. Average maximum height of Emory's baccharis (BAEM) vs. soil type and seeding rate in 7-gallon pot trials. 92
Figure 23. Average stem count of Emory's baccharis (BAEM) and sweetscent (PLOD) vs. soil type and seeding rate in 7-gallon pot trials. 93
Figure 24. Average maximum plant height of Emory's baccharis (BAEM) and sweetscent (PLOD) vs. soil type and seeding rate in 7-gallon pot trials. 93
Figure 25. Average above-ground dry biomass of Emory's baccharis (BAEM) and sweetscent (PLOD) vs. soil type and seeding rate in 7-gallon pot trials. 94
Figure 26. Average crown cover of Emory's baccharis (BAEM) and sweetscent (PLOD) vs. soil type and seeding rate in 7-gallon pot trials. 94
Figure 27. Small-scale field study treatment layout on Cibola NWR Field 51. 95
Figure 28. Furrow shaping for small-scale field studies. 96
Figure 29. Furrow and border irrigation plots for small-scale field studies. 96
Figure 30. Instrumentation nest in small-scale study field plot prior to soil backfilling. The red oval encircles an ECH_2O-TE water content, temperature, and salinity sensor at six inches (15 cm) below ground surface, and the blue oval encircles an EC-10 water content sensor at eighteen inches (46 cm) below ground surface. 97
Figure 31. As-built irrigation system for small-scale field studies. 98
Figure 32. Hydroseed application for small-scale field studies. 99
Figure 33. Broadcast seed application for small-scale field studies. 99
Figure 34. Example vegetation survey schematic for small-scale field studies. 100
Figure 35. Canopy cover point-transect for small-scale field studies. 101
Figure 36. Harvested vegetation quadrat for small-scale field studies. 101
Figure 37. Average (per treatment) crown cover of Fremont cottonwood (POFR), saltcedar (TARA), and combined grasses and sedges (Gramineae) in small-scale field studies. 101
Figure 38. Average (per treatment) canopy cover of Fremont cottonwood (POFR), saltcedar (TARA), and combined grasses and sedges (Gramineae) in small-scale field studies. 102
Figure 39. Average (per treatment) biomass of Fremont cottonwood (POFR), saltcedar (TARA), and combined grasses and sedges (Gramineae) in small-scale field studies. 102
Figure 40. Average (per plot) crown cover of Fremont cottonwood (POFR), saltcedar (TARA), and combined grasses and sedges (Gramineae) in small-scale field studies, "No Sprinklers" treatments only. 103
Figure 41. Average (per plot) canopy cover of Fremont cottonwood (POFR), saltcedar (TARA), and combined grasses and sedges (Gramineae) in small-scale field studies, "No Sprinklers" treatments only. 104
Figure 42. Average (per plot) crown cover of Fremont cottonwood (POFR), saltcedar (TARA), and combined grasses and sedges (Gramineae) in small-scale field studies, "Sprinklers" treatments only. 105

Figure 43. Average (per plot) canopy cover of Fremont cottonwood (POFR), saltcedar (TARA), and combined grasses and sedges (Gramineae) in small-scale field studies, "Sprinklers" treatments only. 106
Figure 44. Average (per plot) stem count of Fremont cottonwood (POFR) and saltcedar (TARA) in small-scale field studies, "No Sprinklers" treatments only. 107
Figure 45. Average (per plot) stem count of Fremont cottonwood (POFR) and saltcedar (TARA) in small-scale field studies, "Sprinklers" treatments only. 108
Figure 46. Average (per treatment) stem counts of Fremont cottonwood (POFR) and saltcedar (TARA) in small-scale field studies. 109
Figure 47. Average (per treatment) combined Goodding's and coyote willow (*Salix* spp.) stem count in small-scale field studies. 109
Figure 48. Average (per plot) biomass of Fremont cottonwood (POFR) and saltcedar (TARA) in small-scale field studies, "No Sprinklers" treatments only. 110
Figure 49. Average (per treatment) maximum plant height of Fremont cottonwood (POFR) and saltcedar (TARA) in small-scale field studies. 111
Figure 50. Groundwater elevation date for ten months prior to small-scale field study. The red outline indicates irrigation events for small-scale study pre-planting weed control. 111
Figure 51. Winter groundwater elevation prior to any Field 51 irrigation for small-scale studies, December 15, 2006. 112
Figure 52. Interpolated groundwater elevation following weed control irrigation, but prior to seeding, May 15, 2007. 112
Figure 53. Interpolated groundwater elevation following ten days of small-scale study irrigation, May 27, 2007. 113
Figure 54. Change in groundwater elevation following ten days of irrigation (elevation on May 26, 2007 minus elevation on May 16, 2007). 113
Figure 55. Groundwater elevations and depth to groundwater as affected by irrigation events for one growing season, Field 51 small-scale studies. 114
Figure 56. Soil volumetric water content versus time for small-scale field study plots YCHF 2 and YUHF 2. 114
Figure 57. Soil volumetric water content versus time for small-scale field study plots YCHB 3 and NCBF 2. 115
Figure 58. Soil salinity (EC) and temperature (T) versus time for small-scale field study plots YCHF 1 and YUHF 2. 115

APPENDICES

Appendix A: Datasheets Used During Calendar Year 2007

Appendix B: Detailed Data for Seed Collections Conducted During Calendar Year 2007

Appendix C: Detailed Germination Study Results for All Cottonwood-Willow Seed Preservation Methods

Appendix D: Detailed Data Collected during Greenhouse Pot Studies

Appendix E: Detailed Data Collected for 2007 Small-scale Field Studies

Appendix F: Small-scale Field Study Soil Instrument Data

EXECUTIVE SUMMARY

GeoSystems *Analysis*, Inc., in conjunction with the University of Arizona Office of Arid Lands Studies is conducting a three-year research plan to determine the feasibility of using native seeds for restoration of riparian and transition vegetation the Lower Colorado River (LCR). This feasibility study is funded by the Bureau of Reclamation in support of habitat restoration activities conducted under the LCR Multi-Species Conservation Plan. The tasks associated with this research plan are as follows.

- Task 1 consists of assessing seed collection and preservation feasibility for the riparian cohort species Fremont cottonwood (*Populus fremontii* Watts), Goodding's willow (*Salix gooddingii* Ball), and coyote willow (*S. exigua* Nutt).
- Tasks 2 through 4 consist of small-scale (7-gallon, approximately one square foot) greenhouse pot studies for cohorts of mesquite, riparian, and shrub species, respectively.
- Task 5 consists of a small-scale field study for riparian cohort species at the Cibola National Wildlife Refuge (Cibola NWR) Field 51.
- Task 6 consists of a large-scale field study at Cibola NWR Field 51.

This report presents task activities and results for calendar year 2007 (Year 2) which consisted of the following greenhouse and small-scale studies:

1) Task 1: Continue cottonwood and willow seed storage germination studies for frozen seed treatments to compare seed cleaning versus no cleaning and storage with or without oxygen. Seed viability was tested intermittently via incubator and soil germination studies.

2) Task 2: Conduct greenhouse 7-gallon pot studies to evaluate the following seeding rate and soil condition effects on germination, establishment, and growth of screwbean mesquite (*Prosopis pubescens* Benth.), honey mesquite (*P. glandulosa* Torr.), and quailbush::
   a) Three different soil treatments; loose Field 51 topsoil, Field 51 topsoil with a compacted subsurface layer, sand soil.
   b) Three different seeding rates; 30, 60 and 120 total pure live seed per square foot (10, 20 and 30 seeds per species).

3) Task 3: Conduct greenhouse 7-gallon pot studies to evaluate the following treatment effects on germination, establishment, and growth of Fremont cottonwood, Goodding's willow, and coyote willow:
   a) Year-old vs. freshly-collected seed.
   b) Cleaned vs. un-cleaned seed.
   c) Organic fertilizer addition.

4) Task 4: Conduct greenhouse 7-gallon pot studies to evaluate the following seeding rate and soil condition effects on germination, establishment, and growth of mule's fat (*Baccharis salicifolia* (Ruiz & Pavón) Pers.), Emory's baccharis (*B. emoryi* Gray), and desertbroom (*B. sarothroides* Gray) and sweetscent (*Pluchea odorata* (L.) Cass.):

a) Cleaned vs. un-cleaned seed.
b) Three different soil treatments; loose Field 51 topsoil, Field 51 topsoil with a compacted subsurface layer, sand soil.
c) Three different seeding rates; 4, 20, and 100 pure live seed per square foot of Emory's baccharis; 2, 10 and 50 pure live seed per square foot of sweetscent. Seeding rate mixes were proposed to be 4, 60, and 30 PLS/ft2 each of Emory's baccharis, mule's fat, and desertbroom. Errors in plant identification and unforeseen reductions and seed viability resulted in (1) omission of mule's fat and desertbroom from studies, (2) lower than proposed seeding rates for Emory's baccharis, and (3) addition of sweetscent to un-cleaned baccharis pots.

5) Task 5: Conduct small-scale field studies at Cibola NWR Field 51 to evaluate the following planting technique, seed treatment, and irrigation type effects on germination, establishment, and growth of Fremont cottonwood, Goodding's willow, and coyote willow for one growing season:
   a) Germination period sprinkler irrigation; three weeks of sprinkler irrigation vs. surface irrigation only.
   b) Seed application method; cleaned broadcast seed, cleaned hydroseed, and un-cleaned hydroseed.
   c) Surface irrigation method; furrow versus border (small-scale basin) irrigation.

6) Task 6 continued the site characterization of Field 51 at Cibola NWR to determine variability in various soil characteristics, soil moisture and groundwater elevation monitoring. These additional analyses, instrumentation methods and results are presented in a separate site characterization report.

YEAR 2007 RESULTS

Key findings from Task 1 germination studies include:

- The viability of seed stored at room temperature (21°C) declined rapidly after eight weeks for all three riparian species.
- Freezing treatments resulted in viability greater than 80% for a period of at least 21 months. Germination trials will be continued through April 2009.
- Oxygen removal from seed storage containers did not extend viability of seeds stored at room temperature. The long-term effects of oxygen concentration under freezing conditions are still unknown.
- Removing seed hairs (cleaning) resulted in higher germination rates on soil beds due to enhanced soil contact, but did not affect germination rates in incubators.
- Pore water electrical conductivity (EC) of 5 dS/m (mS/cm) reduced cottonwood and willow germination and survival by approximately 90% from 1 dS/m. There was no survival at EC levels 10 dS/m or greater.
- Pore water salinity trials with upland shrub species were characterized by low germination rates due to overly wet soil conditions.

Key findings from Task 2 mesquite bosque 7-gallon pot greenhouse studies include:

- In general, favorable growth of mesquite was observed,

- Honey mesquite dominated crown cover and biomass.
- Quailbush growth was minimal, likely due to competition from mesquite.
- Soil treatment did not affect plant establishment (stem density), but changed growth rates. The best growth rates were observed in loose Field 51 topsoil, followed by compacted layer Field 51 topsoil with the lowest growth rates in sand.
- Higher seeding rates resulted in higher plant establishment, but biomass only increased for honey mesquite. Crown cover of target species did not increase with higher seeding rates, and individual plant growth rates were decreased at higher seeding rates.

Key findings from Task 3 riparian species pot studies include:

- High establishment and diversity of cottonwood and willow was observed, particularly with cleaned seed at intermediate seeding rates (60 PLS/ft^2).
- High seeding rates reduced establishment and growth of invasive non-seeded species.
- Higher seeding rates favored Fremont cottonwood dominance, decreased Goodding's and coyote willow establishment, and decreased growth rates of all three species.
- Seed cleaning approximately doubled plant establishment and biomass.
- Soil treatment did not affect plant establishment (stem density), but changed growth rates. The best growth rates were observed in loose Field 51 topsoil, followed by compacted layer Field 51 topsoil, and lowest growth rates were in sand.
- Organic fertilizer (Biosol®) increased growth rates in sand, but reduced riparian tree establishment, and did not increase individual plant growth in Field 51 topsoil..
- Experiments with year-old and fresh seed showed:
    - Seed stored in freezers for one year showed establishment and growth of riparian species similar to freshly-collected seed.
    - Overall, seed cleaning approximately doubled combined riparian plant establishment and biomass.
    - Cleaned 2006 (year-old) Goodding's willow seed showed reduced establishment in pots for unknown reasons.

Key findings from Task 4 baccharis and sweetscent pot studies are the following:

- Poor viability was observed for all baccharis species seed after five months of storage at 21°C.
- Baccharis grew slowly relative to riparian and mesquite species.
- Soil treatment resulted in variable plant establishment (stem density) and growth rates. The highest establishment and growth rates were observed in loose Field 51 topsoil, followed by compacted layer Field 51 topsoil. No baccharis or sweetscent established in sand soil.
- Higher seeding rates resulted in increased establishment, and did not decrease per-plant growth through one growing season.

Key findings from Task 5 small-scale field studies are the following:

- Fremont cottonwood establishment on small-scale plots averaged approximately 7% of the seeding rate, or 18 stems per m^2.

- Goodding's and coyote willow establishment on small-scale plots was less than 1% of the seeding rate.
- Non-target species established in abundance. Grass dominated many plots. Saltcedar established an average of 25 stems per m^2, but was generally in the understory (average of 4% crown cover).
- Sprinklers did not affect (increase or decrease) riparian plant establishment. Sprinklers decreased saltcedar establishment.
- Sprinklers decreased growth rates of all non-grass species.
- Un-cleaned hydroseeding increased canopy cover, stem density, and biomass of Fremont cottonwood and Goodding's willow compared to cleaned hydroseeding and cleaned broadcast seeding.
- Furrow irrigation increased cottonwood height and biomass compared to border irrigation. No effects were observed on cottonwood establishment or canopy cover.
- Furrow irrigation increased Goodding's willow establishment, canopy cover, height, and biomass compared to border irrigation.
- Plot position resulted in decreased Fremont cottonwood cover, plant establishment, plant height, and biomass in the north end of Field 51 compared to the middle and southern portions of Field 51. Trends for willow were not significant.
- Increased seeding rates resulted in increased cottonwood and Goodding's willow plant establishment. Coyote willow establishment was unaffected.
- Increased seeding rates did not result in decreased plant height.

1.0 INTRODUCTION

This report documents activities conducted by GeoSystems *Analysis*, Inc. (GSA) and the University of Arizona (The GSA Team) for Contract No. 06CR308057, *Feasibility Study Using Native Seeds in Restoration, California-Arizona-Nevada*, during calendar year 2007. The feasibility study consists of a three-year research program funded 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 such methods is desired given the long-term revegetation goals of the LCR Multi-Species Conservation Program (MSCP), and the current high costs of vegetative propagation. The following plant species are the focus of investigations in order of significance:

1) Riparian Tree Species: Fremont cottonwood (*Populus fremontii* S Wats., POFR), Goodding's willow (*Salix gooddingii* Ball, SAGO), and coyote willow (*S. exigua* Nutt, SAEX).

2) Mesquite Bosque Tree Species: honey mesquite (*Prosopis glandulosa* Torr., PRGL), screwbean mesquite (*P. pubescens* Benth., PRPU), and possibly desert willow (*Chilopsis linearis* (Cav.) Sweet, CHLI).

3) Shrub Species: mule's fat (*Baccharis salicifolia* (Ruiz & Pavón) Pers., BASAL), Emory's baccharis (*B. emoryi* Gray, BAEM), desertbroom (*B. sarothroides* Gray, BASAR) quailbush (*Atriplex lentiformis* (Torr.) S. Wats., ATLE), fourwing saltbush (*A. canescens* (Pursh) Nutt.), cattle saltbush (*A. polycarpa* (Torr.) S. Wats.), wolfberry (*Lycium* spp.), and desert globemallow (*Sphaeralcea ambigua* Gray).

A combination of greenhouse and field-scale studies were designed to be 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 (GSA, 2006a, 2006b, 2007c). Specific tasks and schedules are as follows.

Year 1 (2006) Greenhouse Studies

- Task 1: Conduct germination studies to determine the best methods to collect, process, and store cottonwood and willow seed from the LCR. In addition, conduct studies to evaluate the effect of different levels of soil salinity on riparian seed germination and seedling survival.
- Task 3: Conduct greenhouse 7-gallon pot studies to evaluate seed treatment, seeding rate, and soil condition effects on germination, establishment, and growth of Fremont cottonwood, Goodding's willow, and coyote willow.

- Task 4: Conduct greenhouse 7-gallon pot studies to evaluate seeding method, seeding rate, and soil condition effects on germination, establishment, and growth of various shrub species native to the LCR: quailbush, fourwing saltbush, cattle saltbush, and desert thorn[1].

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

- Task 1: Continue cottonwood and willow seed storage and viability study for frozen seed treatments to determine potential for long term seed storage prior to seeding.
- Task 2: Conduct greenhouse 7-gallon pot studies to evaluate seeding rate and soil condition effects on germination, establishment, and growth of screwbean mesquite, honey mesquite, and quailbush.
- Task 3: Conduct greenhouse 7-gallon pot studies to evaluate one-year of frozen seed storage and organic fertilizer effects on germination, establishment, and growth of Fremont cottonwood, Goodding's willow, and coyote willow.
- Task 4: Conduct greenhouse 7-gallon pot studies to evaluate different seeding rate and soil condition effects on germination, establishment, and growth of mule's fat, Emory's baccharis, and desertbroom.
- Task 5: Conduct 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 Fremont cottonwood, Goodding's willow, and coyote willow for one growing season.
- Task 6: Continue site characterization of Field 51 to incorporate ongoing soil and groundwater data collection. Initiate planning for Year 3 (2008) studies.

Updated results for Task 1 are presented in Section 2. Germination trials are ongoing, and final results will be provided in the 2008 annual report. Final results are presented for greenhouse 7-gallon pot studies Tasks 2, 3 and 4 in Section 2. Task 5 (small-scale field studies) results through one growing season are presented in Section 4. Detailed site characterization work at Field 51 is presented in GSA (2008).

[1]For 2006 studies, desert thorn (*Lycium exsertum* Gray, LYEX) was used for analysis of *Lycium* spp.

2.0 TASK 1: LCR SEED AVAILABILITY AND SALICACEAE GERMINATION STUDY

During 2007, GSA continued the analysis of MSCP vegetation seed availability on the LCR. In addition, germination studies were continued at the University of Arizona NPC. The primary objectives of the 2007 germination studies were as follows:

- Evaluate the effectiveness of frozen seed storage treatments in extending periods of seed viability for riparian tree species: Fremont cottonwood, Goodding's willow, and coyote willow.
- Evaluate the effect of salinity on seed germination and survival of mule's fat, Emory's baccharis, and desertbroom.

Task 1 results were used to guide seed collection timing and seed storage for 2008 field studies. Specifically, cottonwood and willow seed was collected over three months, and stored in freezers after collection. Task 1 results also provide confidence in the feasibility of bulk collection and longer-term freezer storage, and will help in the development of best management practices for seed collection and storage.

2.1 Technical Approach

2.1.1 Seed Availability and Collection Techniques

MSCP target species seed availability was analyzed during 2007 to supplement initial observations in 2006 (GSA 2007a). During 2007, seed was collected from Bill Williams River NWR, the Ahakhav Tribal Preserve, Havasu NWR, and Cibola NWR, for use in study tasks. Fremont cottonwood and Goodding's willow seed was collected March through May. Coyote willow seed was collected in April and May. Mule's fat, desertbroom, and Emory's baccharis seed was collected during December 2006. No saltbush or mesquite seed was collected. Seed collection location detail is provided below for sites utilized during 2007.

Bill Williams River NWR

Seed collections were conducted in two general regions of Bill Williams NWR, herein denoted Bill Williams River NWR West and Bill Williams River NWR at Mineral Wash. Bill Williams River NWR West consists of the Bill Williams River Reach from Lake Havasu upstream to Cohen Ranch. Bill Williams River NWR at Mineral Wash consisted of the Bill Williams River floodplain immediately upstream of the confluence of Mineral Wash and the Bill Williams River. All target plants in the area are assumed native to the area. During 2006, quailbush and baccharis seed was collected at both sites on Bill Williams River. During 2007, Fremont cottonwood and Goodding's willow seed was collected from both sites.

Cibola NWR

Seed collection was conducted at Cibola NWR in three general areas. The Nature Trail area consists of The Nature Trail and vegetation along an adjacent field. The source plants at this location were either planted, or established naturally. The Levee Road area consists of the vegetation along and between levees of the current main channel of the Colorado River. These native plants are the result of passive revegetation following levee construction. The Island Unit consists of areas west of the secondary levee road on the west side of the Colorado River. Native and revegetated plants of target species are present in the area. During 2006, Fremont cottonwood, Goodding's willow, coyote willow, Emory's baccharis, quailbush, honey mesquite, and screwbean mesquite were collected at Cibola NWR for use in Task 2, and potential use in Tasks 5 and 6. Species collected in 2007 for Tasks 4 through 6 were the same as collected in 2006, except that in 2007 quailbush and mesquite species seed were not collected.

The Ahakhav Tribal Preserve

Cottonwood and willow seed collection was conducted throughout the Ahakhav Tribal Preserve during 2006 and 2007. Goodding's willow and Fremont cottonwood trees are abundant through the center of the preserve. Coyote willow is most prevalent on the west and southwest sides of the preserve. The original source of these plants is not well-documented. However, timing of seed production indicates that Fremont cottonwood and Goodding's willow were established from Bill Williams River NWR cuttings.

Havasu NWR

Goodding's and coyote willow seed was collected at the Beal Lake area of Havasu NWR during 2007. Both species were located at the Beal Lake Riparian Restoration Area (Beal Lake), and additional coyote willow was located along the levee road leading to the Beal Lake. Trees in the Beal Lake area are from both potted plants and seed of native LCR trees.

Pratt Restoration Site

Emory's baccharis seed was collected from naturally-established trees at Pratt Restoration Site during 2006. No seed collection was conducted at the site during 2007.

Cibola Valley Conservation Area

Desertbroom, mule's fat, and coyote willow seed was collected from the Cibola Valley Conservation Area (CVCA) nursery during 2007. Because of ongoing research at this area, coyote willow and mule's fat seed was only collected on the extreme east side of the CVCA, and desertbroom seed was only collected at the extreme west end of the CVCA. Coyote willow was established by mass transplanting, and mule's fat and desertbroom were established with rooted stock. The source of these trees is unknown to GSA personnel.

Imperial NWR

GSA planned to collect Fremont cottonwood and willow seed from native trees on the Imperial NWR for this study. However, 2006 analysis indicated poor accessibility of cottonwood, and late maturation for coyote and Goodding's willow (GSA 2007a). Seed collection at the Imperial NWR was not attempted during 2007.

During collection efforts, UTM coordinates and other data (e.g. abundance of collected species, ease of collection, tree size, etc.) for all cottonwood, Goodding's willow, and mesquite individuals used for collection were recorded on datasheets (Appendix A). It was frequently impossible to distinguish between individuals of the species because of vegetative propagation and/or high density of plants. When this situation occurred, at least one UTM coordinate was taken using a handheld GPS unit (GPSMAP® 60CS, Garmin International, Inc., Olathe, KS) at each general collection site, and a site description was recorded on the seed collection datasheets. Clinometer (Brunton Clino Master® 31198, Brunton, Riverton, WY) readings were used to determine tree height, as detailed in GSA (2007a).

2.1.2 Seed Treatment and Storage Trials

Germination studies are being conducted at the NPC for Fremont cottonwood, Goodding's willow, and coyote willow, as detailed in GSA (2007a). Seed storage specifications are provided in Table 1, and detail on seed source trees used for the germination study is provided in Table 2. Nine germination trials were conducted for cottonwood and willow seed during 2007. The germination trial schedule through November 2007 is provided in Table 3.

Original seed collections were split to allow for eight months of trials (one per month). For all three species, seed stored at room temperature was no longer viable after five months. Therefore, germination studies for these treatments were discontinued in September 2006. However, 2006 study results indicated that extended storage of viable seed might be possible when the seed is frozen (GSA 2007a). Therefore, germination trials for frozen seed will be continued through April 2008, when the seed supply is exhausted.

Because of the extended viability observed for frozen seed, this seed was supplemented with additional frozen seed that was collected during April 2006; the seed was stored un-cleaned, with ambient oxygen. An initial germination trial with the supplemental seed (January 2, 2007) indicated comparable viability to the seed that was initially split into treatments (refer to Figure 1, Figure 2, and Figure 3 for Fremont cottonwood, Gooding's willow, and coyote willow, respectively). Therefore, this seed was assumed an appropriate surrogate to the original seed. Since January 2007, the supplemental seed has been used to fill in gaps in trials of original seed under the treatments "cleaned, frozen, ambient oxygen", and "un-cleaned, frozen, ambient oxygen". In January 2007, half of this supplemental seed was cleaned to represent the former treatment.

Following observations that soil temperature did not affect germination success during 2006 trials, variable soil temperature trials were discontinued for 2007.

Seed Viability Determination

During 2007, seed viability was evaluated in incubators and on un-heated soil. Incubator trials were conducted by placing seed between moist paper towels and placed in an incubator (VWR Economy Incubator CSA1500E, VWR International, West Chester, PA) for several days. A minimum of 20 seeds of each treatment were placed in the incubators. Two incubators were used to maintain optimal conditions for germination (i.e. 19 ^{o}C for Fremont cottonwood, and 27 ^{o}C for Goodding's and coyote willow (Baskin and Baskin, 1998)).

To mimic germination conditions at the site, soil used for germination trials was collected from Field 51 at Cibola NWR. Five-gallon buckets were filled with soil at the site on several occasions (April 2006, November 2006, and May 2007) adjacent to the small-scale field study area. Because the germination trials were designed only to establish seed viability trends, the seed bank was removed by pasteurization of the soil. Pasteurization was achieved via a steam generator passing steam through a covered bin (fabricated by the University of Arizona) at the Controlled Environment Agricultural Center for a period of one hour. Finally, the soil was sieved through a 1-inch by 5/16-inch (25.4 mm by 7.93 mm) screen to remove large plant waste.

After sieving, the soil was placed into seeding trays by hand and moderately compressed to prevent caving when watered. Trays were placed into a plastic bin containing approximately one inch of water. Soil was allowed to moisten by capillary action. Finally, five to ten seeds of each seed species and treatment were placed on the surface of each cell, with three cells for each species-treatment combination.

2.1.3 *Baccharis* spp. Salinity Trials

Germination studies were planned to assess the salinity tolerance of mule's fat, desertbroom, and Emory's baccharis seed under controlled conditions at the NPC. However, poor viability of this seed following five months of storage at room temperature (additional detail in provided in Section 0.5.5391646723.1.3) precluded these trials.

2.1.4 Data Analysis

Data was analyzed graphically and statistically using Microsoft Excel®. Data for storage trials are presented graphically. Ninety-five percent probability distributions are provided, where the error band size (L) is given by Equation 2.2:

$$L = z\sqrt{\hat{p}(1-\hat{p})} \qquad 2.1$$

where $\hat{p}$ is the observed proportion (i.e. viability), and z is the z-distribution statistic (1.96 for 95% confidence interval on the mean seed viability) (Milton 1999). Thus, non-overlapping error bars indicate a significant difference at P=0.05.

2.2 Seed Availability and Germination Study Results

A brief update to seed availability and collection techniques is provided below. Germination study results for riparian species are ongoing. Herein, results and discussion for trials through November 30, 2007 are presented.

2.2.1 Seed Availability and Seed Collection

Cottonwood, willow, and baccharis seed were collected from various locations on the LCR during 2007 for use in Tasks 2 through 5 experiments (Section 2.1.1). Mesquite, saltbush, and other MSCP target species seed were not collected during 2007. A list of locations utilized is provided in Table 4, and detail for source plants is provided in Appendix B. Recommended source locations and detail are provided below. For each species, the source locations are listed in order of decreasing recommendation for future seed collection.

Fremont Cottonwood

Fremont cottonwood seed was collected by pruning seeding branches off of the tree, and cutting racemes off of branches with hand pruners. Several centimeters of stem were left attached to racemes. Optimal timing for collection was indicated by the presence of many open (actively dispersing) capsules on the tree. Racemes were packed loosely in paper bags and transported to the NPC. After several days of drying in paper bags the capsules opened, and fluffy seed was removed from paper bags by hand. The seed was transferred to sealed plastic bags and placed in freezers.

Abundant Fremont cottonwood seed was available for collection on the LCR. Recommended collection locations are provided below.

1. Ahakhav Tribal Preserve: Abundant cottonwood trees were available for seed collection at the preserve during March, 2007. Vehicular access is excellent, and seed production was very high. Additionally, GSA was permitted to harvest large cottonwood branches, which greatly increased collection efficiency.
2. Cibola NWR: Within Cibola NWR, a limited number of native cottonwood trees were observed. Trees along the levee roads near Cibola Lake have very poor access. Existing cottonwood trees within the Nature Trail proper and most other revegetated areas of the refuge were observed to have low seed production. However, trees along the south side of the road between the Cibola NWR headquarters and the Nature Trail produce abundant seed, easily collected during early May. A large cottonwood is also present at the northwest corner of the “cornfield”, adjacent to the Nature Trail. This tree (POFR 4) has

produced abundant seed during both 2006 and 2007, available for collection throughout April and early May.

3. Bill Williams River NWR: Trees on the Bill Williams River NWR provided great amounts of seed during 2007. The easiest trees to collect from were located on the Bill Williams River NWR floodplain east of Mineral Wash. Trees accessed from the road at Bill Williams River NWR West produced seed high in the canopies, which was not accessible even with a step ladder and pruning pole. Although vehicular access is limited within Mineral Wash, very high seed production was observed. However, if Fremont cottonwood seed from the Ahakhav Tribal Preserve is equally desirable, that restoration site is preferable due to ease of collection. Collection at the Mineral Wash site required approximately 40 km of off-road travel (four-wheel drive recommended), followed by one km of hiking.
4. Other locations: Abundant Fremont cottonwood trees are accessible at Havasu NWR, both in the nursery and at Beal Lake. Cottonwood seed was not collected from this area, and the optimal time of collection is unknown. GSA personnel observed no cottonwood seed available for collection on April 12, 2007. Abundant cottonwood trees are also present at Pratt Restoration Site. This location has not been visited by GSA during the spring; therefore, seed abundance and production timing is unknown.

Goodding's Willow

Goodding's willow seed was collected by pruning seeding branches off of the tree. Racemes were picked from large branches by hand—or left on small branches—and placed loosely in paper bags. After several days of drying in paper bags the capsules opened, and fluffy seed could was removed from paper bags by hand. The seed was transferred to sealed plastic bags and placed in freezers.

Abundant Goodding's willow seed was available for collection on the LCR. Recommended collection locations are provided below.

1. Ahakhav Tribal Preserve: Abundant Goodding's willow trees were available for seed collection at the Ahakhav Tribal Preserve during April 2007. Vehicular access is excellent, and seed production was very high.
2. Cibola NWR: Within Cibola NWR, many native Goodding's willow trees were observed. Trees along the levee roads near Cibola Lake have very poor access, but those between levee roads on the west side of the main Colorado River channel had good access. Seed production was limited for these trees during 2007 because of fires during 2006. Some mortality was observed, but many trees are re-sprouting and will likely produce seed during 2008. Several trees are also available for collection in the East Meander on the Island Unit. All native Goodding's willow trees (i.e. all trees at Cibola NWR with the exception of those at the Nature Trail were observed to have later seed availability (May through June). Several Goodding's willow trees are available for collection in the Nature

Trail where seed was most abundant during late April, 2007.

3. Havasu NWR: Abundant Goodding's willow seed was available in the Beal Lake Riparian Habitat Restoration site during April. Even small Goodding's willow trees produce seed in great abundance. It is likely that other restoration sites on the LCR (e.g. CVCA) will provide excellent seed sources for Goodding's willow as well.
4. Bill Williams River NWR: Many Goodding's willow trees had favorable access and seed production on Bill Williams River NWR. However, GSA's primary seed collection trip on this refuge was conducted in March. Seed availability is likely greater in April. Goodding's willow trees on the refuge were generally adjacent to the river channel and therefore required some hiking.

Coyote Willow

Coyote willow seed was collected by picking racemes off of branches by hand. Racemes were placed loosely in paper bags for transport to the NPC. After several days of drying in paper bags the capsules opened, and fluffy seed could was removed from paper bags by hand. The seed was transferred to sealed plastic bags and placed in freezers.

Abundant coyote willow seed was observed on the LCR, although easily-accessed seed is not currently abundant. Because these plants are aggressively establishing at restoration sites, seed availability is likely to increase during 2008. Recommended collection locations are provided below.

1. Ahakhav Tribal Preserve: Several large stands of coyote willow are present in the preserve, primarily on the west and southwest side. Seed production was very high during mid April.
2. Cibola Valley Conservation Area: Coyote willow on the northeast side of the nursery produced abundant seed in May 2007.
3. Havasu NWR: Many coyote willow plants are located along the levee road leading to Beal Lake. Extensive pole harvesting apparently took place prior to spring of 2007, greatly reducing the availability of seeding racemes. Nevertheless, some seed was available from these plants in April 2007.
4. Cibola NWR: Although seed production in the Nature Trail has been very limited, coyote willow is common along the levee roads on the east side of the main Colorado River channel. Specifically, several large stands were located during 2007 approximately 2.5 km south of the Cibola NWR northern border. Additional small plants are located along the levee between the Island Unit Bridge and Cibola Lake.

Mule's Fat

Mule's fat seed was collected by picking seed heads off of branches by hand and placed loosely in paper bags for transport to the NPC. In preparation for potential germination studies during 2008, one-third of collected seed has been placed in freezers, refrigerators, and in paper bags at room temperature.

Limited mule's fat seed was available for collection on the LCR. Recommended collection locations are provided below.

1. Cibola Valley Conservation Area: Plants on the east side of the nursery produced seed during December 2007.
2. Bill Williams River NWR: Abundant plants are located at Bill Williams River NWR West. Several plants are located along the dirt road. However, plants are most abundant in the Cohen Ranch area. Extensive hiking is required to access this site. Seed was available for collection in the area during December 2006.
3. Other Locations: Several mule's fat plants were observed at the Ahakhav Tribal Preserve. The site was not visited during the winter, but it is likely that seed is available from these plants in December. Mule's fat was not observed at other locations on the LCR.

Desertbroom

Desertbroom seed was collected by pulling seed heads off of seeding branches by hand and packing in paper bags. In preparation for potential germination studies during 2008, one-third of collected seed has been placed in freezers, refrigerators, and in paper bags at room temperature.

Desertbroom seed is not abundant on lower reaches of the LCR. Recommended collection locations are provided below.

1. Cibola Valley Conservation Area: During 2007, desertbroom seed was collected from the extreme west side of the CVCA. Despite small size, the plants produced abundant seed. However, a relatively small number of plants are available for collection.
2. Other Locations: Desertbroom was not observed on Cibola NWR despite extensive surveys. This species has been observed in Parker, Arizona and upstream thereof. GSA will monitor seed availability of this species more extensively during 2008, and results will be presented in the 2008 annual report.

Emory's Baccharis

Emory's baccharis seed was collected by pulling seeding branches off of the plant by hand and packing in paper bags. In preparation for potential germination studies during 2008, one-third of

collected seed has been placed in freezers, refrigerators, and in paper bags at room temperature.

Emory's baccharis is abundant on lower reaches of the LCR, and establishes regularly at revegetation sites (e.g. The Nature Trail, Pratt Restoration Site). Recommended collection locations are provided below.

1. Cibola NWR: Abundant Emory's baccharis is available within and on the perimeter of the Nature Trail. Seed was readily available in December 2006 and 2007.
2. Pratt NWR: Abundant Emory's baccharis is available within and on the perimeter of the Nature Trail. Seed was readily available in December 2006 (not visited during 2007).

Other Species

Seed of other target MSCP species was not collected during 2007. Seed of honey mesquite, screwbean mesquite, and quailbush were collected in 2006 (GSA, 2007a). Summary observations are re-visited below.

Honey mesquite seed were most efficiently collected with a leaf rake where seeds had fallen on bare ground. Abundant native honey mesquite was observed at Cibola NWR, with optimal collection in July. Most trees used for collection during 2006 were located between levee roads along the main Colorado River channel. Seed production was also high in the Nature Trail. However, morphology of these trees indicates possible hybridization of species. Therefore, honey mesquite seed collected from this location is not recommended for revegetation.

Seed was most efficiently collected with a leaf rake for screwbean mesquite as well. When collecting from trees with a grassy understory, efficiency of collection was increased by placing tarps below trees and shaking seed from branches. Many native screwbean mesquite trees were located at Cibola NWR along the levee roads of the main Colorado River channel during July, but seed was not abundant. Screwbean mesquite is abundant on revegetated areas of the Island Unit, and seed production was high during July and August. Abundant screwbean mesquite was observed at Havasu NWR, where seed production and timing has not been assessed.

Quailbush seed is efficiently collected by shaking seeding branches above paper bags. This species is common throughout the LCR, and seed is abundant during December. Recommended collection areas are the Nature Trail and levee roads of Cibola NWR. Quailbush is also abundant at Bill Williams River NWR.

2.2.2 Storage Trials for Salicaceae Species

Summary results through November 2007 are provided in Figure 1 through Figure 9, and expanded data are available in Appendix C. Overall, favorable viability has been maintained for Fremont cottonwood, Goodding's willow, and coyote willow for 19 months. It is of note that a reduction was observed in willow germination rates during July 2007 trials across all seed

storage treatments. Because the trend was not consistent, it is probable that procedural errors occurred while training new staff at the NPC. Species-specific observations are provided below.

Fremont Cottonwood

Incubator viability of frozen cottonwood seed stored since May 2006 has typically been greater than 80%. As of November 30, 2007, incubator viability of frozen seed at ambient oxygen concentrations was 84% for cleaned seed and 100% for un-cleaned seed (Figure 1). Oxygen removal has not resulted in consistent incubator viability differences from ambient oxygen storage (Figure 1).

Germination on soil continues to be (approximately three to four times) higher for frozen cleaned seed than for frozen un-cleaned seed (Figure 4). As discussed previously in GSA (2007a), this is likely due to better seed-soil contact resulting in higher moisture availability. The average germination rate for frozen cleaned seed on soil beds was higher for ambient oxygen storage than oxygen removal (Figure 5). However, the opposite trend has been observed for frozen un-cleaned seed (data in Appendix C).

Goodding's willow

Incubator viability of frozen Goodding's willow seed stored since May 2006 has also typically been greater than 80%. As of November 30, 2007, incubator viability of seed stored in freezers at ambient oxygen concentrations was 100% for cleaned seed and 84% for un-cleaned seed (Figure 2). No consistent effect of oxygen removal on incubator viability has been observed.

Germination on soil continues to be (three to four times) higher for frozen cleaned seed than frozen un-cleaned seed (Figure 6). The average germination rate for cleaned seed on soil beds was higher for oxygen removal than ambient oxygen storage (Figure 7). The same trend was observed for un-cleaned seed on soil beds (data in Appendix C).

Coyote willow

Incubator viability of frozen coyote willow seed stored since May 2006 has also typically been greater than 80%; the only incubator trials indicating less than 80% viability were in July 2007. As of November 30, 2007, incubator viability of frozen seed in ambient oxygen concentrations was 100% for cleaned seed and 96% for un-cleaned seed (Figure 3). Oxygen removal has not had a consistent effect on incubator viability of coyote willow (Figure 3).

Germination on soil continues to be (three to four times) higher for cleaned seed than un-cleaned seed (Figure 8). The average germination rate for frozen cleaned seed on soil beds was slightly higher for oxygen removal than ambient oxygen storage (Figure 9). Soil germination rates for un-cleaned seed in the oxygen removal and ambient oxygen storage treatments were approximately equal (data in Appendix C).

3.0 TASKS 2, 3, AND 4: SMALL-SCALE GREENHOUSE POT STUDIES

Tasks 2 through 4 greenhouse pot studies were conducted at the University of Arizona NPC to determine germination and growth of cohorts of mesquite, riparian, and shrub species, respectively.

The primary objectives of the additional Task 3 (riparian tree) 2007 studies were to evaluate the effect of the following parameters on seed germination and growth:

- Freshly collected (March and April 2007) versus year-old (April 2006) seed collections.
- Cleaned versus un-cleaned seed.
- Organic fertilizer versus no organic fertilizer.

The primary objectives of the 2007 Task 2 (mesquite bosque) and Task 4 (baccharis) studies were to evaluate the effect of the following treatment conditions on seed germination and plant growth

- Topsoil and (mimicked) subsurface sand soil types found at Field 51 of Cibola NWR.
- Uncompacted (loose) versus loose with compacted subsurface layer Field 51 topsoil.
- Cleaned versus un-cleaned seed (baccharis only).
- Three seeding rates.

In conjunction with Task 5 field studies, the results of Tasks 2 through 4 will be used to guide experimental design for Task 6 studies.

3.1 Technical Approach

Seven-gallon plastic pots (Poly-Tainer Basket, Hummert International, Earth City, MO) were used to allow for replications to test the effect of a diverse set of treatment variables on various target MSCP species. The species have been separated into four cohorts:

1. Mesquite bosque species (Task 2). Honey mesquite, screwbean mesquite, and quailbush.
2. Riparian tree species (Task 3). Fremont cottonwood, Goodding's willow, and coyote willow.
3. Upland shrub species (Task 4). Quailbush, fourwing saltbush, cattle saltbush, desert thorn, and desert globemallow.
4. Baccharis shrub species (Task 4). Mule's fat, desertbroom, and Emory's baccharis.

The following greenhouse 7-gallon pot studies were conducted during 2007 to complete Tasks 2 through 4:

- Task 2: Mesquite bosque studies to analyze soil conditions and seeding rate.
- Task 3: Additional riparian tree studies to analyze long-term seed storage, seed cleaning, and organic soil amendment.
- Task 4: Baccharis shrub studies to analyze soil conditions and seeding rate.

In 2006, riparian tree species cohort studies (Task 3) were conducted to analyze effects of soil conditions and seeding rates. Task 4 studies were also conducted in 2006 to analyze effects of soil conditions and seeding rates on upland shrub specie cohorts. Results of these 2006 studies are available in GSA (2007a).

3.1.1 Riparian Year-old Seed 7-Gallon Pot Trials

Riparian cohort greenhouse 7-gallon pot trials were implemented to determine the effect of one-year duration freezer storage, and organic amendment on the establishment and growth of Fremont cottonwood, Goodding's willow, and coyote willow. The treatment variables are presented in Table 5. Treatment reasoning is provided below.

Soil Treatment

During 2006 greenhouse studies, riparian plant growth was greatest is loose Field 51 topsoil compared to compacted layer soil and sand (GSA, 2007a). The goal of 2007 greenhouse studies was to analyze only the effects of seed storage duration, seed cleaning, and fertilizer addition. Therefore, all 2007 riparian greenhouse studies were conducted in the loose Field 51 topsoil soil type.

Seed Collection Year

The goal of the seed collection year treatment was to determine if long-term seed storage results in decreased plant growth rates for Fremont cottonwood, Goodding's willow, or coyote willow. Germination studies have indicated that cottonwood and willow seed viability can be preserved in freezers for at least one year. However, long-term storage of seed may result in decrease in seed vigor—the rate at which seedling growth occurs (e.g. Delouche and Caldwell, 1960). To quantify the potential changes in vigor of cottonwood and willow seed, growth rates of seed collected during 2006 (approximately fourteen months of storage) were compared with those for seed collected during 2007 (approximately two months of storage).

Seed Type

The goal of the seed type variable was to determine if seed cleaning affected establishment and growth of year-old cottonwood and willow seed. During 2006 greenhouse studies, seed cleaning resulted in an approximate doubling of riparian plant establishment (GSA, 2007a). For 2007 studies, it was desired to determine if year-old seed could be cleaned prior to seeding without reductions in seed vigor or plant growth.

Organic Amendment

Biosol® (Biosol Organic Fertilizers, Denver, CO) was added at a rate of either 0 lbs/acre (control) or 1500 lbs/acre, as during 2006 Task 3 and 4 studies (GSA, 2007a). The goal was to determine if organic fertilizer amendment would increase plant growth rates, and therefore overcome potential decreases in seed vigor that might occur following long-term storage.

Seed Collection and Preparation

Riparian seed was collected during April 2006, March 2007 and April 2007. The seed was stored un-cleaned in freezers until the day of seeding. Pure live seed (PLS) rates were determined from incubator study results conducted the previous week (note that un-cleaned seed was used for incubator viability analysis). The goal of the viability analysis was to determine appropriate total seeds to place in each pot such that the resulting pure live seed rates were identical for year-old and freshly collected seed.

On the day of seeding, seed was removed from freezers. Seed for the cleaned seed treatments were cleaned by seed hair removal in a Wiley mill (Model #2 and Model #4, Arthur H. Thomas Company, Philadelphia, PA) with subsequent separation of seed from debris with a #25 sieve (Newark Wire Cloth Company, Newark, NJ). Final cleaning was accomplished with an air-screen machine, which uses a stream of air to separate debris from seeds based on weight and aerodynamics (Model D, E.L. Erickson Products, Brookings, SD). Seeds were counted by hand for each pot, and placed in an envelope labeled with the appropriate pot number.

Riparian study pots were seeded on June 1, 2007, and harvested between October 3 and October 8, 2007.

3.1.2 Mesquite Bosque 7-Gallon Pot Trials

Greenhouse studies were implemented to determine the effects of soil conditions and seeding rates on the establishment and growth of honey and screwbean mesquite and quailbush as outlined in Table 6. Treatment reasoning is provided below.

Soil Treatment

The goal of the soil treatment variable was to determine whether the different soil types and range of soil bulk densities observed at the Cibola NWR will affect establishment and growth. Soil type could affect success due to differences in fertility and plant available water holding capacity. Increased soil bulk density (compaction) can cause variation in survival and growth rates of plants (Smith et al., 2001).

Seeding Rate

The goal of the seeding rate variable was to determine the optimum seeding rate capable of out-

competing undesirable species while promoting high growth rates, plant species diversity and suitable habitat for LCR MSCP avian species. If seeding density is too low, soil and sunlight resources will allow for colonization by invasive species. However, excessive seeding rates will be economically inefficient, and might result in detrimental competition between target species.

Mesquite PLS rates were higher than proposed due to variability in scarification effectiveness, as discussed below. Nevertheless, 2007 studies analyzed a four-fold increase in seeding rates, ranging from 30 to 120 PLS/ft^2.

Seed Collection and Preparation

Honey and screwbean mesquite seed were collected from Cibola NWR during July and August, 2006. Seed was removed from seed pods by processing with a hammer mill (Model G5HFSI, Prater Industries, Inc., Chicago, IL), which breaks seed pods apart. The output material was then sieved to separate seeds from chaff.

To determine the PLS rates for mesquite seed, incubator germination studies were conducted to analyze the effectiveness of immersion in 2 M sulfuric acid, boiling, and sanding with an electric sander (following Vitela and Ravetta, 2001). Germination results indicated viability of 54% for honey mesquite following acid immersion, and 33% for screwbean mesquite following sanding. Sufficient seed was processed for the pot study, and PLS was determined based on these incubator results. However, greenhouse study results indicated double the viability observed in incubators. Thus, PLS rates for mesquite were revised based on observed establishment. Adjusted PLS rates are provided in Table 6.

Quailbush seed was collected from Cibola NWR in December 2006, and stored at room temperature until seeding. The seed did not require cleaning.

Seed was counted by hand for each pot, and placed in an envelope labeled with the appropriate pot number. The pots were seeded on June 14, 2007, and harvested the week of October 8, 2007.

3.1.3 Emory's Baccharis and Sweetscent Trials

Baccharis spp. (Baccharis) cohort trials were intended to determine the effects of soil treatment, seed cleaning, and seeding rate on the establishment and growth of mule's fat, Emory's baccharis, and desertbroom, as outlined in GSA 2007c. However, as described below, mistakes during seed preparation, and unforeseen reductions in seed viability resulted in inadvertent changes to the study design.

Poor Baccharis Viability

Additionally, germination requires extended duration of soil contact relative to cottonwood and willow. Germination studies for baccharis would have pushed the seeding date for baccharis into late summer. Viability was assumed to be 80% for seeded species in order to allow for a mid-

June seeding date. Actual viability estimated from the maximum number of germinated individuals observed at each seeding rate in the pots was approximately 40% for Emory's baccharis and 0% for mule's fat.

Plant Identification Errors

Following seed collection in December 2006, baccharis plant species were identified by UA students in cooperation with the University of Arizona herbarium. Baccharis species at the Bill Williams River NWR were identified as mule's fat and desertbroom, and baccharis from Cibola NWR and the Pratt Restoration Site were identified as desertbroom and Emory's baccharis. The plants were seeded in the greenhouse study according to these initial identifications. Subsequent analysis by GSA indicated that the species identified as desertbroom were also Emory's baccharis, and that no desertbroom was collected in 2006.

During seed preparation, un-cleaned seed of sweetscent (*Pluchea odorata* (L.) Cass.), collected from Bill Williams River NWR, was apparently confused with un-cleaned mule's fat seed. As a result, sweetscent was accidentally seeded in place of mule's fat in the un-cleaned baccharis pots.

In summary, Emory's baccharis was seeded at twice the desired rates in both the cleaned and un-cleaned baccharis studies, and sweetscent replaced mule's fat in the un-cleaned pots. It is of note that mule's fat would not have grown due to the lack of seed viability. Because seed composition was different between cleaned and un-cleaned pots, the results are analyzed independently. Therefore, the effects of sweetscent and Emory's baccharis seed cleaning could not be assessed. Through these inadvertent changes in the study design, GSA has identified potential problems for long-term storage of mule's fat, and gained information about another native species, an annual or perennial native riparian obligate, which may or may not be of interest to Reclamation for revegetation.

Treatment Summary

The treatments for the Emory's baccharis greenhouse study are outlined in Table 7. The effects of soil conditions and seeding rates were analyzed. Seeding rates were obtained from count results during the pot harvest. The treatments for the Emory's baccharis and sweetscent greenhouse study are outlined in Table 8. Treatment reasoning is provided below.

Soil Treatment

The goal of the soil treatment variable was to determine whether the different soil types and range of soil bulk densities observed at the Cibola NWR will affect establishment and growth, as described in Section 3.1.2.

Seed Treatment

The goal of the seed treatment variable was to determine whether removing hairs from baccharis seed will affect seed viability or plant establishment. Removing seed hair could reduce wind and water transport after seeding in a field setting, as is likely for cottonwood and willow (USBR, 2005).

Seeding Rate

The goal of the seeding rate variable was to determine the optimum seeding rate capable of out-competing undesirable species while promoting high growth rates, plant species diversity and suitable habitat for LCR MSCP avian species as described in Section 3.1.2.

Seed Collection and Preparation

Baccharis seed was collected from various locations on the LCR during December, 2006. Emory's baccharis seed was collected from Pratt Restoration Site, Cibola NWR. Mule's fat was collected from Bill Williams River NWR. Initial observations suggested that desertbroom seed was also collected from Bill Williams River NWR. However, as discussed above, no desertbroom seed was collected. Additionally, sweetscent seed was accidentally collected from Bill Williams NWR (see above).

All seed was stored un-cleaned in paper bags from December 2006 to June 2007. The laboratory temperature was maintained at 21 ^{o}C. In May, 2007, seed was cleaned using the Wiley Mill, as described in Section 3.1.1 for cottonwood and willow.

Seed was counted by hand for each pot, and placed in an envelope labeled with the appropriate pot number. It is of note that baccharis seed is much more easily separated from hairs than cottonwood and willow. Much of the seed separated from hairs during transport.

The pots were seeded on June 14, 2007, and harvested the week of October 8, 2007.

3.1.4 Soil Collection and Pot Preparation

Approximately 6 tons of topsoil was collected from Field 51 at the Cibola NWR and transported to the NPC in an eight-wheel haul truck in February, 2007, for use in the Task 2 through 4 greenhouse pot studies. The soil was collected from the southeast quadrant of Field 51. The topsoil was sieved through a 1-inch by 5/16-inch (25.4 mm by 7.93 mm) screen (fabricated by the University of Arizona Office of Arid Lands Studies) to remove large organic matter and break up soil clods. In addition, 3.5 tons of mortar sand was purchased from Pioneer Landscaping Materials (Tucson, AZ) for use in the sand treatment. The sand was selected as representative of the sand layers observed at Field 51 at depths of 118 cm to greater than 190 cm below ground surface (GSA, 2008).

Soil Treatments

For the loose and compacted layer Field 51 topsoil pot treatments, 3 cm of sand was placed in the bottom of each seven gallon pot to facilitate drainage. The loose Field 51 topsoil pots were filled by shoveling sifted material into the pots to a depth of 23.5 cm (3 cm below the rim of the containers). Compacted layer Field 51 topsoil pots consisted of the lower half (by depth) of the pot containing soil compacted to the maximum dry bulk density observed topsoil at Field 51 (1.45 g/cm^3, GSA, 2008), with the remaining half filled with loose soil. Soil was placed into the compacted pots in a series of three lifts—two compacted lifts of 5.9 cm depth each and one 11.8 cm loose soil lift. The sand soil treatment was prepared by shoveling loose sand into the pots to a depth of 26.5 cm. Additional detail is available in GSA (2007a).

Seed Application

Riparian cohort un-cleaned seed was pressed lightly to the soil as would occur from using a cultipacker behind a field-scale broadcast seeder. Riparian cleaned seed was not sprinkled onto soil, and was not pushed into the soil. Mesquite and quailbush seeds were harrowed into the soil—soil was raked to one side of the pot, seed was placed on the soil and then covered with soil to an approximate depth of 2 cm as per recommended seed burial depth (USDA 2002). Baccharis and sweetscent seed was spread onto the soil surface. Un-cleaned seed was pressed lightly to the soil as would occur from using a cultipacker behind a field-scale broadcast seeder.

3.1.5 Greenhouse Layout and Irrigation

As during the 2006 greenhouse studies, pot placement was randomized block within the greenhouse, whereby one repetition of each treatment combination was placed in one of three blocks of the greenhouse based on distance from the evaporative cooling pads. However, to allow for different irrigation application to accommodate mesic (riparian) and xeric (baccharis and mesquite) species, one bench was designated for riparian species, and the other four were designated for baccharis and mesquite. The final greenhouse layout is provided in Figure 10.

The irrigation frequency was designed to promote similar moisture status in the different soil treatments. It was also desired to maintain more mesic (wetter) soil conditions in the riparian pots than in the mesquite and baccharis soil pots to account for higher moisture requirements of cottonwood and willow. Drainage rates were an additional consideration: more drainage occurred in sand pots than in loose soil pots, which experienced more drainage than compacted layer soil pots. Because of irrigation system constraints (a maximum of three different irrigation schedules), the irrigation frequency for the sandy soil mesquite and baccharis pots was the same as that of the riparian loose soil pots. The final irrigation schedule was as outlined in Table 9.

3.1.6 Bermudagrass Control

Grass-specific herbicide was applied to the 7-gallon pots on June 26, 2007 to reduce the abundance of Bermudagrass (*Cynodon dactylon* (L.) Pers.). Select® 2EC Herbicide (Arysta

LifeScience North America Corporation, Cary, NC) was applied via spraying from a backpack tank. For consistency across treatments, sand pots were sprayed with herbicide as well. Minimal burning of seeded species was observed.

3.1.7 Vegetation Data Collection and Analysis

Vegetation success during the small-scale greenhouse studies was monitored at two different times, mid-season and end-of-season. The mid-season data collection consisted of plant crown cover measurements to determine the ability of seeded species to dominate the initial crown cover. End-of-season measurements consisted of plant measurements following harvest of all plants to include: count of seeded species; height of seeded species, above-ground biomass per target species, above-ground biomass for total non-target species, and below-ground biomass per pot. Plants were identified to species when possible; however, some plants were not yet mature enough to allow for species identification. In this case, classification was determined to family or genus level.

Mid-season Crown Cover Point Transects

Species-specific crown cover was estimated via point transects. Two wooden dowels were used to suspend twine above each pot, bisecting the pot from North to South. The twine was marked at ½-inch (1.27-cm) intervals. A third dowel (1/8-inch diameter) was held vertical at each transect point, and lowered until first contact (i.e. "hit") with a live plant, litter (dead plant material), or bare ground, which therefore represented crown cover at that point. Crown cover percentage of each component was obtained by dividing the number of hits by the number of sample points, as described by Equation 3.1:

$$Cover = \frac{n}{26} \times 100\% \qquad 3.1$$

where n is the number of hits of a given cover, and 26 is the number of observation points (i.e. 12 ½ inches of pot diameter with 1 observation per ½ inch).

End-of-Season Data Collection

Species count, height, and biomass data were assessed at the end of the study. The protocols for end-of-season harvesting are described below:

Target species were cut at the soil surface using hand pruners. The height of each stem was determined to the nearest 0.5 cm with a measuring tape by laying the plant on the ground and measuring the distance from the end of the trunk to the tip of the longest shoot. The number of height measurements was used to tabulate stem density (stems per square foot).

Following harvest, above-ground material from each pot was separated into each seeded species, non-seeded species, and litter, and placed in paper bags. Material within paper bags was

desiccated in a drying room at the NPC. After one week of drying, plant material within each bag was weighed to the nearest 0.01 gram.

Total dry root biomass was measured for each pot. Following harvest of the above-ground material, soil and roots from each pot was wet sieved at the NPC. Root clumps were broken, and soil was washed from the roots. Total root biomass per pot (non species-specific) was placed in paper bags and desiccated in a drying room at the NPC. After one week of drying, root material was measured to 0.01 gram.

Statistical Analysis

For graphical purposes, statistics were obtained via Student's t-tests for analysis of treatment variable effects. Additionally, linear analysis of variance (ANOVA) modeling was accomplished through use of JMP 6™ (SAS Institute, Cary, N.C.) to determine the impacts of treatments (soil treatment, seed cleaning, seeding method, Biosol® addition, and seeding rate) on the following results:

- Crown cover of target and non-target species (mid-season).
- Stem counts of target species (end-of-season), herein synonymous with plant establishment.
- Dry biomass of each target species, total non-target species, litter, and roots (end-of-season).
- Height of target species (end-of-season).

Significant treatments effects and interactions on a given result were determined by F tests. Least-squared means were compared via Student's t-tests for the determination of significant differences between treatments.

3.2 Greenhouse Study Results

Results from the various 2007 pots studies are discussed in detail below. Because placement of pots within a greenhouse block (repetition location) did not significantly affect results (Table 10 through Table 15) it is a reasonable assumption that the three pots are true repetitions. Therefore, this treatment will not be discussed in detail. A list of non-target species and relative abundance is provided in Table 16. Extended data are provided in Appendix D.

Graphically, results are presented with 95% confidence intervals on the mean. Thus, non-overlapping error bars indicate significant differences at P = 0.05. In ANOVA tables, the P-values for effects and interactions are based on F-tests. Significant differences for least-squared means are based on Student's t-tests with P=0.05.

3.2.1 Riparian Year-old 7-Gallon Pots

ANOVA results for the trials are provided in Table 10 and Table 11 for mid-season and harvest data, respectively. Treatment effects are discussed in detail below.

Seed Cleaning

As during the 2006 greenhouse studies, cleaned seed showed increased crown cover of Fremont cottonwood and total target species compared to un-cleaned seed (Table 10, Figure 11). Seed cleaning increased stem counts (Figure 12) and biomass (Figure 13) of Fremont cottonwood and coyote willow (Table 11), for an approximate doubling in target species counts and biomass (Table 11) compared to un-cleaned seed.

Poor establishment was observed for cleaned 2006 Goodding's willow seed (Figure 12). Therefore, the ANOVA showed a significant decrease in stem counts for 2006 Goodding's willow due to seed cleaning. However, the cleaned 2007 Goodding's willow seed resulted in higher stem counts compared to un-cleaned seed from 2007 (Figure 12). Seed cleaning did not have an effect on plant height (Table 11, Figure 14).

Seed Storage Duration

Seed collection year did not result in decreased plant growth, as measured by crown cover (Figure 11, Table 11), species counts (Figure 12), dry plant biomass (Figure 13), or plant height (Figure 14). There was a large decrease in Goodding's willow establishment (stem counts) with cleaned 2006 seed compared to 2007 seed (Figure 12)—resulting in lower least-squared means in the ANOVA results. However, un-cleaned Goodding's willow seed from both years resulted in similar crown cover, stem counts, and biomass (Table 11).

Organic Fertilizer

As during 2006 greenhouse studies, organic fertilizer reduced riparian tree establishment (stem counts for seeds planted in Field 51 soil (Table 11, Figure 12). No increase in individual plant growth (height) was also observed (Figure 14). Therefore, crown cover (Table 10) and biomass (Table 11) were reduced due to decreased stem count.

3.2.2 Mesquite Bosque 7-Gallon Pots

ANOVA results for the trials are provided in Table 12 and Table 13 for mid-season and harvest data, respectively. Treatment effects are discussed in detail below.

Soil Treatment

Loose versus compacted layer Field 51 soil treatment did not affect target species crown cover (per species or total). Lower crown cover of honey mesquite was observed in sand pots, due to

decreased per-plant growth. Crown cover of screwbean mesquite increased with sand soil, likely due to less honey mesquite and non-target (unseeded) species growth (Table 12).

Mesquite stem counts were unaffected by soil treatment (Table 13 and Figure 15). However, mesquite biomass (Figure 16), mesquite height (Figure 17), and total root biomass decreased progressively from loose soil to compacted layer Field 51 soil to sand (Table 13). The reduction in mass of screwbean mesquite from loose to compacted layer Field 51 soil was greater than 50%. Honey mesquite was less affected, with a reduction in biomass of approximately 25%. Biomass in sand was approximately 10% and 5% of that in loose Field 51 soil for screwbean and honey mesquite, respectively.

Seeding Rate

Crown cover of target species did not significantly increase with higher seeding rates (Table 12), likely due to rapid growth of plants at low seeding rates. Higher seeding rates resulted in higher plant establishment (Figure 15), but only increased the biomass of honey mesquite (Figure 16), which dominated screwbean mesquite. The large contribution of honey mesquite biomass resulted in a significant increase in total target species biomass from low to high seeding rates (Table 13). Mesquite height decreased from low to high seeding rates (Table 13, Figure 17).

The maximum height for honey mesquite was lower in compacted than loose Field 51 soil at the low and medium seeding rates, but was approximately equal at high seeding rates, indicating that the higher seeding rate reduced the maximum plant height (Figure 17), but as shown in Figure 16, the effect of soil compaction on biomass does not appear to be exacerbated by higher seeding rates. For example, in Figure 17 the biomass at the higher seeding rate in compacted soil was approximately equal to the biomass in loose soil at the lower seeding rate. Similarly, the effect of soil compaction on stem length (Figure 18) does not appear to strongly vary with seeding rate.

General Observations

Favorable growth of mesquite was observed during the greenhouse pot study. Honey mesquite in particular exhibited high growth rates for the first growing season (similar to Fremont cottonwood in Task 3 trials). Although counts of honey mesquite and screwbean mesquite were comparable across treatments (e.g. Figure 15), honey mesquite tended to dominate crown cover and biomass (Figure 18 and Figure 16, Table 13). Establishment of quailbush was relatively minimal (Figure 15) compared to 2006 greenhouse studies (GSA 2007a); this was likely due to enhanced competition from mesquite compared to the upland shrubs only test pots planted in 2006.

3.2.3 Emory's baccharis and Sweetscent 7-Gallon Pots

3.2.3.1 Cleaned Emory's Baccharis

ANOVA results for the trials are provided in Table 14 for both mid-season and harvest data. Treatment effects are discussed in detail below.

Soil Treatment

Growth in sand was minimal during the mid season, and no live Emory's baccharis plants were observed in sand during the harvest (end-of-season) survey. Soil treatment did not affect crown cover, likely because cover was low in all pots during the mid-season survey (Table 14 and Figure 19). Plant counts decreased significantly from loose Field 51 soil to compacted layer Field 51 soil to sand in (Figure 20 and Table 14). Lower establishment in compacted layer soil was possibly due to excessive soil moisture in the compacted layer pots. Further, baccharis biomass was higher in loose than compacted layer Field 51 soil than sand (Figure 21 and Table 14). Soil treatment did not significantly affect plant height (Table 14, Figure 22).

Seeding Rate

No significant effect was observed between the low and medium seeding rates. However, crown cover, counts, and biomass increased at higher seeding rates (Figure 19, Figure 20, and Figure 21). Growth per Emory's baccharis plant did not decrease at higher seeding rates. As mentioned previously, Emory's baccharis seeding rates did not significantly affect the root biomass, likely because this species comprised a relatively small portion of overall plant biomass (Table 14).

General Observations

Emory's baccharis exhibited relatively slow growth early after seeding, which resulted in low crown cover (Table 14, Figure 19). However, after four months of growth, numerous Emory's baccharis plants had grown to over 0.4 m.

3.2.3.2 Un-cleaned Emory's Baccharis and Sweetscent

ANOVA results for the trials are provided in Table 15 for both mid-season and harvest data. Treatment effects are discussed in detail below.

Soil Treatment

Sweetscent crown cover and biomass were approximately one order of magnitude higher in loose Field 51 soil pots compared to compacted layer Field 51 soil pots, due to a higher number of individuals (Figure 23, Table 15) and increased plant height (Figure 24, Table 15). The increased germination in the loose soil pots is possibly due to excessive soil moisture in the compacted layer pots. No sweetscent was observed in the sand pots.

Crown cover and biomass of Emory's baccharis did not vary between soil treatments. As mentioned previously, there was delayed growth of baccharis which resulted in few individuals observed during the mid-season survey. At harvest, stem count (Figure 23, Table 15) and biomass (Figure 25, Table 15) of Emory's baccharis was approximately double in loose compared to compacted layer Field 51 soil. No live Emory's baccharis plants were observed at the end of the season in sand pots.

Seeding Rate

Crown cover, count and biomass of sweetscent and Emory's baccharis increased from low to high seeding rates, and higher seeding rates did not result in decreased growth rates (Table 15). Because target species accounted for up to half of total plant biomass in the pots, the increased seeding rates also resulted in increased root biomass (Table 15).

General Observations

Despite lower sweetscent seeding rates compared to Emory's baccharis (refer to Table 8), growth of sweetscent were greater than those of Emory's baccharis, based on crown cover (Figure 26) and biomass (Figure 25).

4.0 TASK 5: SMALL-SCALE FIELD STUDIES AT CIBOLA NATIONAL WILDLIFE REFUGE

Small-scale field studies were implemented during 2007 to determine the effectiveness of seeding method (seed cleaning and seed-application technique) on the establishment and growth of Fremont cottonwood, Goodding's willow, and coyote willow. These 6 by 12 m plot studies are being conducted on the east end of Cibola NWR Field 51 (Figure 27). The following treatment variables were tested:

- Early-time (germination period) sprinkler irrigation versus surface irrigation only.
- Cleaned versus un-cleaned seed.
- Hydroseeding (cleaned and un-cleaned seed) versus broadcast seeding (cleaned seed only).
- Border (small-scale basin) versus furrow surface irrigation method.
- Location within Field 51 and associated soil conditions.

Plot preparation and instrument installation for soil water monitoring was initiated in April, and all plots were seeded on May 16. Soil water content, temperature and electrical conductivity data and groundwater elevation data are collected at ½-hour intervals. Vegetation monitoring was conducted September 7 through September 23, 2007 to determine establishment and growth after one growing season (herein defined as four months of growth, from seeding through September). The results from Task 5 will guide Task 6 (large-scale) studies, specifically regarding seeding and irrigation methods most likely to result in successful riparian revegetation. Additionally, limitations of soil quality and competition from weed species are analyzed.

4.1 Technical Approach

4.1.1 Small-scale Field Study Variables

Small-scale study variables were designed to analyze potential large-scale seeding and irrigation methods for the establishment of cottonwood and willow from native seed. Small-scale study variables are presented in Table 17. Additional detail and reasoning are provided below.

Irrigation Method

The early-time sprinkler irrigation treatment was implemented to determine if sprinkler irrigation would increase germination and decrease spatial variability of desired species compared to surface irrigation only. Sprinkler irrigation minimizes soil inundation and surface flow, and decreases salt concentration on furrow crests compared to surface irrigation only. Additional detail on sprinkler irrigation design is provided in Section 4.1.3.

Seed Cleaning

The seed cleaning treatment was implemented to investigate potential increases in cottonwood and willow establishment due to removal of seed hairs. During 2006 7-gallon test pot studies, cleaned seed resulted in an approximate doubling of target species establishment (GSA 2007a). Consequently, it was anticipated that seed cleaning would minimize seed translocation from wind and water flow, and maximize germination due to better soil-seed contact.

Furrow and border-strip surface irrigation methods were applied to determine the effects of these standard irrigation methods on plant establishment and growth. Border-strip irrigation consisted of small-scale basins enclosed by soil berms on all sides. Small ditches were present on three sides of the perimeter which minimizes sheet overflow, as water travels around the plots in the ditches before cresting onto the seeded area. Furrow irrigation was implemented via ripping and bed shaping (Figure 28). Furrows were placed on 1.02 m (40 inch) centers, and furrow depth was approximately 0.16 m (6 inches). Following seeding of plots, berms were constructed at the ends of plots to eliminate surface tailwater. Example furrow and border strip irrigation plots are shown in Figure 29, and additional irrigation specifications are provided in Section 4.1.3.

Seeding Method

The seeding method treatment was implemented to determine the effectiveness of standard large-scale seeding techniques on cottonwood and willow establishment. Standard seeding techniques include drill seeding, broadcast seeding, and hydroseeding. GSA originally proposed that drill seeding and broadcast seeding be analyzed in the small-scale field studies (GSA, 2007b). However, it was determined that “fluffy seed” broadcasters (e.g. Truax) and drill seeders would not be effective for un-cleaned cottonwood and willow seed (Robby Everhardt, Sunwest Golf and Reclamation, personal communication), and that the small weight of seed required for the Task 5 studies was insufficient for correct operation of a rangeland drill seeder. Consequently, the following seed methods were used for the small-scale field studies:

- Broadcast, un-cleaned seed.
- Hydroseed, cleaned seed.
- Hydroseed, un-cleaned seed.

These changes in the research design are incorporated into the final treatment design, as shown in Table 17.

For statistical analysis seed cleaning and seed application method are combined into a single effect, denoted “Seed Treatment”. This simplification allows for a block factorial study design and data modeling even though un-cleaned seed was not applied via broadcast seeding.

Plot Position

Treatment combinations were tested in triplicate, with replications numbered from one to three (increasing from north to south). Because of variation observed in soil salinity and subsurface texture within the eastern portion of Field 51 (GSA, 2008), it was likely that plot position might have a significant effect on plant establishment and growth. Therefore, "Plot Placement" was designated as a treatment variable, allowing for analysis of variation in growth in the study section of the field, and automatic correction for spatial variation in the ANOVA analysis. Plot position was denoted by the Block 1, Block 2, or Block 3 (refer to Figure 27).

Seeding Rate

The design seeding rate for the small-scale plots was 125 PLS/ft^2, which consisted of 25 PLS/ft^2 of Fremont cottonwood, and 50 PLS/ft^2 each of Gooding's and coyote willow. Weight calibrations were conducted at the NPC to determine the weight of cleaned and un-cleaned riparian seed. For the calibration, 1000 seeds of each species were counted onto Petri dishes, and the net weight was determined with an analytical scale (precision of 0.0001 g). Calibrated seed weights are provided in Table 18.

Although variable seeding rate was not a design variable, the seeding rate varied between hydroseeded plots due to variable application time per plot (range of 100 to 172 PLS/ft^2). For the hydroseeded plots, the actual seeding rate was estimated based on the duration of application from the hydroseeder (See Section 4.1.4).

Treatment Randomization

The small-scale field study consisted of a block factorial design based on the early-time sprinkler irrigation treatment. Because of sprinkler irrigation infrastructure, it was logistically impossible to randomly place all treatment combinations. Additionally, because variation in plant success was likely as a result of soil salinity and texture, it was desired to have a randomized block design to account for north to south variation in soil properties. Within sprinkler blocks, placement of the six treatment combinations of seeding treatment and surface irrigation method were randomized. The final layout for field treatments is provided in Figure 27. This layout resulted in three blocks, which were used for the "Plot Placement" variable.

4.1.2 Site Characterization

GSA has characterized soil conditions and depth to groundwater at Cibola NWR Field 51 since April 2006. Additional characterization of the small-scale study area was conducted via additional soil sampling and instrumentation of the small-scale plots. Detailed methods and results are provided in GSA (2007b). Soil characterization and instrumentation methods are briefly discussed below, and summary results are provided in Section 4.2.7.

Soils Analysis

Soils characterization consisted of analysis of physical and chemical soil parameters of interest for vegetation:

- Soil geochemistry: 12 soil samples were collected from within the small-scale study area during July, 2006. 9 samples were taken from 0 to 1 foot (0 to 30 cm) below ground surface (bgs), and 3 samples from 2 to 3 feet bgs (61 to 91 cm) bgs. Soil samples were tested for macro- and micro-nutrients, and screened for phytotoxic levels of elements.
- Soil salinity: Soil geochemistry samples were analyzed for soil salinity to provide salinity levels prior to intensive irrigation. Additionally, soil core samples were collected between 0 to 38 inches (0 to 97 cm) bgs in the center of each small-scale study plot following one growing season (November and December, 2007), to determine the effects of irrigation on soil salinity, and to provide comparison with ECH_2O-TE sensors (see below). Depth intervals of 4 to 8 inches (10 to 20 cm), 16 to 20 inches (41 to 51 cm), and 34 to 38 inches (86 to 97 cm) bgs were analyzed for soil salinity.
- The soil core intervals tested for soil salinity were also analyzed for soil texture (percent sand, silt, and clay) via visual-manual methods calibrated to hydrometer results.

Soil Water Content, Temperature and Electrical Conductivity

An instrument nest was placed in the center of each plot. An ECH_2O-TE (Decagon Devices, Inc., Pullman, WA) sensor was placed at six inches (15 cm) bgs to monitor soil temperature, soil specific conductance (EC), and soil volumetric water content. EC-10 sensors (Decagon Devices, Inc. Pullman, WA) were placed at eighteen inches (46 cm) and 36 inches (91 cm) bgs to monitor soil volumetric water content. Sensors were installed into the side wall of excavated pits (Figure 30). In furrow-irrigated plots, the instrument nest was placed below one of the two crests adjacent to the north-south median of each plot and the depth bgs was measured from the adjacent furrow crest. Additional detail on instrumentation methods, including installation and calibration, is provided in GSA (2008).

Groundwater Monitoring

Eight well point piezometers have been established across Field 51, and instrumented with pressure transducers and dataloggers to record groundwater elevations. The piezometers also allow analysis of groundwater mounding and dissipation following irrigation of Field 51 and adjacent fields. Five well points were installed in July, 2006, one in each corner of the field, and one in the center. Three additional piezometers were established in May, 2007, at three locations on either side of the small-scale study area. The piezometer locations are shown in Figure 27.

4.1.3 Plot Design and Implementation

Plot Dimensions and Spacing

The small-scale study plots were designed to accommodate the limitations of furrowing equipment and sprinkler equipment dimensions. The furrowing tractor attachment has a breadth of 20 feet (6 m). Therefore, the plots were designed as 20 feet (6 m) by 40 feet (12 m). Spacing between plots was either ten feet (between "No Sprinkler" plots) or fifteen feet (adjacent to all sprinkler-irrigated plots) to accommodate 40 foot sprinkler mainlines. A soil berm was placed between plots with no sprinklers. Two soil berms were placed between sprinkler-irrigated plots. Plot spacing and irrigation detail are shown in Figure 31.

Sprinkler Irrigation

Sprinklers were placed on a regular grid, with 40 foot (north-south) lateral spacing at by 30 foot (east-west) sprinkler spacing. Sprinkler mainlines were placed on the east side of the small-scale study plots. Sprinkler laterals were run between and on the outside of small-scale study plots with the early-time sprinkler irrigation treatment. Splash guards were placed on sprinkler heads between sprinkler and no sprinkler plots to prevent spraying of sprinklers onto no sprinkler plots. The sprinkler pump was placed along the east side of the plots, adjacent to the culvert previously used for flood irrigation of Field 51. The as-built sprinkler design is provided in Figure 31. Sprinkler irrigation was applied for three weeks after seeding (initiated May 16, 2007, and removed on June 7, 2007, when cottonwood seedlings were several inches tall). Sprinklers were run during daylight hours, and were actively managed to prevent drying of the surface soil while minimizing ponding.

A low-volume flowmeter was placed on the sprinkler irrigation mainline. The standard sprinkler application rate is 0.1 inches (0.25 cm) per hour (RainBird Corporation, Glendora, CA). This application rate was used to estimate applied water during early-time irrigation for the sprinkler irrigation plots. To estimate actual water requirements, average sprinkler application efficiency was assumed as 85%, following Schneider and Howell (1993). After sprinklers were removed, the flowmeter on the gated pipe mainline was used to monitor surface water application to all plots.

Border Strip and Furrow Irrigation

Six-inch outer diameter aluminum gated pipe was used to maximize uniformity of irrigation water distribution for border and furrow methods. A gated pipe lateral was placed along each side of the center, north-south plot dividing berm, as shown in Figure 31. This highly-controlled surface irrigation system allowed for minimal variation between plots and therefore reduced potential for study bias due to water availability.

A totalizing flow meter was placed adjacent to the gated pipe pump. During the first three weeks of irrigation, flow volumes were recorded for each irrigation event. Thereafter, cumulative flow volumes were noted upon each visit to the research site.

During the first three weeks of irrigation, GSA monitored differences in irrigation water requirement between furrow and border-irrigated plots. To quantify applied water for surface irrigation methods, the following protocol was implemented:

1) Open gates of all furrow-irrigated plots (no-sprinkler treatments only).
2) Record cumulative flow volume from totalizing flow meter.
3) Start gated pipe pump. Record time.
4) Allow irrigation to continue until water levels in furrow troughs are approximately 2/3 of the height of furrow crests.
5) Turn pump off. Record time and cumulative flow volume.
6) Close gates in furrow-irrigated plots. Open gates in border irrigated plots.
7) Start gated pipe pump. Record time.
8) Allow irrigation to continue until approximately 75% of the soil surface in border plots is inundated.
9) Turn pump off. Record time and cumulative flow volume.

The order of irrigation was reversed during subsequent irrigation events, such that border-irrigated plots would be irrigated first on the next day of irrigation.

For the first two irrigation events after sprinklers were removed, the gates were adjusted such that the required time of irrigation for all of the plots on the each half of the field were approximately equal to the duration of sprinkler operation on a full tank of gas. Therefore, the irrigation technician needed only to open the appropriate valves, fill the pump gas tank, and turn the pump on.

4.1.4 Seed Collection, Preparation and Application

Riparian seed for the small-scale studies was collected from various sources on the LCR. Cottonwood and Goodding's willow seed was collected March 12 to 16, 2007 at the Bill Williams River NWR and the Ahakhav Tribal Preserve. Additional Fremont cottonwood seed was collected from the Ahakhav Tribal Preserve and Cibola NWR April 11 to 16, 2007. Gooding's and coyote willow seed was collected from the Beal Lake Habitat Restoration Site, Ahakhav Tribal Preserve, and Cibola NWR during April 11 to 16, 2007.

Seed was allowed to dry in the laboratory for a minimum of one week. After drying, seed was stored un-cleaned in freezers. Sufficient seed of each species was cleaned using Wiley mills and

air screen machines as described in Section 3.1.1 for the 7-gallon pot studies. After cleaning, seed was returned to freezers. Incubator germination studies were then conducted for each seed source to determine the PLS rate for the small-scale studies.

Sufficient seed was obtained for each seeding method by mixing seed of source trees. As discussed below, cleaned, broadcast treatment seed was allocated per plot at the rate of 25 PLS/ft^2 of Fremont cottonwood, and 50 PLS/ft^2 each of Goodding's and coyote willow. Hydroseed treatment seed was allocated for thirteen plots, to allow sufficient seed for the twelve treatment plots and an additional test area. The allocated seed was then placed back in freezer bags, and stored in the NPC freezers until transport to Field 51 small scale plots for seeding.

One day prior to seeding in small-scale plots, on May 15, 2007, seed was transported to Blythe, California in insulated coolers. Block ice was placed in the bottom of coolers, and the seed was placed above. Upon arrival in Blythe, seed was transferred to hotel room freezers. On the morning of seeding (approximately 4:30 AM), the seed was returned to coolers and transported to Cibola NWR Field 51. Coolers with seed were stored in shade on-site until placement in plots.

Hydroseed was applied with a 550-gallon capacity Finn Hydroseeder (Finn Corporation, Fairfield, OH), as shown in Figure 32. The application rate was approximately 2300 gallons per acre of hydroseed consisting of water, mulch, and seed. Note that no chemical tackifiers were applied. Mulch consisting of Conwed® Fibers 2000 wood fiber (Profile Products, LLC, Buffalo Grove, IL) cellulose fiber was applied at approximately 100 pounds per acre. A known number of seeds was placed in the hydroseeder mixing tank based on 125 PLS/ft^2 and an assumed application rate of 2300 gallons per acre (3.52 m^3 per hectare). The actual time of seed application in each plot was noted in field books, as was the total duration of seed application (unused seed was sprayed onto an adjacent portion of the field until all seed was applied). The seeding rate for a given plot was then calculated from Equation 4.1:

$$\frac{PLS}{ft^2} = \frac{\frac{T_p}{T_t}(S_t)}{A} \qquad 4.1$$

where T_p is the time of application within a given plot, T_t is the total time of hydroseed application, S_t is the total seeds placed in the hydroseeder, and A is the plot area (800 ft^2). These calculations apply to both cleaned and un-cleaned hydroseed treatments, as one tank of hydroseed was applied for each seed type. Hydroseeding was completed by 11:35 AM on May 16, 2007.

Broadcast seeding was accomplished with a broadcast spreader (The Scotts Company, Marysville, OH), as shown in Figure 33. The seeding rate for broadcast-seeded plots was the nominal rate (i.e. 125 PLS/ft^2 total). The seed for each plot was placed in the spreader, and all seed was spread in each plot. Broadcast seeding was completed by 12:45 PM on May 16, 2007.

4.1.5 Vegetation Monitoring

Vegetation monitoring consisted of canopy cover measurements and harvested quadrats. The monitoring was a stratified random design, whereby one sample type was located randomly within each third of the plot (plot divisions based on distance from the gated pipe). The survey design for a hypothetical plot is provided in Figure 34.

Vegetation success during the small-scale field studies was monitored via point transects to determine crown and canopy cover, and quadrat harvests to determine stem density, height, and above-ground dry biomass. Data was collected in September 2007, after approximately four months of growth. Although plant growth continued into October 2007, surveys were implemented in September in order to avoid leaf drop by cottonwood and willow in the fall.

For crown and canopy cover estimation, plant identification was to the species level when possible. When plants were not yet mature enough to allow for species identification, classification was determined to family or genus level. However, to simplify plant material processing and data analysis, species were lumped as appropriate. Species specific data was analyzed for seeded riparian species (Fremont cottonwood, Goodding's willow, and coyote willow), saltcedar (*Tamarix ramosissima* Ledeb., TARA), and Colorado River hemp (*Sesbania herbacea* (P. Mill), McVaughn, SEHE). Grasses and sedges were lumped as Gramineae—no rushes were observed—and other species were classified as groups of shrubs and forbs. Non-target species observed in small-scale plots are listed in Table 19.

Cover Point Transects

Species-specific crown cover was estimated via point transects September 7 and September 8, 2007. Two wood stakes were used to stretch twine above the canopy across the plot from north to south (Figure 35), with the east-west location determined via random numbers (refer to Figure 34). The twine was marked at transect points separated by 1 ft. A dowel was held vertical at each transect point, and each cover type below the dowel was recorded on datasheets (Appendix A). Each cover type was recorded a maximum of once per point. Cover percentage of each component was obtained by dividing the number of "hits" by the number of sample points, as described by Equation 4.2:

$$Cover = \frac{n}{63} \times 100\% \qquad 4.2$$

where n is the number of hits of a given cover, and 63 is the number of observation points per plot (i.e. 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. Canopy cover included both crown cover and understory cover. Crown cover indicates the dominant (tallest and widespread) 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 must equal 100%, whereas the total canopy cover per species must be less than or equal to 100%.

Quadrat Sampling and Analysis

Quadrats consisted of three, 1- by 0.5-m rectangles (0.5 m^2) per plot constructed from ¾-inch diameter PVC pipe (Figure 36). The one-meter side of the quadrat was oriented north to south so that the length covered the entire width between furrows. This minimized potential bias from a furrow trough or crest, while providing a sufficient yet manageable survey area for the expected density of target plant species. 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. 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. An example survey layout is provided in refer to Figure 34.

Within quadrats, plant cover of all species was visually estimated using sociologic classification—crown and canopy cover for each observed species was estimated to the classes outlined in Table 20. Every plant in the quadrat was harvested at the soil surface using hand pruners. Fremont cottonwood, Goodding's willow, coyote willow, saltcedar, and Colorado River hemp stems were measured to the nearest 0.5 cm, and the number of height measurements was used to tabulate stem density (stems per square meter). Gramineae species were harvested together and placed into one paper bag, as were other shrubs and forbs. Biomass was determined using the oven drying method as described for the greenhouse pot studies.

As for transect surveys, data for the three quadrats per plot were combined to provide an overall estimate for the plot. Quadrat area represented approximately two percent of the total plot area.

Root Surveys

Root surveys were initially proposed within the small-scale study area after one growing season (GSA, 2007b). However, following discussion with Reclamation, the root survey was tentatively postponed to fall 2008 (i.e. after two growing seasons) in anticipation of increased riparian plant above and below-ground growth.

Statistical Analysis

For graphical purposes, statistics were analyzed via Student's t-tests for treatment variable effects. Additionally, linear analysis of variance (ANOVA) modeling was accomplished through use of JMP 6™ (SAS Institute, Cary, N.C.) to determine the impacts of treatments (sprinkler irrigation, seed application method, surface irrigation method, plot position, and seeding rate) on

the following results:

- Crown cover of target and non-target species.
- Canopy cover of target and non-target species.
- Stem density of target species and saltcedar.
- Height of target species and saltcedar.
- Dry biomass of target species, saltcedar, Gramineae, and various shrubs and forbs.
- Dry biomass per stem for Fremont cottonwood and saltcedar.

Significant treatment effects and interactions on a given result were determined by F-tests. Least-squared means were compared via Student's t-tests for the determination of significant differences between treatments.

As with the 7-gallon pot studies, graphical results are presented with 95% confidence intervals from the mean. Thus, non-overlapping error bars indicate significant differences at P = 0.05. In the ANOVA tables, the P-values for effects and interactions are based on F-tests. Significant differences for least-squared means are based on Student's t-tests with a P of 0.05.

Because the seeding rate was not a major variable, it could not be included as part of the factorial design, but was included as a continuous variable in the ANOVAs. Therefore, least-squared means were not available in the results. However, direct (increasing) or inverse (decreasing) relationships were calculated, and P-values associated with those relationships.

4.2 Small-scale Field Study Results

Linear ANOVA modeling results are provided in Table 21 and Table 22, and treatment effects are discussed in detail below. All field data are provided in Appendix E Because low establishment of willow species resulted in a lack of data for certain treatment results, crown cover results are only presented for cottonwood, saltcedar, and Gramineae (combined grasses and sedges—no rushes were observed). Average height results are only presented for cottonwood and saltcedar. Because the quadrat sampling size was designed for high establishment of plants, the survey methods may have limited the effectiveness of characterization for willow species. A more effective long-term monitoring method will be to conduct complete censuses of each plot for Goodding's and coyote willow. Such a count was not possible during the 2007 survey period because plants many plants were too small to be observed.

4.2.1 Early-time (germination period) Sprinkler Irrigation Treatment Effects

Sprinkler irrigation resulted in decreased cottonwood (Table 21) and saltcedar crown and canopy cover (Table 22, Figure 37, Figure 38), coupled with an increase in Gramineae crown cover (Table 22, Figure 37). Gramineae biomass (Figure 39, Table 22) and canopy cover (Figure 38,

Table 22) were not increased, indicating that grass growth remained approximately the same between the sprinkler and non-sprinkler irrigated plots.

The number of cottonwood, Goodding's willow, and coyote willow stems per m^2 did not significantly increase or decrease with sprinkler irrigation (Table 21). The number of saltcedar stems decreased by approximately 50% (Table 22). Biomass of both cottonwood and saltcedar decreased with sprinkler irrigation (Figure 39), by approximately 70% (Table 21) and 80% (Table 22), respectively.

For non sprinkler-irrigated plots, the crown cover of cottonwood was greater than that of saltcedar for twelve of eighteen plots (Figure 40), and canopy cover of cottonwood was greater than that of saltcedar for four of eighteen plots (Figure 41). For sprinkler-irrigated plots, the crown cover of cottonwood was greater than that of saltcedar for thirteen of eighteen plots (Figure 42), and the canopy cover of cottonwood was greater than that of saltcedar for eleven of eighteen plots (Figure 43). Canopy cover of cottonwood and Goodding's willow decreased by approximately 50% (Table 21) from sprinkler irrigation. Saltcedar canopy cover decreased by approximately 75% (Table 22) due to sprinkler irrigation. A significant effect was not observed for coyote willow canopy cover.

In the non-sprinkler irrigated plots, more stems per m^2 of saltcedar were observed than stems per m^2 of cottonwood in fifteen of eighteen plots (Figure 44). In sprinkler irrigated plots, more stems per m^2 of saltcedar were observed than stems per m^2 of cottonwood in ten of eighteen plots (Figure 45). For treatment averages, there were more stems per m^2 of saltcedar than cottonwood in all treatments except NUHF, YCBF, and YCHB (Figure 46).

In summary, these data indicate that sprinkler irrigation did not affect cottonwood or willow establishment rates, but decreased the growth rate of established plants. Saltcedar establishment and growth rates were reduced in sprinkler-irrigated plots.

4.2.2 Seed Cleaning and Application Method (Seed Treatment)

The un-cleaned seed hydroseeding method resulted in the highest canopy cover, stem counts, and biomass for all three seeded species (Table 21). The values for each of these parameters were significantly higher compared to the cleaned broadcast seed treatment (Table 21). However, differences for coyote willow were not significant in respect to stems or biomass per m^2 (Table 21). The un-cleaned seed hydroseeding method also resulted in increased Goodding's willow canopy cover and cottonwood stem count compared to cleaned hydroseeding (Table 21). It is of note that no willows were found within quadrats of sprinkler-irrigated, cleaned seed, broadcast treatments (YCBB and YCBF in Figure 47).

The seed treatment variable did not have a significant effect on any of the non-target indicators, as shown in Table 22.

4.2.3 Surface Irrigation Method

Furrow irrigation significantly increased Goodding's willow canopy cover, stem count, plant height, and biomass compared to border-strip irrigation (Table 21). Fremont cottonwood maximum height and biomass per stem also increased significantly with furrow irrigation. No other target species indicators showed significant differences (Table 21).

No significant effects were observed for non-target species as a result of furrow or border irrigation methods (Table 22).

From general observation furrow irrigation without sprinklers typically resulted in a lack of plant growth on the crest of furrows. The furrow crests were wetted during irrigation through capillary action. However, seed germination and plant growth on the crest may have been prevented by salt accumulation due to evaporation, and lack of leaching on the crest.

4.2.4 Plot Position

Plots within Block 1 on the north end of the field (Figure 27) had lower cottonwood cover, plant establishment, maximum plant height, and biomass per m^2 than plot Block 2 or 3 (Table 21). For non sprinkler-irrigated plots, the crown cover of cottonwood was lower in Block 1 than both Block 2 and 3 (Figure 40), and the canopy cover of cottonwood in Block 1 was less than that of Block 3 for all treatments (Figure 41). Sprinkler-irrigated plots did not consistently show this trend (Figure 42 and Figure 43). Willow establishment growth was not significantly affected by plot placement. However, as mentioned previously, the low abundance of willow could not be accommodated by surveys, and might therefore have masked plot position effects.

The large variation in cottonwood growth observed may be due to higher subsurface soil salinity in the extreme northeast corner of Field 51 (GSA 2008). Non-target species did not show a consistent trend as a result of plot position (Table 22) which could be due to the higher salinity tolerance of saltcedar (Desert Research Institute, 1990) and the various grasses observed (Marcum et al., 2005).

4.2.5 Seeding Rate

Actual seeding rates in the hydroseeded plots varied from 80 to 140 PLS/ft^2, with an average of 96 PLS/ft^2. All cleaned broadcast seed application was assumed to be at the nominal rate of 125 PLS/ft^2. Seeding rate was directly correlated with cottonwood and Goodding's willow plant establishment (stems/m^2), as well as cottonwood biomass. Other relationships were not significant at P=0.05 (Table 21 and Table 22). Specifically, the biomass per stem of Fremont cottonwood did not significantly decrease with higher seeding rates. This result indicates that, at least for one growing season, intraspecific competition did not reduce plant growth rates for cottonwood. Long-term monitoring is required to determine competition effects for mature trees.

4.2.6 Small-scale Field Study Vegetation Summary

At least one Fremont cottonwood tree was observed in every small-scale study plot. Quadrat stem counts ranged from zero (YCBB1 and YCHB1, Figure 45) to greater than 59 per m^2 (NUHF3, Figure 44). The average cottonwood stem density was approximately 18 per m^2 (establishment of approximately 7% of seeded PLS rates). Establishment of willow species in the plots was much lower than for cottonwood. Goodding's willow was observed in quadrats of 12 of the 36 plots. Coyote willow was observed in quadrats of six plots. Generally, growth of desired plants increased from north to south across the study site. The maximum cottonwood biomass was 220.3 g per m^2 (NUHF3, Figure 48), and the average was 45.2 g per m^2. The maximum Goodding's willow biomass was 5.6 g per m^2, and the average was 0.46 g per m^2. The maximum coyote willow biomass was 1.9 g per m^2, and the average was 0.14 g per m^2.

Undesired plants were abundant in study plots. Specifically, Bermudagrass established immediately after irrigation, and grew faster than seeded species. Arrow 2EC grass-specific herbicide was applied to all plots on June 25th approximately 5 weeks after the seeding. This application resulted in variable Bermudagrass mortality, but retarded grass growth in all areas. In the following weeks, barnyard grass other grasses increased in abundance, and composed the majority of cover (Figure 37 and Figure 38) and biomass (Figure 39) during surveys.

Saltcedar was abundant in small-scale study plots. The stem counts ranged from two to 70 per m^2 (Figure 44), with an average of 25 per m^2. Biomass was as high as 93.5 g per m^2 (NCHF2, Figure 48). However, saltcedar was primarily in the understory, with an average crown cover of less than 4%.

Canopy cover of saltcedar was greater than that of cottonwood in all non sprinkler-irrigated treatments except NUHF, whereas canopy cover of saltcedar was less than that of cottonwood for all sprinkler irrigated plots except YCBB (Figure 38). However, crown cover per treatment of cottonwood was greater than that of saltcedar for all treatments except YCBB (Figure 40), and average biomass of cottonwood per treatment was greater than that of saltcedar for all treatments except NCBB, YCBB, and YUHF (Figure 49). The maximum tree height of cottonwood was greater than that of saltcedar for all treatments except NCBB, NCHF, YCBB and YCHB (Figure 49). In summary, these results indicate that saltcedar was abundant, but cottonwood growth was greater than saltcedar.

4.2.7 2007 Site Characterization Data

Detailed site characterization data is provided in GSA (2008). Summary observations are provided below.

Soil Salinity

Surface soil paste EC was less than 2 dS/m for all but one sample prior to irrigation of the small-scale study plots (July, 2006). The average salinity for 0 to12 inches (0 to 30 cm) bgs was 1.64

dS/m. Following irrigation for the 2007 growing season (November and December, 2007), the average near-surface (4 to 8 inches, 10 to 20 cm bgs) soil salinity was 5.5 dS/m, which approaches the tolerance for cottonwood and willow seedlings. The average salinity at 16 to 20 cm (41 to 51 cm) bgs was 10.5 dS/m. The average salinity at 34 to 38 inches (86 to 97 cm) bgs was 7.36 dS/m. Surface soil salinity following irrigation was highest in the northern small-scale study plots (YCBB 1, YCHB 1). At depth, lower salinity values were observed for coarser-grained (sandy) soils.

Geochemistry

Soil macro-nutrients ranged from very low to very high within the small-scale study area, and did not show consistent spatial trends. Soil copper (Cu), iron (Fe), and sulfur (S) were consistently high across the small-scale study area. With the exception of high manganese (Mn) and low boron (B), other micro-nutrients were not measured at very low or high concentrations. Soils consistently showed high pH and alkalinity.

Soil Texture

In the small-scale study area, surface soils (i.e. less than 50 cm bgs) were predominantly silt and silt loam. On the southern portion of the small-scale study area, the soil texture was coarser at depth, with sand and sand loam soil textures more prevalent. Silt loam and silt soils were consistent to depths of one m bgs on the northern portion of the small-scale study area.

Irrigation Water Application

The irrigation schedule for the first three weeks of the small-scale plot study is provided in Table 23, and the surface irrigation schedule for the remainder of the growing season (June 7 through October 11, 2007), is provided in Table 24. Surface irrigation was applied sixteen times during the first three weeks by GSA personnel. After this time, plots on the northern half of the field were watered 22 times between June 7 and October 11, 2007 using the gated pipe. Plots on the southern half of the field were watered nineteen times with the gated pipe during the same period. All plots were also watered by a sub-contractor on August 15, September 11, and September 29, 2007, using the large-scale Field 51 irrigation system instead of the gated pipe. For unknown reasons, the sub-contractor constructed a large berm on the west side of the small-scale study area, and flood irrigated all of the small scale plots by inundating this larger-scale basin, rather than using the gated pipe as designed. The result was poorly-distributed irrigation events, where plots adjacent to the irrigation culvert received water, and those on the west side of the small-scale study area received little or no water.

The combination of less frequent irrigation application than planned, and failure to utilize the gated pipe for all irrigation events likely resulted in mortality of Fremont cottonwood trees in plots. More than ten dead cottonwood trees were observed in NUHB 1, NCBB 1, YUHF 1,

YCBB 2 during the transect survey (Appendix E). These plots were spatially distant from the irrigation culvert.

During the first three weeks of irrigation 2.4 feet (0.74 m) of water were used for furrow surface irrigation, 3.3 feet (1.00 m) of water were used for border surface irrigation, and 1.8 feet (0.53 m) were estimated to be applied for sprinkler irrigation (Table 23). The actual applied water during the 2007 study cannot be determined due to irrigation water application from the large-scale irrigation infrastructure (i.e. gated culvert). However, for the first three weeks of irrigation, border irrigation without sprinklers required the most water of the irrigation treatment combinations analyzed. Furrow irrigation water use was approximately 24% less, and sprinkler water use was the lowest, at 53% of border irrigation use.

Soil and Groundwater Instrumentation

Depth to groundwater during the summer of 2006 (i.e. prior to regular irrigation for the current feasibility study) varied between 2.2 and 2.6 m bgs. Groundwater elevations generally increased during the winter of 2006-2007 (Figure 50), resulting in a groundwater elevation gradient from the northeast side of the field (Figure 51). This gradient is likely due to inundation of the Cornfield (northeast of Field 51) for waterfowl use. Groundwater elevations on the northwest side of the field were relatively constant (Figure 50). During late winter 2007 the groundwater elevations decreased and in early spring became and increasingly variable, likely due to irrigation of Field 51 as a part of the pre-planting weed control program (GSA, 2007b), and irrigation of adjacent fields.

Following the onset of irrigation for small-scale study pre-planting weed control, groundwater mounding occurred on the east side of Field 51, resulting in a general east to west gradient (Figure 52). Following ten days of intensive irrigation for the small-scale test plot studies, this east-west gradient was enhanced (Figure 53) due to groundwater mounding of greater than 0.4 m in the southern portion of the small-plot study area (Figure 54), possibly due to higher permeability soils in the area (GSA, 2008). As shown in Figure 55, groundwater elevation responded quickly to small-scale study surface irrigation events, and groundwater elevations were generally reduced beginning in mid-June, after the frequency of irrigation was decreased (Figure 55).

Figure 56 shows the effects of irrigation over time on soil volumetric water content for plots YCHF 2 and YUHF 2. An extended reduction in soil moisture is observed for YUHF 2 compared to YCHF 2 during August and September, 2007. This variation is due to sub-contractors utilizing the irrigation culvert for irrigation instead of the gated pipe pump (detail below).

Figure 57 shows the difference in volumetric water content response for a plot with high cottonwood and saltcedar establishment and growth compared to that for a plot with relatively little cottonwood and salt cedar growth (YCHB 3 and NCBF 2, cottonwood and saltcedar

combined biomass of approximately 18 g per m^2 versus 193 g per m^2). Water content decreased more rapidly after irrigation events for NCBF 2, likely indicating transpiration from cottonwood and willow.

Figure 58 shows the temperature and salinity instrument data at six inches (10 cm) bgs for a relatively saline plot (YCHF 1, estimated 10 cm bgs saturated paste extract salinity of 10.9 dS/m on December 19, 2007) compared to that of a relatively low-salinity plot (YUHF 2, 20 cm bgs saturated paste extract salinity of 2.7 dS/m on November 19, 2007). Salinity measured at the YCHF 6-inch sensor depth shows peaks immediately after irrigation which indicates accumulation of salts at the soil surface that are flushed down into the profile with the irrigation water. A similar response is not observed in YCHF 1. Of note are the initially high EC values observed in the YCHF 1 plot (> 5 dS/m) and the persistence of salinity throughout the growing season even after repeated irrigation events. These data indicate that excessive salinity in YCHF 1 was only partially mitigated by irrigation due to poorly drained soils, and excessive evapo-concentration in the northern end of the test plots.

5.0 CONCLUSIONS

Task 1 Riparian Seed Availability and Long-Term Storage Germination Trials

Seed of Fremont cottonwood, Gooddings willow and Coyote willow species is generally available in abundance on the LCR, and is not perceived as a constraint to large-scale revegetation (i.e. several cottonwood Gooding's willow trees would provide sufficient seed for several acres. A higher number of coyote willow source trees would be required for the same amount of area.). Seed of Emory's baccharis, honey mesquite, screwbean mesquite, and quailbush is likewise readily available. Currently, there is limited availability of native mule's fat on the LCR and propagation in Reclamation nurseries may be needed. Desertbroom seed is not available in abundance on Cibola NWR; availability on northern portions of the LCR will be evaluated in 2008.

Fremont cottonwood, Goodding's willow, and coyote willow seed viability is not favorable after two months of storage at room temperature. The viability of cottonwood and willow seed can be extended by freezing to at least 21 months. Seed cleaning and oxygen removal has not increased seed viability of seed to this point in the study.

Task 2 Mesquite Bosque Greenhouse 7-gallon Pot Studies

Favorable establishment and growth of mesquite species was observed, even at the lowest seeding rates evaluated (10 PLS/ft^2 each of honey and screwbean mesquite). However, extensive competition was observed between honey mesquite, screwbean mesquite, and quailbush. Quailbush was out-competed by mesquite at all seeding rates. Screwbean mesquite was dominated by honey mesquite, particularly at high seeding rates. Therefore, separation of species or reduction of honey mesquite seeding rates may be required for field revegetation efforts.

Honey and screwbean mesquite establishment did not differ between topsoil and sand soil pots. However, growth was greatly reduced from loose topsoil to compacted layer topsoil to sand pots.

Task 3 Riparian 7-gallon Pot Studies

Storage of riparian seed for one year did not decrease establishment or growth of riparian tree species. Organic fertilizer decreased plant establishment, and is unnecessary in Field 51 topsoil. It is currently not possible to determine with certainty the reason for decreased establishment of cleaned 2006 Goodding's willow seed. It is possible that the Wiley Mill resulted in a reduction in seed viability, either through seed obliteration or heating. This result demonstrates the need for germination trials prior to large-scale seeding.

Task 4 Baccharis Greenhouse 7-gallon Pot Studies

Emory's baccharis exhibited relatively slow growth rates in the pots compared to other MSCP

target species. However, plants were well-established by the end of the growing season. As observed on the LCR, baccharis species are shade tolerant relative to riparian plants. For example, baccharis has established in the understory of the Nature Trail and mass planting fields adjacent to Field 51. Therefore, low initial growth rates for baccharis should not necessarily be considered a limitation.

Further investigations are necessary to determine the feasibility of direct-seeding mule's fat on the LCR. Mule's fat seed exhibited no viability after five months of storage at laboratory temperature. Poor viability of Emory's baccharis was also observed after five months of storage. Further investigation is required to determine the optimal methods of seed storage to maintain viability of these species prior to seeding at revegetation sites.

Sweetscent established well on loose Field 51 topsoil. However, this plant established poorly in compacted soil pots. Further investigations are required for this and other understory species prior to implementation of large-scale seeding on the LCR.

Emory's baccharis establishment and biomass decreased from loose topsoil to compacted layer soil treatments. No establishment was observed for baccharis or sweetscent in sand pots.

Task 5 Riparian Small-Scale Field Studies

Fremont cottonwood established and grew well during the first growing season after seeding, and dominated the crown cover of many plots. However, Goodding's and coyote willow establishment was poor. Non-target species (primarily grass and sedges) dominated biomass in the small-scale plots and saltcedar showed a significant proportion of total stem counts. These results indicate that grass must be sprayed earlier and more effectively following the onset of irrigation. Additionally, more extensive site preparation should be undertaken during future studies to reduce weed seed banks.

The actual water applied during 2007 field studies varied between plots due to unplanned irrigation with the large-scale Field 51 culvert, and hence. Based on 2007 data from May 16, 2007 through June 6, 2007, border irrigation (no sprinklers) requires the most applied water. Furrow irrigation (no sprinklers) required less water use, and sprinkler application required the least.

However, early-time sprinkler irrigation showed negative effects on target species plant growth, although plant establishment was not significantly different due to sprinkler irrigation. Sprinkler irrigation may be a viable option for revegetation where site conditions are not favorable for surface irrigation (e.g. sandy soils or uneven topography). Furrow irrigation did not increase Fremont cottonwood establishment in small-scale studies. However, plant height was greater in furrow-irrigated plots, and cottonwood biomass per stem was also greater.

Hydroseeding un-cleaned seed resulted in increased establishment of riparian tree species. Hydroseed application for a typical revegetation project (e.g. 15-20 acres) would cost approximately $600.00 per acre, whereas broadcast seed application would cost approximately $300.00 per acre. However, broadcast seeding requires seed cleaning, which would offset a significant portion of the decreased application costs.

Groundwater instrumentation results indicate short-term groundwater mounding following irrigation events. Soil water content monitoring indicates that many of the small-scale study plots did not receive irrigation for extended periods during July through September, 2007. The persistence of salinity in the northern test plot area may preclude successful riparian tree establishment.

6.0 RECOMMENDATIONS

Germination Studies

Germination studies should be continued for riparian tree species until current seed stores are exhausted (April 2008). Should viability remain favorable, longer-term storage trials may be justified to determine if seed of these species can be stored in freezers for several years. Because of the poor success of baccharis species in greenhouse pot studies, germination studies should be implemented to evaluate different storage methods and determine the potential for long-term storage of baccharis seed.

Field Study and Demonstration Plots

Vegetation monitoring of the Task 5 small-scale study plots should be continued during 2008 to determine long-term success of Fremont cottonwood, and monitor for presence of previously unobserved willow trees. It is recommended that long-term monitoring areas (quadrats) be established in spring 2008 for long-term monitoring of cottonwood-saltcedar dynamics. Because of the irrigation infrastructure and groundwater and soil moisture monitoring systems established in 2007, the existing small-scale study also provides a unique opportunity to conduct irrigation water use and optimization studies for Fremont cottonwood.

Additional small-scale study plots should be implemented to analyze willow establishment from seed. To enhance the potential for success, an intensive weed control plan should be implemented to include irrigation, herbicide application, and tillage prior to seeding. Grass-specific herbicide should be applied within two weeks after irrigation initiation, and repeated as needed for at least one growing season. Study plots should be seeded with only willow species, so that Fremont cottonwood does not out-compete willow species, as observed during greenhouse studies (GSA 2007a). Appropriate variables for Goodding's willow small-scale studies include furrow versus border irrigation and seed application methods. Timing of seeding should also be considered. Goodding's willow on Cibola NWR tend to seed in June and July, and it is possible therefore that seeding during these months to mimic natural seedfall would result in improved establishment and growth rates.

Larger demonstration plots are recommended for mesquite species and Fremont cottonwood since they have shown viability at the field scale. Demonstration plots should be implemented with extensive weed control. Completed and planned seed collection would also allow comparison of year-old versus freshly-collected cottonwood seed in a field setting.

7.0 ACKNOWLEDGMENTS

We thank the Reclamation Lower Colorado Regional office for its funding and guidance for this project. Additionally, we thank the Fish and Wildlife Service management and staff at Cibola NWR for their assistance at the field site and those at Bill Williams NWR and Havasu NWR for their permission and assistance for seed collection efforts. Finally, we thank the Bureau of Land Management for their permission and guidance in seed collection at Pratt Restoration Site.

8.0 REFERENCES

Baskin, C.C., and J.M. Baskin, 1998. Seeds: Ecology, Biogeography, and Evolution of Dormancy and Germination. Academic Press. San Diego, California.

Delouche, J.C., and W.P. Caldwell, 1960. Seed vigour and vigour tests. Proceedings of the Association of Official Seed Analysts 50:124–129.

Desert Research Institute. 1990. Assessment of the salinity tolerance of eight Sonoran Desert riparian trees and shrubs. Prepared for Bureau of Reclamation, Lower Colorado Region, Yuma Projects Office, Yuma, Arizona. September 10, 1990.

GeoSystems Analysis, Inc. 2007a. Feasibility Study Using Native Seeds in Restoration, California-Arizona-Nevada" (Bureau of Reclamation Contract No. 06CR308057) – 2006 Annual Report. Prepared for Bureau of Reclamation, Lower Colorado Region, February 1, 2007.

GeoSystems Analysis, Inc. 2007b. Year 2 Proposed Study Plan - Feasibility Study Using Native Seeds in Restoration, California-Arizona-Nevada. Prepared for Bureau of Reclamation, Lower Colorado Region, April 5, 2007.

GeoSystems Analysis, Inc., 2008. Site Characterization: Cibola National Wildlife Refuge Field 51. Prepared for Bureau of Reclamation, Lower Colorado Region, March 31, 2008.

GSA, see GeoSystems Analysis, Inc.

Marcum, K.B., M. Pessarakli, and D.M. Kopec. 2005. Relative tolerance of 21 turf-type desert saltgrasses compared to bermudagrass. Horticultural Science 40:827-829.

Milton, S. J.,1999. Statistical Methods in the Biological and Health Sciences. McGraw-Hill, Boston, MA.

Schneider, A.D. and T.A. Howell. 1993. Reducing Sprinkler Water Losses. Proceedings of the Central Plains Irrigation Short Course. Sterling,CO. Feb. 2 and 3. pp. 43-47.

Smith, K.D., May, P.B., and G.M. Moore, 2001. The influence of compaction and soil strength on the establishment of four Australian landscape trees. Journal of Arboriculture 27(1): 1-7.

USDA, 2002. Conservation Practice Standard, Arizona: Range Planting. Handbook No. 550 (Draft), Natural Resources Conservation Service.

USBR. 2005. Beal Lake Habitat Restoration. US Department of the Interior, Bureau of Reclamation. Lower Colorado Region, Boulder City, Nevada.

TABLES

Table 1. Seed storage treatments for Fremont cottonwood, Goodding's willow, and coyote willow germination trials.

Variable	Treatment	Specifications
Seed Cleaning	Cleaned	Seed removed from pods, blown through a sieve series using compressed air to remove hairs.
	Un-Cleaned	Seed removed from pods, stored with hairs still attached.
Oxygen Condition	Oxygen Purged	Oxygen removed via air purging with a vacuum and replacement with nitrogen gas. Seed stored in vials.
	Ambient	Seed stored at ambient oxygen. Seed stored in envelopes (ambient temperature) or plastic bags (frozen).
Storage Temperature	Frozen	Seed stored in freezers at -10°C (Goodding's willow and coyote willow) or -19°C (Fremont cottonwood).
	Ambient	Seed stored in the laboratory at an average temperature of 21°C (thermostat-controlled).

Table 2. Seed source information for Fremont cottonwood, Goodding's willow, and coyote willow germination trials.

Seed Description	Species[1]	Tree Number	Collection Date	UTM Easting (m)[2]	UTM Northing (m)	Tree Location	Tree Source
Original Seed—Split April 2006 into Eight Storage Treatments	POFR	4	4/28/2006	715838	3694760	North of the Nature Trail (Cibola NWR)	Native
	POFR	22	4/26/2006	716410	3694158	Along Goose Loop adjacent to the Nature Trail	Mountain State Nursery
	SAGO	2	4/27/2006	716169	3694398	The Nature Trail	Mountain State Nursery
	SAGO	21	4/27/2006	716043	3694381	The Nature Trail	Mountain State Nursery
	SAEX	18	4/27/2006	745724	3779004	The Ahakhav Tribal Preserve	Unknown
	SAEX	32	4/27/2006	745711	3779205	The Ahakhav Tribal Preserve	Unknown
Supplemental—Stored as Frozen, Un-Cleaned	POFR	4	4/10/2006	715838	3694760	North of the Nature Trail (Cibola NWR)	Native
	SAEX	20	4/14/2006	745720	3779012	The Ahakhav Tribal Preserve	Unknown
	SAGO	5	4/10/2006	716076	3694376	The Nature Trail	Mountain State Nursery

1 Species codes indicate Fremont cottonwood (POFR), Goodding's willow (SAGO), and coyote willow (SAEX).
2 UTM coordinates are NAD 83, Zone 11.

Table 3. Schedule for Fremont cottonwood, Goodding's willow, and coyote willow germination trials.

Trial Number	Seeding Date	Original Seed	Supplemental Seed[1]	Notes
1	5/05/06	X		Initial viability trial (Un-cleaned seed, room temperature storage only)
2	5/26/06	X		
3	6/07/06	X		
4	6/22/06	X		
5	7/06/06	X		
6	7/21/06	X		
7	8/08/06	X		
8	8/23/06	X		
9	9/08/06	X		
10	10/12/06	X		21°C (room temperature) storage treatment trials discontinued
11	11/16/06	X		
12	12/6/06	X		Heated soil trials discontinued
13	1/2/07		X	Incubator only
14	2/15/07	X		
15	4/18/07	X		
16	6/4/07	X		
17	7/18/07		X	Poor viability for Salix spp.
18	8/22/07		X	
19	10/5/07	X		
20	10/29/07		X	
21	11/29/07		X	

1 Supplemental seed consists of seed collected in April 2006, and stored thereafter in freezers with ambient oxygen conditions.

Table 4. Seed collection sites utilized during calendar year 2007.

Collection Site[1] and Species	Comments (Favorable Collection Periods)
Cibola NWR—The Nature Trail	Easily accessed by vehicle. Some easy hiking required for interior trail access. Special use permit required from the US Fish and Wildlife Service (US FWS).
Quailbush	Abundant along farm roads, with high seed production (December).
Mule's Fat	Not observed.
Desertbroom	Not observed.
Emory's Baccharis	Abundant (November-December).
Fremont Cottonwood	Abundant, but minimal seed production. One tree (POFR 4) northwest of the cornfield had easy access by vehicle and very abundant seed (April-May).
Honey Mesquite	Abundant plants with high seed production (July-August).

Collection Site[1] and Species	Comments (Favorable Collection Periods)
Screwbean Mesquite	Abundant plants with moderate seed production. Late maturity (not yet mature in mid-August). Plants in poor condition during 2007.
Coyote Willow	Abundant plants in poor condition. Low seed production.
Goodding's Willow	Abundant plants in variable condition. Moderate seed production (April).
Cibola NWR—Levee Roads	Easily accessed by vehicle, but plants away from road have very poor access due to steepness of levee banks, dense saltcedar, and/or saturated/flooded soils. Care should be taken when driving to avoid sharp rocks. Special use permit required from US FWS.
Quailbush	Abundant plants. Widely dispersed. High seed production (December).
Mule's Fat	Not observed.
Desertbroom	Not observed.
Emory's Baccharis	Abundant (November and December).
Fremont Cottonwood	Abundant plants, but poor access.
Honey Mesquite	Abundant plants, with variable access. Easy collection when pods fall on bare ground (July-August).
Screwbean Mesquite	Abundant plants, with variable access. Easy collection when pods fall on bare ground (early July).
Coyote Willow	Several widely dispersed plants, poor seed production.
Goodding's Willow	Several widely dispersed mature plants. Seed production minimal during 2007 due to July 2006 fires.
Cibola NWR—Island Unit	Easily accessed by vehicle, variable hiking required dependent on site. Revegetated sites were most easily accessed. Special use permit required from US FWS.
Quailbush	Abundant along roads, with high seed production (December-January).
Mule's Fat	Not observed.
Desertbroom	Not observed.
Emory's Baccharis	Few plants (November and December).
Fremont Cottonwood	Variable access and production. Collection time varies by site (April-May).
Honey Mesquite	Abundant and easily accessed (July-August).
Screwbean Mesquite	Abundant at revegetated sites, uncommon elsewhere. Later maturity than along levee roads (August-September).
Coyote Willow	Not observed.
Goodding's Willow	Common at revegetated sites and marshes (i.e. East Meander). Later maturity than the Nature Trail (late April-May).
The Ahakhav Tribal Preserve	Easily accessed by vehicle. Some easy hiking required. Permission required from Colorado River Indian Tribes.
Quailbush	Uncommon.
Mule's Fat	Several plants (November-December).
Desertbroom	Not observed.
Emory's Baccharis	Abundant source plants and (November and December).
Fremont Cottonwood	Abundant, with high seed production (March-April).
Honey Mesquite	Not evaluated.
Screwbean Mesquite	Not evaluated.
Coyote Willow	Several large stands with high seed production (April).
Goodding's Willow	Abundant, with high seed production (April).
Bill Williams River NWR West—Lake Havasu to Cohen Ranch	Some access along road, but enhanced greatly by approximately 2 km of moderate hiking to Cohen Ranch. Special use permit required from US FWS.
Quailbush	Abundant, with high seed production (December).
Mule's Fat	Common. Moderate seed production (November-December).

Collection Site[1] and Species	Comments (Favorable Collection Periods)
Desertbroom	Common. High seed production (November-December).
Emory's Baccharis	Abundant. High seed production (November-December).
Fremont Cottonwood	Common, but variable access (March).
Honey Mesquite	Common, seed production not analyzed.
Screwbean Mesquite	Rare, seed production not analyzed.
Coyote Willow	Not observed.
Goodding's Willow	Common, high seed production (April)
Bill Williams River NWR at Mineral Wash	Some access along road, but enhanced greatly by moderate hiking. Special use permit required from US FWS.
Quailbush	Common. Moderate seed production (November-December).
Mule's Fat	Common. High seed production (November-December).
Desertbroom	Common. High seed production (November-December).
Emory's Baccharis	Common. High seed production (November-December).
Fremont Cottonwood	Abundant and accessed with some hiking. High seed production (March).
Honey Mesquite	Common, seed production not analyzed.
Screwbean Mesquite	Not observed.
Coyote Willow	Not observed.
Goodding's Willow	Common, high seed production (April).
Havasu NWR—Beal Lake Habitat Restoration Site	Easy access along roads. Special use permit required from US FWS.
Quailbush	Not analyzed.
Mule's Fat	Not analyzed.
Desertbroom	Not analyzed.
Emory's Baccharis	Not analyzed.
Fremont Cottonwood	Abundant and accessed with some hiking. Seed not observed in April.
Honey Mesquite	Not analyzed.
Screwbean Mesquite	Common, seed production not analyzed.
Coyote Willow	Common along levee road. Low seed production during 2007 because of pole harvesting (April).
Goodding's Willow	Common, high seed production (April).
Pratt Restoration Site	Easily accessed by vehicle, but limited access due to hiking restrictions. Permission required from the Bureau of Land Management. Not utilized during 2007.
Quailbush	Not evaluated.
Mule's Fat	Not observed.
Desertbroom	Not observed.
Emory's Baccharis	Abundant source plants and (November and December).
Fremont Cottonwood	Abundant plants. Seed production not evaluated.
Honey Mesquite	Not evaluated.
Screwbean Mesquite	Not evaluated.
Coyote Willow	Not evaluated.
Goodding's Willow	Not evaluated.

1 In order of increasing proximity from Cibola NWR.

Table 5. Summer 2007 riparian species cohort 7-gallon pot study specifications.

Variable	Treatment	Specifications
Soil Treatment	Loose	Loose soil shoveled into pots, not manually compacted.
Seed Collection Year	2007	Seed collected during March and April 2007 (approximately two months before seeding).
	2006	Seed collected during March and April 2007 (approximately 14 months before seeding.
Seed Type	Cleaned (C)	Pubescence removed from seed coats using Wiley Mill.
	Un-cleaned (U)	Pubescence not removed from seed coats.
Organic Amendment	0 lbs/acre	Biosol organic fertilizer not applied.
	1500 lbs/acre	Biosol organic fertilizer applied at a nominal rate of 1500 lbs/acre.
Greenhouse Block (Repetition)	1	Repetition 1, in block on north end of the greenhouse.
	2	Repetition 2, in middle block of the greenhouse.
	3	Repetition 1, in block on south end of the greenhouse.

Table 6. Summer 2007 mesquite bosque species cohort 7-gallon pot study specifications.

Variable	Treatment	Specifications
Soil Treatment	Loose	Loose soil shoveled into pots, not manually compacted.
	Compacted	Bottom 12 cm of soil compacted to a bulk density of 1.45 g/cm^3. Top 12 cm of soil not compacted.
	Sand	Soil consists of “mortar sand” from local materials supplier.
Seeding Rate	Low	30 PLS/ft^2 total (10 each per PRGL, PRPU, and ATLE).
	Medium	60 PLS/ft^2 total (20 each per PRGL, PRPU, and ATLE).
	High	120 PLS/ft^2 total (40 each per PRGL, PRPU, and ATLE).
Greenhouse Block (Repetition)	1	Repetition 1, in block on north end of the greenhouse.
	2	Repetition 2, in middle block of the greenhouse.
	3	Repetition 1, in block on south end of the greenhouse.

Table 7. Summer 2007 Emory's baccharis 7-gallon pot study specifications.

Variable	Treatment	Specifications
Seed Type	Cleaned (C)	Pubescence removed from seed coats using Wiley Mill.
Soil Treatment	Loose	Loose soil shoveled into pots, not manually compacted.
	Compacted	Bottom 12 cm of soil compacted to a bulk density of 1.45 g/cm^3. Top 12 cm of soil not compacted.
	Sand	Soil consists of "mortar sand" from local materials supplier.
Seeding Rate	Low	4 PLS/ft^2.
	Medium	20 PLS/ft^2.
	High	100 PLS/ft^2.
Greenhouse Block (Repetition)	1	Repetition 1, in block on north end of the greenhouse.
	2	Repetition 2, in middle block of the greenhouse.
	3	Repetition 1, in block on south end of the greenhouse.

Table 8. Summer 2007 un-cleaned Emory's baccharis and sweetscent cohort 7-gallon pot study specifications.

Variable	Treatment	Specifications
Seed Type	Un-cleaned (U)	Pubescence not removed from seed coats.
Soil Treatment	Loose	Loose soil shoveled into pots, not manually compacted.
	Compacted	Bottom 12 cm of soil compacted to a bulk density of 1.45 g/cm^3. Top 12 cm of soil not compacted.
	Sand	Soil consists of "mortar sand" from local materials supplier.
Seeding Rate	Low	4 PLS/ft^2 of BAEM, 2 PLS/ft^2 of PLOD.
	Medium	20 PLS/ft^2 of BAEM, 10 PLS/ft^2 of PLOD.
	High	100 PLS/ft^2 of BAEM, 50 PLS/ft^2 of PLOD.
Greenhouse Block (Repetition)	1	Repetition 1, in block on north end of the greenhouse.
	2	Repetition 2, in middle block of the greenhouse.
	3	Repetition 1, in block on south end of the greenhouse.

Table 9. Irrigation schedule for 2007 7-gallon pot studies.

Pots	Irrigation Frequency	Irrigation Duration
Riparian Loose Soil Pots	Daily	Six Minutes
Mesquite Bosque and Baccharis Sand Pots	Daily	Three Minutes
Mesquite Bosque and Baccharis Loose Soil Pots	Four Days per Week	Six Minutes
Mesquite Bosque and Baccharis Compacted Layer Soil Pots	Three Days per Week	Six Minutes

Table 10. ANOVA linear modeling results for riparian tree cohort 7-gallon pot study mid-season canopy cover data.

Crown Cover[1]	POFR[2]	SAGO	SAEX	Target	NT	BG	L	Total
	p Values[3]							
Main Effects								
Seed Collection Year	.073	0.154	0.149	0.144	0.071	0.638	0.417	0.638
Seed Type	<0.0001	0.0005	1.000	0.0001	0.049	0.352	0.033	0.352
Biosol Rate	0.015	<0.0001	0.149	0.0005	0.001	0.075	0.891	0.075
Greenhouse Block	0..373	0.939	0.134	0.327	0.148	0.203	0.423	0.203
Interactions								
Seed Type*Seed Collection Year	0.294	0.623	1.000	0.218	0.486	0.638	0.785	0.638
Seed Type*Biosol Treatment	0.099	0.0005	1.000	0.178	0.687	0.352	0.498	0.352
Biosol Treatment*Seed Collection Year	0.555	0.154	0.149	0.265	0.840	0.638	0.185	0.638
Seed Type*Biosol Treatment*Seed Collection Year	0.636	0.623	1.000	0.705	0.547	0.638	0.586	0.638
Seed Collection Year	Means and Significant Differences[4]							
2007	0.154 A	0.045 A	0.006 A	0.205 A	0.622 A	0.029 A	0.050 A	0.971 A
2006	0.256 A	0.026 A	0.000 A	0.282 A	0.500 A	0.035 A	0.026 B	0.965 A
Seed Type								
Cleaned	0.362 A	0.006 B	0.003 A	0.579 A	0.496 B	0.026 A	0.109 B	0.974 A
Un-cleaned	0.048 B	0.064 A	0.003 A	0.423 B	0.628 A	0.038 A	0.218 A	0.961 A
Biosol Rate								
0 lbs/acre	0.279 A	0.071 A	0.006 A	0.356 A	0.433 B	0.045 A	0.167 A	0.955 A
1500 lbs/acre	0.1310 B	0.000 B	0.000 A	0.131 B	0.689 A	0.019 A	0.160 A	0.981 A
Greenhouse Block								
1	0.179 A	0.034 A	0.000 A	0.211 A	0.625 A	0.043 A	0.120 A	0.957 A
2	0.260 A	0.038 A	0.000 A	0.298 A	0.471 A	0.038 A	0.192 A	0.961 A
3	0.179 A	0.034 A	0.010 A	0.221 A	0.587 A	0.014 A	0.178 A	0.986 A

1 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 (26) examined.
2 Cover codes are for Fremont cottonwood (POFR), Goodding's willow (SAGO), coyote willow (SAEX), combined POFR, SAGO, and SAEX (Target), un-seeded species (NT), bare ground (BG), litter (L), and total canopy cover (Total).
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.

Table 11. ANOVA linear modeling results for riparian tree cohort 7-gallon pot study results (end-of-season data).

Results	POFR[1] Count[2]	SAGO Count	SAEX Count	Target Count	POFR Biomass[3]	SAGO Biomass	SAEX Biomass	TARGET Biomass	NT Biomass	Root Biomass	Average POFR Height[4]	Average SAGO Height	Average SAEX Height	Tallest POFR	Tallest SAGO	Tallest SAEX
	p Values[5]															
Main Effects																
Seed Collection Year	0.191	<0.0001	0.092	0.143	0.677	0.812	0.846	0.715	0.575	0.351	0.031	--[6]	--	0.030	--	--
Seed Type	<0.0001	0.040	0.0002	<0.0001	<.0001	0.020	0.008	0.0001	0.028	0.143	0.306	--	--	0.054	--	--
Biosol Rate	<0.0001	<0.0001	<0.0001	<0.0001	0.014	0.009	0.029	0.008	<0.0001	0.045	0.180	--	--	0.290	--	--
Greenhouse Block	0.928	0.414	0.589	0.973	0.240	0.186	0.506	0.351	0.980	0.775	0.085	0.108	0.367	0.045	0.430	0.430
Interactions																
Seed Type*Seed Collection Year	0.423	<0.0001	0.047	0.166	0.350	0.005	0.248	0.571	0.756	<0.05	0.380	--	--	0.644	--	--
Seed Type*Biosol Treatment	0.002	0.040	0.024	0.0005	0.324	0.621	0.589	0.366	0.877	0.481	0.095	--	--	0.011	--	--
Biosol Treatment*Seed Collection Year	0.787	<0.0001	0.092	0.332	0.833	0.216	0.986	0.955	0.566	0.145	0.234	--	--	0.583	--	--
Seed Type*Biosol Treatment*Seed Collection Year	1.000	.0005	0.047	0.858	0.717	0.275	0.189	0.794	0.431	0.681	0.334	--	--	0.691	--	--
Seed Collection Year	Means and Significant Differences[7]															
2007	9.00 A	5.42 A	2.83 A	17.25 A	12.31 A	1.03 A	0.218 A	13.56 A	29.27 A	4.88 A	60.18 B	21.68 A	-	89.4 B	39.0 A	-
2006	7.33 A	2.58 B	4.50 A	14.42 A	13.45 A	0.956 A	0.202 A	14.61 A	31.49 A	6.69 A	76.79 A	-	-	108.0 A	-	-
Seed Type																
Cleaned	13.00 A	3.42 B	6.00 A	22.42 A	20.42 A	0.582 B	0.341 A	21.34 A	25.63 B	7.24 A	72.12 A	-	12.2 A	106.8 A	-	19.8 A
Un-cleaned	3.33 B	4.58 A	1.33 B	9.25 B	5.34 B	1.41 A	0.079 B	6.83 B	35.13 A	4.33 A	64.85 A	23.9 A	-	90.6 A	40.3 A	-
Biosol Rate																
0 lbs/acre	11.67 A	6.33 A	6.17 A	24.17 A	16.64 A	1.47 A	0.313 A	18.43 A	17.71 B	7.85 A	73.24 A	21.6 A	12.4 A	102.8 A	44.1 A	20.4 A
1500 lbs/acre	4.67 B	1.67 B	1.17 B	7.50 B	9.12 B	0.517 A	0.108 B	9.74 B	43.05 A	3.73 B	63.73 A	-	-	94.6 A	-	-
Greenhouse Block																
1	8.50 A	4.25 A	3.00 A	15.75 A	9.80 A	1.43 A	0.200 A	11.43 A	30.44 A	5.39 A	57.04 A	-	-	84.0 B	-	-
2	8.00 A	4.25 A	3.88 A	16.13 A	13.23 A	0.848 A	0.154 A	14.23 A	29.88 A	5.24 A	72.72 A	-	-	104.3 A	-	-
3	8.00 A	3.50 A	4.13 A	15.63 A	15.61 A	0.713 A	0.276 A	16.60 A	30.83 A	6.74 A	75.70 A	-	-	107.8 A	-	-

1 Codes are for Fremont cottonwood (POFR), Goodding's willow (SAGO), coyote willow (SAEX), combined POFR, SAGO, and SAEX (TARGET), and un-seeded species (NT).
2 Count is the number of stems observed in pots (equal to stems per square foot).
3 Biomass is oven-dried mass (g).
4 Height is the shoot length (cm).
5 Tests were run using JMP V 6.0.0 (SAS Institute, Cary, NC).
6 "--" indicates that insufficient data was available to determine effects, interactions, and/or least-squared means.
7. 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.

Table 12. ANOVA linear modeling results for mesquite bosque cohort 7-gallon pot study mid-season canopy cover data.

Crown Cover[1]	PRPU[2]	PRGL	ATLE	Target	NT	BG	Total
	p Values[3]						
Main Effects							
Soil Treatment	0.020	0.073	0.390	0.477	0.0006	<0.0001	<0.0001
Seeding Rate	0.870	0.010	0.390	0.004	0.062	0.002	0.002
Repetition	0.971	0.807	0.390	0.734	0.535	0.856	0.856
Interactions							
Soil Treatment*Seeding Rate	0.440	0.529	0.436	0.605	0.471	0.0004	0.0004
Main Effects	Means and Significant Differences[4]						
Soil Treatment							
Loose	0.030 B	0.637 A	-	0.667 A	0.291 A	0.013 B	0.987 A
Compacted	0.047 B	0.551 A	0.004 A	0.602 A	0.355 A	0.013 B	0.987 A
Sand	0.150 A	0.406 B	-	0.556 A	0.000 B	0.444 A	0.556 B
Seeding Rate[5]							
Low	0.064 A	0.350 A	-	0.415 B	0.329 A	0.226 A	0.774 B
Medium	0.077 A	0.568 A	0.004 A	0.650 A	0.154 B	0.171 A	0.829 B
High	0.085 A	0.675 A	-	0.761 A	0.162 B	0.073 B	0.927 A
Repetition							
1	0.073 A	0.496 A	-	0.568 A	0.265 A	0.162 A	0.838 A
2	0.081 A	0.551 A	0.004 A	0.637 A	0.184 A	0.162 A	0.838 A
3	0.073 A	0.547 A	-	0.620 A	0.197 A	0.145 A	0.855 A

1 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 (26) examined.
2 Cover codes are for Prosopis pubescens (PRPU), Prosopis glandulosa (PRGL), Atriplex lentiformis (ATLE), combined PRPU, PRGL, and ATLE (Target), un-seeded species (NT), bare ground (BG), and total canopy cover (Total).
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 Seeding rate (PLS/ft^2) for PRPU and PRGL was 10 (low), 20 (medium), and 40 (high) and ATLE was 10 (low), 20 (medium), and 40 (high).

Table 13. ANOVA linear modeling results for mesquite bosque cohort 7-gallon pot study results (end-of-season data).

Results	PRPU[1] Count[2]	PRGL Count	ATLE Count	Target Count	PRPU Biomass[3]	PRGL Biomass	ATLE Biomass	Target Biomass	NT Biomass	Root Biomass	PRPU Avg Height[4]	PRGL Avg Height	ATLE Avg Height	PRPU Max Height	PRGL Max Height	ATLE Max Height
	p Values[5]															
Main Effects																
Soil Treatment	0.240	0.117	0.099	0.834	<0.0001	<0.0001	0.005	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	-[6]	<0.0001	<0.0001	-
Seeding Rate	<0.0001	<0.0001	0.001	<0.0001	0.749	<0.0001	0.055	0.0003	0.036	0.0003	0.004	0.0004	-	0.314	<0.0001	-
Repetition	0.818	0.554	0.118	0.331	0.702	0.462	0.383	0.730	0.654	0.400	0.472	0.673	0.730	0.419	0.205	0.458
Interactions																
Soil Treatment*Seeding Rate	0.921	0.462	0.284	0.621	0.939	0.0001	0.011	0.050	0.350	0.030	0.226	0.093	-	0.873	0.002	-
Main Effects	**Means and Significant Differences[7]**															
Soil Treatment																
Loose	14.78 A	17.67 A	5.56 A	38.00 A	27.50 A	122.90 A	0.200 A	150.60 A	19.32 A	35.64 A	53.37 A	86.62 A	6.51 B	87.22 A	116.56 A	10.86 A
Compacted	16.44 A	17.89 A	3.44 AB	37.78 A	12.91 B	90.26 B	0.273 A	103.44 B	16.34 A	22.94 B	38.16 B	74.16 B	11.30 A	67.44 B	105.72 B	17.06 A
Sand	19.67 A	13.78 A	2.44 B	35.89 A	2.21 C	4.79 C	0.028 B	7.03 C	0.000 B	4.18 C	13.78 C	21.64 C	-	22.44 C	31.16 C	-
Seeding Rate[8]																
Low	8.11 C	7.22 C	1.00 B	16.33 C	15.09 A	52.73 C	0.068 B	67.89 C	14.17 A	14.91 B	42.82 A	70.55 A	-	64.72 A	94.67 A	-
Medium	16.11 B	15.67 B	3.11 B	34.89 B	15.11 A	72.88 B	0.227 A	88.22 B	14.61 A	21.82 A	35.32 AB	58.37 B	8.12 A	58.72 A	84.50 B	13.50 A
High	26.67 A	26.44 A	7.33 A	60.44 A	12.42 A	92.33 A	0.207 A	104.96 A	6.89 B	26.03 A	27.17 B	53.51 B	6.26 A	53.67 A	74.28 C	12.22 A
Repetition																
1	16.00 A	15.11 A	2.44 A	33.56 A	12.44 A	74.38A	0.179 A	87.00 A	10.30 A	22.60 A	32.39 A	59.41 A	-	54.89 A	81.06 A	-
2	17.11 A	17.11 A	3.56 AB	37.78 A	15.89 A	73.72 A	0.207 A	89.80 A	12.38 A	20.17 A	35.86 A	62.43 A	-	58.00 A	85.61 A	-
3	17.78 A	17.11 A	5.44 A	40.33 A	14.31 A	69.84 A	0.116 A	84.27 A	12.99 A	20.00 A	37.06 A	60.59 A	-	64.22 A	86.78 A	-

1 Codes are for Prosopis pubescens (PRPU), Prosopis glandulosa (PRGL), Atriplex lentiformis (ATLE), combined PRPU, PRGL, and ATLE (TARGET), un-seeded species (NT).
2 Count is the number of stems observed in pots (equal to stems per square foot).
3 Biomass is oven-dried mass (g).
4 Height is the shoot length (cm).
5 Tests were run using JMP V 6.0.0 (SAS Institute, Cary, NC).
6 "--" indicates that insufficient data was available to determine effects, interactions, and/or least-squared means.
7 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.
8 Seeding rate (PLS/ft^2) for PRPU and PRGL was 10 (low), 20 (medium), and 40 (high) and ATLE was 10 (low), 20 (medium), and 40 (high).

Table 14. ANOVA linear modeling results for Emory's baccharis 7-gallon pot study results (mid-season crown cover and end-of-season harvest data).

Results	BAEM[1] Crown Cover[2]	NT Crown Cover	BG Crown Cover	Total Crown Cover	BAEM Count[3]	BAEM Biomass[4]	NT Biomass	Root Biomass	BAEM Average Height[5]	BAEM Maximum Height
	p Values[6]									
Main Effects										
Soil Treatment	0.262	<0.0001	<0.0001	<0.0001	0.0003	0.001	<0.0001	0.054	0.512	0.426
Seeding Rate	0.006	0.598	0.383	0.383	<0.0001	0.0004	0.438	0.674	0.089	0.861
Repetition	0.262	0.941	0.809	0.809	0.664	0.308	0.110	0.238	0.381	0.233
Interactions										
Soil Treatment* Seeding Rate	0.461	0.628	0.466	0.004	0.0004	0.018	0.910	0.539	0.647	0.880
Main Effects	Means and Significant Differences[7]									
Soil Treatment										
Loose	0.038 A	0.803 A	0.021 B	0.979 A	16.00 A	4.83 A	29.47 A	5.70 A	32.27 A	47.61 A
Compacted	0.034 A	0.816 A	0.047 B	0.953 A	9.44 B	1.90 B	28.81 A	3.43 AB	28.82 A	39.90 A
Sand	0.009 A	0.000 B	0.991 A	0.009 B	0.000 C	0.000 B	0.000 B	0.000 B	-[8]	-
Seeding Rate[9]										
Low	0.009 B	0.560 A	0.355 A	0.645 A	0.311 B	0.226 A	21.26 A	3.62 A	35.72 A	43.25 A
Medium	0.004 B	0.538 A	0.363 A	0.637 A	1.13 B	0.171 A	21.09 A	1.92 A	33.42 A	41.59 A
High	0.068 A	0.521 A	0.342 A	0.658 A	5.29 A	0.073 B	15.93 A	3.59 A	22.50 A	46.42 A
Repetition										
1	0.038 A	0.538 A	0.359 A	0.641 A	9.11 A	3.06 A	14.37 B	34.79 A	12.44 A	55.46 A
2	0.034 A	0.534 A	0.350 A	0.650 A	9.44 A	1.39 A	19.21 AB	30.18 A	15.89 A	37.25 A
3	0.008 A	0.547 A	0.350 A	0.650 A	6.89 A	2.29 A	24.70 A	26.66 A	14.31 A	38.55 A

1 Codes are for Baccharis emoryi (BAEM), un-seeded species (NT), and bare ground (BG).
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 (26) examined.
3 Count is the number of stems observed in pots (equal to stems per square foot).
4 Biomass is oven-dried mass (g).
5 Height is the shoot length (cm).
6 Tests were run using JMP V 6.0.0 (SAS Institute, Cary, NC).
7 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.
8 "-" indicates that insufficient data was available to determine effects, interactions, and/or least-squared means.
9 Seeding rate (PLS/ft^2) for BAEM was 4 (low), 20 (medium), and 100 (high).

Table 15. ANOVA linear modeling results for Emory's baccharis and sweetscent cohort 7-gallon pot study results (mid-season crown cover and end-of-season harvest data)

Results	BAEM[1] Crown Cover[2]	PLOD Crown Cover	Target Crown Cover	NT Crown Cover	BG Crown Cover	Total Crown Cover	BAEM Count[3]	PLOD Count	Target Count	BAEM Biomass[4]	PLOD Biomass	Target Biomass	NT Biomass	Root Biomass	BAEM Average Height[5]	PLOD Average Height	BAEM Maximum Height	PLOD Maximum Height
	p Values[6]																	
Main Effects																		
Soil Treatment	0.394	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0005	<0.0001	<0.0001	0.002	<0.0001	<0.0001	<0.0001	<0.0001	0.146	0.330	0.554	0.011
Seeding Rate	0.067	0.006	0.004	0.090	<0.0001	<0.0001	0.0002	<0.0001	<0.0001	0.009	0.013	<0.0001	0.003	0.014	0.214	0.363	0.674	0.392
Repetition	0.250	0.828	0.662	0.993	0.609	0.308	0.345	0.323	0.362	0.874	0.251	0.128	0.203	0.102	0.801	0.987	0.769	0.994
Interactions																		
Soil Treatment*Seeding Rate	0.765	0.003	0.006	0.007	0.0001	0.0001	0.0005	<0.0001	<0.0001	0.133	0.004	<0.0001	0.008	0.235	0.930	0.906	0.637	0.534
Main Effects	Means and Significant Differences[7]																	
Soil Treatment																		
Loose	0.034 A	0.261 A	0.295 A	0.632 B	0.013 B	0.987 A	26.67 A	10.11 A	36.78 A	4.18 A	10.40 A	14.58 A	21.42 B	6.37 A	23.41 A	43.15 A	38.24 A	71.17 A
Compacted	0.017 A	0.013 B	0.030 B	0.876 A	0.034 B	0.966 A	9.33 B	1.67 B	11.00 B	2.12 B	0.911 B	3.03 B	27.81 A	5.18 A	32.17 A	29.59 A	42.75 A	30.29 B
Sand	0.009 A	0.000 B	0.009 B	0.000 C	0.816 A	0.184 B	0.000 B	0.00 B	0.00 B	0.000 C	0.000 B	0.00 C	0.00 C	0.00 B	-[8]	-	-	-
Seeding Rate[9]																		
Low	0.009 AB	0.000 B	0.009 B	0.560 A	0.355 A	0.645 B	0.778 B	0.667 C	1.44 B	0.322 B	1.34 B	1.67 C	19.60 A	2.42 B	34.09 A	44.71 A	37.39 A	46.32 A
Medium	0.004 B	0.132 A	0.137 A	0.487 AB	0.269 B	0.731 A	5.89 B	3.00 B	8.89 B	2.22 AB	4.04 AB	6.27 B	19.12 A	3.39 B	28.42 A	42.23 A	44.83 A	61.69 A
High	0.047 A	0.141 A	0.188 A	0.462 B	0.239 B	0.761 A	29.33 A	8.11 A	37.44 A	3.76 A	5.92 A	9.68 A	10.51 B	5.73 A	20.86 A	22.17 A	39.25 A	44.17 A
Repetition																		
1	0.038 A	0.094 A	0.132 A	0.504 A	0.294 A	0.705 A	16.67 A	4.22 A	20.89 A	2.39 A	3.37 A	5.76 AB	14.59 A	4.91 A	27.88 A	36.88 A	44.08 A	49.95 A
2	0.013 A	0.077 A	0.090 A	0.500 A	0.291 A	0.709 A	9.22 A	4.44 A	13.67 A	1.98 A	2.84 A	4.82 B	15.66 A	2.60 B	29.75 A	37.36 A	37.65 A	50.97 A
3	0.009 A	0.103 A	0.111 A	0.504 A	0.278 A	0.722 A	10.11 A	3.11 A	13.22 A	1.93 A	5.10 A	7.03 A	18.99 A	4.03 AB	25.74 A	34.88 A	39.75 A	51.26 A

1 Codes are for Pluchea odorata (PLOD), Baccharis emoryi (BAEM), combined PLOD and BAEM (Target), un-seeded species (NT), and bare ground (BG).
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 (26) examined.
3 Count is the number of stems observed in pots (equal to stems per square foot).
4 Biomass is oven-dried mass (g).
5 Height is the shoot length (cm).
6 Tests were run using JMP V 6.0.0 (SAS Institute, Cary, NC).
7 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.
8 "-" indicates that insufficient data was available to determine effects, interactions, and/or least-squared means.
9 Seeding rate (PLS/ft^2) for BAEM was 4 (low), 20 (medium), and 100 (high) and PLOD was 2 (low), 10 (medium), and 50 (high).

Table 16. Non-seeded species observed and relative abundance in 7-gallon pot studies.

Common Name[1]	Scientific Name[1]	Family	Duration[2]	Nativity[3]	Frequency[4]
Fragrant Flatsedge	*Cyperus odoratus* L.	Cyperaceae	A/P	N	Abundant
Colorado River Hemp/ Bigpod Sesbania	*Sesbania herbacea* (P. Mill) McVaugh	Fabaceae	A	N	Common
Salt Heliotrope	*Heliotropium curassavicum* L.	Boraginaceae	A/P	N	Rare
Jungle Rice	*Echinochloa colona* (L.) Link	Poaceae	A	I	Abundant
Polygonum	*Chamaesyce* sp.	Euphorbiaceae	A	N	Abundant
Cheeseweed Mallow	*Malva parviflora* L.	Malvaceae	A/B/P	I	Common
Spiny Sowthistle	*Sonchus asper* (L.) Hill	Asteraceae	A	I	Trace
Seaside Petunia	*Calibrachoa parviflora* (Juss.) D'Arcy	Solanaceae	A	N	Abundant
Spoonleaf Purple Everlasting	*Gamochaeta purpurea* (L.) Cabrera	Asteraceae	A/B	N	Trace
Pigweed	*Chenopodium* spp.	Chenopodiaceae	A/P	N/I	Abundant
Little Hogweed	*Portulaca oleracea* L.	Portulacaceae	A	I	Common

1 Following United States Department of Agriculture, Natural Resources Conservation Service.
2 Annual (A), Biennial (B), and/or Perennial (P).
3 Native (N) or Introduced (I).
4 Relative abundance in Field 51 topsoil, as observed during greenhouse studies.

Table 17. Summer 2007 riparian cohort small-scale field study specifications.

Variable	Treatment	Specifications
Early-Time Sprinkler Irrigation	No Sprinklers	No sprinklers used, surface irrigation implemented immediately after seeding.
	Sprinklers	Sprinklers irrigation used during germination period (3 weeks after seeding), surface irrigation thereafter.
Seeding Treatment	Un-cleaned, hydroseed	Pubescence not removed from seed coats, seed applied with a hydroseeder.
	Cleaned, hydroseed	Pubescence removed from seed coats, seed applied with a hydroseeder.
	Cleaned, broadcast	Pubescence removed from seed coats, seed applied with a broadcast seed spreader.
Surface Irrigation Method	Border	Small-scale basin irrigation.
	Furrow	Furrows on 1.02 m spacing.
Plot Position	Block 1	Northernmost replication.
	Block 2	Middle replication.
	Block 3	Southernmost replication.
Seeding Rate	Variable	Estimated by hydroseed application duration.

Table 18. Seed weight calibrations obtained for riparian cohort small-scale field studies.

Species	Seed Type	Weight Per Seed (g)	Seeds per Gram	Grams per Plot[1]	Pounds per Acre[1]
Fremont Cottonwood	Un-Cleaned	2.87E-03	349	71.74	8.61
	Cleaned	1.03E-03	972	25.71	3.09
Goodding's Willow	Un-Cleaned	7.59E-04	1,318	37.95	4.56
	Cleaned	1.30E-04	7,669	6.52	0.78
Coyote Willow	Un-Cleaned	2.87E-04	3,481	14.36	1.72
	Cleaned	3.69E-05	27,076	1.85	0.22

1 Rates are based on the small-scale study seeding rates (i.e. 25 PLS/ft^2 Fremont cottonwood, 50 PLS/ft^2 each Goodding's and coyote willow) with 80% seed viability.

Table 19. Non-target species observed in riparian cohort small-scale field study plots.

Species	Common Name	Growth Form	Lifespan	Nativity	Relative Abundance
Tamarix ramosissima	Saltcedar	Shrub or Tree	Perennial	Non-Native	Abundant
Chenopodium spp.	Goosefoot	Shrub or Forb	Annual or Perennial	Some Native, some Non-Native	Abundant
Cyperus odoratus	Fragrant flatsedge	Sedge	Annual	Native	Common
Cynodon dactylon	Bermudagrass	Sod Grass	Perennial	Non-native	Abundant
Echinochloa colona	Barnyard Grass	Bunchgrass	Perennial	Non-native	Abundant
Prosopis glandulosa	Honey Mesquite	Tree	Perennial	Native	Few
Sesbania herbaceae	Colorado River Hemp	Forb	Annual	Native	Few
Leptochloa mucronata	Mucronate Sprangletop	Bunchgrass	Annual	Native	Common
Panicum capillare	Witchgrass	Bunchgrass	Annual	Native	Common
Setaria pumila	Yellow Foxtail	Bunchgrass	Annual	Non-native	Common
Un-Identified Grass	Unknown	Bunchgrass	Perennial	Unknown	Abundant

Table 20. Sociologic relevé classifications used for small-scale test plot study quadrat estimation of cover.

Relevé Class	Cover Percentage	Description
R	<1%	Less than one percent of crown or total canopy cover, only one plant present.
+	<1%	Less than one percent of crown or total canopy cover, more than one plant present.
1	1-5%	One or more plants, canopy covering between one and five percent of the survey area.
2	5-25%	One or more plants, canopy covering between five and 25 percent of the survey area.
3	25-50%	One or more plants, canopy covering between five and 25 percent of the survey area.
4	50-75%	One or more plants, canopy covering between 50 and 75 percent of the survey area.
5	75-100%	One or more plants, canopy covering between 75 and 100 percent of the survey area.

Table 21. ANOVA linear modeling results for target riparian species in the small-scale field study (Task 5).

Results	POFR[1] Crown Cover[2]	POFR Canopy Cover[3]	SAGO Canopy Cover	SAEX Canopy Cover	POFR Stems/ m^2	SAGO Stems/ m^2	SAEX Stems/ m^2	POFR Average Height[4]	POFR Maximum Height	SAGO Maximum Height	SAEX Maximum Height	POFR Biomass[5]/ m^2	SAGO Biomass/ m^2	SAEX Biomass/ m^2	POFR Biomass/ Stem
Main Effects	**p Values[6]**														
Sprinklers	0.0001	0.001	0.039	0.057	0.998	0.651	0.069	<0.0001	<0.0001	0.110	0.243	0.0008	0.118	0.232	<0.0001
Seed Treatment	0.413	0.038	0.0008	0.094	0.038	0.0007	0.494	0.200	0.130	0.160	0.251	0.051	0.064	0.521	0.199
Surface Irrigation Method	0.830	0.966	<0.0001	0.063	0.690	0.036	0.352	0.121	0.007	0.008	0.201	0.204	0.017	0.189	0.028
Plot Position	0.001	0.0006	0.012	0.383	0.009	0.247	0.148	0.687	0.003	0.205	0.207	0.036	0.532	0.315	0.054
Seeding Rate PLS/m^2	0.863	0.106	0.556	0.077	0.037	<0.0001	0.084	0.978	0.639	0.860	0.160	0.018	0.317	0.257	0.920
Interactions															
Sprinklers*Seed Treatment	0.114	0.335	0.001	0.322	0.117	0.760	0.332	0.667	0.586	0.107	0.698	0.060	0.064	0.649	0.131
Sprinklers*Surface Irrigation Method	0.587	0.726	0.030	0.028	0.403	0.193	0.553	0.347	0.954	0.174	0.957	0.403	0.095	0.742	0.087
Seed Treatment* Surface Irrigation Method	0.127	0.031	0.001	0.345	0.096	0.142	0.714	0.232	0.040	0.285	0.634	0.133	0.134	0.622	0.196
Sprinklers*Seed Treatment*Surface Irrigation Method	0.427	0.083	0.0007	0.172	0.011	0.016	0.226	0.786	0.408	0.004	0.241	0.654	0.020	0.301	0.718
Sprinklers	**Means and Significant Differences[7]**														
No Sprinklers	0.120 A	0.212 A	0.006 A	0.002 A	17.63 A	0.489 A	0.472 A	63.21 A	117.03 A	21.81 A	9.33 A	69.30 A	0.705 A	0.222 A	4.28 A
Sprinklers	0.036 B	0.106 B	0.003 B	0.0001 A	17.63 A	0.400 A	0.046 A	31.08 B	57.28 B	9.83 A	2.97 A	21.09 B	0.214 A	0.052 A	0.606 B
Seed Treatment															
Un-cleaned Hydroseed	0.090 A	0.206 A	0.009 A	0.003 A	24.03 A	0.963 A	0.437 A	49.36 A	94.74 A	25.10 A	12.48 A	65.45 A	0.972 A	0.241 A	2.20 A
Cleaned Hydroseed	0.084 A	0.161 AB	0.002 B	0.002 AB	12.79 B	0.526 A	0.230 A	53.04 A	91.43 A	15.00 A	3.85 A	44.66 AB	0.329 AB	0.125 A	3.29 A
Cleaned Broadcast	0.060 A	0.110 B	0.002 B	0.000 B	16.07 AB	0.000 B	0.111 A	39.04 A	75.29 A	7.35 A	2.12 A	25.47 B	0.076 B	0.044 A	1.84 A
Surface Irrigation Method															
Border-strip	0.080 A	0.160 A	0.000 B	0.0002 A	16.94 A	0.225 B	0.153 A	42.34 A	75.65 B	5.15 B	2.64 A	37.13 A	0.065 B	0.043 A	1.71 B
Furrow	0.076 A	0.159 A	0.009 A	0.002 A	18.32 A	0.664 A	0.365 A	51.95 A	98.66 A	26.49 A	9.67 A	53.26 A	0.853 A	0.231 A	3.18 A
Plot Position															
Block 1	0.024 B	0.083 C	0.008 A	0.0002 A	9.40 B	0.594 A	0.294 A	43.83 A	66.14 B	19.54 A	9.75 A	20.95 B	0.702 A	0.212 A	1.42 B
Block 2	0.094 A	0.153 B	0.003 B	0.002 A	20.63 A	0.538 A	0.522 A	50.22 A	93.77 A	21.67 A	0.000 A	55.10 A	0.358 A	0.000 A	3.41 A
Block 3	0.117 A	0.242 A	0.002 B	0.002 A	22.86 A	0.202 A	0.000 A	47.38 A	101.55 A	6.25 A	9.45 A	59.53 A	0.318 A	0.214 A	2.50 AB
Seeding Rate, PLS/m^2															
Correlation Relationship[8] direct		0.106	0.556	0.077	0.0369	<0.0001			0.639			0.018	0.317		
Correlation Relationship[8] inverse	0.863						0.084	0.978			0.160				0.920

1 Codes are for Fremont cottonwood (POFR), Goodding's willow (SAGO), and coyote willow (SAEX).
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). 0.860 0.257
5 Biomass is oven-dried mass (g).
6 Tests were run using JMP V 6.0.0 (SAS Institute, Cary, NC).
7 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.
8 Relationships denote a direct or inverse correlation between treatments and respective seeding rates.

Table 22. ANOVA linear modeling results for non-target riparian species in the small-scale test plot study (Task 5).

Results		TARA[1] Crown Cover[2]	Gramineae[3] Crown Cover[4]	S/F[5] Crown Cover	TARA Canopy Cover	Gramineae Canopy Cover	S/F Canopy Cover	TARA Stems/ m^2	TARA Average Height[6]	TARA Maximum Height	TARA Biomass[7]/ Stem	TARA Biomass/ m^2	Gramineae Biomass/ m^2	S/F Biomass/ m^2
Main Effects		**p Values[8]**												
Sprinklers		<0.0001	<0.0001	0.236	<0.0001	0.078	0.013	0.0004	0.032	0.032	0.007	0.0009	0.773	0.061
Seed Treatment		0.505	0.931	0.659	0.518	0.690	0.165	0.195	0.997	0.665	0.879	0.875	0.449	0.585
Surface Irrigation Method		0.336	0.330	0.614	0.209	0.206	0.534	0.145	0.265	0.258	0.071	0.318	0.654	0.837
Plot Position		0.299	0.004	0.048	0.147	0.021	0.190	0.140	0.663	0.245	0.642	0.916	0.103	0.125
Seeding Rate, PLS/m^2		0.107	0.222	0.585	0.721	0.403	0.050	0.461	0.138	0.759	0.265	0.261	0.926	0.241
Interactions														
Sprinklers*Seed Treatment		0.018	0.015	0.634	0.122	0.129	0.020	0.213	0.953	0.580	0.785	0.619	0.361	0.251
Sprinklers*Surface Irrigation Method		0.564	0.288	0.423	0.259	0.310	0.101	0.156	0.227	0.347	0.070	0.552	0.750	0.348
Seed Treatment* Surface Irrigation Method		0.783	0.835	0.264	0.891	0.519	0.469	0.275	0.872	0.404	0.638	0.331	0.104	0.612
Sprinklers*Seed Treatment*Surface Irrigation Method		0.452	0.945	0.266	0.511	0.640	0.950	0.209	0.052	0.598	0.336	0.252	0.679	0.133
Sprinklers		**Means and Significant Differences[9]**												
	No Sprinklers	0.067 A	0.731 B	0.073 A	0.296 A	0.938 A	0.518 A	34.00 A	31.29 A	103.03 A	0.970 A	32.96 A	429.34 A	108.14 A
	Sprinklers	0.008 B	0.894 A	0.045 A	0.072 B	0.894 A	0.424 B	15.92 B	24.93 B	57.91 B	0.412 B	7.24 B	445.90 A	56.43 A
Seed Treatment														
	Un-cleaned Hydroseed	0.047 A	0.805 A	0.053 A	0.201 A	0.925 A	0.517 A	29.94 A	28.20 A	76.59 A	0.702 A	21.28 A	387.18 A	86.39 A
	Cleaned Hydroseed	0.035 A	0.820 A	0.050 A	0.194 A	0.922 A	0.462 A	25.22 A	27.94 A	93.68 A	0.747 A	21.51 A	453.91 A	62.60 A
	Cleaned Broadcast	0.031 A	0.813 A	0.075 A	0.157 A	0.900 A	0.434 A	19.73 A	28.18 A	71.14 A	0.623 A	17.51 A	471.78 A	97.87 A
Surface Irrigation Method														
	Border-strip	0.043 A	0.797 A	0.065 A	0.205 A	0.900 A	0.460 A	28.26 A	26.52 A	68.99 A	0.513 A	16.69 A	424.69 A	85.01 A
	Furrow	0.032 A	0.828 A	0.053 A	0.163 A	0.931 A	0.482 A	21.67 A	29.70 A	91.96 A	0.869 A	23.51 A	450.55 A	79.55 A
Plot Position														
	Block 1	0.047 A	0.897 A	0.026 B	0.204 A	0.956 A	0.424 A	28.07 A	26.47 A	65.37 A	0.662 A	18.41 A	478.94 A	42.78 A
	Block 2	0.025 A	0.777 B	0.098 A	0.138 A	0.868 B	0.493 A	18.57 A	29.53 A	104.20 A	0.812 A	20.00 A	347.40 A	101.01 A
	Block 3	0.041 A	0.764 B	0.053 AB	0.210 A	0.923 AB	0.495 A	28.24 A	26.47 A	71.85 A	0.598 A	21.89 A	486.52 A	103.06 A
Seeding Rate, PLS/m^2														
Correlation Relationship[10]	direct		0.222			0.403							0.926	
	inverse	0.107			0.721		0.0501	0.461	0.138	0.759	0.265	0.261		0.241

1 Code is for Tamarix ramosissima (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 Gramineae is for combined grasses and sedges, no rushes observed; see Table 19.
4 Canopy cover is the total canopy cover of the given vegetation type, including crown cover.
5 Code is for combined shrubs and forbs (S/F) excluding TARA; see Table 19.
6 Height is the shoot length (cm).
7 Biomass is oven-dried mass (g).
8 Tests were run using JMP V 6.0.0 (SAS Institute, Cary, NC).
9 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.
10 Relationships denote a direct or inverse correlation between treatments and respective seeding rates.

Table 23. Irrigation schedule and applied water (AW) for first three weeks of irrigation.

Irrigation Method:	Sprinkler				Furrow	Border
Date	Start Time	Stop Time	Hours	AW[1], m	AW, m	AW, m
5/16/2007	1430	2200	8.5	0.02	0.09	0.15
5/17/2007	720	2200	14.5	0.04	0.05	0.07
5/18/2007	800	2000	12	0.03	0.07	0.02
5/19/2007	635	2000	13.5	0.03	0.02	0.06
5/20/2007	1300	2200	9	0.02	0.02	0.05
5/21/2007	715	2000	12.5	0.03	0.02	0.05
5/22/2007	1020	2200	11.5	0.03	0.02	0.05
5/23/2007	1030	1840	8	0.02	0.03	0.05
5/24/2007	900	1910	10	0.03	0.05	0.07
5/25/2007	820	1900	11	0.03	0.06	0.06
5/26/2007	900	1920	10.5	0.03	--	--
5/27/2007	830	1910	9.5	0.02	0.07	0.06
5/28/2007	900	1750	9	0.02	--	--
5/29/2007	910	1800	9	0.02	0.05	0.07
5/30/2007	1230	2030	8	0.02	0.03	0.07
5/31/2007	1030	1900	8.5	0.02	--	--
6/1/2007	1015	1800	8	0.02	0.07	0.08
6/2/2007	1030	1830	8	0.02	--	--
6/3/2007	1000	1730	7.5	0.02	0.05	0.03
6/4/2007	1000	1800	8	0.02	--	--
6/5/2007	900	1500	7	0.02	0.04	0.06
6/6/2007	1040	1700	6.5	0.02	--	--
Total:	--	--	210	0.53	0.74	1.00
Average[2]:	--	--	9.5	0.02	0.04	0.06

1 Assuming sprinkler application rate of 0.25 cm per hour and application efficiency of 85%.
2 Excludes first irrigation event.

Table 24. Surface irrigation schedule for June 7, 2007 through October 12, 2007.

Date	North Plots	Elapsed Days[1]	South Plots	Elapsed Days
6/7/2007	x	2	x	2
6/9/2007	x	2	x	2
6/13/2007	x	4	x	5
6/16/2007	x	3	x	2
6/17/2007	x	1		
6/18/2007			x	2
6/20/2007	x	3		
6/21/2007			x	3
6/26/2007	x	6	x	5
6/28/2007	x	2	x	2
7/1/2007	x	3	x	3
7/3/2007	x	2	x	2
7/5/2007	x	2	x	2
7/9/2007	x	4	x	4
7/13/2007	x	4		
7/17/2007	x	4	x	8
7/19/2007	x	2		
7/22/2007	x	3	x	5
7/25/2007			x	3
7/26/2007	x	4		
7/29/2007	x	3		
7/30/2007			x	5
8/15/2007[2]	x	17	x	16
8/29/2007	x	14	x	14
9/11/2007[2]	x	13	x	13
9/16/2007	x	5		
9/29/2007[2]	x	13	x	18
10/3/2007	x	4	x	4
10/11/2007	x	8		
10/12/2007			x	9

1 Days since previous irrigation event.
2 Plots irrigated with large-scale Field 51 irrigation culvert.

FIGURES

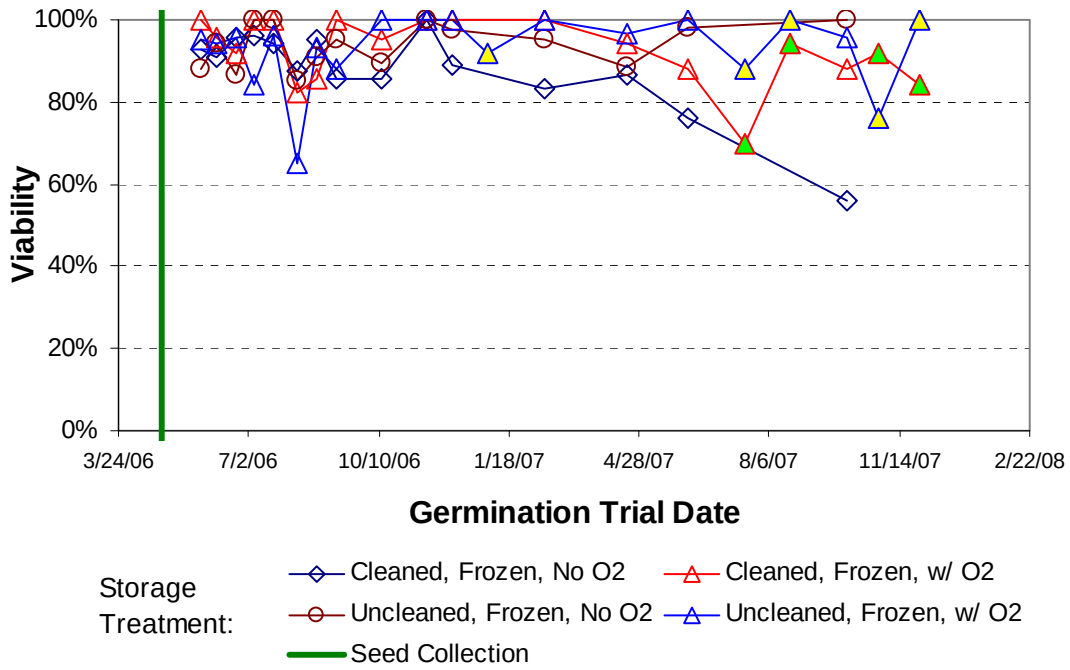

Figure 1. Incubator viability for frozen Fremont cottonwood seed germination trials. Yellow or green data symbols indicate "supplemental seed" analysis.

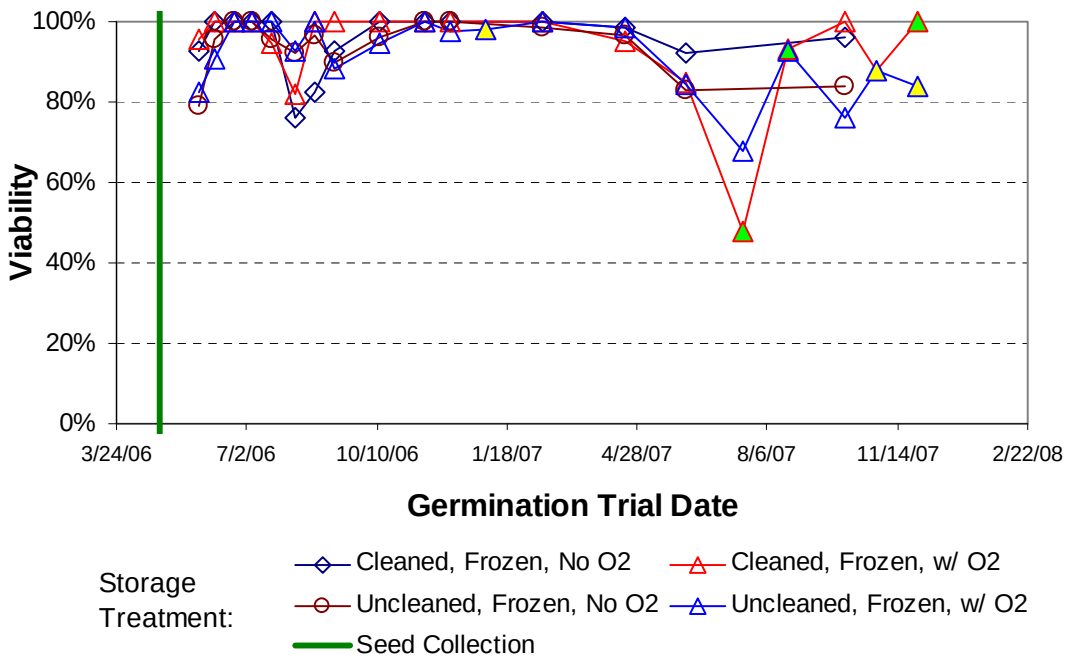

Figure 2. Incubator viability for frozen Goodding's willow seed germination trials. Yellow or green data symbols indicate "supplemental seed" analysis.

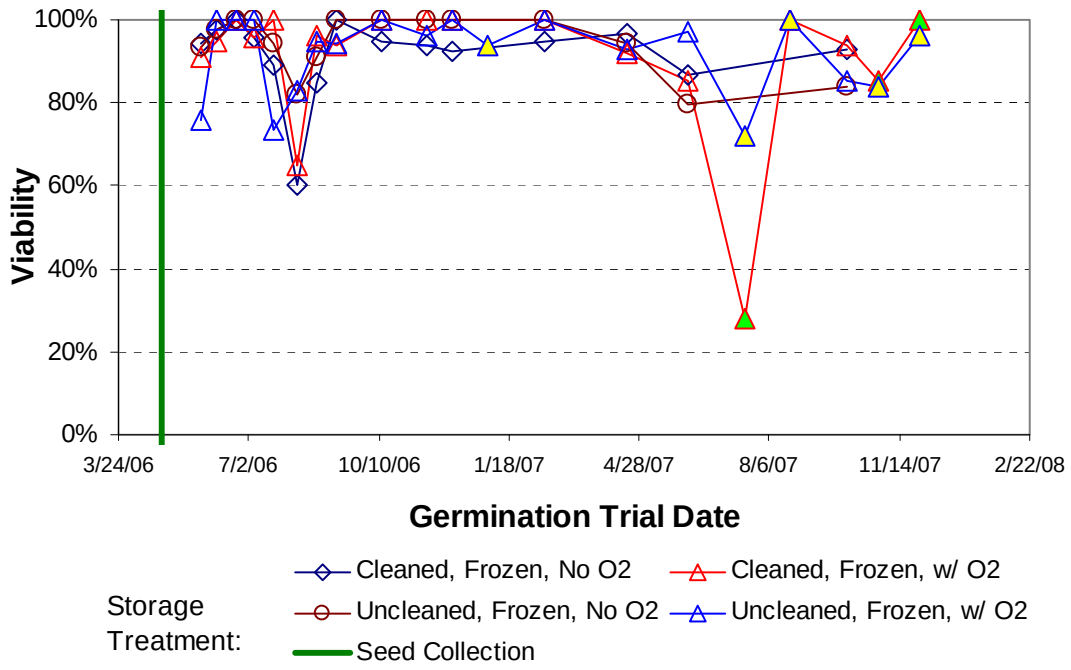

Figure 3. Incubator viability for frozen coyote willow seed germination trials. Yellow or green data symbols indicate "supplemental seed" analysis.

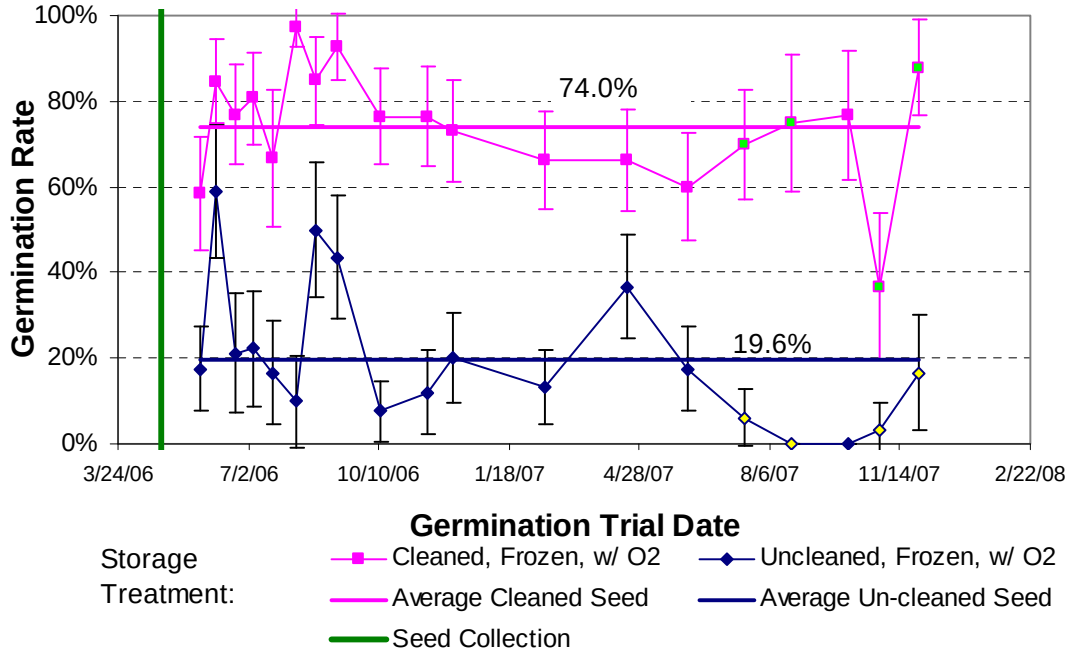

Figure 4. Soil germination rates for cleaned versus un-cleaned Fremont cottonwood seed (frozen, ambient oxygen) germination trials. Yellow or green data symbols indicate "supplemental seed" analysis.

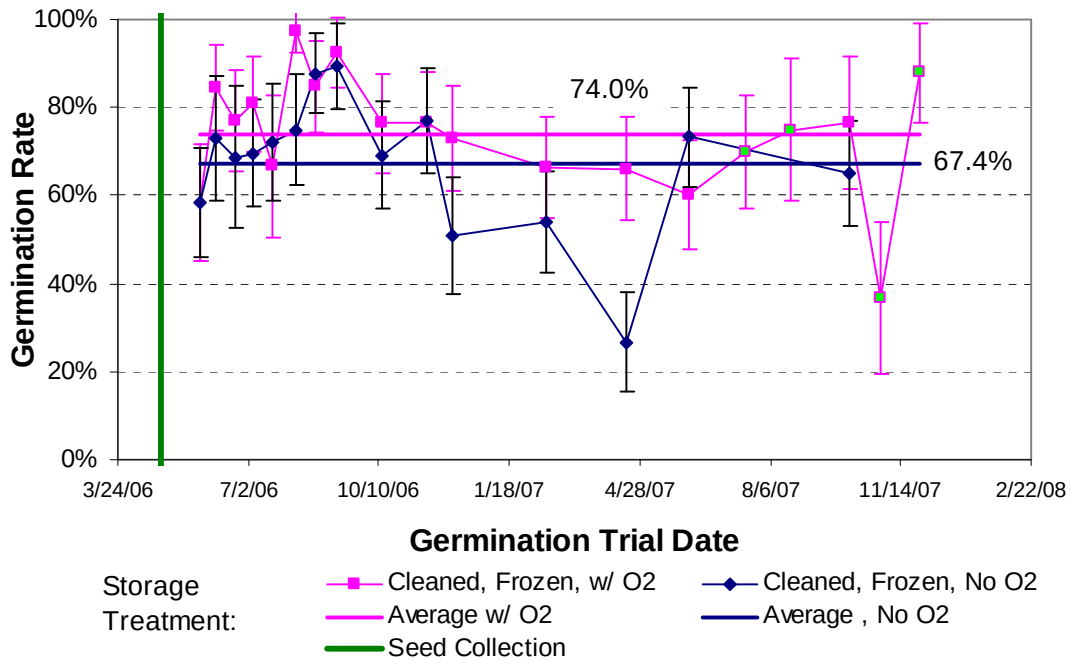

Figure 5. Soil germination rates for ambient versus oxygen-removal treatment for Fremont cottonwood seed (frozen, cleaned) germination trials. Green data symbols indicate "supplemental seed" analysis.

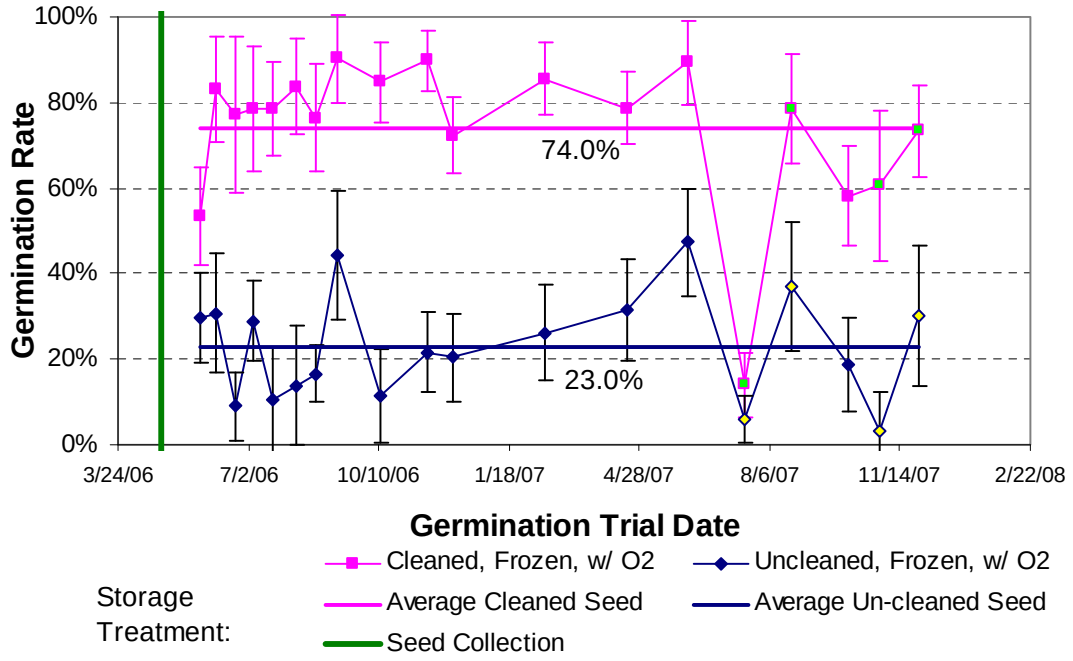

Figure 6. Soil germination rates for cleaned versus un-cleaned Goodding's willow seed (frozen, ambient oxygen) germination trials. Yellow or green data symbols indicate "supplemental seed" analysis.

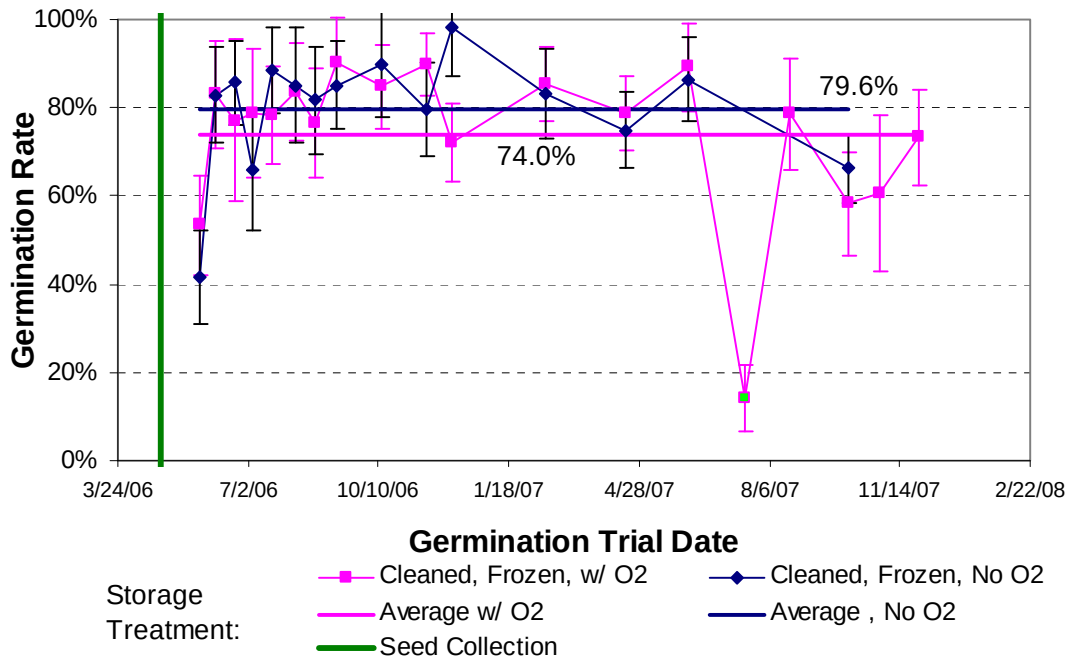

Figure 7. Soil germination rates for ambient versus oxygen-removal treatment for Goodding's willow seed (frozen, cleaned) germination trials. Green data symbols indicate "supplemental seed" analysis.

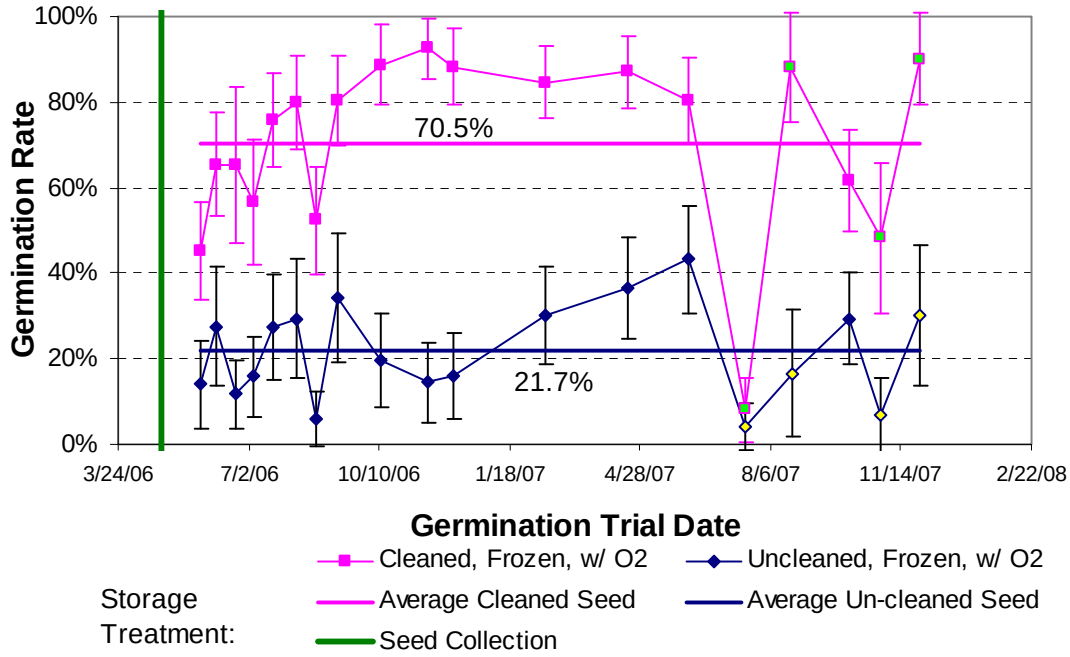

Figure 8. Soil germination rates for cleaned versus un-cleaned coyote willow seed (frozen, ambient oxygen) germination trials. Yellow or green data symbols indicate "supplemental seed" analysis.

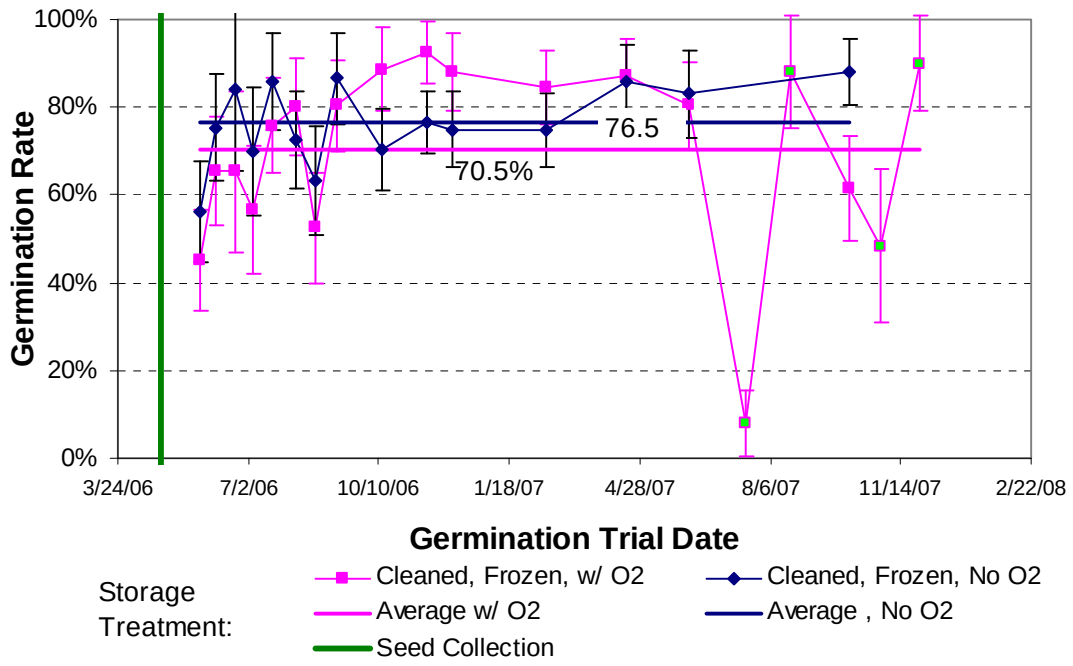

Figure 9. Soil germination rates for ambient versus oxygen-removal treatment for coyote willow seed (frozen, cleaned) germination trials. Green data symbols indicate "supplemental seed" analysis.

	Evaporative Cooling Pads											
	Bench 1: Riparian		Bench 2		Bench 3		Bench 4		Bench 5	
Repetition 1	--	--	BP LM 1	--	B SL 1	--	--	BP CM 1	M LL 1	--
	R UNN 1	--	--	--	BP LH 1	B CH 1	--	BP CH 1	--	BP CL 1
	R UYO 1	R CNN 1	M SM 1	--	B SH 1	--	--	--	--	B LH 1
	--	--	--	--	--	B CM 1	--	--	--	--
	R UYN 1	R CYN 1	--	--	--	--	--	M SH 1	BP LL 1	--
	--	--	--	B CL 1	M SL 1	M CL 1	--	--	M LH 1	BP SL 1
	R CNO 1	R UNO 1	B LM 1	B SM 1	--	--	M LM 1	--	M CH 1	B LL 1
	R CYO 1	R CNN 2	BP SM 1	BP LH 2	--	--	BP SH 1	BP SM 2	M CM 1	--
Repetition 2	--	--	--	--	--	--	B LM 2	M SM 2	--	--
	R CYO 2	--	B CH 2	B SM 2	--	B CL 2	M SH 2	BP CH 2	--	--
	R CYN 2	R UYO 2	--	--	B LH 2	--	--	BP LL 2	BP CM 2	--
	R UYN 2	R UNN 2	--	--	--	--	M CH 2	B CM 2	--	--
	R CNO 2	--	M LM 2	BP SH 2	--	B SL 2	B SH 2	--	M SL 2	--
	--	--	B LL 2	--	--	M CM 2	M LL 2	M LH 2	--	--
	--	R UNO 2	--	M CL 2	--	BP LM 2	--	BP CL 2	--	BP SL 2
Repetition 3	--	R UYN 3	B SL 3	--	--	BP CM 3	--	--	BP LH 3	--
	--	--	--	M LH 3	--	--	--	B CL 3	--	--
	R UNO 3	R CNN 3	M CL 3	--	--	--	--	B CM 3	--	B SH 3
	--	--	M CH 3	BP SM 3	--	--	B LL 3	--	--	--
	--	R CNO 3	M SL 3	--	B SM 3	--	BP LM 3	BP CH 3	M LM 3	--
	R UNN 3	R CYO 3	--	B LH 3	--	BP SL 3	BP SH 3	--	BP CL 3	M SH 3
	--	R CYN 3	--	--	--	B CH 3	M SM 3	B LM 3	--	--
	R UYO 3		--		M LL 3		BP LL 3		M CM 3	

TREATMENT KEY (In Sequential Order)						
Species	Soil	Seed Cleaning	Biosol	Seed Type	Seeding Rate	Replication
R = Riparian	Loose	C = Cleaned	N = No	O = Old (2006)	60 PLS/sq ft	1 = Rep 1
		U = Un-cleaned	Y = Yes, 1500 lbs/acre	N = New (2007)		2 = Rep 2
						3 = Rep 3
BP = *Baccharis emoryi* and *Pluchea odorata*	L = Loose	Un-cleaned	No	N/A	L = 4 PLS/sq ft	1 = Rep 1
	C = Compacted				M = 20 PLS/sq ft	2 = Rep 2
	S = Sand				H = 100 PLS/sq ft	3 = Rep 3
B = *Baccharis emoryi*	L = Loose	Cleaned	No	N/A	L = 4 PLS/sq ft	1 = Rep 1
	C = Compacted				M = 20 PLS/sq ft	2 = Rep 2
	S = Sand				H = 100 PLS/sq ft	3 = Rep 3
M = Mesquite	L = Loose	N/A	No	N/A	L = 30 PLS/sq ft	1 = Rep 1
	C = Compacted				M = 60 PLS/sq ft	2 = Rep 2
	S = Sand				H = 120 PLS/sq ft	3 = Rep 3

Figure 10. Greenhouse layout for 2007 small-scale greenhouse Task 2-Task 4 studies.

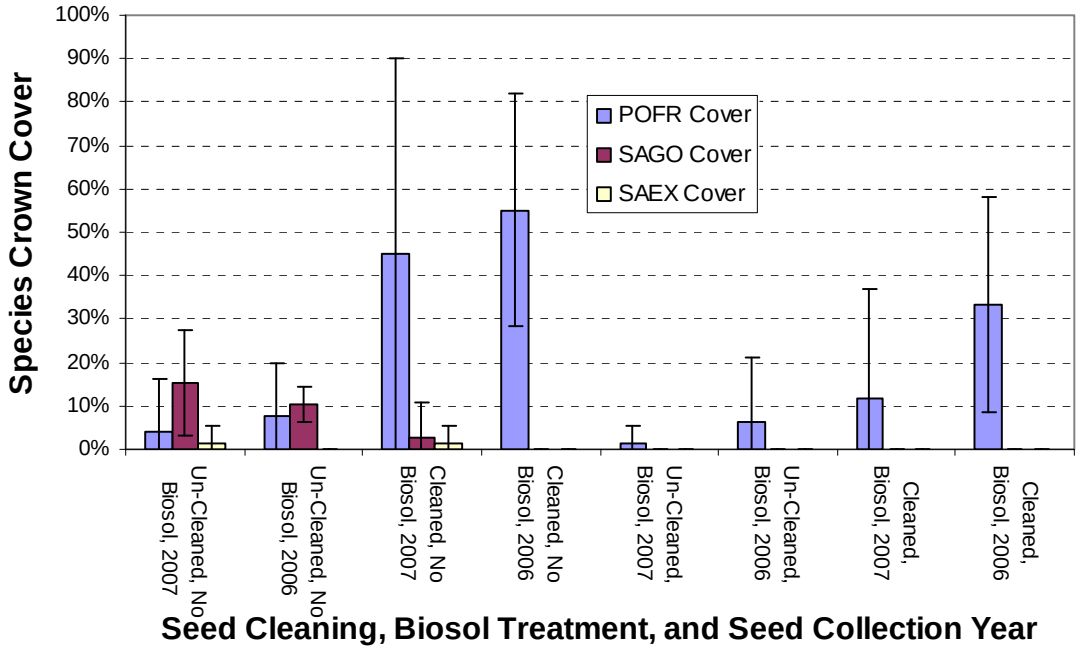

Figure 11. Average crown cover of Fremont cottonwood (POFR), Goodding's willow (SAGO), and coyote willow (SAEX) vs. seed cleaning, Biosol® addition, and storage duration in year-old seed 7-gallon pot trials.

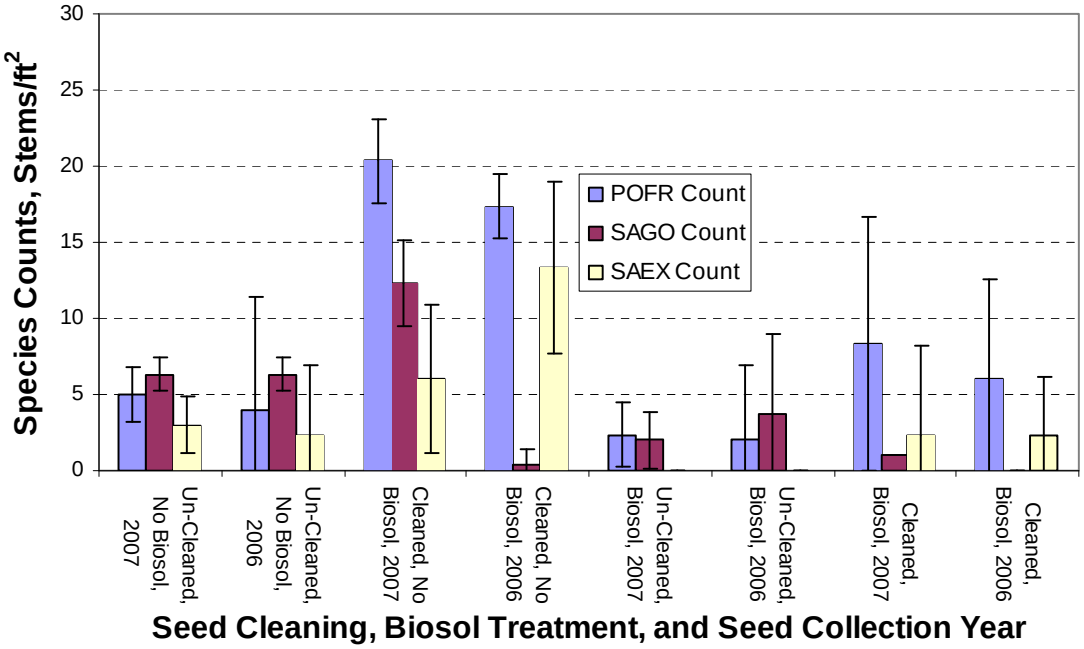

Figure 12. Average stem count of Fremont cottonwood (POFR), Goodding's willow (SAGO), and coyote willow (SAEX) vs. seed cleaning, Biosol® addition, and storage duration in year-old seed 7-gallon pot trials.

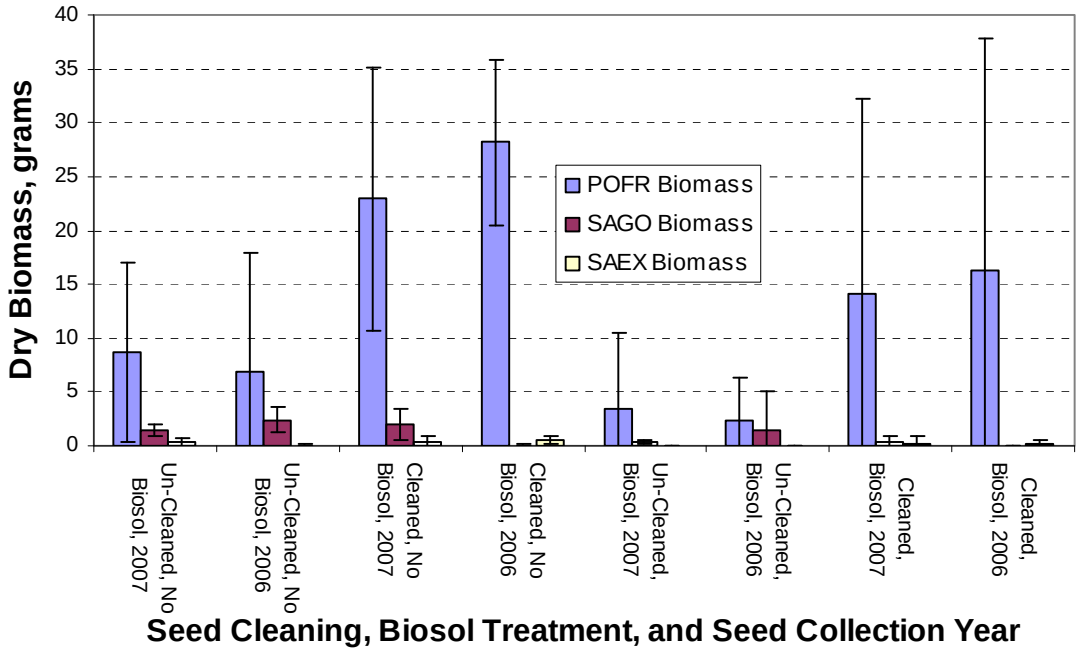

Figure 13. Average above-ground dry biomass of Fremont cottonwood (POFR), Goodding's willow (SAGO), and coyote willow (SAEX) vs. seed cleaning, Biosol® addition, and storage duration in year-old seed 7-gallon pot trials.

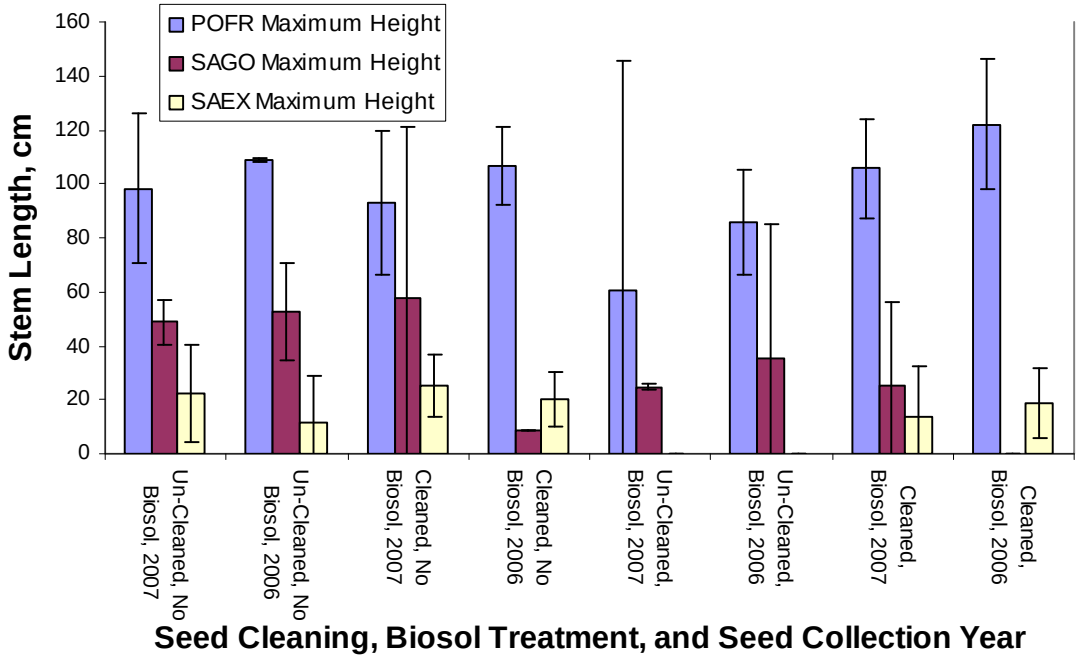

Figure 14. Average maximum height of Fremont cottonwood (POFR), Goodding's willow (SAGO), and coyote willow (SAEX) vs. seed cleaning, Biosol® addition, and storage duration in year-old seed 7-gallon pot trials.

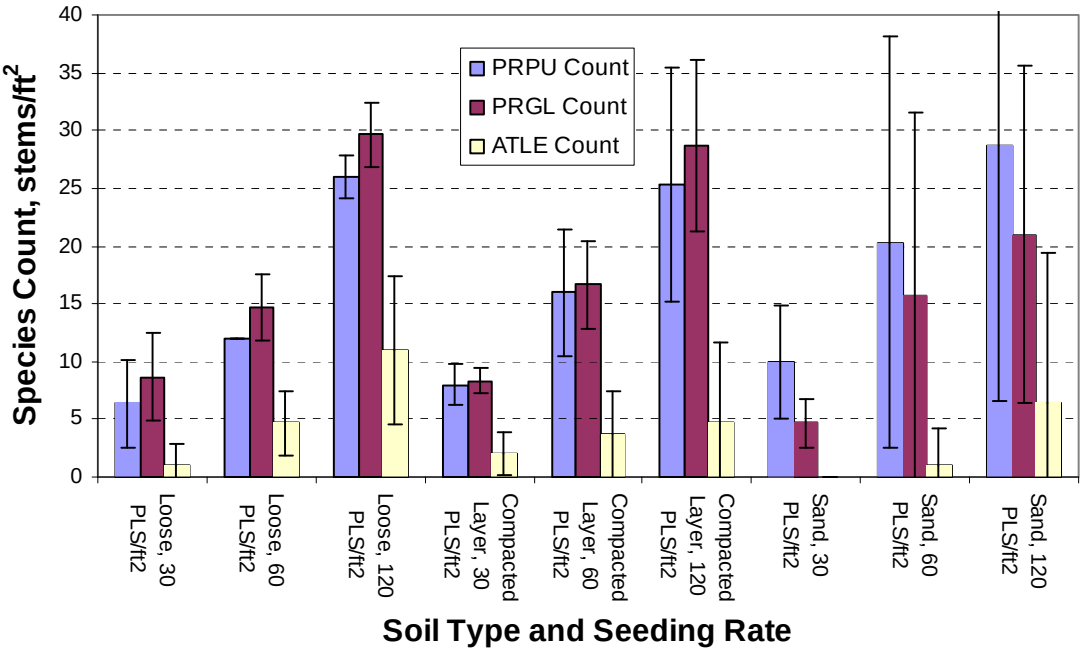

Figure 15. Average stem count of screwbean mesquite (PRPU), honey mesquite (PRGL), and quailbush (ATLE) vs. soil type and seeding rate in 7-gallon pot trials.

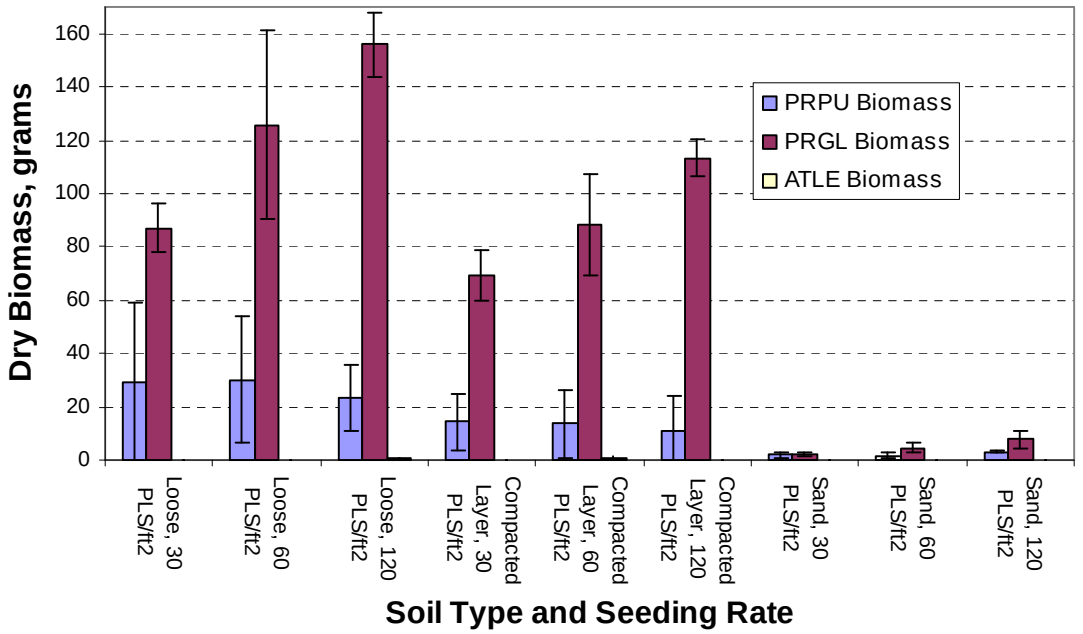

Figure 16. . Average above-ground dry biomass of screwbean mesquite (PRPU), honey mesquite (PRGL), and quailbush (ATLE) vs. soil type and seeding rate in 7-gallon pot trials.

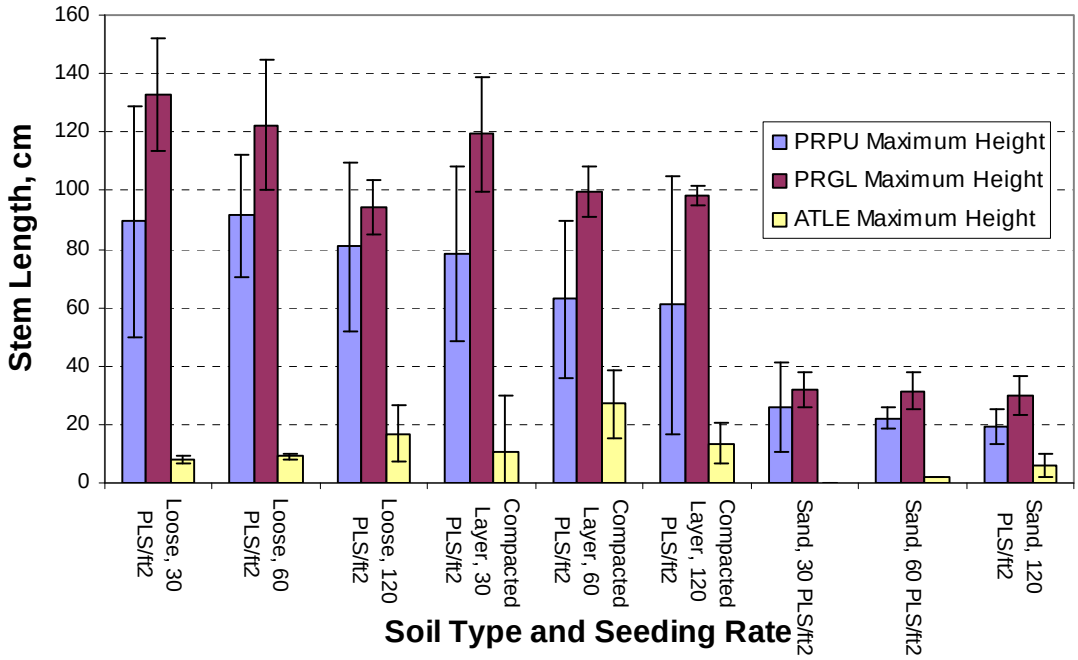

Figure 17. Average maximum height of screwbean mesquite (PRPU), honey mesquite (PRGL), and quailbush (ATLE) vs. soil type and seeding rate in 7-gallon pot trials.

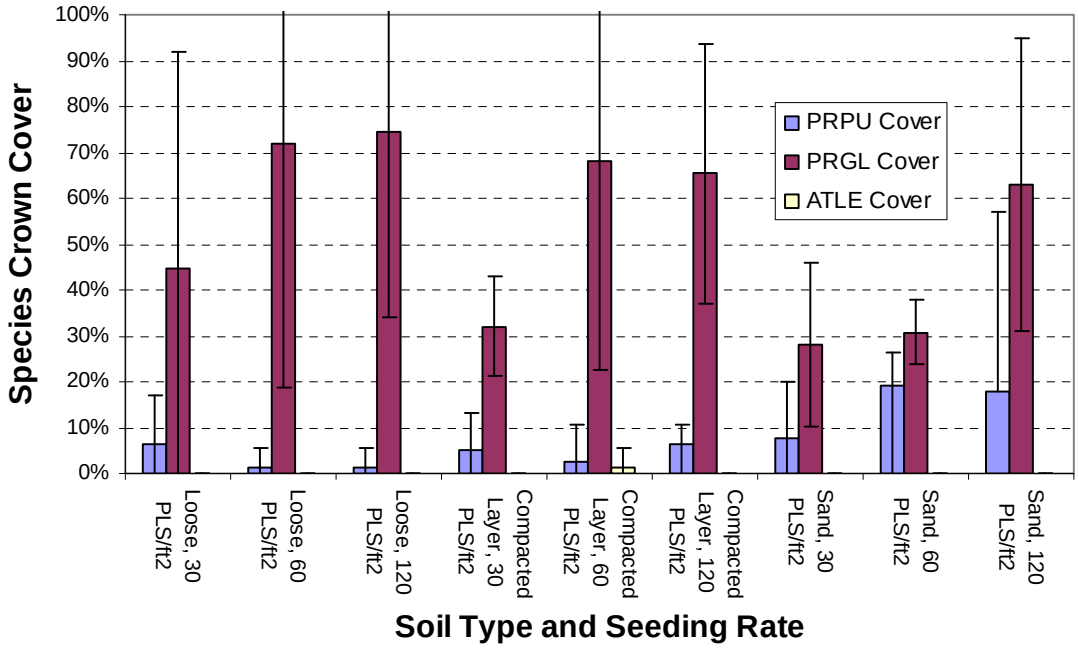

Figure 18. Average crown cover of screwbean mesquite (PRPU), honey mesquite (PRGL), and quailbush (ATLE) vs. soil type and seeding rate in 7-gallon pot trials.

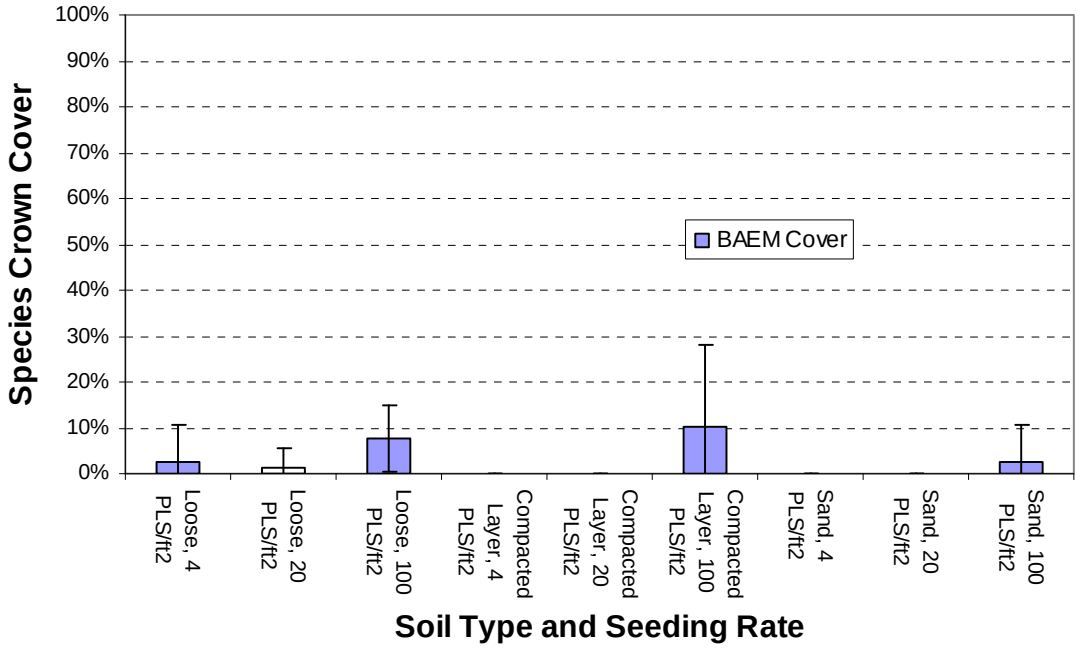

Figure 19. Average crown cover of Emory's baccharis (BAEM) vs. soil type and seeding rate in 7-gallon pot trials.

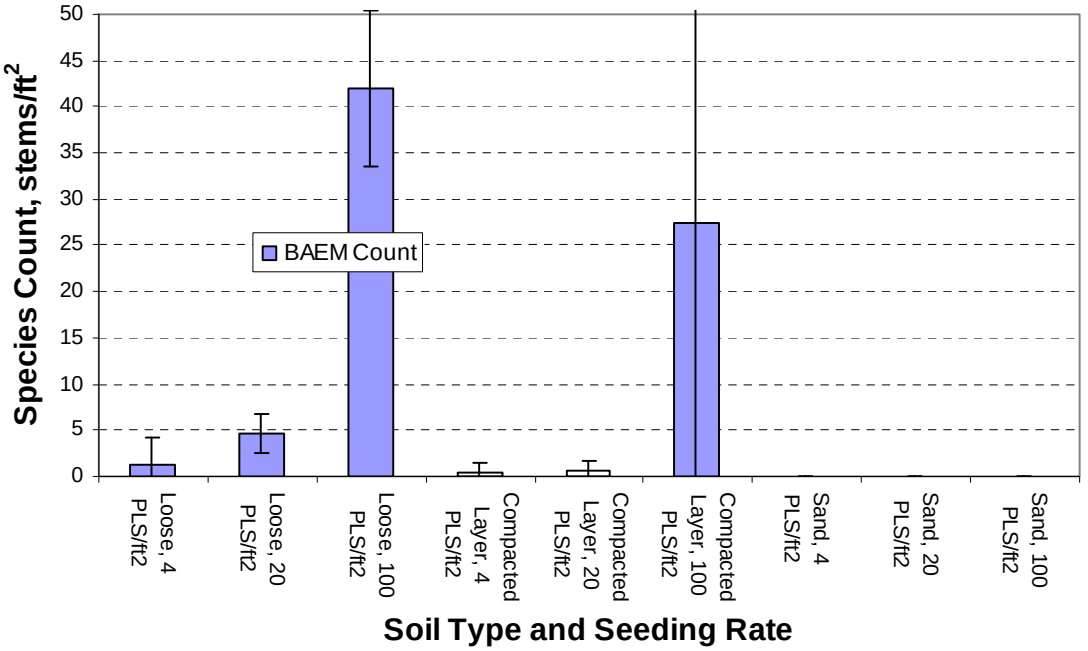

Figure 20. Average stem count of Emory's baccharis (BAEM) vs. soil type and seeding rate in 7-gallon pot trials.

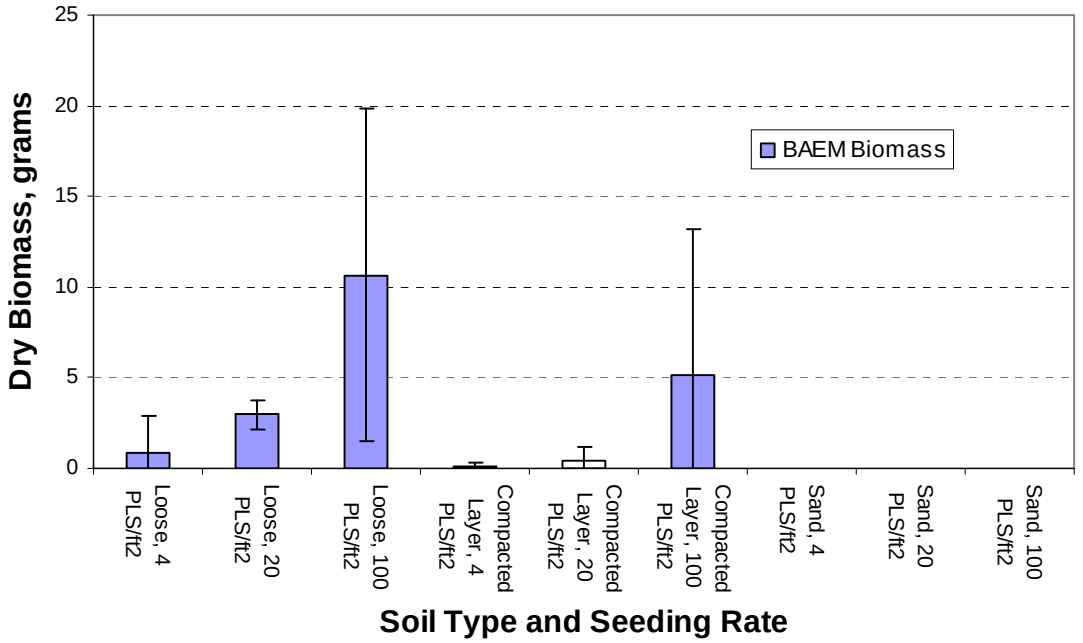

Figure 21. Average above-ground dry biomass of Emory's baccharis (BAEM) vs. soil type and seeding rate in 7-gallon pot trials.

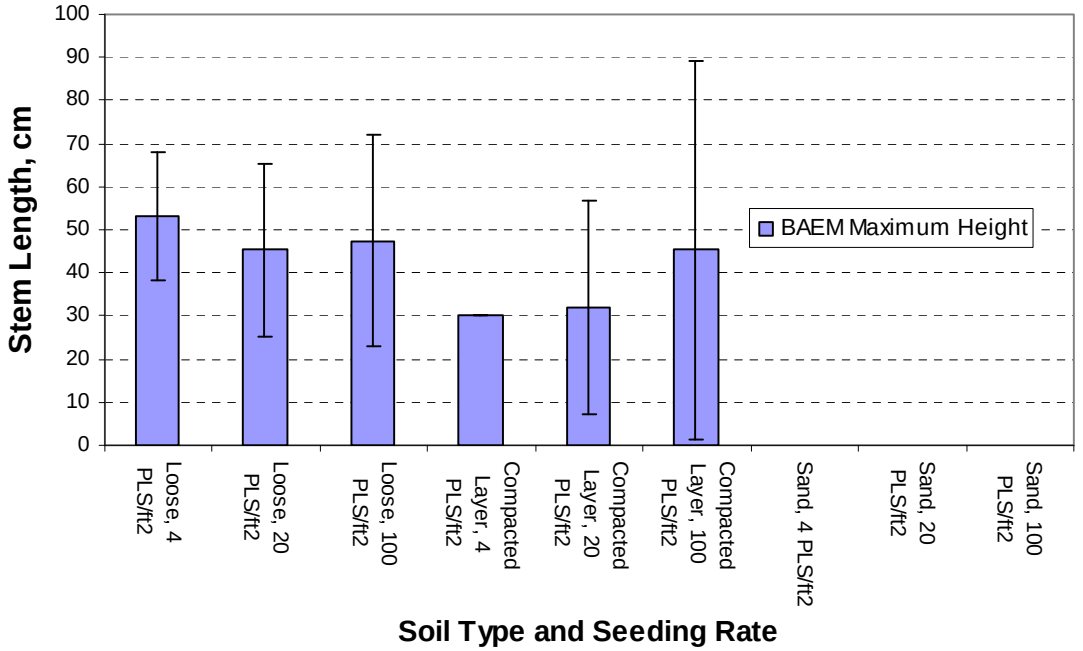

Figure 22. Average maximum height of Emory's baccharis (BAEM) vs. soil type and seeding rate in 7-gallon pot trials.

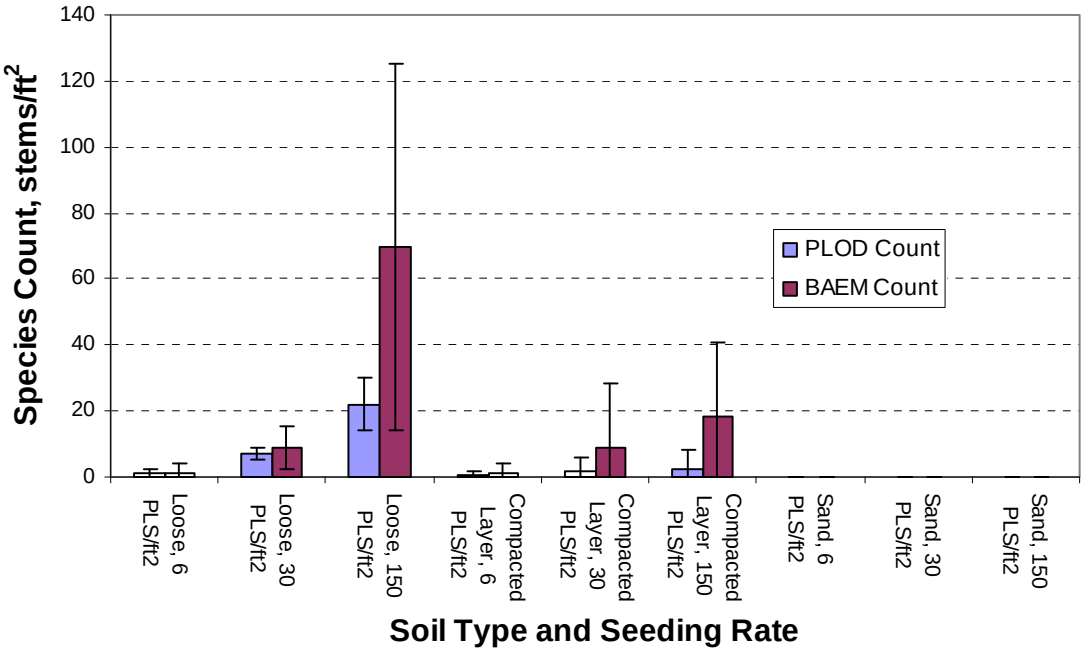

Figure 23. Average stem count of Emory's baccharis (BAEM) and sweetscent (PLOD) vs. soil type and seeding rate in 7-gallon pot trials.

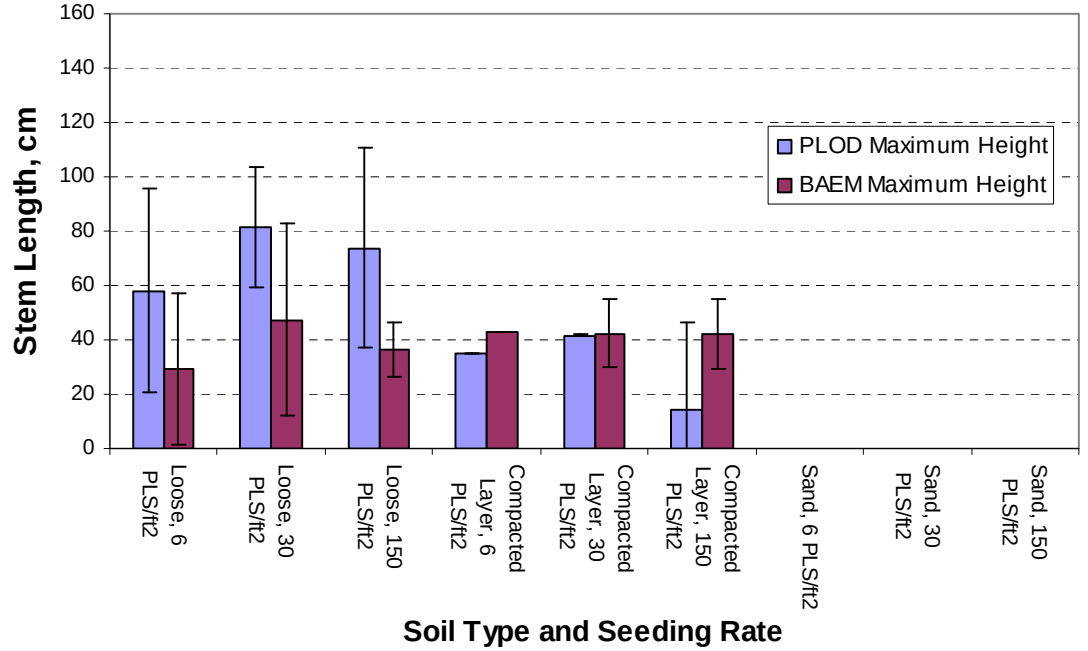

Figure 24. Average maximum plant height of Emory's baccharis (BAEM) and sweetscent (PLOD) vs. soil type and seeding rate in 7-gallon pot trials.

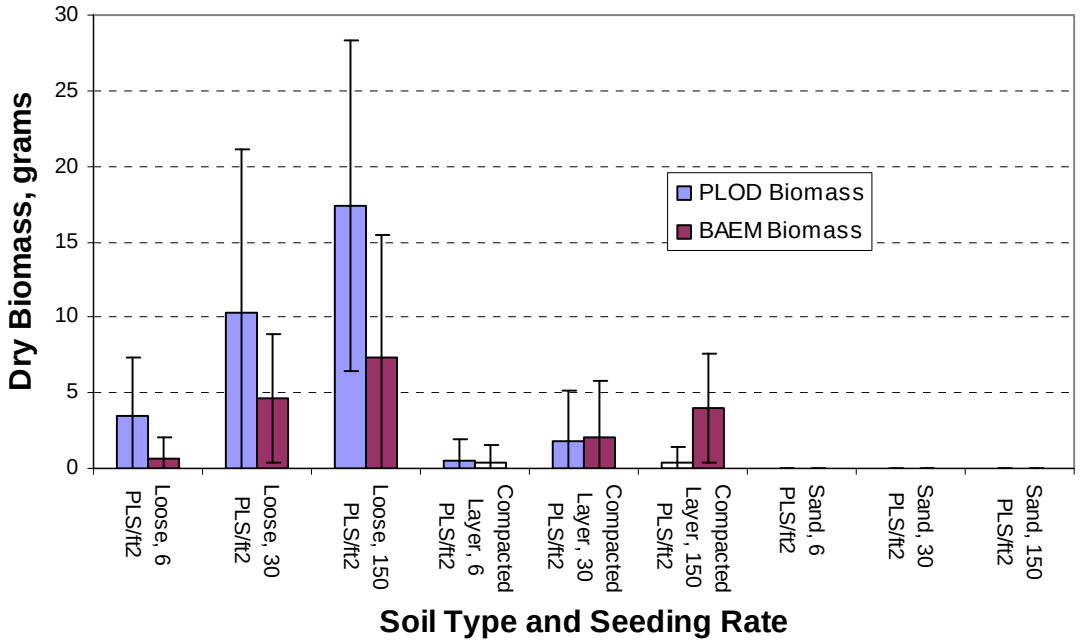

Figure 25. Average above-ground dry biomass of Emory's baccharis (BAEM) and sweetscent (PLOD) vs. soil type and seeding rate in 7-gallon pot trials.

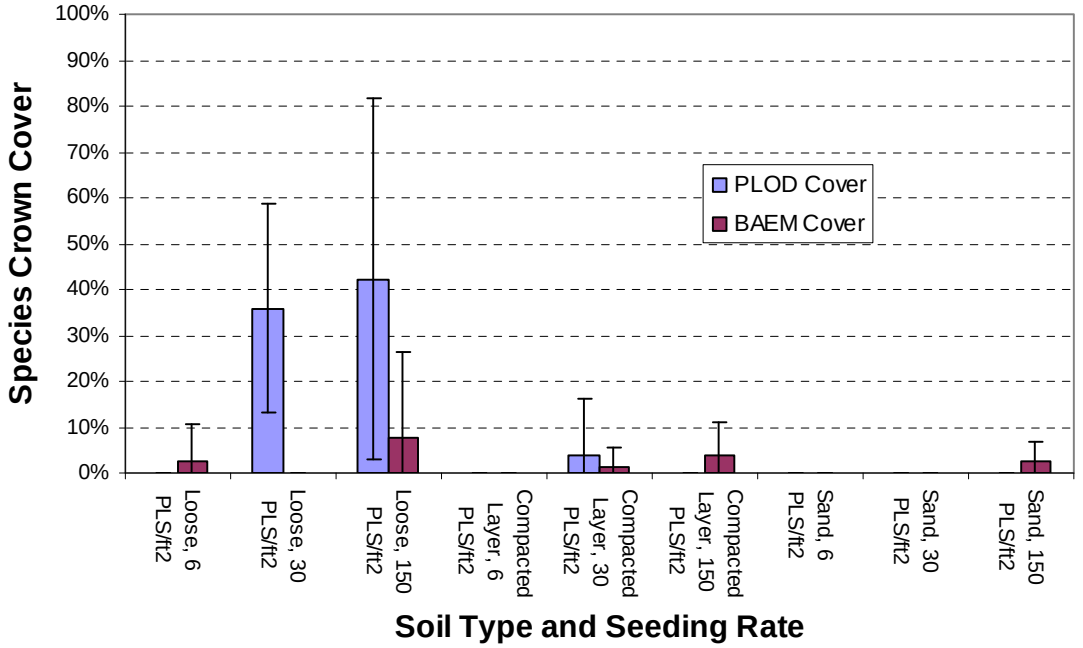

Figure 26. Average crown cover of Emory's baccharis (BAEM) and sweetscent (PLOD) vs. soil type and seeding rate in 7-gallon pot trials.

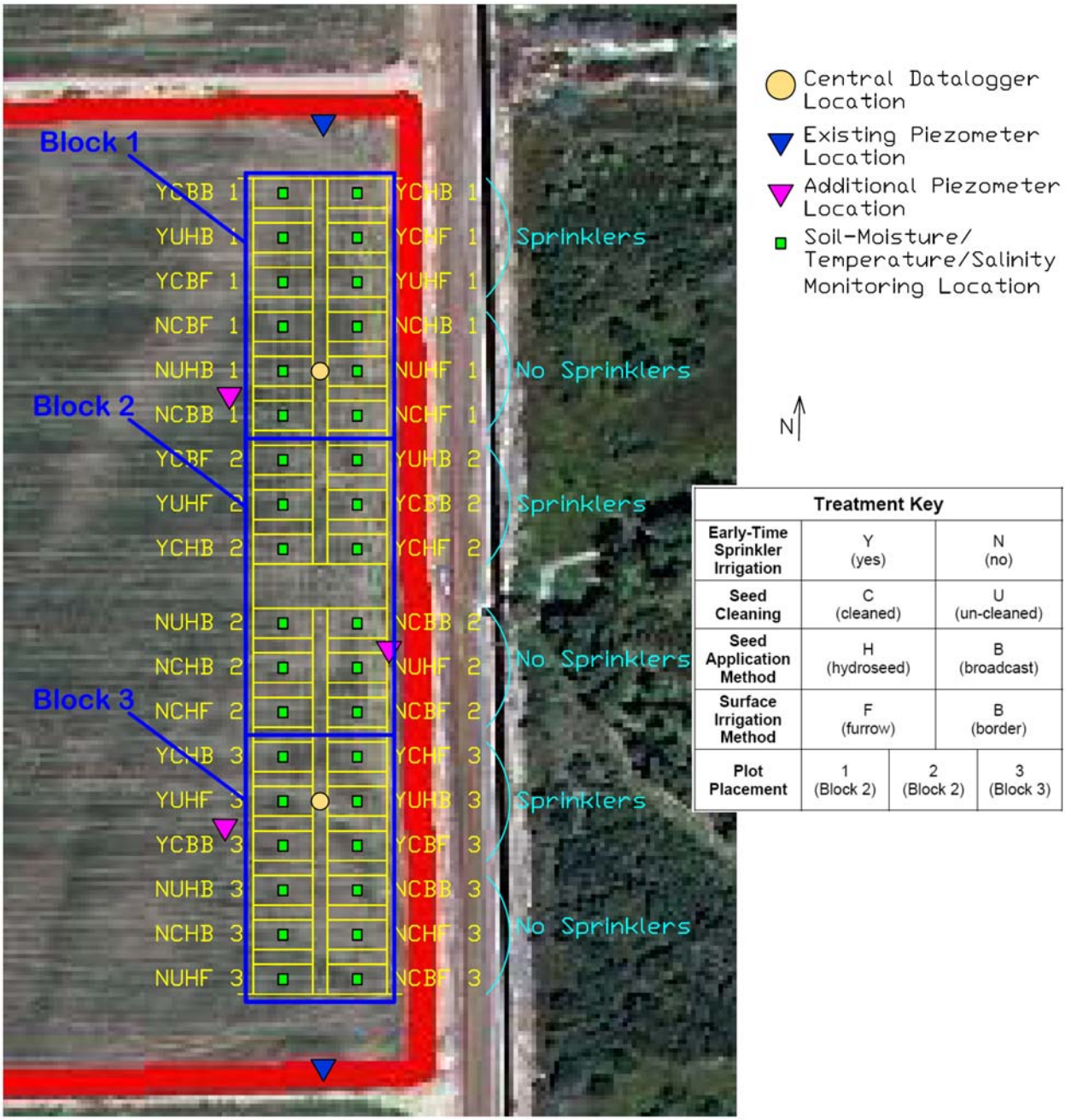

Figure 27. Small-scale field study treatment layout on Cibola NWR Field 51.

Figure 28. Furrow shaping for small-scale field studies.

Figure 29. Furrow and border irrigation plots for small-scale field studies.

Figure 30. Instrumentation nest in small-scale study field plot prior to soil backfilling. The red oval encircles an ECH_2O-TE water content, temperature, and salinity sensor at six inches (15 cm) below ground surface, and the blue oval encircles an EC-10 water content sensor at eighteen inches (46 cm) below ground surface.

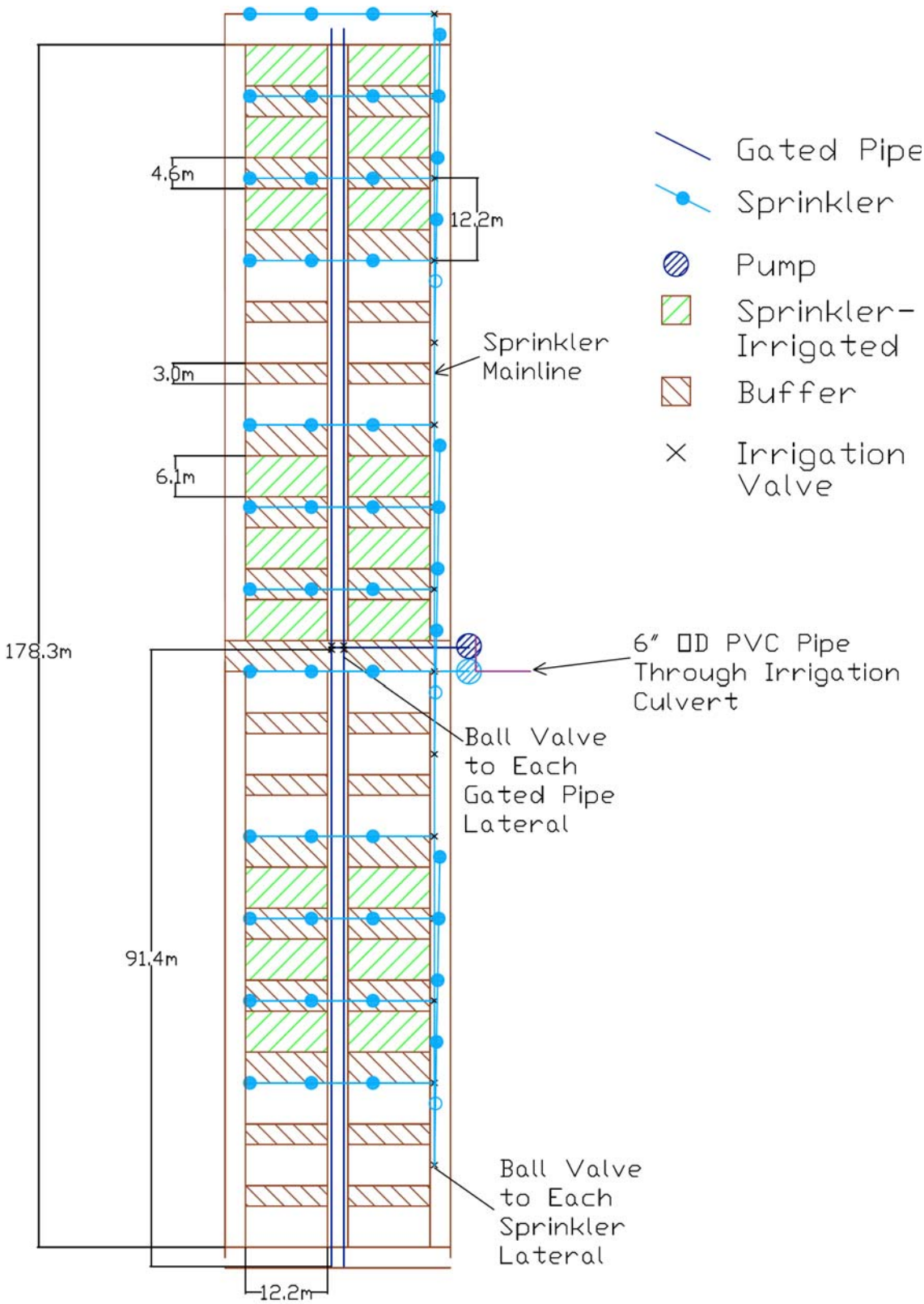

Figure 31. As-built irrigation system for small-scale field studies.

Figure 32. Hydroseed application for small-scale field studies.

Figure 33. Broadcast seed application for small-scale field studies.

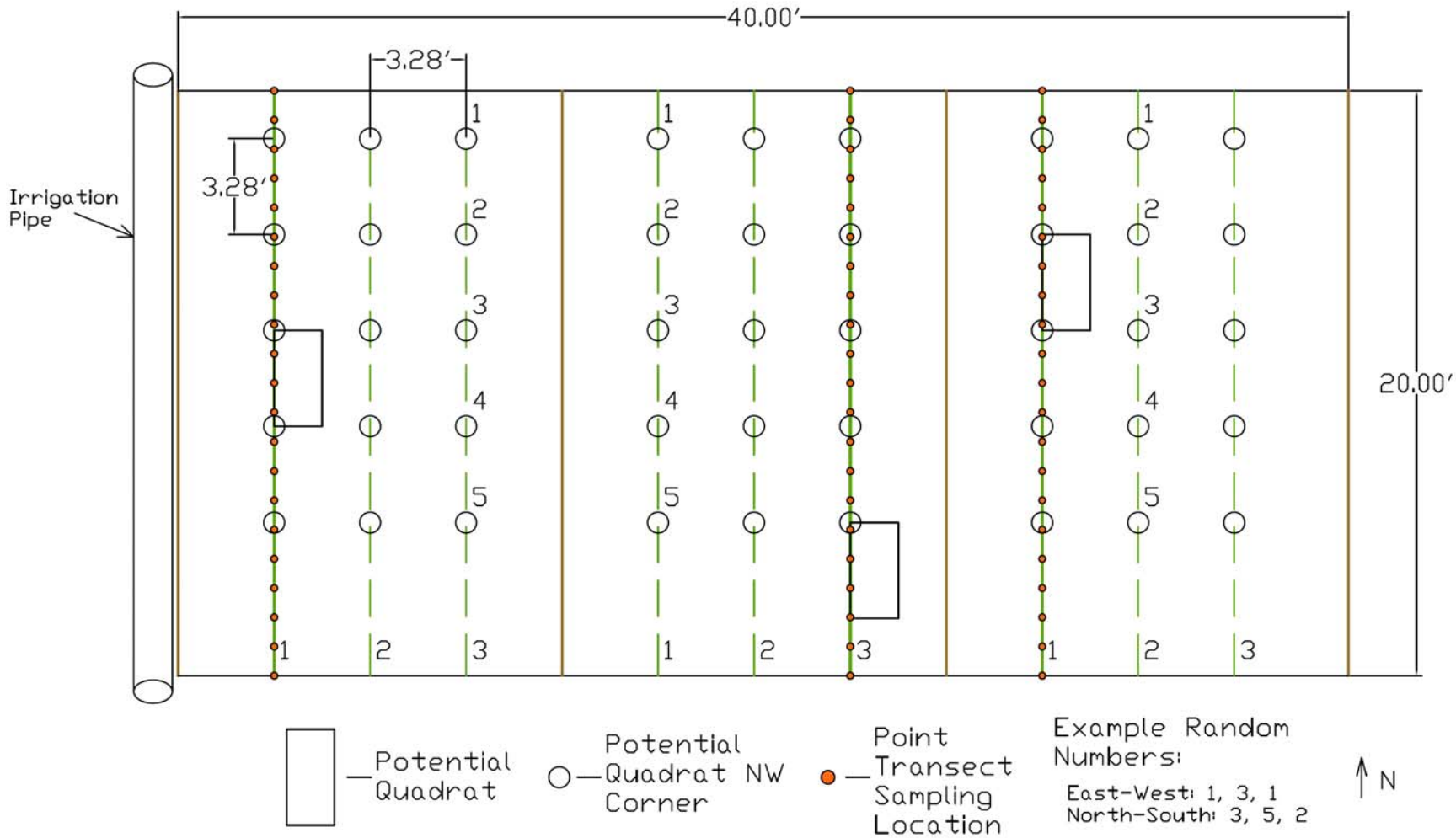

Figure 34. Example vegetation survey schematic for small-scale field studies.

Figure 35. Canopy cover point-transect for small-scale field studies.

Figure 36. Harvested vegetation quadrat for small-scale field studies.

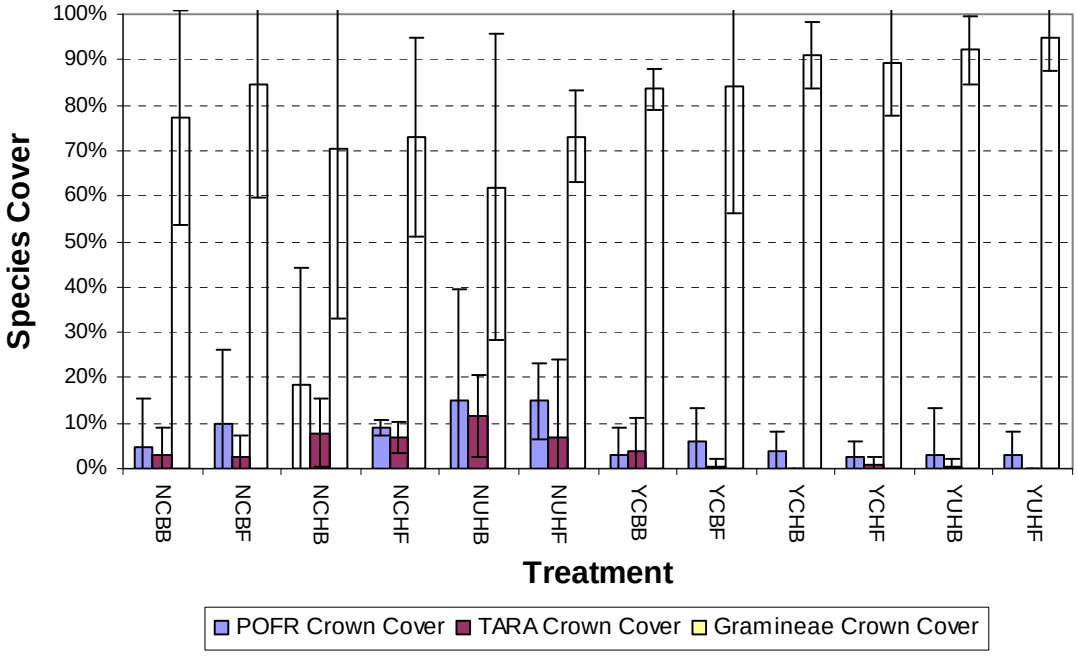

Figure 37. Average (per treatment) crown cover of Fremont cottonwood (POFR), saltcedar (TARA), and combined grasses and sedges (Gramineae) in small-scale field studies.

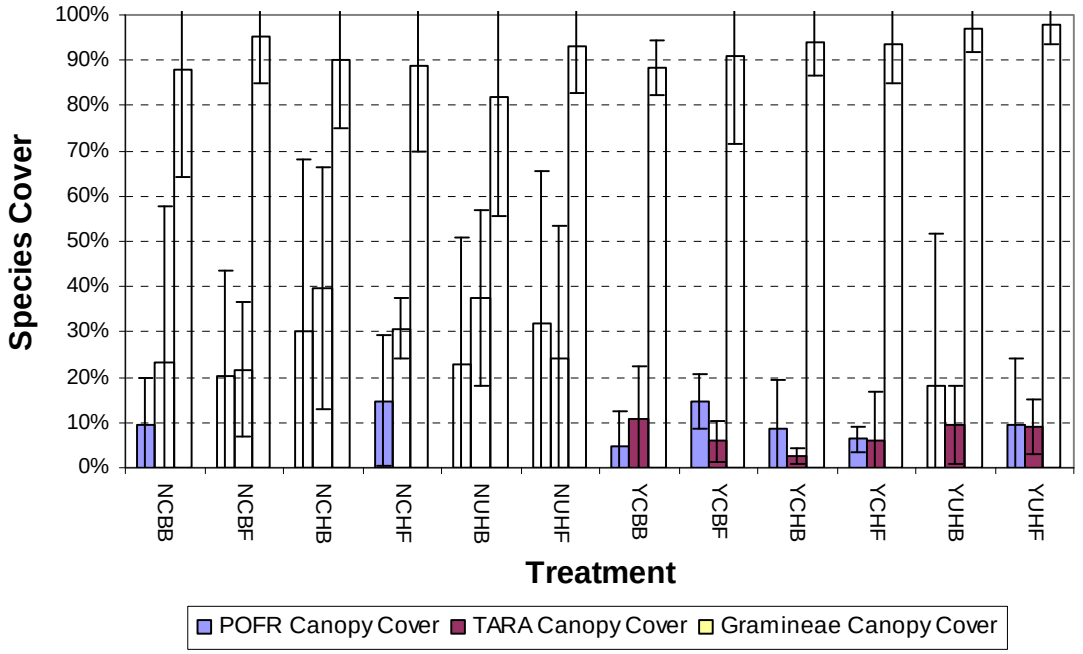

Figure 38. Average (per treatment) canopy cover of Fremont cottonwood (POFR), saltcedar (TARA), and combined grasses and sedges (Gramineae) in small-scale field studies.

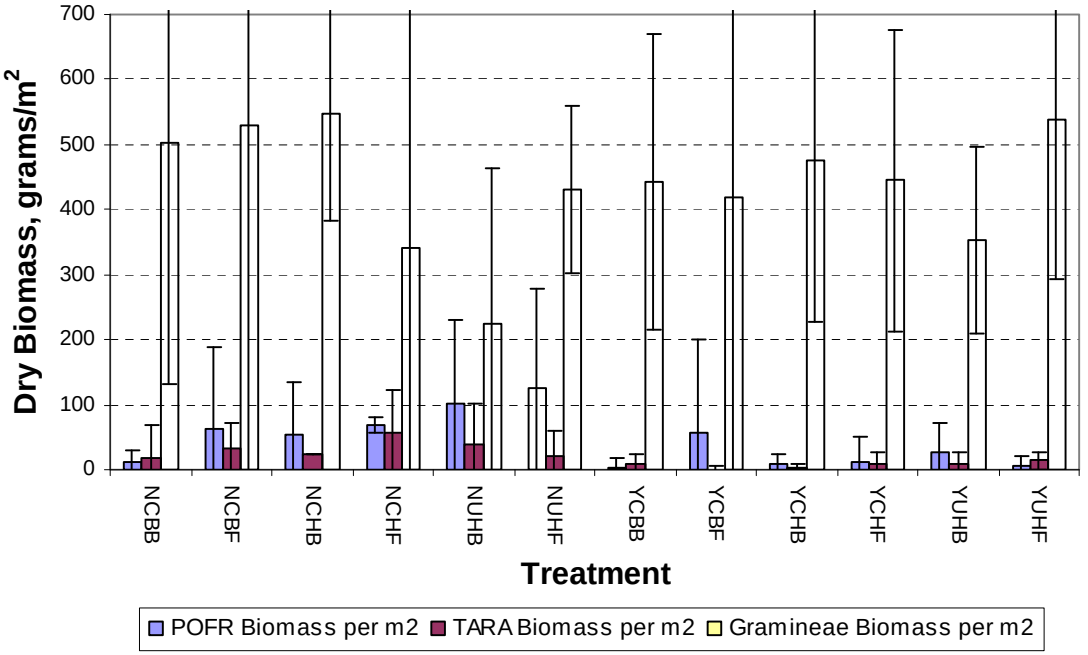

Figure 39. Average (per treatment) biomass of Fremont cottonwood (POFR), saltcedar (TARA), and combined grasses and sedges (Gramineae) in small-scale field studies.

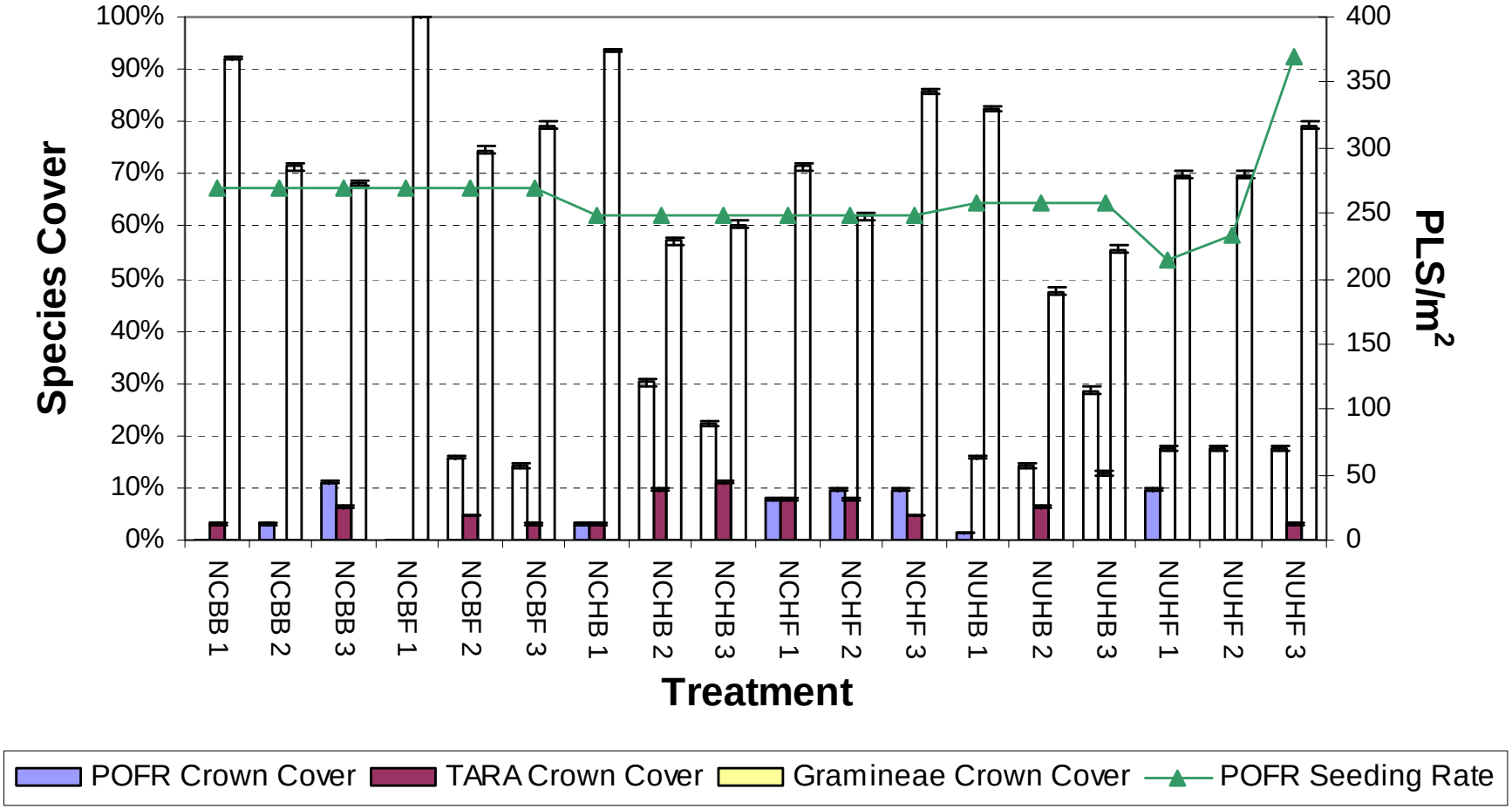

Figure 40. Average (per plot) crown cover of Fremont cottonwood (POFR), saltcedar (TARA), and combined grasses and sedges (Gramineae) in small-scale field studies, "No Sprinklers" treatments only.

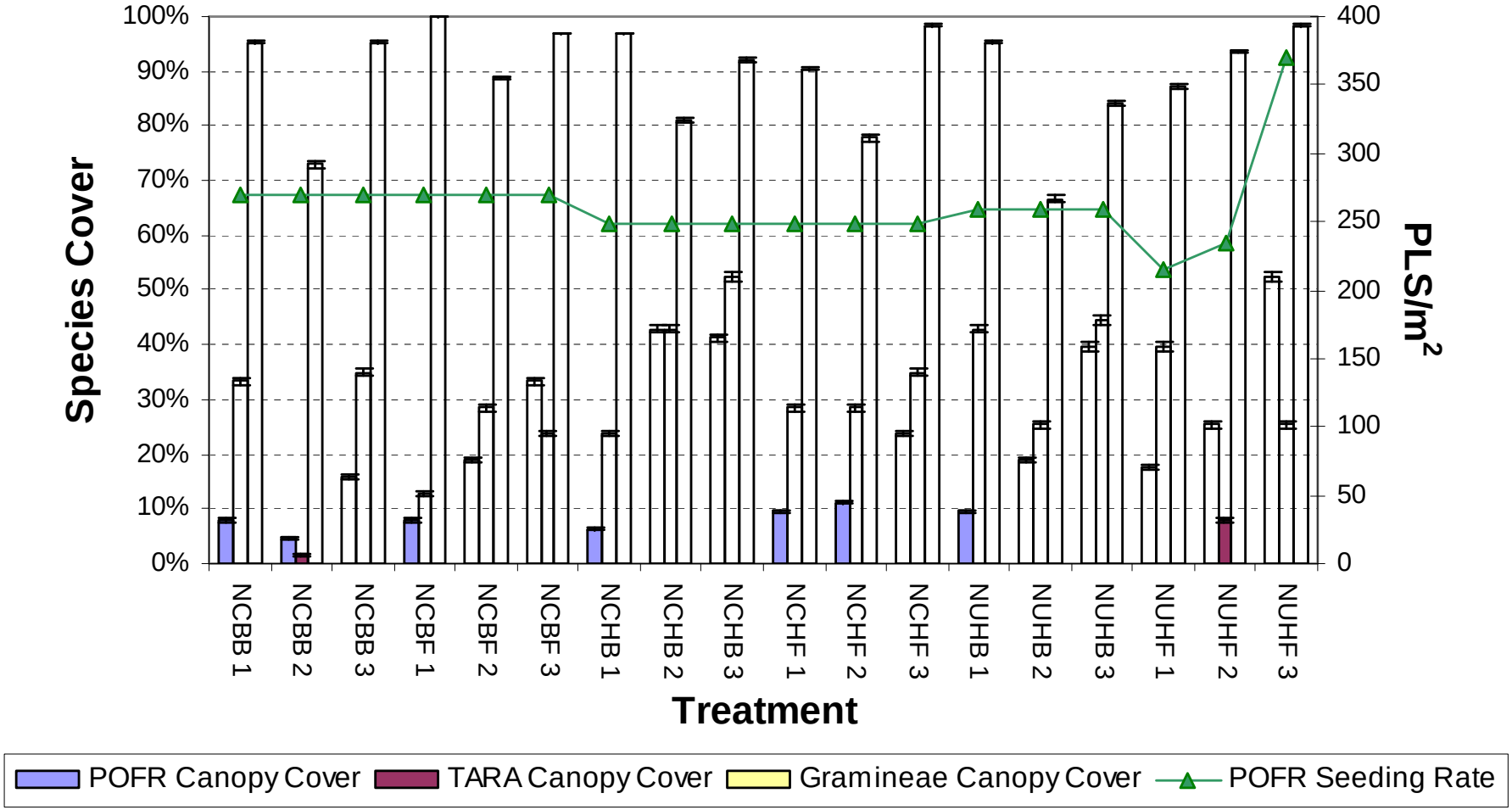

Figure 41. Average (per plot) canopy cover of Fremont cottonwood (POFR), saltcedar (TARA), and combined grasses and sedges (Gramineae) in small-scale field studies, "No Sprinklers" treatments only.

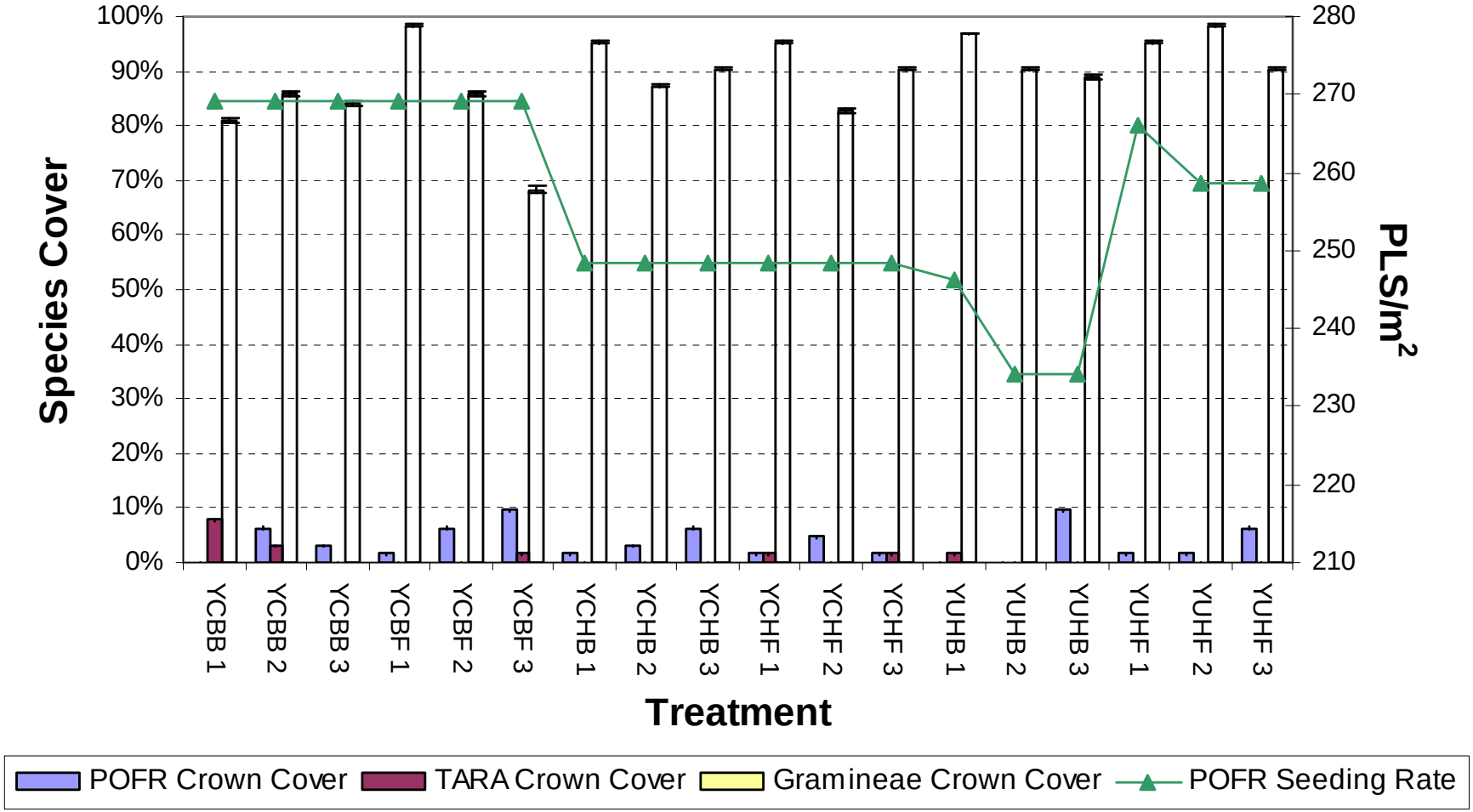

Figure 42. Average (per plot) crown cover of Fremont cottonwood (POFR), saltcedar (TARA), and combined grasses and sedges (Gramineae) in small-scale field studies, "Sprinklers" treatments only.

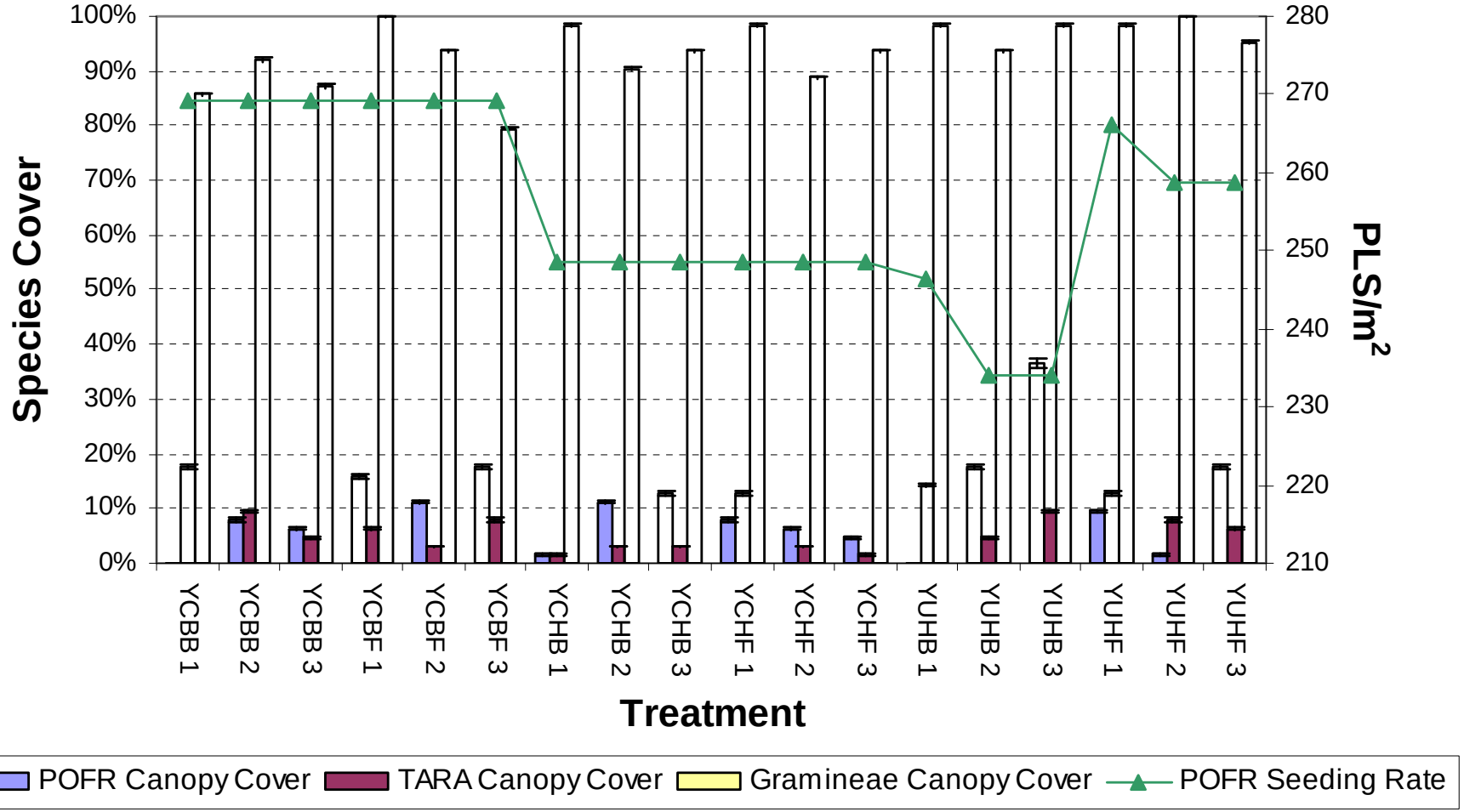

Figure 43. Average (per plot) canopy cover of Fremont cottonwood (POFR), saltcedar (TARA), and combined grasses and sedges (Gramineae) in small-scale field studies, "Sprinklers" treatments only.

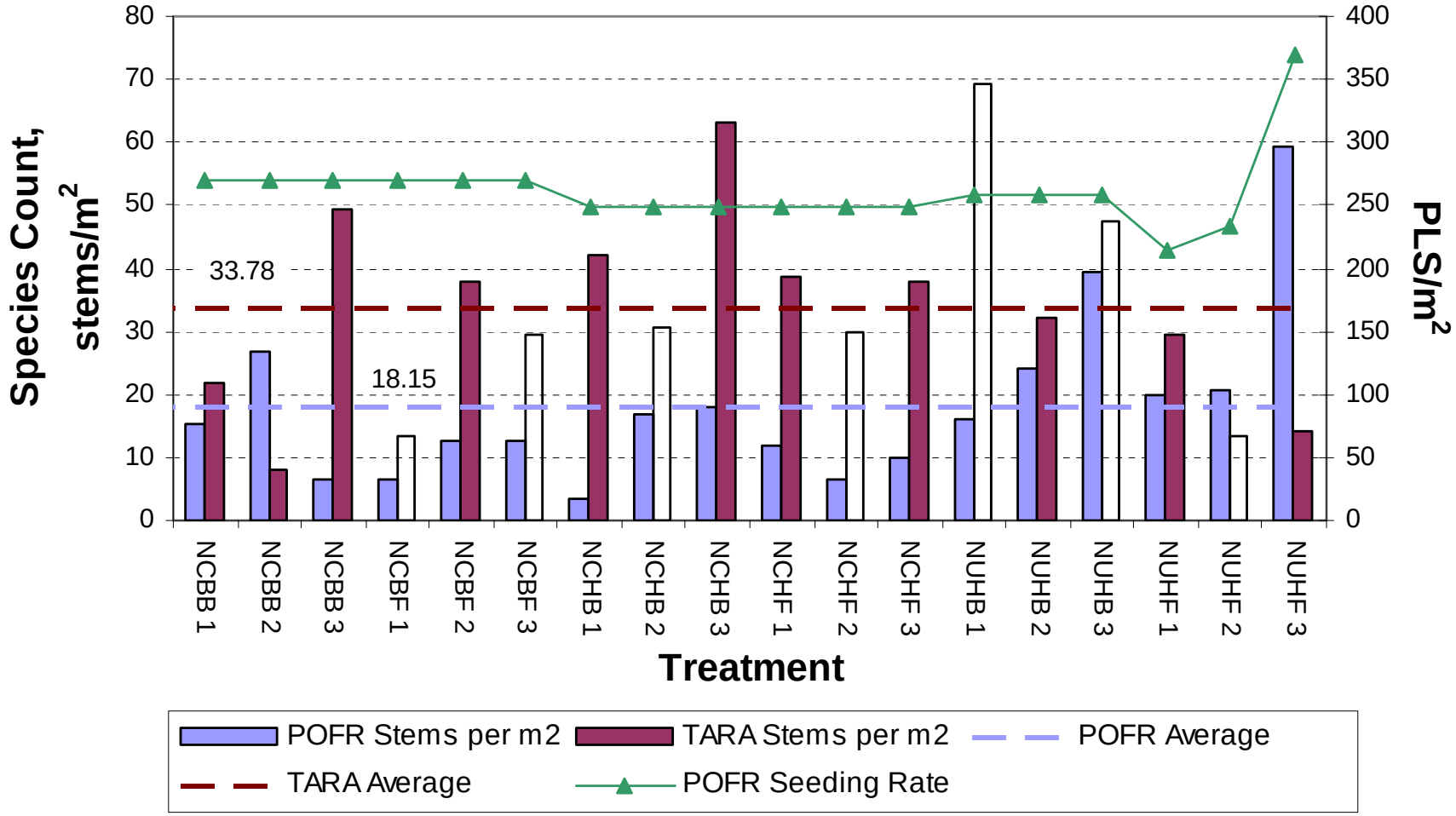

Figure 44. Average (per plot) stem count of Fremont cottonwood (POFR) and saltcedar (TARA) in small-scale field studies, "No Sprinklers" treatments only.

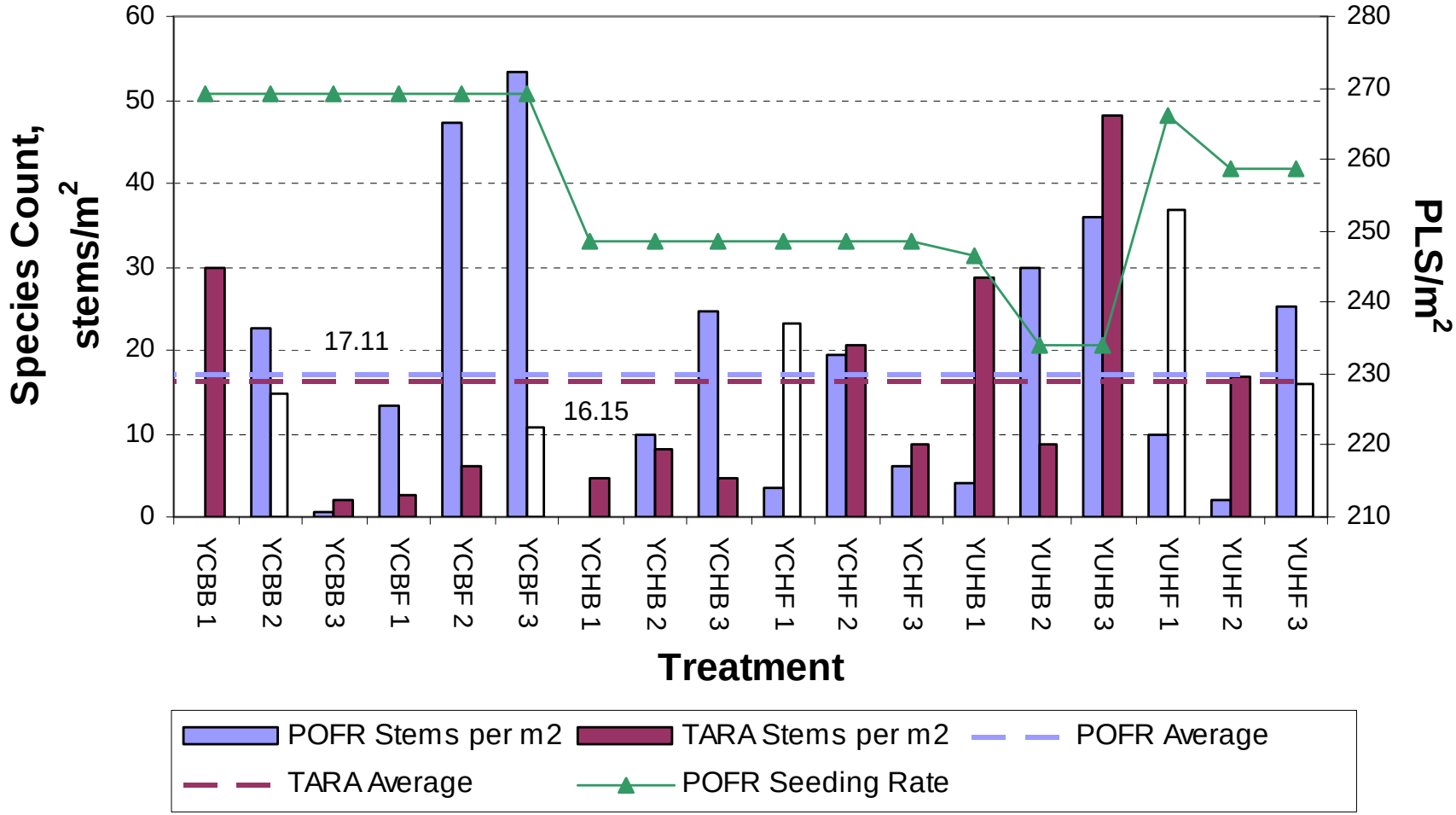

Figure 45. Average (per plot) stem count of Fremont cottonwood (POFR) and saltcedar (TARA) in small-scale field studies, "Sprinklers" treatments only.

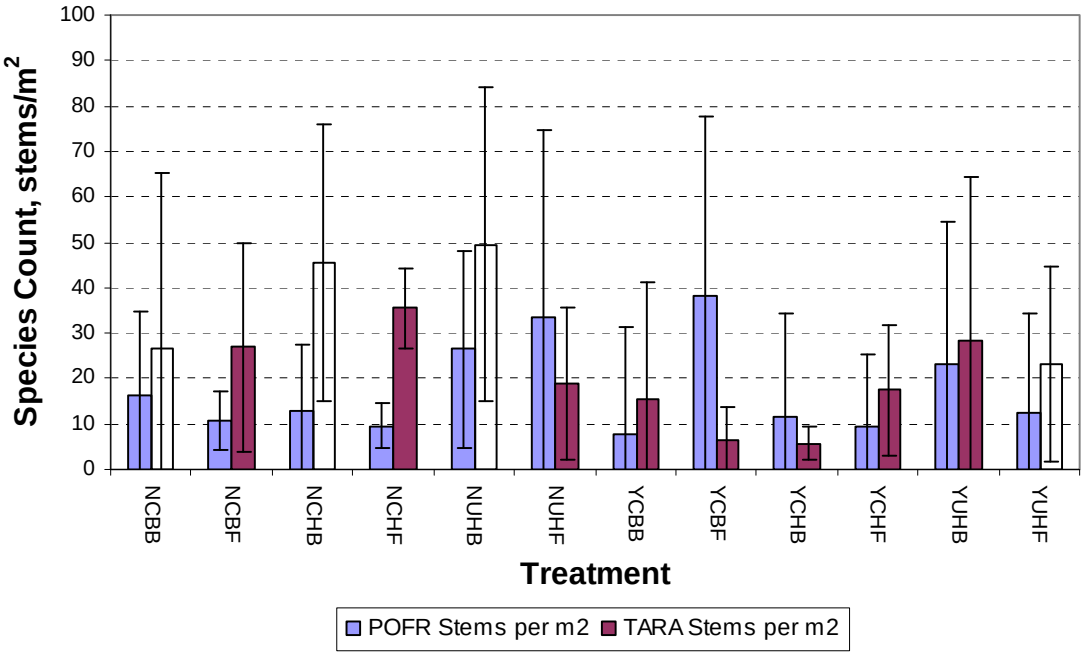

Figure 46. Average (per treatment) stem counts of Fremont cottonwood (POFR) and saltcedar (TARA) in small-scale field studies.

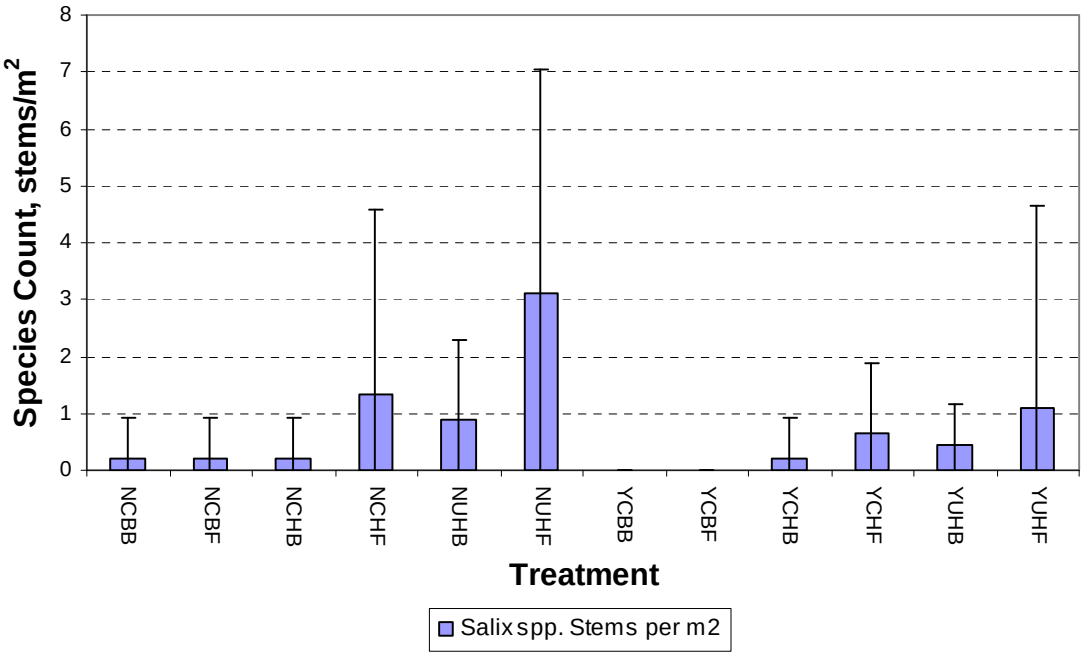

Figure 47. Average (per treatment) combined Goodding's and coyote willow (*Salix* spp.) stem count in small-scale field studies.

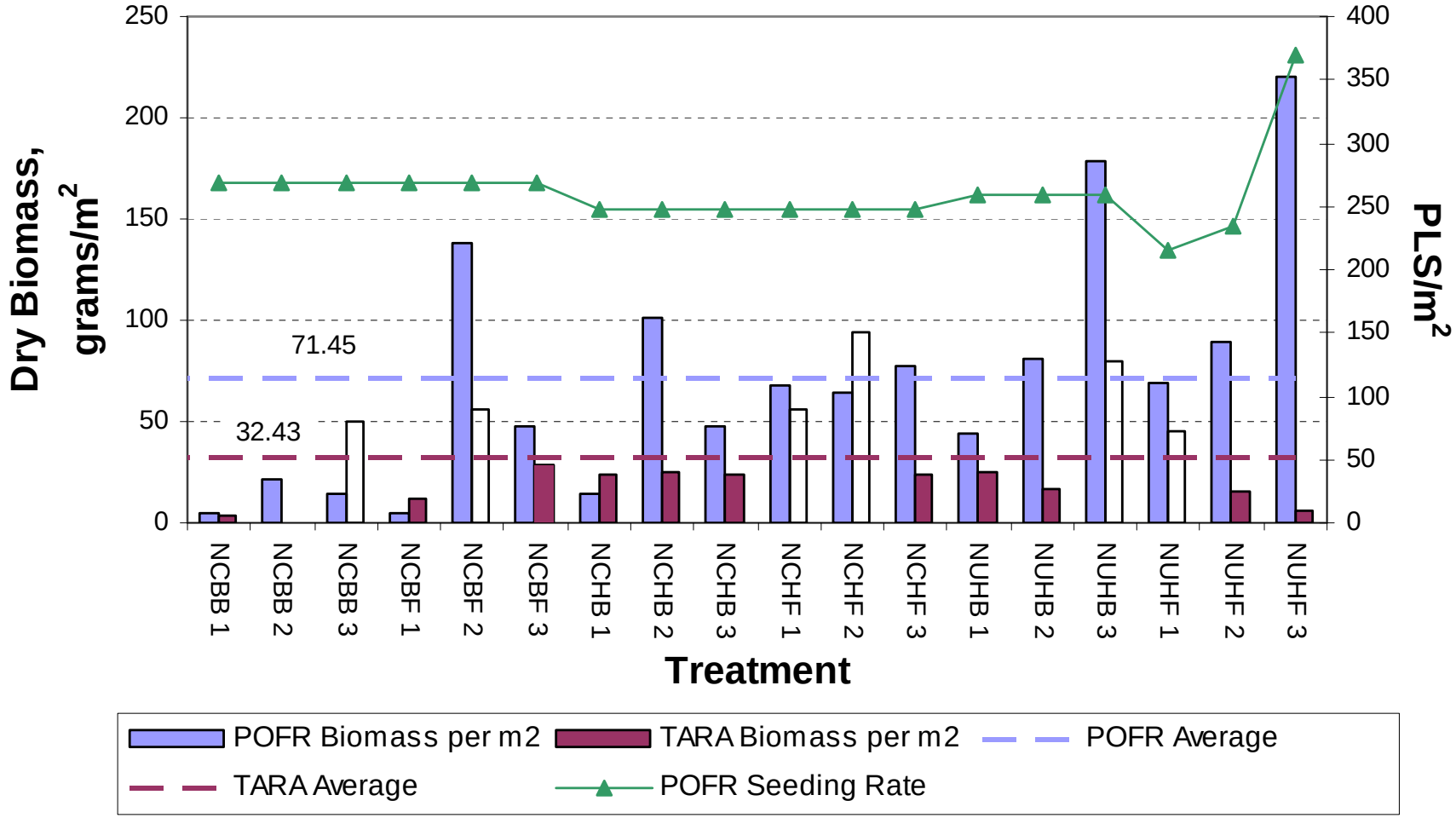

Figure 48. Average (per plot) biomass of Fremont cottonwood (POFR) and saltcedar (TARA) in small-scale field studies, "No Sprinklers" treatments only.

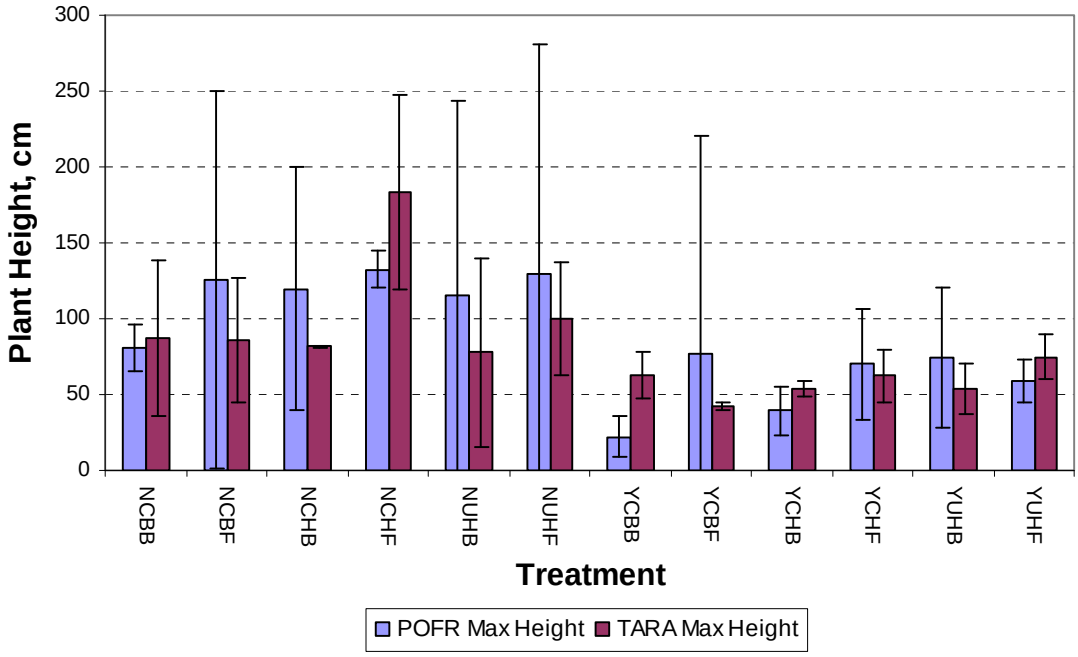

Figure 49. Average (per treatment) maximum plant height of Fremont cottonwood (POFR) and saltcedar (TARA) in small-scale field studies.

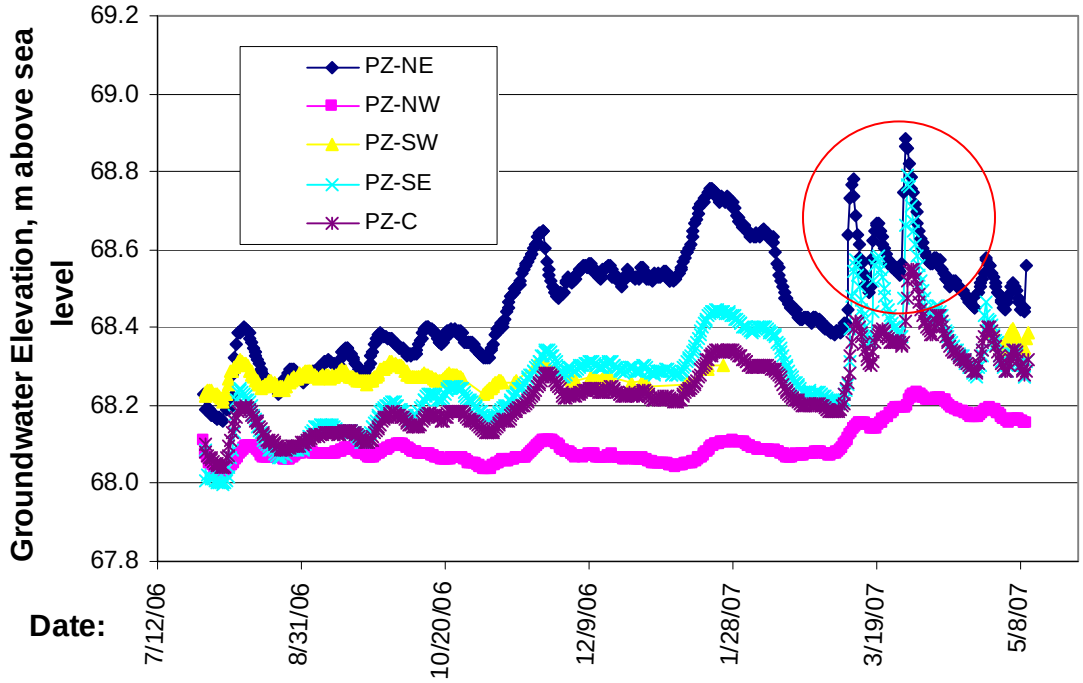

Figure 50. Groundwater elevation date for ten months prior to small-scale field study. The red outline indicates irrigation events for small-scale study pre-planting weed control.

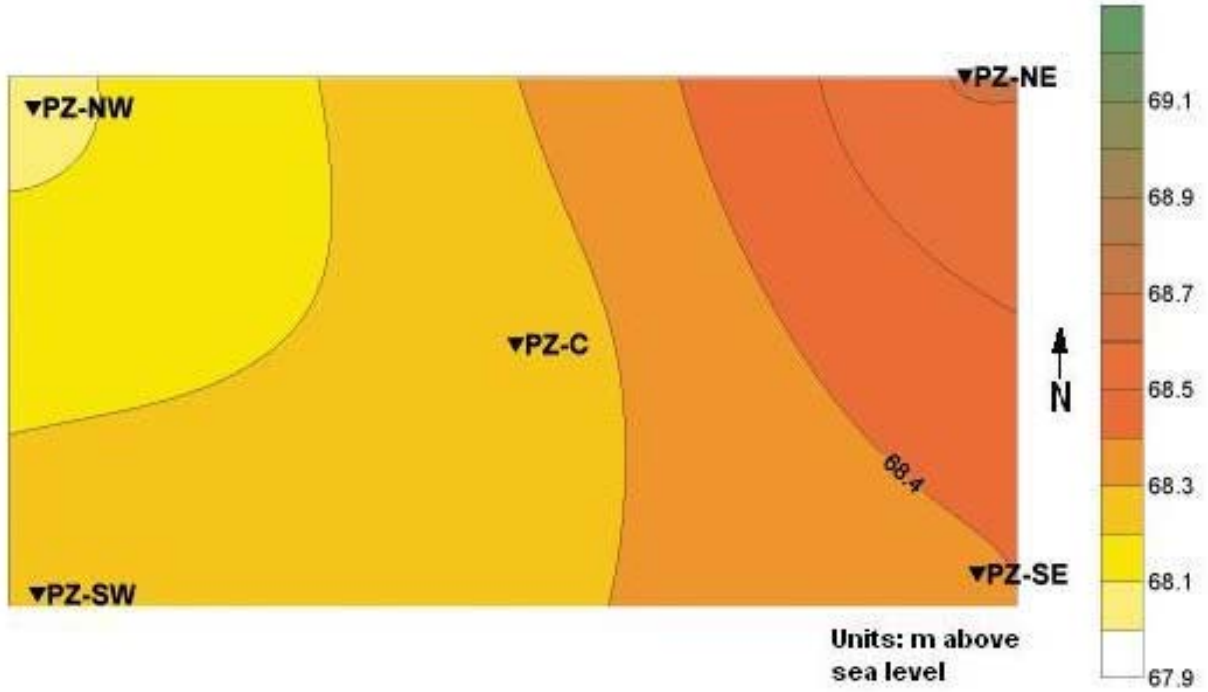

Figure 51. Winter groundwater elevation prior to any Field 51 irrigation for small-scale studies, December 15, 2006.

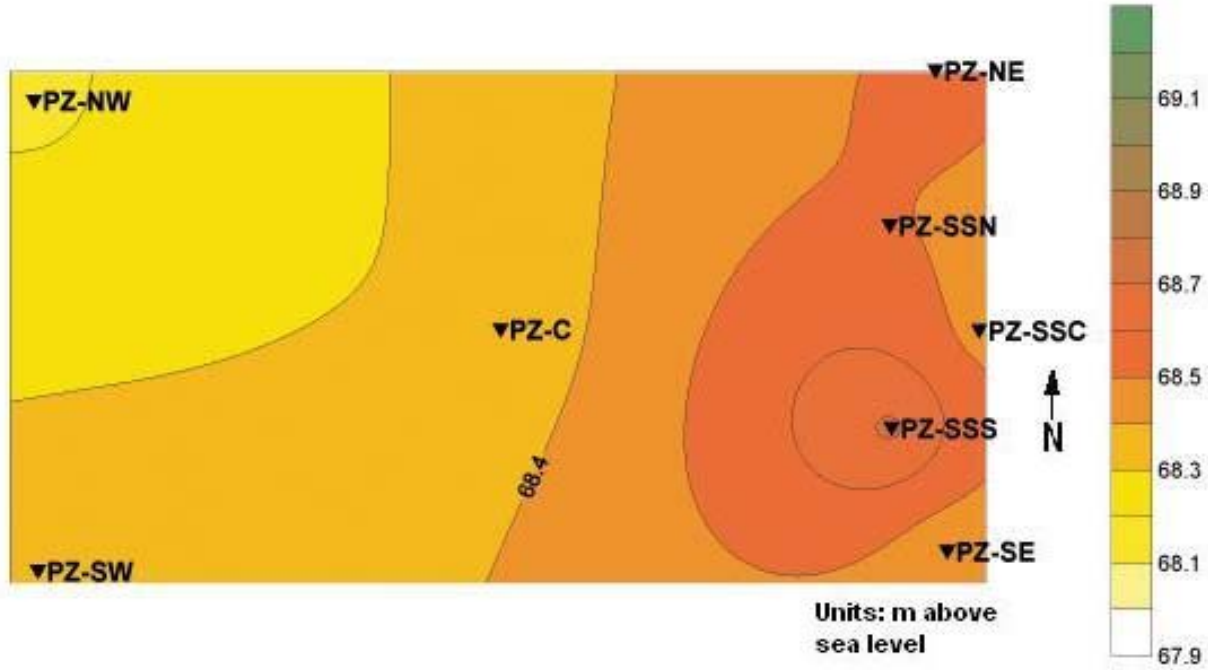

Figure 52. Interpolated groundwater elevation following weed control irrigation, but prior to seeding, May 15, 2007.

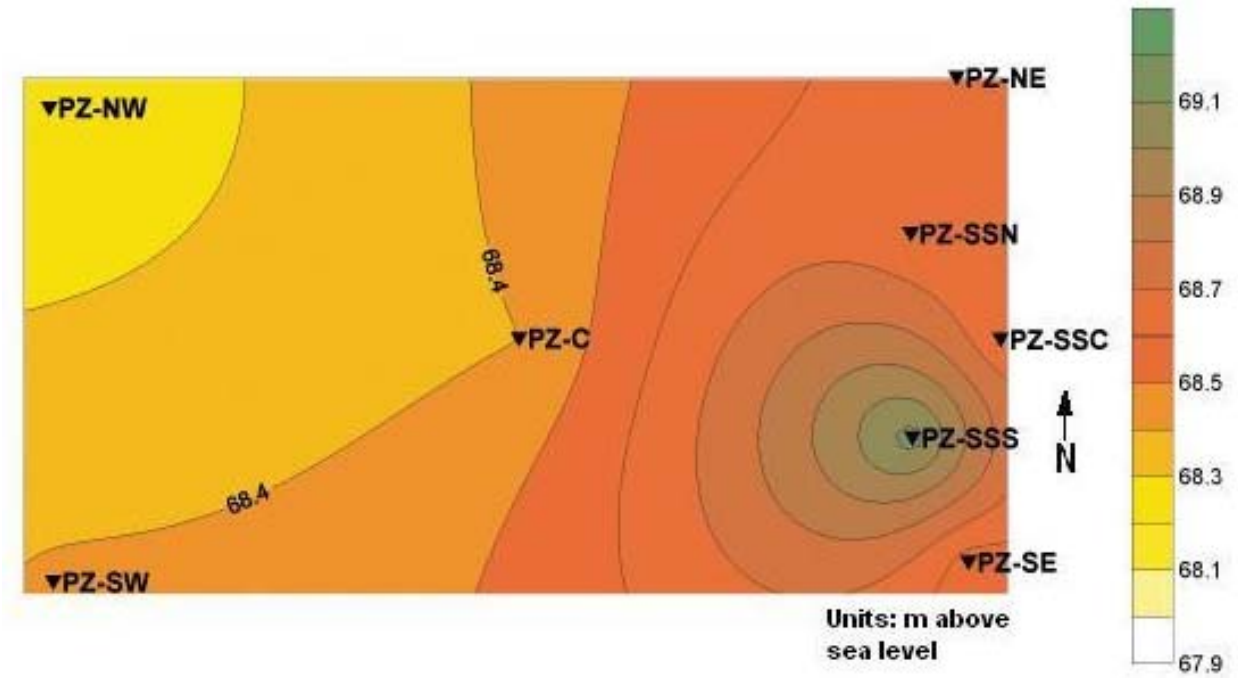

Figure 53. Interpolated groundwater elevation following ten days of small-scale study irrigation, May 27, 2007.

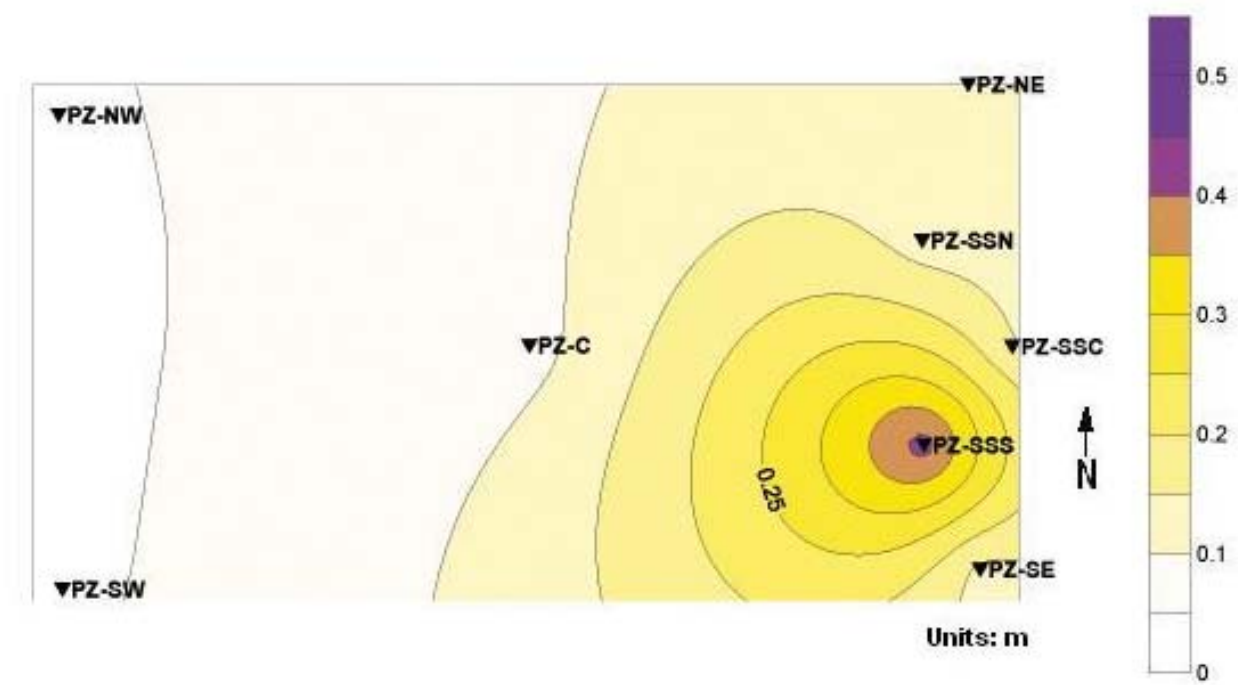

Figure 54. Change in groundwater elevation following ten days of irrigation (elevation on May 26, 2007 minus elevation on May 16, 2007).

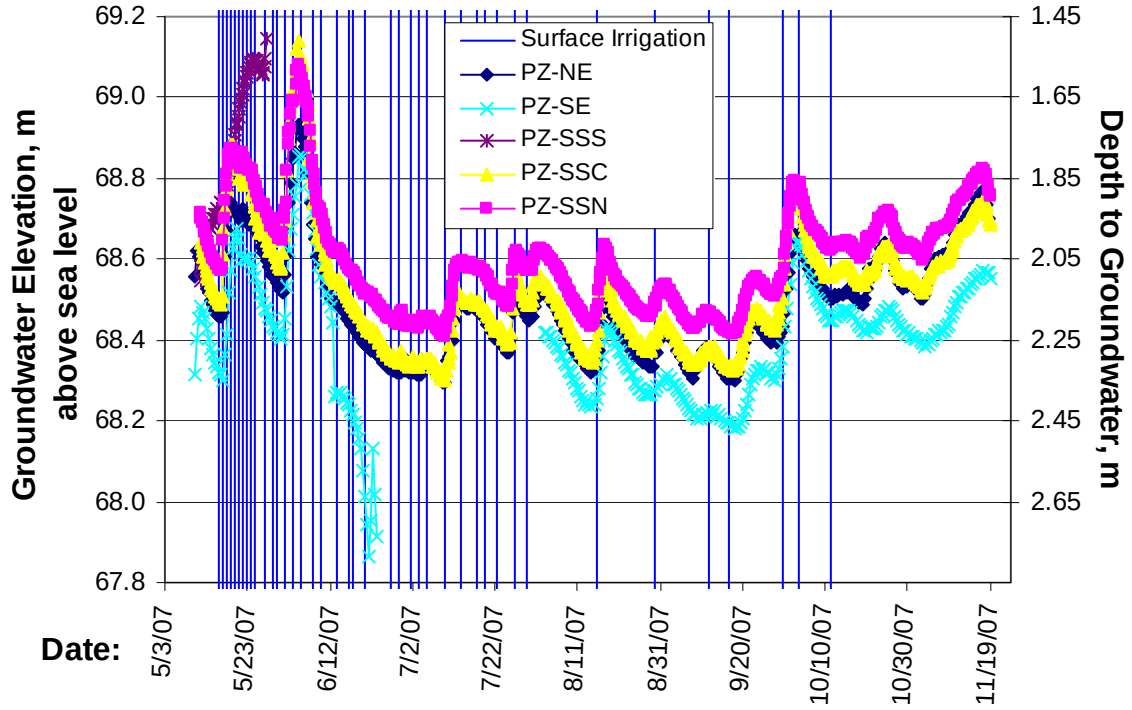

Figure 55. Groundwater elevations and depth to groundwater as affected by irrigation events for one growing season, Field 51 small-scale studies.

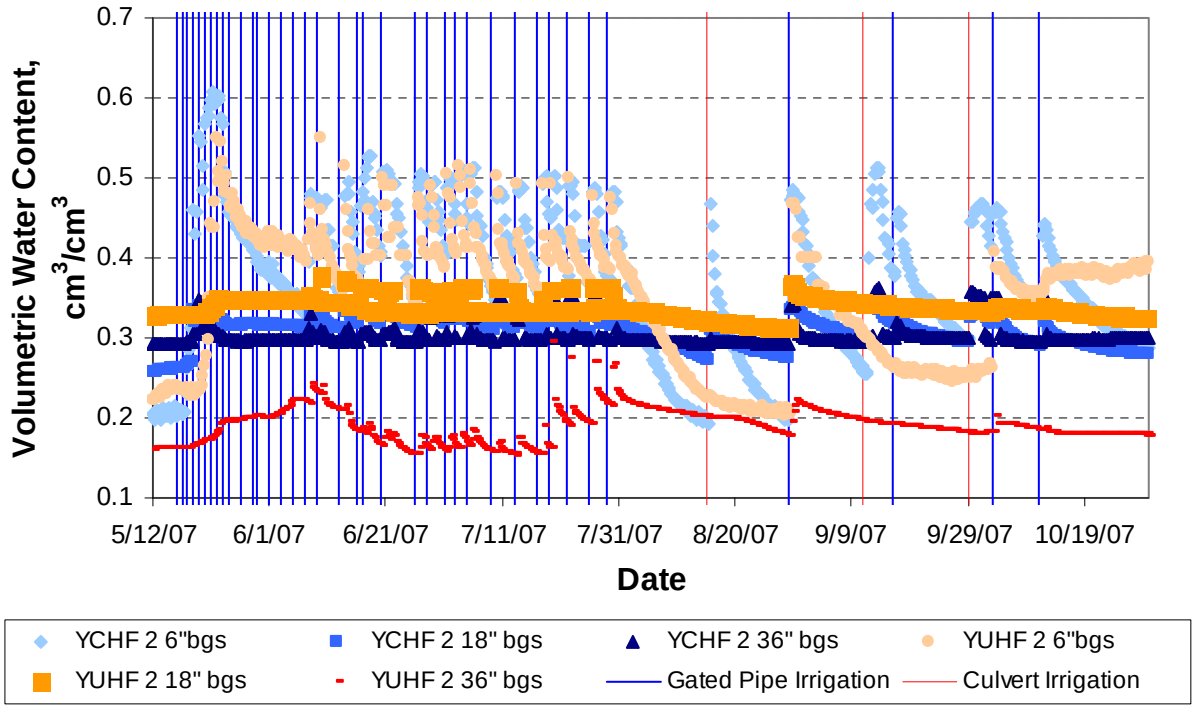

Figure 56. Soil volumetric water content versus time for small-scale field study plots YCHF 2 and YUHF 2.

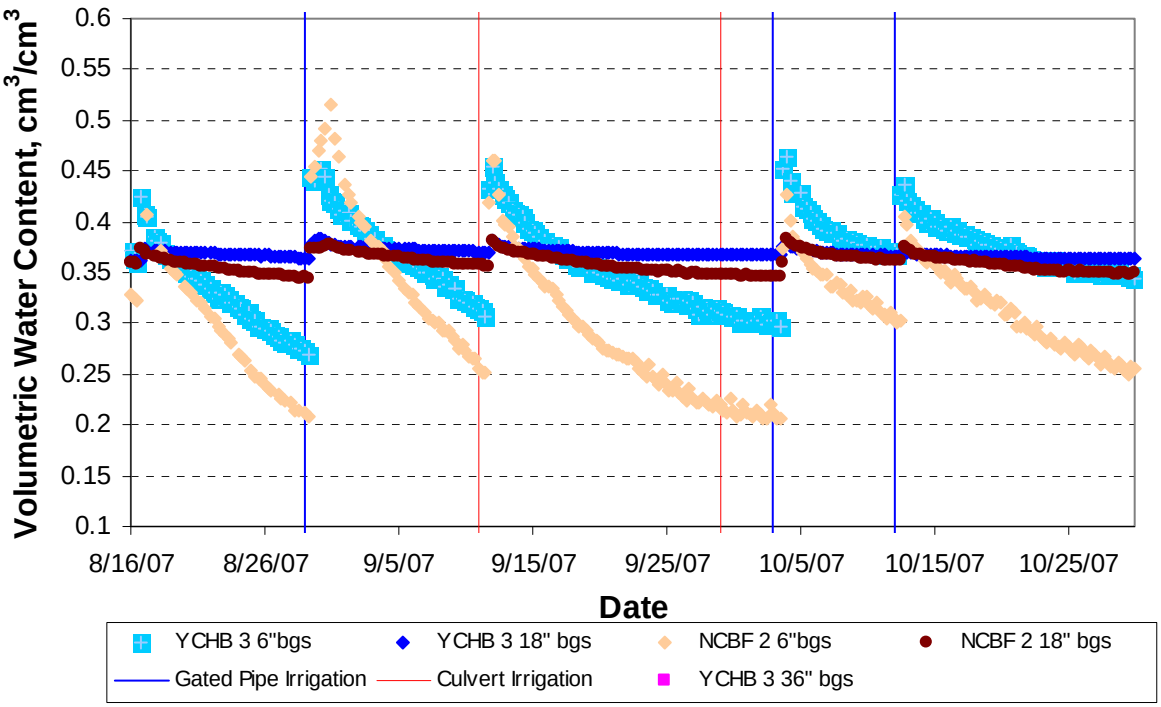

Figure 57. Soil volumetric water content versus time for small-scale field study plots YCHB 3 and NCBF 2.

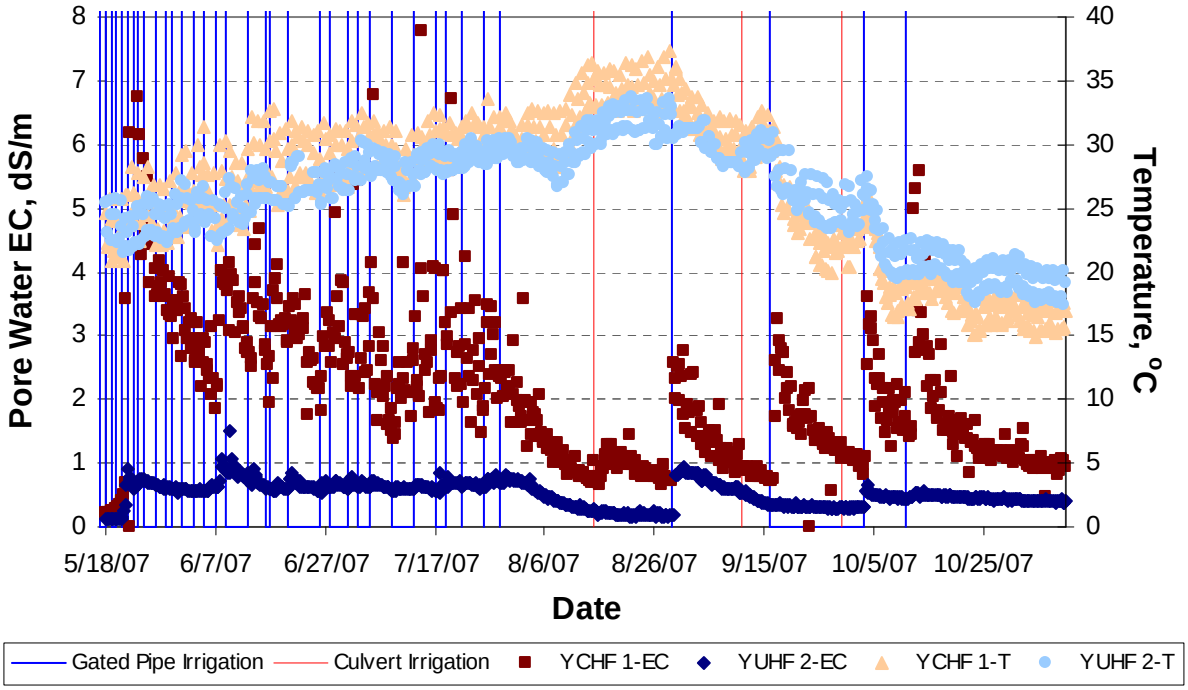

Figure 58. Soil salinity (EC) and temperature (T) versus time for small-scale field study plots YCHF 1 and YUHF 2.