Upper Colorado Saltcedar Control Project: Biological Control Component

TSSWCB Project # 03-11

FINAL REPORT

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EXECUTIVE SUMMARY

The E.V. Spece Reservoir (Segment 1411) was placed on the *State of Texas 1998 Clean Water Act Section 303(d) List* because of sulfate and total dissolved solids (TDS) concentrations exceeded the water quality standards criteria of 450 mg/L, and 1500 mg/L, respectively. These loadings are a result of both natural and man-made, nonpoint source pollution which is prevalent in numerous locations within the basin. Inproper brine disposal, leaking oil well casings, and the over-pressurization of down-hole formations are the prime sources of the man-made pollution. Surface water traveling across mineral beds such as salt flats, the dissolution of natural underground mineral deposits, and the concentration effects of certain types of plants are the primary causes of the natural pollution.

The proliferation of exotic, invasive saltcedars in riparian areas of western Texas is a major problem in water management because of its great consumption of groundwater, reduction in water quality, increase in soil salinity and displacement of native plant communities and wildlife habitat. Three species that occur in the E.V. Spence Reservoir watershed include juniper, saltcedar, and mesquite. These plants have a high water consumption rate and easily out-compete most native species. A single mature plant can absorb as much as 200 gallons of water a day. Because salt cedar is a deciduous plant, salt stored in the leaves is concentrated at the soil surface when leave are dropped in the fall. Saltcedar is especially detrimental to water quality because of its ability to transport salts from ground water to its leaves. Saltcedar can tolerate chloride concentrations as high as 35,000 mg/L, much higher than most plant species. This makes it almost impossible for native species to take root.

In 1999, the Texas Commission on Environmental Quality and the Colorado River Municipal Water District (CRMWD) developed two Total Maximum Daily Loads (TMDLs), one for sulfate and the second for TDS, with the primary focus area being on Segment 1412 of the Colorado River between Lake J.B. Thomas and the E.V. Spece Reservoir. In August 2001, the TCEQ adopted the *Implementation Plan for Sulfate and Total Dissolved Solids TMDLs in the E.V. Spece Reservoir*. The goal of the implementation plan (I-Plan) is to achieve reductions in annual-average concentration and total-annual loading of sulfate and TDS in the E.V. Spence Reservoir watershed. The Texas State Soil and Water Conservation Board (TSSWCB) utilized Clean Water Act Section 319(h) Nonpoint Source grant funding to initiate the *Upper Colorado Saltcedar Control Project: Biological Control Component* to demonstrate the effectiveness, safety, environmental compatibility and cost effectiveness of biological control as a compliment or an alternative to the conventional control methods. This project complemented the TSSWCB project 03-06 *Targeted Brush Control in the E.V. Spence Reservoir Watershed* that implemented targeted brush control measures as described in the I-Plan.

Biological control, with the consequent ca. 95+% reduction in green biomass of saltcedar, is expected to improve water quality through several interactions with the environment that presently are harmful. Major harmful effects on water quality and quantity are: 1) Its great use of water reduces stream flow, causing pollutants in the streams to increase in concentration, 2) It directly reduces streamflow and groundwater supplies needed for irrigated agriculture, and for municipal, industrial and environmental use. 3) It deposits salts taken from the groundwater onto the soil surface, killing or impeding the growth of most plants -- this will be reduced by the

amount of saltcedar biomass reduction. 4) Biological control will produce slow saltcedar root kill, allowing the still living roots to continue stabilizing the streambanks and reducing bank erosion, particulates in the water and sedimentation of downstream reservoirs. 5) Biological control will have no adverse affects on other plant species, allowing them to grow and increase more rapidly than herbicide damaged plants; this also will provide rapid stream bank stabilization after control.

The actions demonstrated in this biological control project were to introduce and release three species of leaf beetles of the genus *Diorhabda* (originally thought to be ecotypes of the same species) from Asia and the Mediterranean area, into saltcedar infested areas of western Texas and to monitor their effectiveness and safety in controlling saltcedar and the effects on rangeland, native plant and animal communities. The project released and monitored *Diorhabda* beetle populations and their dispersal, predator and competitor insects, defoliation and death of saltcedar, the effects of biological control on native plant and animal (bird) communities, and facilitated public education and participation. The data from this project will provide the basis for calculating a mathematical model of beetle dispersal (TSSWCB project 04-15). Two sites with five subsites were established for release and monitoring. Site 1 was at Lake Thomas along the upper Colorado River and Site 2 was located along Beals Creek near Big Spring.

This project has demonstrated the effectiveness and safety of biological control of saltcedar. In April through August 2004, 2400 *Diorhabda* (from Crete, Greece) were released within a 70 m diameter area near Beals Creek east of Big Spring, TX; they increased and defoliated one large and a few small trees by October. They defoliated 2 acres during 2005, 10 acres in 2006, and in 2007-2008 dispersed up and down Beals Creek defoliating 90-98% of the saltcedar trees along a 6.4 mile reach of the Creek (about 140 acres of saltcedar). During 2008, with little food left in the original 10 ha area, they formed into swarms, flew 1 to 5 miles to green saltcedar and started 10 satellite colonies in a 4.5 by 13 mile area, and had killed 25% of the trees defoliated more than 3 years. Also, the stressed plants ceased flowering and seed production, reducing the saltcedar reinfestation and spread. One to two years after defoliation, the native pasture grasses and forbs had recovered naturally with a dense, luxuriant growth in the areas of nearly bare ground under the former saltcedar thickets. Monitoring before and after the beetles arrived revealed much greater populations and diversity of plants and moderately greater populations and number of species of birds in native than in saltcedar communities. No beetle damage whatsoever was seen on any other plants. The low rate of establishment (ca. 10% of the releases made) seen through 2007 has increased substantially with the improved release methodologies developed during this project, especially for the survey and control of predaceous ants. Conventional herbicidal, mechanical or fire controls were not used in any of the biologically controlled areas.

The United States Department of Agriculture (USDA)- Agricultural Research Service (ARS) also took Crete beetles from the Higgins Ranch for releases and made along the Rio Grande, at Balmorhea, and at Matador Wildlife Management Area, and assisted in releasing the beetles at these locations. At the larger project on the Rio Grande between Presidio and Candelaria, funded by an USDA Natural Resources Conservation Service (NRCS) Grazing Lands Conservation Initiative grant to the Rio Grande Institute, ARS conducted an overwintering, caged test of Crete, Tunisian and Uzbek beetles, wrote the release and monitoring plans, provided Crete beetles for release, and conducted the vegetation and bird monitoring and data analysis, as part of the overall objectives of extending the control program to other areas. Texas AgriLife Research and Extension Service (Dallas and Ft. Stockton) also obtained beetles from the Big Spring Site 1 after 2005 (over 45,000 in 2007) for release at other sites along the Upper Colorado River and its tributaries and along the Pecos River, TX.

INTRODUCTION

The Saltcedar Problem

Taxonomy and Distribution of Saltcedars. Saltcedars (commonly called *cedro salado* in Mexico) are a genus of 54 species of small trees or shrubs native only in the Old World (Table 1). The genus evolved in riparian habitats in arid, saline areas of Central Asia, with a secondary center of speciation in the eastern Mediterranean area (Baum 1978) (Fig. 1A). Ten species have been introduced into the United States since 1823 as ornamentals and to control streambank erosion in the West. Four highly invasive species and their hybrids have become serious pests in the West (Table 1, Fig. 2A-C). The large, evergreen, exotic tree, *Tamarix aphylla* (called athel or *pinebete* in Mexico) (Fig. 2D-E, F), is commonly used for shade trees and windbreaks in northern Mexico and to a lesser extent in the southwestern U.S.; it is less aggressive and not a target for biological control. No species of *Tamarix* or of the family Tamaricaceae are native in the Western Hemisphere.

Table 1. Taxonomic relationships of *Tamarix*.

SUBCLASS CAROPHYLLIDAE Group 2 (after Spichiger and Salvolainen 1997)
- Polygonalian Lineage
  - Order Tamaricales
    - ► Family Tamaricaceae
      - ■ Genus *Tamarix* - 54 spp., all Old World (Baum 1978) 10 spp. introd. into N. America, 8 naturalized, 4 weedy (Baum 1967; Crins 1989)
        - ● *Tamarix ramosissima* & *T. chinensis*- principle weedy U.S. invaders, hybrids common (Gaskin and Schaal 2002)
        - ● *T. parviflora* - weedy mainly in California
        - ● *T. canariensis* - weedy along Texas coast, hybridizes with *T. ramosissima* and *T. chinensis*
        - ● *T. aphylla** - minor beneficial shade tree and windbreak, beginning to invade in some localities of the Sonoran and Chihuahuan deserts (major invader in Australia)
      - ■ Genus *Myricaria* - Eurasia
      - ■ Genus *Reaumuria* - Asia
      - ■ Genus *Hololachna* – Asia
    - ► Family Frankeniaceae*
      - ■ Genus *Frankenia* - ca. 80 spp. in Australia, Chile, N. America, Asia (Whalen, 1987)

Invasion, Physiology, Damage Caused. Saltcedars were introduced into the United States beginning in 1823 as ornamentals and later to prevent stream bank erosion. The trees spread rapidly along streams and reservoirs of the western U.S. and since the 1920's have come to dominate the native riparian ecosystems where they are causing one of the worst ecological disasters in the recorded history of this region. Today, saltcedars occupy over 2 million acres of the most highly valuable lands along streams and lakeshores from the central Great Plains to the Pacific and from Montana into Northern Mexico (Robinson 1965, Fig. 1B). Texas has more

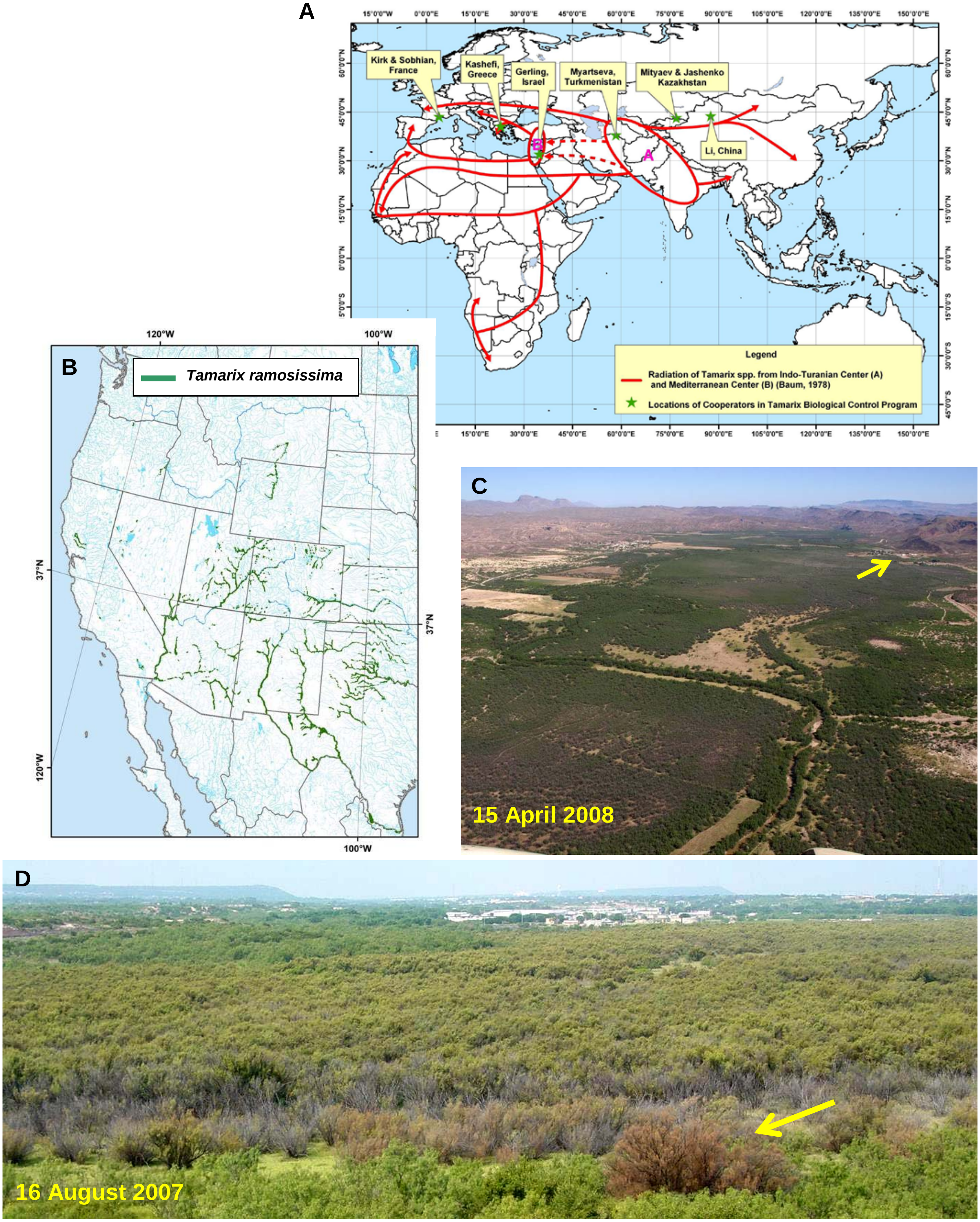


Figure 1. Saltcedar. A) Distribution of *Tamarix* in the Old World, B) Distribution in western U.S. riparian areas, C) Along the Rio Grande, 70 mi north of Presidio, TX, looking north towards and beyond Candelaria (arrow to Candelaria; photo by Jim Everitt), D) City of Big Spring Wastewater Treatment Plant Area (arrow to beetle-defoliated satellite tree).

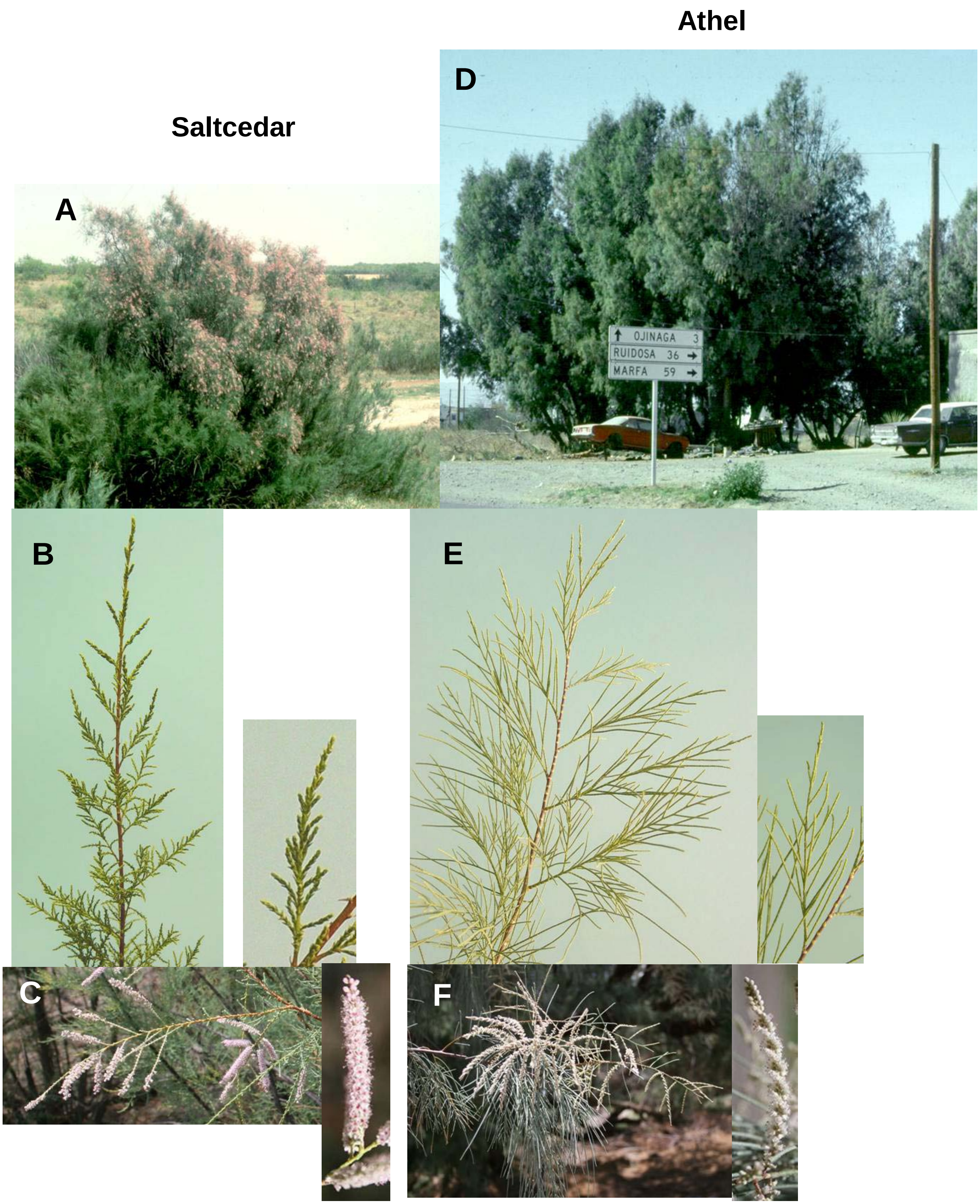


Figure 2. Appearance of saltcedar versus athel: Saltcedar, A) small saltcedar tree near Candelaria, TX, B) foliage of saltcedar, C) flowers of saltcedar; large Athel (T. aphylla), D) shade trees in Presidio, TX, E) foliage of athel; F) flowers of athel.

acres infested by saltcedar than any other state and the infested area is still increasing. For example, no saltcedar occurred in the E.V. Spence or O.H. Ivie Reservoirs in 1996 but recently E.V. Spence Reservoir (9,000 acres) was sprayed and O.H. Ivey Reservoir (with 11,000 acres in 2008) is a biological control site (CRMWD 2002).

Saltcedars (Fig. 2A, B, C) are deciduous; cold, fire, flood and drought tolerant trees. They are insect pollinated and reproduce by huge quantities of short-lived, wind or water dispersed seeds throughout the season. Saltcedars are deep-rooted, facultative phreatophytes and halophytes that can utilize both ground water and soil moisture. They can utilize saline water by excreting excess salts through leaf glands; these saline excretions form a layer of salt on the soil surface, to which they are tolerant, but kill or retard cottonwoods and willows (C/W), the prime wildlife habitat in western riparian areas. Thus, saltcedars can occupy areas further from the streambanks and use more water across a floodplain than can the shallow-rooted native C/W that are obligate phreatophytes and grow only in areas of shallow water tables nearer the streams (Smith et al. 1998). Saltcedar thickets burn more frequently than the native riparian vegetation but are tolerant of fire (they resprout from underground buds and can grow 2-3 m tall the next year after burning) that can kill cottonwoods and other native plants.

Extensive saltcedar thickets have caused lowered water tables, dried up desert springs, reduced stream flow, or converted streams with permanent flow to intermittent flow (Busch and Smith 1995), lowered water quality, caused severe bank aggredation, blocked channels and increased flooding; changed stream channel and riffle structure; increased wildfire frequency and intensity; and increased soil surface salinity. Saltcedar thickets typically use 4 to 5 feet of water per unit area per year (Gatewood et al. 1950, Weeks et al. 1987) that in a drought severely reduces water available for agricultural irrigation, municipal and environmental use.

Saltcedars are relatively unpalatable to livestock but whose browsing damages or kills many native riparian plants. Most native plants have guilds of native insects and pathogens that suppress their growth and abundance but saltcedars are seldom attacked. Saltcedars form dense stands that require control, but recover quickly from the mechanical or fire and eventually also from herbicide controls that kill the C/W and other native plants that grow among mixed stands. Many of the present large saltcedar stands were initiated by floods or fires, sometimes aggravated by overgrazing that killed the native plants and allowed saltcedars to establish. Also, natural conditions of high soil/water salinity, or stream diversion and groundwater pumping for agricultural or municipal use are more damaging to C/W than to saltcedars (Tomanek et al. 1962, Everitt 1980, DeLoach 1989, 1991, D'Antonio and Dudley 1997, DeLoach and Tracy 1997, DiTomaso 1998, DeLoach et al. 2000).

The above innate characteristics of saltcedar allow it to be preadapted to the natural and human modified arid, saline western riparian areas, which are similar to those areas where it evolved in Asia, southern Europe and northern Africa. Also, saltcedars were introduced without the natural enemies that suppress their populations in the Old World. The combination of saltcedar's innate characteristics plus the lack of natural enemies in North America have allowed it to increase unrestricted once introduced outside its native area (DeLoach et al. 2000).

Detrimental Effects of Saltcedar on Water Quality and Quantity. The proliferations of invasive species of brush in the western portions of Texas, especially of saltcedar in riparian areas, are a recognized problem in water management. Three major invasive species that occur in the E.V. Spence Reservoir and most other west Texas watersheds are native juniper and mesquite, and exotic saltcedar. Saltcedar is especially detrimental to water quality because of its ability to transport salts from ground water to its leaves where it excretes excess salt through leaf glands which drips to the soil, and also falls with the leaves in the autumn, where it forms a layer of salt on the soil surface. Saltcedar can tolerate chloride concentrations as high as 35,000 mg/L, much higher than most plant species. This, plus several inherent characteristics, human-produced environmental/habitat changes, and saltcedar's ability to interact with the human changes in a synergistic, feed-forward manner make saltcedar almost impossible for native species to take root or be able to compete.

Major detrimental effects on water quality and quantity, which are closely related, are: 1) The large usage of water by saltcedar reduces streamflow causing pollutants to increase in concentration. 2) It directly reduces streamflow and groundwater supplies needed for irrigated agriculture, and for municipal, industrial and environmental use. 3) The action of saltcedar to utilize saline groundwater and to deposit the excess salt on the soil surface kills or retards the growth of most plants, and 4) The dense saltcedar thickets along streams, with channel narrowing and blockage, increases the amount of water that must be released from reservoirs to reach downstream agricultural and municipal areas, and also increases flooding.

The large consumptive use of groundwater by saltcedar is well documented (Gatewood et al. 1950, van Hylckama 1980, Gay 1985). A consensus of the various studies indicates that saltcedar uses 3 to 5 ft of water per unit area annually. However, documentation of water salvage downstream is less clear, probably because of the large scope, complexity and difficulties in making valid measurements along meaningful distances (a few miles) and over several years of variable ecoclimatic conditions in nature (Weeks et al. 1987, DeLoach 1991). The recent control program on the Pecos River, TX (Hart 2005) where pre-control and postcontrol differences in daily water table levels were compared, indicate a reduction in annual water usage caused by saltcedar of 0.43 to 1.18 m annually.

Dense saltcedar thickets increase sedimentation, bank aggredation and the narrowing and even elimination of main stream channels to form small meandering streamlets (as on the Rio Grande below El Paso and the Pecos River below Artesia, NM), increase the amount of water that must be released from reservoirs by an estimated one-third to reach downstream agricultural and municipal areas, and increases flooding (as the 2006 flooding of El Paso/Juarez).

Contributions of Biological Control to Improved Water Quality. Biological control is expected to substantially improve both water quality and quantity through: 1) The consumptive use of groundwater by saltcedar will be reduced in direct proportion to the reduction in green biomass produced by biological control (currently 95 to 98% along Beals Creek, at Big Spring, TX). 2) The reduced deposition of salts on the soil surface also will be in direct proportion to the reduction in saltcedar green biomass produced by biological control. 3) The reduction in pollutant concentration in flowing streams also will be in some proportion to the increased stream flow but the amount is less certain because the increase in stream flow is less certain (see above). 4) Biological control will produce slow saltcedar root kill, allowing the still living roots to continue stabilizing the streambanks and reducing bank erosion. 5) Biological control of saltcedar will have no adverse affects on other plant species, allowing them to grow and increase more rapidly than herbicide damaged plants; this also will provide improved stream bank stabilization after control.

Saltcedar Effects on Western Native North American Ecosystems. The saltcedar invasion has produced profound changes in the natural and agricultural ecosystems in riparian areas of the west, where vast areas of native plant communities have been replaced with near monotypic thickets of saltcedar (Horton 1976, 1977, Bush and Smith 1995, Smith et al. 1998). This has produced major control efforts to conserve water for agricultural, municipal and domestic use (Gatewood et al. 1950, van Hylckama 1980, Gay 1985, Weeks et al. 1987) and, since the mid-1960s, also to protect multiple use values including native plant communities, wildlife habitat and recreation (Horton and Campbell 1974, Horton 1976, DeLoach et al. 2000). Shafroth et al. (2005) review the concept of saltcedar and its control on water-use/water-salvage and on wildlife. They discuss control methods and vegetation replacement and that water yield might not always occur and has been substantially lower than expected in water salvage experiments, and that replacement vegetation might use as much water as did the saltcedar. Even so, the native replacement vegetation should be considered as more valuable than the exotic saltcedar.

Conventional Control of Saltcedar

Saltcedars are difficult to control by mechanical methods, fire or many herbicides because of their ability to resprout from underground crowns or roots and to reinvade from their windblown or waterborne seeds. The effectiveness and use of herbicides were reviewed by Sisneros (1990) who reported good control from either Arsenal® (chemical name: imazapyr) used as an aerial spray alone or mixed with Rodeo® (glyphosate) to reduce costs, or Garlon® 4 (triclopyr) as a cut-stump or stem-slash treatment. Treatment of saltcedar along the Pecos River, TX with helicopter applications of Arsenal provided about 90% whole tree kill (Hart 2005) which, after about 8 years will soon require a second treatment in some areas.

The *Targeted Brush Control in the E.V. Spence Reservoir Watershed* project (TSSWCB project 03-06) chemically treated saltcedar in riparian areas along the Colorado River and its tributaries from below Lake J.B. Thomas to the E.V. Spence Reservoir in an effort to reduce nonpoint source pollution loadings resulting from invasive brush species on agricultural land. CRMWD aerially applied Arsenal herbicide, which has an estimated one-time chemical treatment life of 15 years, to 11,391 acres over a 3 year period beginning in 2005. The project also collected water quality data and provided technical and financial assistance to agricultural producers within the Champion Creek Reservoir watershed for targeted brush control activities.

Biological Control of Saltcedar

Biological control of weeds. Classical biological control of weeds has been used worldwide since 1865 in 75 countries, against 134 weed species, in over 1,151 projects (Julien and Griffiths 1998). The philosophy and general protocols have been well developed over the years (Huffaker 1957, Spafford-Jacob and Briese 2003). It has been used in the U.S. and Canada since 1945 against some 39 serious exotic, invasive weeds and 1 in Mexico with 20 of these achieving complete or substantial success over most of the infested area (see Appendix A, Table 1), and several other promising target weeds still under research.

***Diorhabda* Leaf Beetles.** The five species of *Tamarix*-feeding *Diorhabda* leaf beetles are native from northeastern China and northwestern India across Asia and southern Europe to Spain and across northern Africa to the Canary Islands (Fig. 3A). All of our collections were originally identified as *D. elongata* (Brullé) by Russian and U.S. chrysomelid specialists. They were tested in quarantine at Temple, TX, along with 10 other insect species from Eurasia. After the United States Fish and Wildlife Service (FWS) and APHIS clearances, the *Diorhabda* beetles were released into the field at the original 10 sites from May 2001 through 2002. The success of the beetles from Fukang, China in Nevada and Wyoming and of the Chilik, Kazakhstan beetles in Utah (both the same species – *D. carinulata)* were highly successful. However, their failure to establish in Texas and California, led to additional collections and testing of *Diorhabda* in more southern latitudes in Eurasia.

Small differences in appearance and behavior observed in the cultures and tests at Temple, TX and Albany, CA led to detailed morphological examinations (Tracy and Robbins, 2009), indicate four separate species that were once considered as subspecies of *D. elongata*. This was supported by DNA analyses by David Kazmer (ARS, Sidney, MT), cross mating experiments by David Thompson (NM State University, Las Cruces), and pheromone comparisons (Cossé et al. 2005, ARS, Peoria, IL).

These species are *D. carinulata* from Fukang and Chilik, released at the original 10 sites in 2001; and three species later released south of the 38th parallel in Texas, New Mexico and California (Fig. 3A, E–H): *D. elongata* from Crete and Posidi Beach (near Thessaloniki, Greece) released in 2003; *D. sublineata* (Lucas) from Tunisia in 2005; and *D. carinata* (Faldermann) from Qarshi, Uzbekistan, release in 2006; a fifth species, *D. meridionalis* Berti and Rapilly from coastal Iran was not brought into the U.S. – these are all the *Tamarix*-feeding *Diorhabda* beetles known. The releases made to date indicate that the Crete ecotype is well adapted to central Texas, the Uzbek to northern Texas and the Tunisian to southern Texas and northern Mexico (Tracy and Robbins, 2009).

In general appearance, the adults are yellowish on the head, thorax, legs and underside; have light brown wing covers with two dark stripes on each (more or less distinct in the different species) (Fig. 3E-H), and average about ¼ inch (5-7 mm) long by 1/8 inch (2-3 mm) wide. The eggs are spherical, tan colored, and laid singly or in clusters of up to about 24 (Fig. 3B). The larvae have 3 instars (stages): 1st instars black, 2nd instars black with a row of yellowish spots on each side (Fig. 3C), and full-grown 3rd instars black to dark brown with a broad yellow stripe on each side, 3/8 inch (9 mm) long (Fig. 3D); the pupae are bright yellow. (Lewis et al. 2003b).

Previous observations and tests by ARS and their cooperators overseas and at ARS Albany, CA determined that both adults and larvae of *Diorhabda* feed on the foliage of saltcedar, the females oviposit (lay their eggs) on the foliage; the mature larvae pupate and the adults overwinter under litter on the soil surface or in bunches of grass, etc. Generation time in the field during the summer is about 33 days – egg stage 5 days, larva 13, pupa 5, adult preoviposition period 5.5, and adult to peak oviposition 4.5 days. Females lay an average 280 eggs over about 16-20 days and the population can double in 6.2 days, at optimum temperatures and if not attacked by natural enemies. The beetles have four generations in Texas (they have two north of the 38th parallel), the adults emerge from overwintering in late March and enter overwintering quarters from mid-September to early November. Daylength regulates the initiation of overwintering diapause (hibernation), with the Fukang ecotypes requiring the long summer daylength (minimum 14 hr 45 min) of northern areas, the Crete and Tunisian adapted to shorter summer daylength in more southern areas, and the Uzbek probably to an intermediate daylength (Lewis et al. 2003b; Milbrath et al. 2007; Bean et al., 2007). All stages are exposed, with little protection from predators.

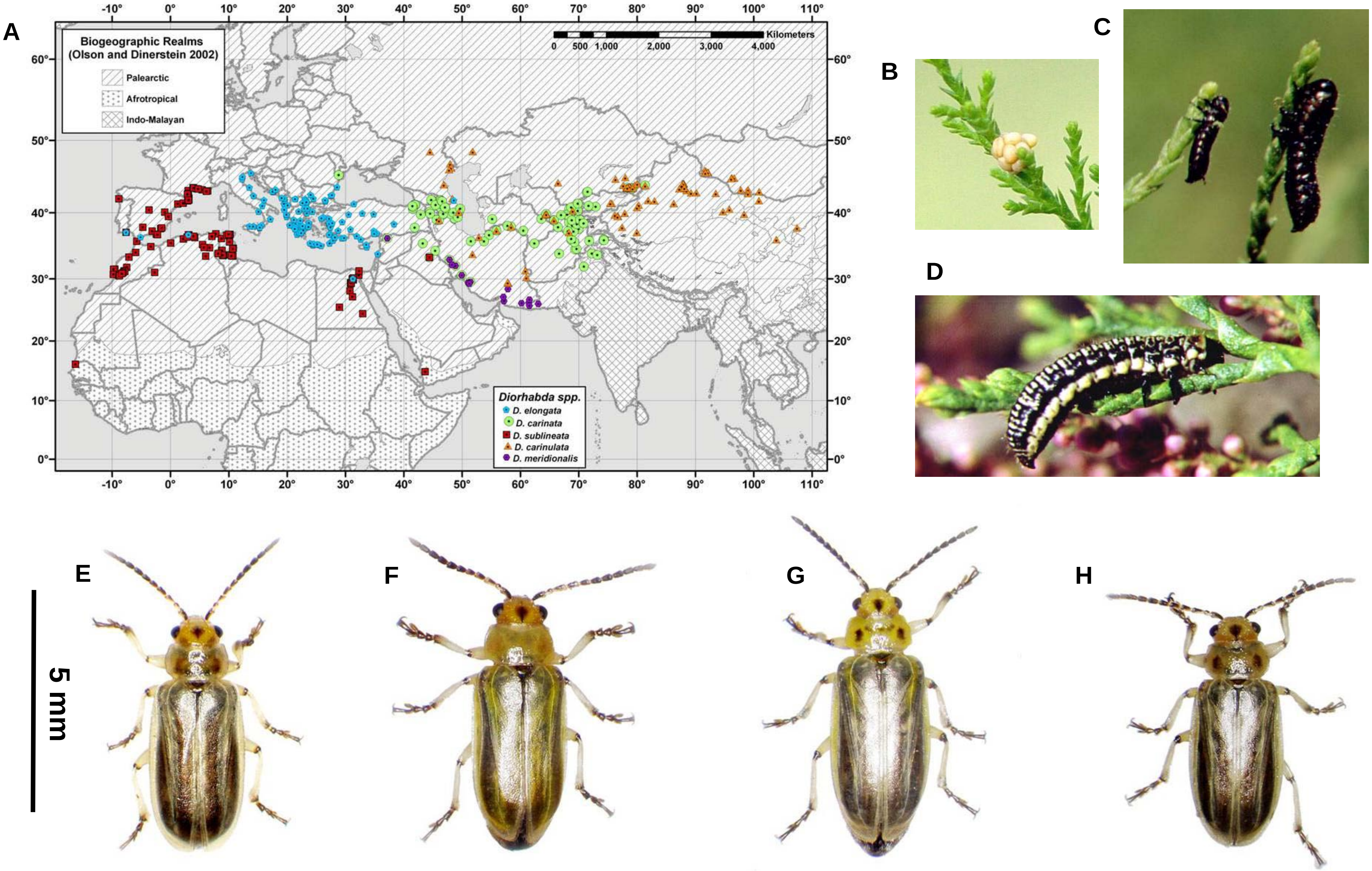


Figure 3. *Diorhabda* spp. leaf beetles; A) Distribution of the 5 species (former ecotypes) in Eurasia and Africa, B) eggs, C) 1st and 2nd instar larvae, D) 3rd instar (full grown) larva (*D. carinulata*), E) *D. carinulata* (Fukang, China/Chilik, Kazakhstan ecotype); F) *D. elongata* (Greece ecotype); G) *D. carinata* (Uzbekistan ecotype); and H) *D. sublineata* (Tunisia ecotype).

Predation by insects, spiders, and other organisms. A number of predators were observed attacking *Diorhabda* beetles – assassin bugs attack adults and larvae on the trees, some ladybird beetles may attack eggs and small larvae, several species of ants may attack pupae and larvae on the ground, and ground beetles, small rodents and near the Texas Gulf Coast, land crabs may attack larvae, pupae or adults on the ground. The incipient establishment at Lake Thomas in 2004 appeared to have been lost to predators (extremely high population of ants on the ground and ladybird beetles in the trees), while Big Spring and the Pecos River, TX had fewer ants and were successful. At Cache Creek, CA the released beetles established only very weakly and success was obtained (presumably) by releasing ca. 200,000 Crete beetles in small areas that overwhelmed the predator populations. Several examples indicate that once the *Diorhabda* population increases to high levels, they can control saltcedar rapidly before the predators can respond. Our recent review of the release data indicates that predation, especially by ants, probably is the major cause of the failure at most of the non-established sites.

This biological control project is part of a larger program to develop biological control of saltcedar south of the 37th parallel (the northern border of OK, NM, AZ and continuing to the Pacific) using southern adapted *Diorhabda* beetles from Greece, Tunisia and Uzbekistan. This has been necessary since the China/Kazakhstan ecotype that was very successful in the northern areas, failed to establish in Texas and California when released in 2001.

METHODS AND MATERIALS

Beginning in September 2001, Raymond I. Carruthers worked with the overseas collaborators to collect southern-adapted *Diorhabda* beetles in Greece, Tunisia, Uzbekistan and China (Fig. 3A, E-H), brought them into quarantine at Albany, CA, and then both the ARS Temple, TX, and the Albany, CA, laboratories conducted detailed host specificity and biological testing (Milbrath and DeLoach 2006a,b; Milbrath et al. 2007, Herr et al. 2009a, Herr and Carruthers 2009b both submitted). The Crete ecotype beetles were released into the open environment in Texas, New Mexico and California during the summer of 2003.

Site Descriptions

As part of the Upper Colorado River (Texas) Saltcedar Control Program – Biological Control Component, two demonstration areas were established for release of the *Diorhabda* beetles (Fig. 4). One site was in the Lake Thomas area in Borden County, ca. 30 miles northeast of Big Spring, and the other was in the Big Spring area in Howard County, both sites potentially extendable to the headwaters of each stream.

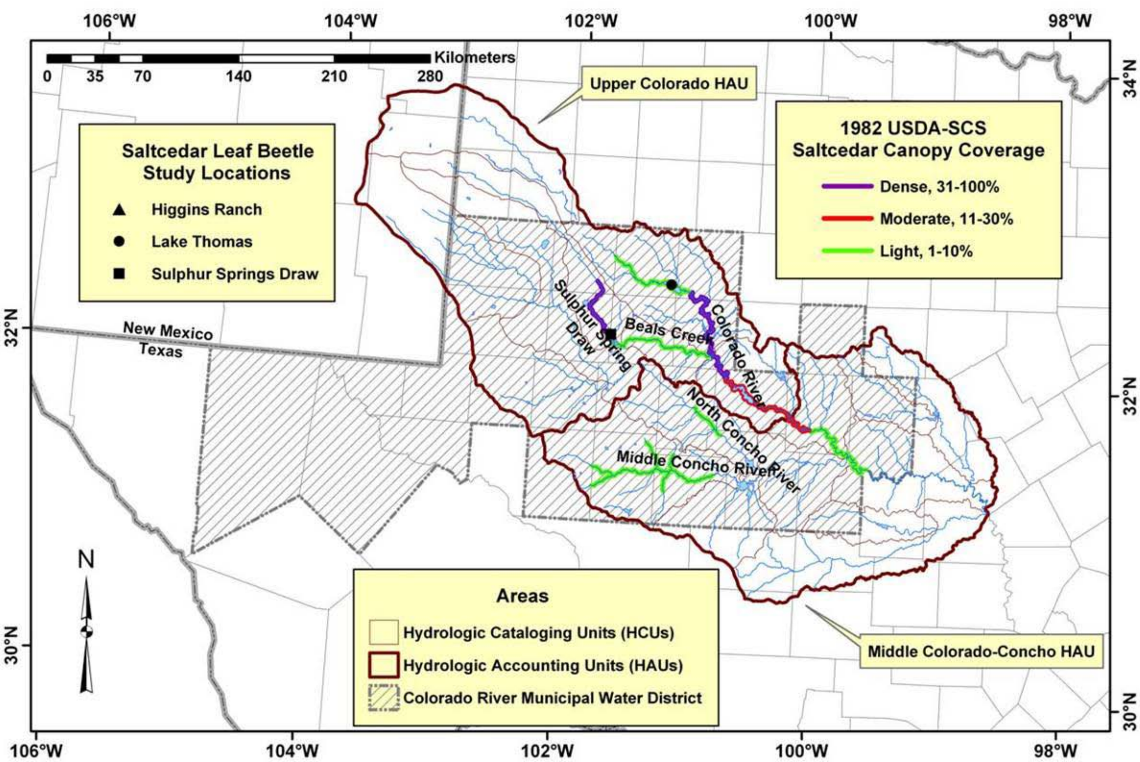


Figure 4. Upper Colorado River, TX, saltcedar infestation levels (1982), CRMWD area, and *Diorhabda* beetle release sites (USDA Soil Conservation Service map. 1982 Texas Brush Inventory). Infestations along Beals Creek had progressed from light in 1987 to dense at the time of the present study in 2004-2008.

ARS released the beetles into a variety of habitats, from complex, species-rich habitats (Lake Thomas lakebed), to simple saltcedar/grass habitats (Higgins Ranch and wastewater disposal plant area near Big Spring). ARS selected sites unlikely to flood; that would not be treated with herbicides, insecticides, mechanical controls or burned; that had a good stand of saltcedar that extended for a few miles that would allow dispersal, and was protected from interference by the public.

Site 1 – Lake J.B. Thomas Area.

This site, with 2 subsites, extended from Lake J.B. Thomas Dam on the Colorado River upstream to its headwaters, with major emphasis on the area from the dam upstream ca. 8 km to the northwest. The site is within an oil field with wells in the upland rangelands, riparian areas along the river, and on islands in the lake (Fig. 5). Both subsites were in the usually dry area within the conservation pool level of Lake Thomas on CRMWD owned land.

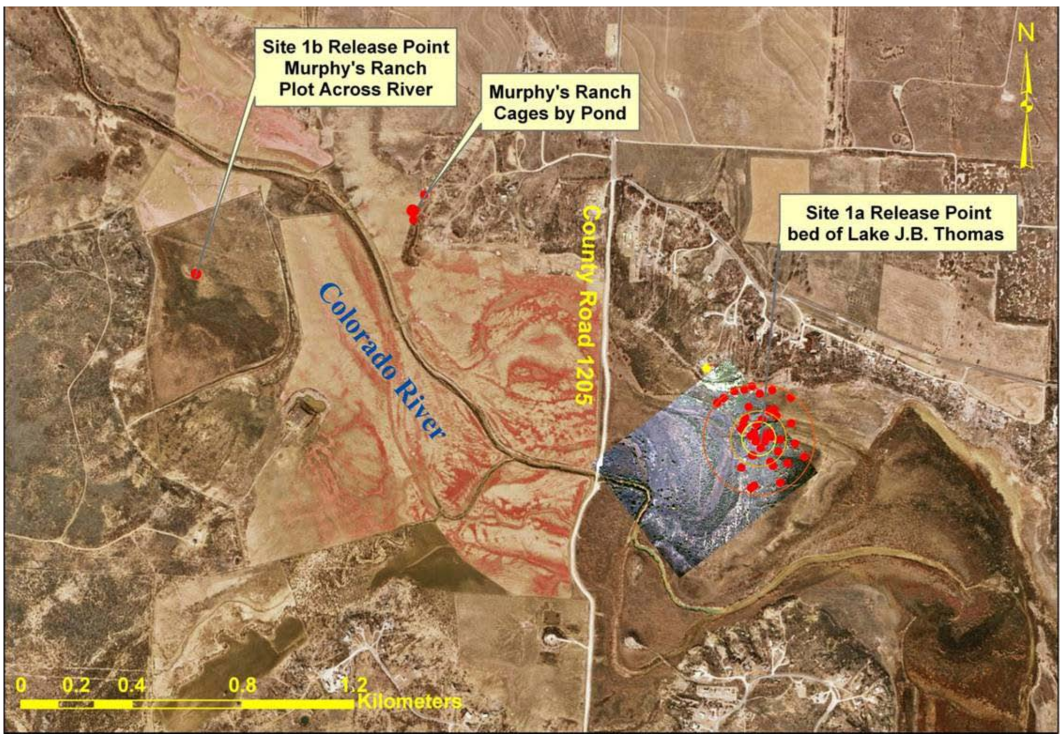


Figure 5. Location of *Diorhabda* release sites 1a and 1b and cages on Murphy's Ranch on the north side of Lake Thomas along the Colorado River west of Snyder, TX.

Beetle Nursery Cages – Murphy Ranch. Two 10 x 12 x 8.5 (h) ft screen nursery cages were located in a small patch of saltcedar along a draw west of the Murphy home in an area that rarely floods and did not flood during this project; 1 cage of Crete and 1 of Turpan ecotype beetles were located between Sites 1a and 1b. This site was located on the private Murphy Ranch upstream from Murphy School Road where it crosses the Colorado River (Fig. 5).

Site 1a – Lake Thomas Lakebed (Fig. 6). The release/monitoring area was about 0.5 km below Murphy School Road and 3.5 km above the usual upper lake shoreline. The area lies within the 0.6 to 1.6 km wide riparian area between steep bluffs along the north and south sides. After occasional periods of heavy rain, the lake level can rise to beyond Murphy School Road, flooding the site. This did not happen during the early 2004 efforts to release, establish and monitor the beetles but it did flood at the end of November 2004 when the lake level rose by 12 ft and again in 2005, blocking the road and interrupting the bird monitoring program at this location.

The vegetation in the usually dry lakebed area consists of dense species-rich, mixed stands of saltcedar, willow baccharis, willows, cottonwoods, other shrubs, forbs, johnsongrass and other grasses, with honey mesquite thickets along the base of the bluffs and mesquite/juniper on the bluffs and above, with excellent bird habitat in areas of natural vegetation. The beetle release point was located at the center of the 10 ha circular sampling area and lay 30 m south of a natural drainage ditch lined with willows and baccharis (Fig. 6). The release point was in a group of saltcedar trees to 5 m tall along the edge of a moderately dense thicket of similar-sized trees to the east and scattered small saltcedar trees on the other sides, among stands of baccharis, bermudagrass, Johnsongrass, sunflowers and other forbs and shrubs.

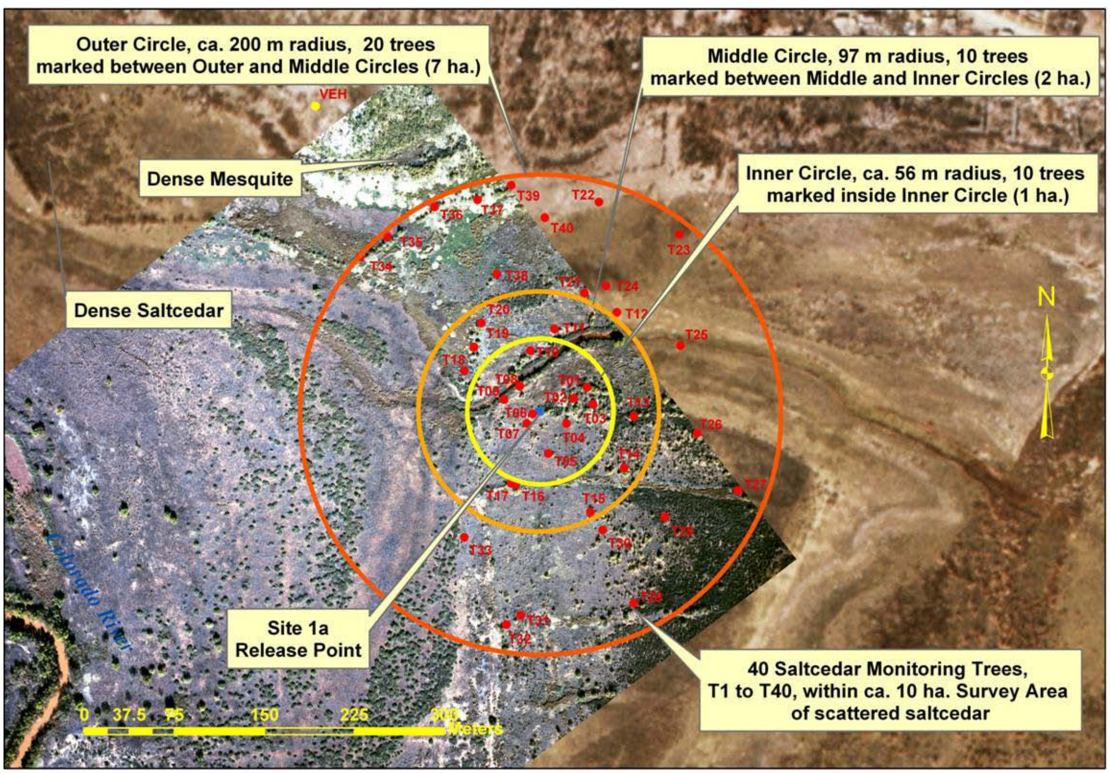


Figure 6. *Diorhabda* release/monitoring area for Site 1a (photography by James Everitt, 22 November, 2002).

Site 1b – Murphy Ranch (Fig. 5). This site lay 2 km upstream from Site 1a, also within the Lake Thomas lakebed owned by the CRMWD with access through the private Murphy Ranch. The site lay in a moderately dense, monotypic saltcedar thicket of a few hectares of medium-sized trees 3 to 4 m tall, with little other vegetation except for saltgrass and a few forbs among the saltcedars. The area was grazed by cattle, and with a roving herd of feral hogs that sometimes bedded here and rooted extensively in the saltcedar thicket. The site may flood if the lake fills but did not flood during this study.

Site 2 – Beals Creek, Big Spring Area (Fig. 7). Site 2 extends for 9 km along Beals Creek (a tributary of the Colorado River). Three subsites were located here – Site 2a on the Higgins Ranch east of Big Spring, Site 2b in the Big Spring Wastewater Treatment Plant area between Site 2a and Loop 700 (Fig. 7), and Site 2c along Buzzard's Draw north of Natural Dam Lake, 15 miles west of Big Spring.

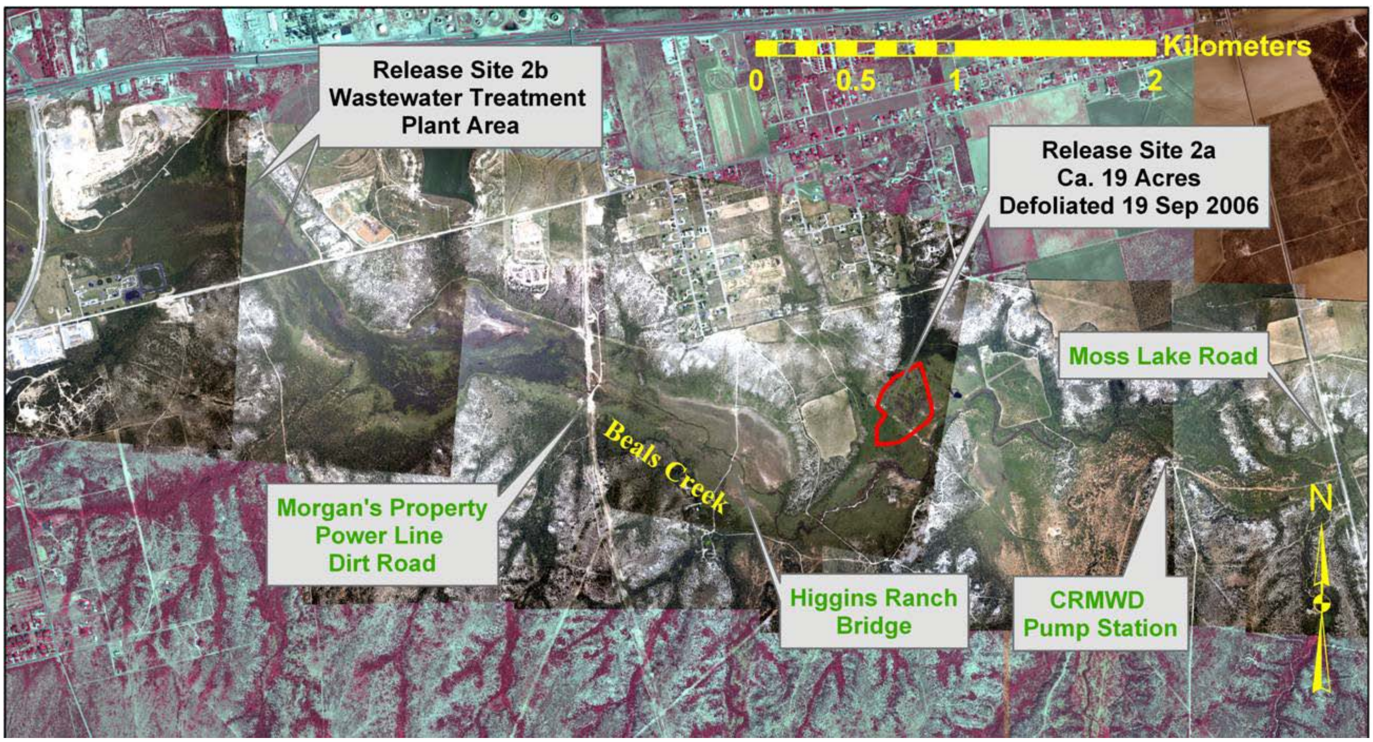


Figure 7. *Diorhabda* release/monitoring area for Sites 2a and 2b along Beals Creek (photography by James Everitt, 8 August, 2007). Powerline Road is the division between Site 2a and 2b.

Nursery cages, 2003. Four peaked-top nursery cages (Fig. 12) were erected at Site 2a (Higgins Ranch). Cage #1 and #2 were adjacent to each other (Cage #2 for overflow population), which contained Crete beetles. Cage #3 was located 250 m south with Crete beetles (Fig. 9) and Cage #4 was located 80 m southeast across from the weather station for Uzbek beetles. ARS placed Crete beetles from the nursery cages at Site 1b into Cages #1 and #2 (Higgins Ranch) on 3 occasions during the summer of 2003 totaling 100 adults and 447 eggs. Increases in adult, egg and larvae populations were monitored through the summer and fall of 2003 (see Appendix A,

Table 3).

Site 2a – Higgins Ranch (Fig. 9). Site 2a is located on the private Higgins Ranch. The site was chosen in part because of the simple ecosystem/habitat, consisting mostly of only saltcedar and pasture grasses in the release area, where ARS assumed that few insects would be produced that might attract predators, which in turn might attack the *Diorhabda* beetles and prevent their establishment. Site 2a extends through pastures of mostly nearly level grasslands, 100 to 200 m wide with scattered trees and moderate stands of saltcedars 3-5 m tall, with larger saltcedar and mesquite trees along the creek, but generally not marshy. Flooding from the creek occurs occasionally to 1 m deep near the creek and out to 100 m from the creek, where it flooded in July and August 2007. The creek channel is well defined, generally 6 to 10 m wide and 3 to 4 m deep; it flows due to the constant inflow from the Big Spring Wastewater Treatment Plant just below Loop 700.

At Site 2a, the initial release/monitoring area (Fig. 9) was a ca. 10 ha saltcedar stand on the Higgins Ranch, in a somewhat saline, nearly level pasture area with a central 10 ha area of dense thickets to moderate stands surrounded by sparse saltcedar stands, and with only dense grasses between the patches. The site extends ca. 600 m northeast along Beals Creek and 375 m west from the creek to higher gravelly slopes, with seeps that water and sometimes flood the site area from 10 to 15 cm-deep outward from the hill after rainy periods. Mesquite stands predominate to the north and south, with mesquite-juniper on the gravely hillsides to the west, an area of pickleweed then dense grasses between the saltcedar thickets and for 125 m to Beals Creek to the east, and several hectares of dense ragweeds to the southeast. Along the creek, the vegetation consists of intermittent thickets of large saltcedar or mesquite trees or in mixed stands and sometimes with other trees, and with shrubs underneath, in strips 10 to 50 m wide. (See Fig. 16 for location of nursery cages, original release tree, first trees defoliated (Trees TO), large defoliated Tree 1 and weather station).

A weather station was maintained during the period (2005 to 2008) of these experiments, with constant recording of temperature, precipitation, relative humidity, wind velocity/direction, and solar radiation (Figs. 8 and 10). In addition, ARS had 20 small “Hobo” temperature/humidity recorders attached to the trunk or major branch near the center of the tree, and a weather station with three cable leads that recorded temperature under litter where the larvae pupate and the adults overwinter (daily high/low temperature and rainfall records).

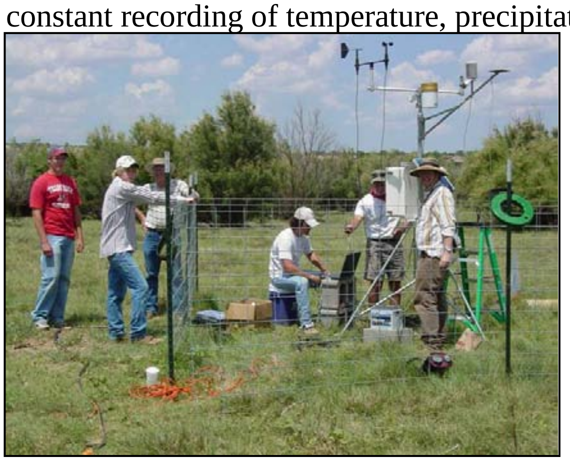


Figure 8. Weather station at Site 2a operated from 2004 through 2008.

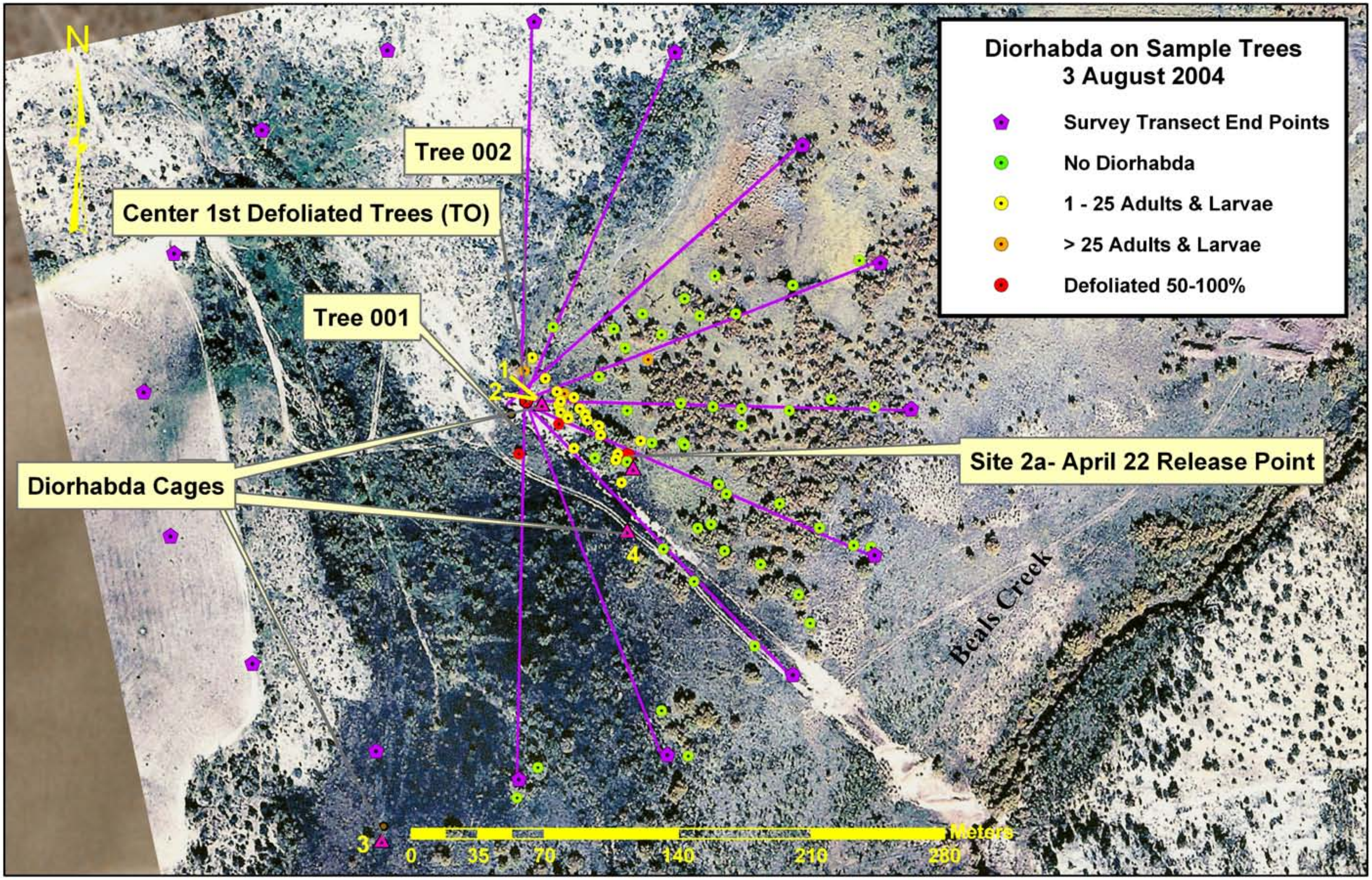
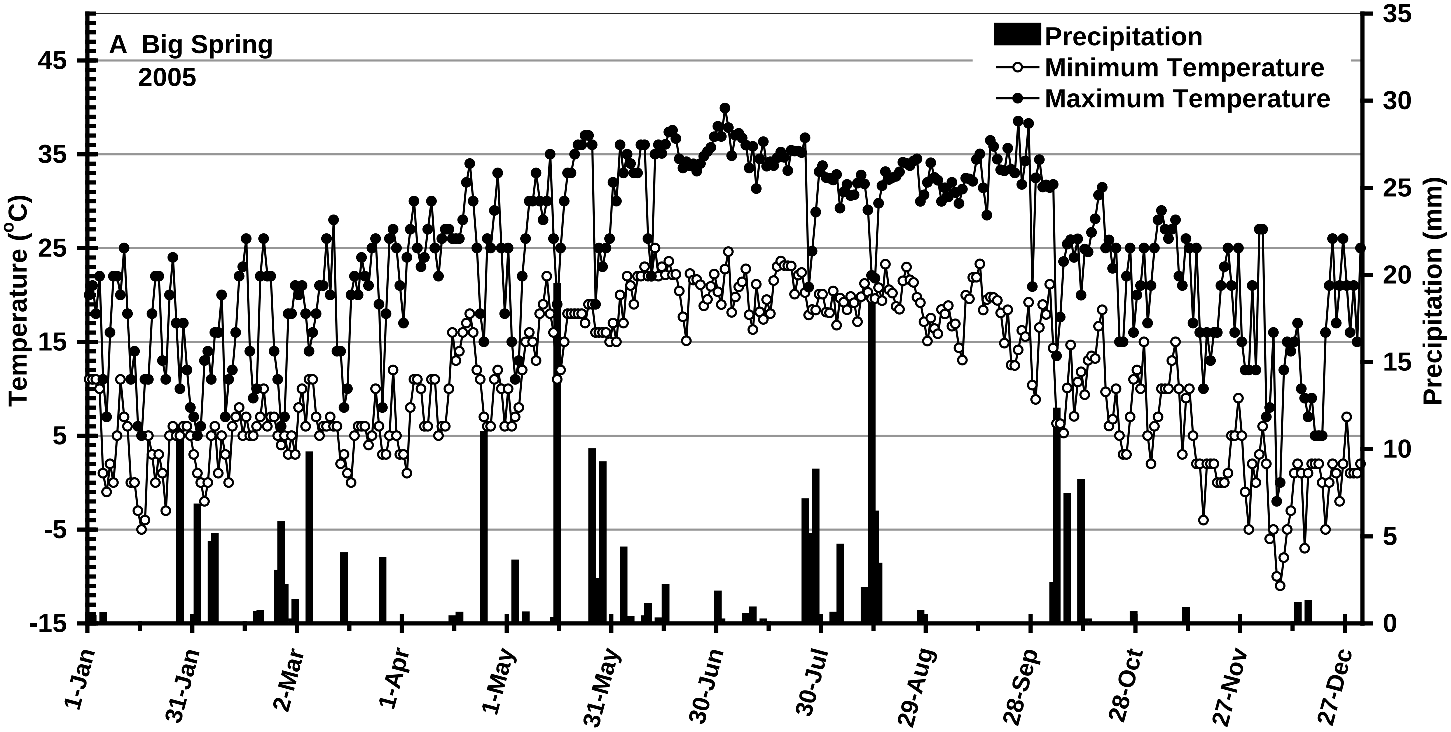


Figure 9. Large-scale layout of demonstration Site 2a for monitoring dispersal and damage by *Diorhabda elongata*. Orange/brown trees and healthy saltcedars in fall color, no damage yet present from *Diorhabda* beetles. (photography by James Everitt, 22 November, 2002).



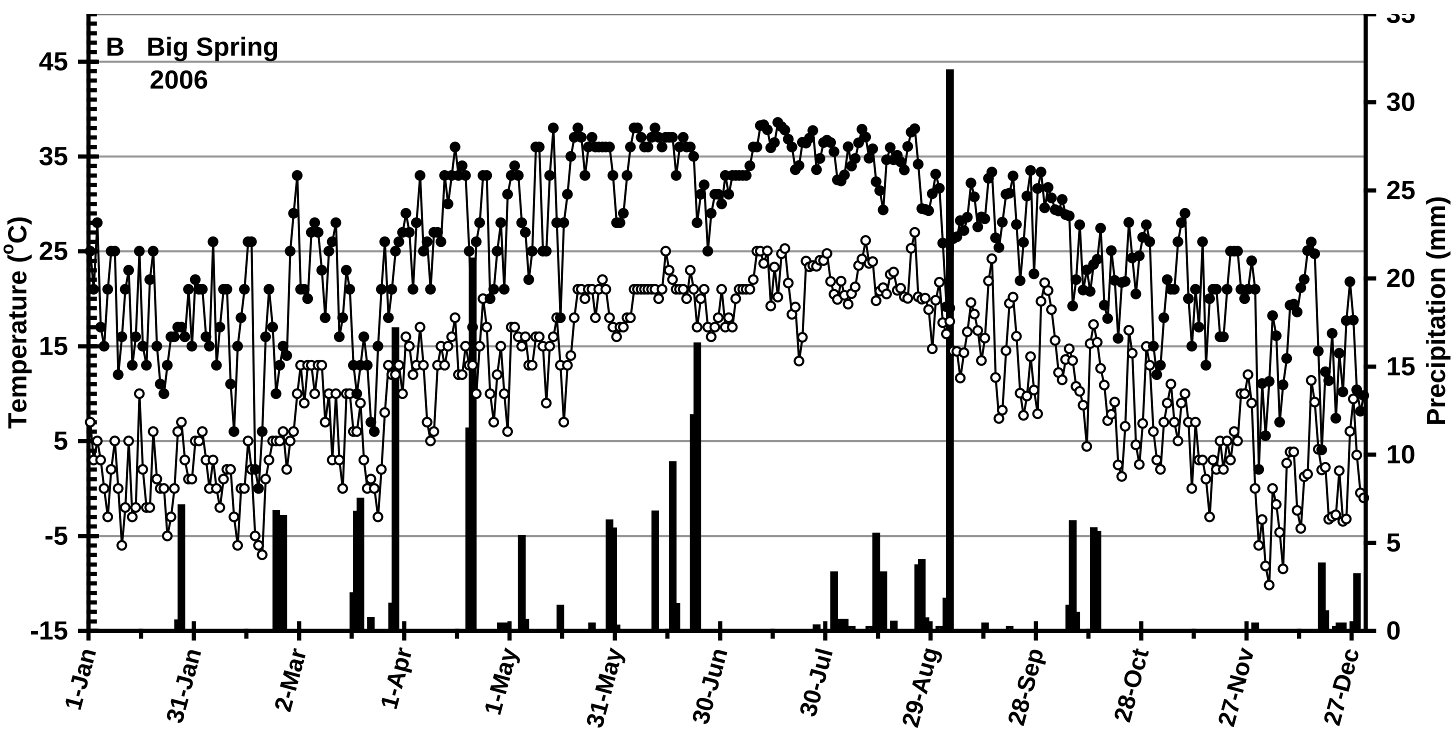


Figure 10. Weather data from Big Spring, Texas at Site 1a in 2005 (A) and 2006 (B).

Site 2b – Big Spring Wastewater Treatment Plant area. Site 2b (Fig. 7) extends from the western limit of Site 2a, power line/road at the Morgan's property upstream (northwestward) across 11th Street and to Loop 700, a total distance of 3.73 km (2.3 miles). This site includes mostly the ca. 80 ha dense, nearly monotypic stand of large saltcedar trees in the wastewater disposal area below the City of Big Spring Wastewater Treatment Plant. The saltcedar stand is ca. 600 m wide in the upper part and narrows to ca. 200 m wide from 11th Street to the power line/pipeline crossing of the creek. In most of this area the channel is shallow or divided into small streamlets because of soil aggredation through the saltcedar thickets; the area sometimes floods, and some areas are often marshy.

Site 2c – Buzzard's Draw (Fig. 11). The almost continuous saltcedar infestation along Beals Creek extends from Loop 700 at Site 2b, across the north side of Big Spring, mostly beside the Union Pacific Railroad, for ca. 5 miles to where both cross Interstate Highway 20, then another 8.5 miles to Natural Dam Lake. Site 2c, Subsite 1, is located on CRMWD owned land along Buzzard's Draw (that enters the north side of the lake) in a small patch of saltcedar trees on a berm beside the draw (Fig. 11). Subsite 2 is located on private land between the lake and Hwy 176 in a nearly level several hectare old field of regrowth saltcedar plants ca. 2-3 m tall in a moderate, continuous stand; this area was mechanically cleared in 2004 by the landowner as required under the USDA Farm Service Agency Conservation Reserve Program.

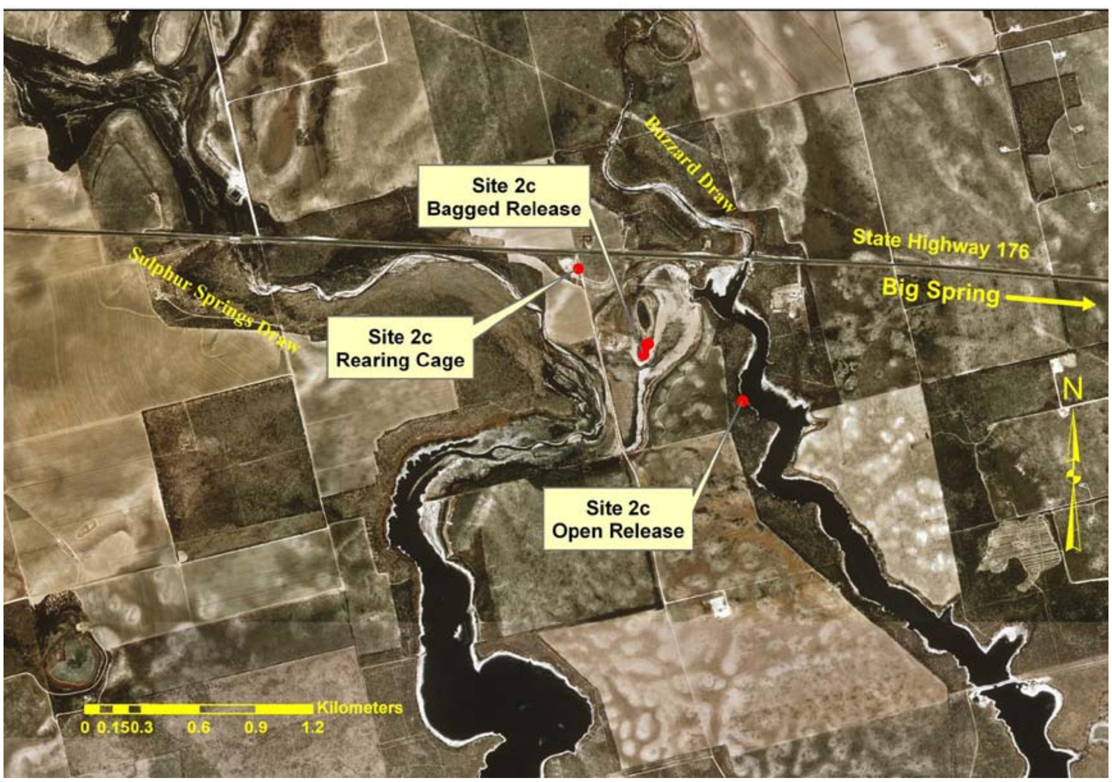


Figure 11. Location of *Diorhabda* release Site 2c on Buzzard's Draw – Subsite 2C (1) is an open-field release on saltcedar along the berm; (2) the beetles were released into two large cages in a previously cultivated field the growing up in saltcedar; (3) the beetles were released in the open.

Release and Establishment of Beetles in the Field

ARS compared releasing the beetles from different types of cages, or directly, into the field, at different times of the year in different numbers, and releasing different life stages of and numbers of beetles. The beetle cultures maintained at the Temple ARS laboratory, or sometimes at other locations, were transferred to the field site in nylon mesh bags with cut branches of saltcedar in an air-conditioned vehicle or in a cool container.

Large Nursery Cages On Site. Both ARS and Texas AgriLife Research and Extension Service (AgriLife) compared several methods of release from the large cages: a) remove the saran screen cage cover and allow the beetles to disperse naturally into the immediate surrounding area. This probably was the least injurious to the beetles but did not allow for an accurate count of the number released, and prior counting before opening the cage was not accurate. This method cannot be used if the beetles are to be released in a different location; b) inside the closed cage, catch the beetles in a sweep-net (often injures the beetles) or by shaking the branches into a funnel-bucket (causes little injury). With an aspirator, catch and count them or catch them directly from the trees with an aspirator; c) shake the caught beetles onto densely foliated, healthy saltcedar branches at the release site, in groups of ca. 25-50 beetles per branch, and 5 to 10 branches per tree; the objective is to obtain a rather dense beetle population that may be held together by the purporated aggregation pheromone produced by the group. At the field sites, the beetles were released directly into our standard peaked-top (Fig. 12) or arched-top (Fig. 13) field cages covered with 32-mesh saran screening, with a brass zipper entryway over a ¾” galvanized steel conduit frame and the bottom edge framework buried 6” deep. The cage was securely guyed using 2 ft steel auger-type anchors ca. 3 ft inside each corner of the cage and tied with wire to the top of the corner. These field nursery/release cages contained 1 to 3 saltcedar trees growing naturally at the site that had been cut back to about 4 ft high 1 to 3 months prior to produce abundant large, new sprouts for food. In the fall, winter or early spring before budbreak all dead limbs were cut off, and raked and the litter was removed to reduce predaceous insects and spiders, all foliage and stems were sprayed with dormant oil to remove leafhoppers and kill

Figure 12. ARS peaked-roof 10 x 12 x 6-8 (h) ft ¾” EMT conduit field cage (note livestock/wildlife fence).

Figure 13. AgriLife arched-top 1 5/8” SS20 piping field cage used in releases at the Murphy Ranch and at Buzzards Draw.

their eggs. The litter was replaced with 3 to 4 inches of grass hay or straw over the soil in the entire cage as a pupating site for the full-grown larvae. Walk boards were placed around the tree to prevent stepping on the pupae. If ants were present, either inside or outside the cage, the area was treated with hydromethylnon ant bait. The cages were stocked with 50-100 adult beetles that were allowed to reproduce inside the cages for usually one (or more) generations to produce ca. 500 or more adults for release,which is about maximum production of one cage without complete defoliation of the plant in the cage. If a cage had to be erected quickly during the growing season, the tree was cut back enough to fit it in the cage or some limbs were tied down. Foliage was not removed or sprayed but the dead limbs and litter were removed and replaced with hay. During 2007 and later hydromethylnon ant bait was applied both inside and outside the cage up to a radius of 25 ft for ant control before stocking with beetles. The purpose of the cage is to provide a refuge from predators until high beetle populations can be achieved. Disadvantages of the large cage are the cost and the time for constructing the frame and erecting the cage (ca. $700 for a peaked-top cage).

Sleeve Bags (Fig. 14). Sleeve bags are installed in the field by tying them on saltcedar branches, 5 to 10 bags per tree (Fig. 14), placing 10 to 20 caught beetles or beetles from laboratory cultures in each bag for 2-3 days until they have laid eggs, then remove the bag and shake or place the beetles on the same branches or move them to a nearby branch.

Sleeve bags are made of ca. 50-mesh Dacron or nylon, ca. 3 ft long and 1.5 ft diam, sewed along the seams and hem sealer applied to prevent ripping. The bag is slipped over a terminal saltcedar branch, the beetles placed inside, and the bag tied shut around the stem with a twist-tie. These are less expensive than the cages but still the cost is not insignificant (ca. $7.00 per bag). Installation in the field is easier and a protective fence is not needed.

Figure 14 . Releasing of *Diorhabda* into sleeve bags near Beals Creek at site 2C on 18 August, 2006.

Directly into the Open Field. Beetles may be released directly into the open field that were produced in nursery cages at a different location. However, some difficulties may be inherent in this method. Site managers have used this method successfully, but ARS' several attempts have been unsuccessful. This method requires large numbers of adults released simultaneously within a small area on only a few trees. If too few beetles are released, they may be eliminated by predators or the aggregation pheromone produced by a swarm may be insufficient to prevent them from dispersing too far and failing to find mates.

Methods of Monitoring

10 ha Concentric Circles – Lake Thomas. The basic monitoring plan used at Lake Thomas in 2004, specifies a 10 ha sampling circle (178.4 m radius) centered at the beetle release point with 100 (later reduced to 40) permanently marked sentinel saltcedar trees within 3 concentric rings of 1 ha (56.4 m radius), 2 ha (56.4-97.7 m radius) and 7 ha (97.7-178.4 m radius) (Fig. 6). *Diorhabda*, insect predators, and other insects were counted and percent defoliation, and plant growth and condition were measured periodically on four marked 40 cm long branch terminals on each saltcedar tree. On each branch, ARS counted all adults, 1st, 2nd and 3rd instar larvae, and eggs of *Diorhabda*; also the number of each predator species, and exotic competitor leafhoppers and scale insects. The height and diameter of each sample tree and light intercept under each tree also were measured, and a visual estimated percent defoliation made of each branch. These counts were scheduled every 2 weeks and plant size and light intercept were measured twice annually.

Quadrats Along Transects (Counts on 1 m Branches) – Big Spring. At the Higgins Ranch, ARS began monitoring on 15 July 2005. The sampling plan was changed to monitoring quadrats along transects. At each quadrat, insects and plant damage were counted periodically on 9 permanently marked 1 m long branches, 3 branches in the lower 1.5 m, 3 in the middle 1.5 to 2.5 m of the tree, and 3 in the upper part of the tree above 2.5 m; the branches were located randomly within the foliage at each level of the quadrat, from foliage of the one or more trees or parts of trees in the quadrat (Fig. 15). On each count date, all *Diorhabda* adults, egg masses, and each instar larvae were counted, as were numbers of all predaceous insects, and other phytophagous insects (mostly exotic leafhoppers and scale insects). During the flowering season, the number of spikes of buds, flowers and seeds were counted on each of the 9 branches per quadrat, present mostly on the upper branches.

Figure 15. Monitoring of a quadrat at Site 2a, Transect 4, Quadrat 4, Higgins Ranch.

The transects radiated outward from the original point of beetle dispersal, with permanent 4 x 4 m monitoring quadrats located at 20 to 100 m intervals, farther apart at greater distances, in anticipation that the beetles would disperse more rapidly over time and at greater distances from the origin (Fig. 16).

On each count date, a visual estimation was made of the percent of green, yellow (mostly leafhopper damage), brown or missing foliage (*Diorhabda* damaged), for original and regrowth foliage (all types to total 100%) on each 1 m branch and by visual overview, the amount of green, yellow and brown/dead (beetle damaged) for the whole quadrat. Also, once a year, the total length of all sub-branches longer than 25 cm on each branch and the total number of 1 m long branches were measured in each quadrat; this allowed the extrapolation of all count numbers to numbers per quadrat and thus also to numbers per m^2 of saltcedar canopy and the m^2 saltcedar canopy in each quadrat. Given the total area of saltcedar canopy cover in a given area from the aerial photographs, insect populations and damage to saltcedar could be calculated on the basis of hectares of saltcedar canopy controlled. Several different methods of estimating damage to saltcedar were also compared – light intercept of the saltcedar canopy using a light bar, difference in temperature of green and defoliated trees, correlation of green mass with branch length measurements (measured in the laboratory from 1 m branches collected in the field), and photographs of each branch *in situ* for subsequent computer measurement of leaf area per branch in the laboratory. All methods proved to be too time consuming and/or too inaccurate; thereafter, used only counts of insects and measurements of branches and tree size and visual estimates of foliage condition were used. During 2005, all quadrats were counted in the four transects as far as the beetles had dispersed (Fig. 16).

During 2006 (Fig. 17), the same four transects were monitored but extended to 500 m on Transect 2 to the Higgins /Kramph property line and 300 m on Transect 4 to Beals Creek and additional quadrats were added and Transects 5 and 7 were added to cover the beetle dispersal area. During 2006, all of Transect 1 and Quadrats 1-6 of Transect 3 were omitted because of lack of time/personnel, and T2, Q1 and 6, and T4, Q1, 2 were omitted for the same reasons and because Q1, 2 were mostly defoliated with few beetles present. During 2007, only Transect 2 was monitored with Q1 omitted (Table 2).

Table 2. Counts made in each quadrat of each transect during the 4 years of monitoring, Site 2a, Higgins Ranch, near Big Spring, Texas.

	Transect/Quadrat														
	1				2										
Year	1	2	3	4	1	2	3	4	5	6	7	8	9	10	11
2005	C	C	C	C	C	C	C	C	C	C					
2006						C	C	C	C		C	C	C	C	C
2007						P	P	P	P		P	P	P	P	P
2008								P	P		P	P			

	3								4							
Year	1	2	3	4	5	6	7	8	1	2	3	4	5	6	7	8
2005	C	C	C	C	C	C			C	C	C	C	C	C		
2006							C	C			C	C	C	C	C	C
2007																
2008																

C = complete counts; counts made every one to two weeks
P = partial counts; counts made every three to four weeks.

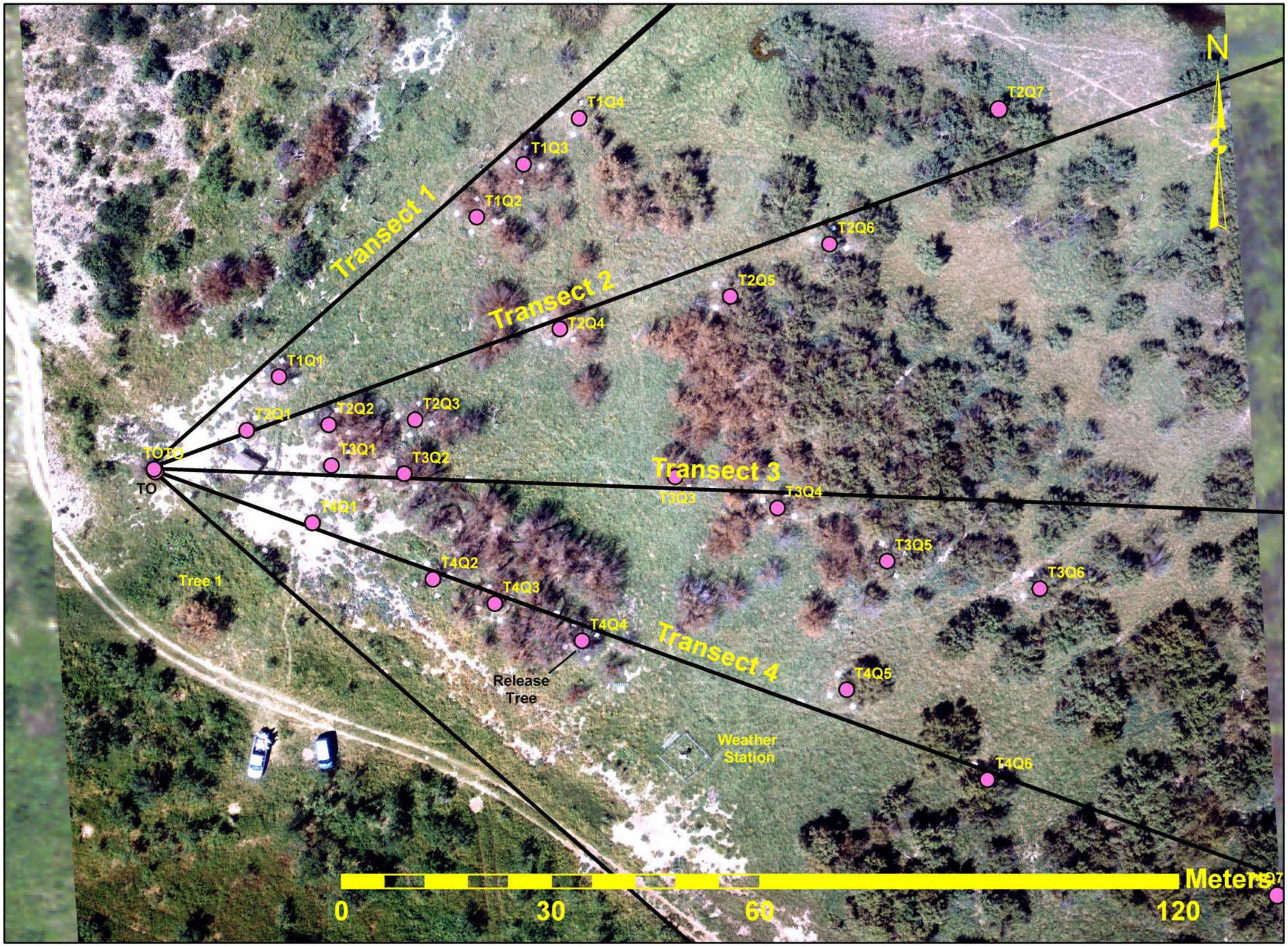


Figure 16. *Diorhabda*/saltcedar monitoring plan for 2005, 4 m^2 quadrats along transects, with saltcedar defoliation (brown trees) on 21 September 2005 – Site 2a. Photo by James Everitt.

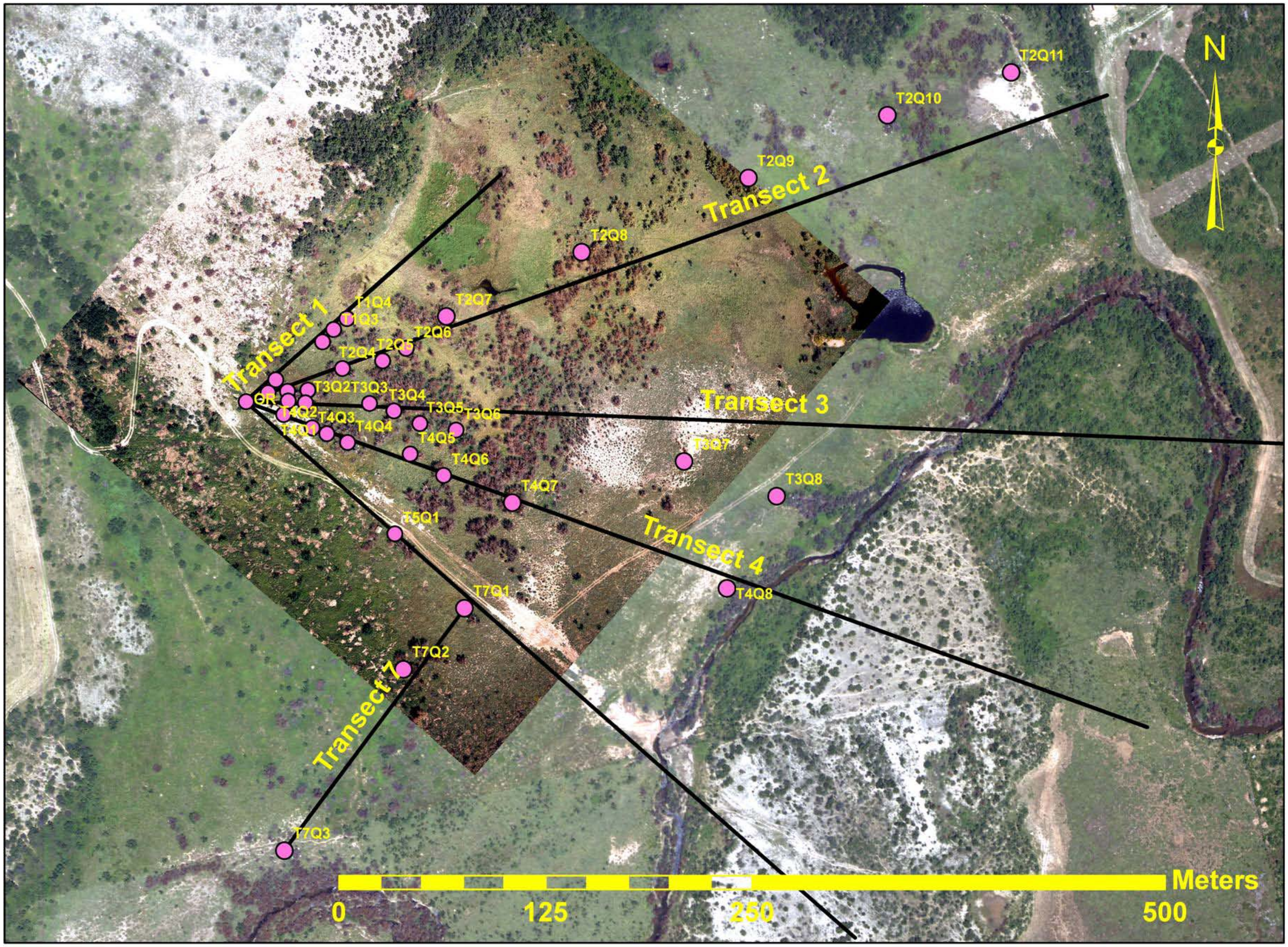


Figure 17. *Diorhabda*/saltcedar monitoring plan for 2006-2008, quadrats along transects with saltcedar defoliation (brown trees) on 19 September 2006, Site 2a. (Inner aerial photo of 19 September, 2006, surrounding photo of 8 August, 2007; photos by James Everitt). Note defoliated saltcedar in surrounding areas and along Beals Creek on 8 August 2007.

Remote Sensing. Remote sensing of release sites was done by James Everitt, ARS- Weslaco, TX, together with his group, René Davis, pilot and Reginald Fletcher, Chenghai Yang and Alfredo Gomez. All aerial photographs in this report are by Everitt's group. The flights were made by an airplane owned by ARS at altitudes between 500 and 5,000 ft to obtain detailed or broad views of the sites – the 500 ft elevation under the best conditions can have a resolution of about 3-4 inches which can detail vehicles, cage, weather station as in Fig. 14A. Best results were obtained using Ektachrome 9-inch aerial photographic film. The sites were photographed once or twice a year usually in September when near maximum defoliation for the year was present. The aerial photographs can be computer analyzed to obtain a measure of m^2 of defoliated saltcedar to compare with the ground-level measurements of m^2 defoliation of the quadrats.

Along Beals Creek – 9 km (5.6 mile) Long Transect 8 (2-minute counts). During 2006 and early 2007, the beetles defoliated most of the saltcedar in the original 10 ha demonstration area and began dispersing and defoliating saltcedar adjacent to and then up and down the creek. On 2 July 2007, ARS established Transect 8 along Beals Creek and began monitoring. In this area, Site 2a and Site 2b were combined and monitored the entire distance as 1 transect, with the migrating beetles moving away from the center of dispersal at our main 10 ha study area on the Higgins Ranch, from the point where Transect 4 ends at Beals Creek; the transect extended from Moss Lake Road to Highway Loop 700 (see Fig. 24) a total distance of 9,043 m.

Permanently marked monitoring trees were established along the creek every 25 m where *Diorhabda* populations and damage to saltcedar were present. *Diorhabda* beetle adults, egg masses and large larvae (2^{nd} and 3^{rd} instars together) and other insects were counted during 2 minutes on each tree, on 4 branches but for a longer period if needed to complete the 4 branches; the total time was recorded and for analysis converted to numbers per minute. After 20 July 2007, only the insects on every second tree were counted, a visual evaluation of foliage condition (% green, yellow and brown) on all sample trees made, and tree size (height at two points and diameter along two lines through the tree at right angles) were measured on every fourth tree.

RELEASE AND ESTABLISHMENT

Site 1 – Lake Thomas Area. Release of Crete Beetles between 2003 and 2004.

Site 1a – Lakebed. On 21 August 2003, ARS removed 100 adults from Cage 2, combined them with 1280 adults from the Murphy Ranch nursery cages (Table 1), and released them directly into a small patch of 4-5 m tall saltcedar trees in the open field near the center of the 10 ha monitoring circle at the Lake Thomas dry lakebed (Figs. 5, 6). On 10 September 2003, the Crete beetles were taken from Cage 4 to Lake Thomas and released them on the same day at the center point of the lakebed monitoring circles but surveys in October failed to detect any beetles. The beetles released in 2003 appeared to have overwintered well at Site 1a; and monitoring on 20 April 2004 revealed ca. 2000 eggs near the release site; however 2 weeks later in early May no larvae were found but numerous ladybird beetles were present. An additional 980 adults were released in July 2004 (Table 3). Activities conducted in 2003 were funded through a separate grant.

During the vegetation survey completed on 10 August 2004 ARS found very abundant small, amber colored, rapidly moving ants (probably *Forelius mccooki*) under all of 10 saltcedar trees examined. These ants probably are predaceous since ARS observed them eating or removing pieces of wasp larvae from a low hanging nest. Either the lady beetles on the trees or the ants on the ground or in the trees may have destroyed the *Diorhabda* beetle larvae and/or the pupae on the ground. Later, ant monitoring during the spring of 2008 detected very high ant populations here.

Site 1b – Murphy Ranch. Crete Beetles, 2004. After the unsuccessful establishment at Site 1a, and the initiation of Site 2a, ARS turned over control of Sites 1a and 1b to Dr. Allen Knutson (AgriLife– Dallas) and Jeremy Hudgeons. Hudgeons erected 16 large cages (Fig. 5) in a several acre patch of saltcedar trees 3-5 m tall at this site 2 km upstream from Site 1a. 2007). After the experiment, Hudgeons and Knutson released several hundred beetles from the cages in August but they failed to establish (Tables 3). Monitoring done during the spring of 2008 revealed high ant populations here.

Table 3. *Diorhabda elongata* (Crete ecotype) released in the field at Site 1 and Site 2 in 2004.[a]

	Numbers released in the open field[b]				
	Lake Thomas		Big Spring		
Date	Lakebed (Site 1a)	Murphy Ranch (Site 1b)[b]	Higgins Ranch (Site 2a)	Wastewater Treatment Plant (Site 2b)	Buzzard's Draw (Site 2c)
22 April			37A	40A, 100E	
1 July			141A		
6 July			30A		
16 July	580A				
21 July	400A			200A	
22 July					3,500L
29 July					150A
6 August			200A		
9 August			2,000A[c]		
11 August		Several 100's			100A
15 October					100A
Total	980A		2,408A	240A 100E	3A 234L

[a]See Appendix A, Tables A-1, A-2 for details of releases.
[b]A = adults, L = larvae, E = eggs
[c]Removed cage cover, allowed all beetles to disperse naturally.

Site 2 – Beals Creek, Big Spring Area. Crete Beetles.

Site 2a – Higgins Ranch.

Nursery Cages. The nursery cages were first monitored at Site 2a on 8 August 2003 (Appendix A, Table 3); the original 100 adults had declined to 17 but many larvae had been produced and were pupating under litter in the cage. Populations in Cage #1 had increased by 3 September to 198 adults and 224 larvae. The beetles had defoliated the tree by 9-10 September and many 2nd and 3rd instar larvae were crawling on the ground and on the cage walls. Eighty adults from Cage #1 plus 70 more from the Murphy Ranch nursery cages were placed in Cage #4. The population continued increasing at Site 2 in Cage #1 and #3 and the beetles defoliated the trees in both cages. The saltcedar trees in Cage #4 were 95% defoliated and by 30 October, the trees in Cages #1 and #3 had produced substantial amounts of regrowth. The remaining Crete beetles at Site 2 were left in cages for overwintering and release during the spring.

First establishment – Releases from Cages into Field. Crete beetles, 2003-2004. Adult Crete beetles in cages overwintered well here and began reproducing during April 2004. On 22 April 2004, ARS released 37 adults from Cage #1 into the open field and onto large, healthy saltcedar trees at the eastern end of the first saltcedar strip thicket, ca. 55 m east of the nursery cage (Fig. 8, 16) (Table 6). In July, ARS released an additional 171 adults from the cage. On 15 July 2004, ARS discovered that 2 small trees of origin (TO) 10 m west of Cage #1 were completely defoliated.

On 3 August 2004, Hudgeons and Knutson marked 62 sentinel trees along 9 of 16 transects radiating from the 2 central defoliated TO. On 3 August, the highest population was on large Tree #001 (54 larvae, 13 adults per 1-minute count) to where they had migrated 75 m from the release tree (RT). Also, on 3 August, 3 trees were 50-100% defoliated and had more than 25 adults and larvae per 1 min count (TO, 001, and 005), 17 trees had 1-25 beetles, and 41 trees had no beetles (Fig. 8). ARS released 2200 adult Crete beetles in August by removing the cage screen cover of Cage #2 and allowing the beetles to disperse naturally. On 31 August, fewer beetles were found near the TO but the beetles had dispersed to other trees. The first 2 defoliated TO had completely resprouted and had 4 adults and 5 third instars/1 min count. Tree #001 was 80% defoliated by 2 September and ca. 98% defoliated by 3 October. On 21-22 October, an average 13.5 larvae and 3 adults/2 min count were found on 10 of 47 transect trees; the 2 center trees (TO) had 17 adults, 1 egg mass and 96 larvae; larvae were still present in several field cages at Higgins and at the Murphy Ranch.

On 2-3 September, ARS added 50 Crete adults from Tree # 001 at Higgins Ranch into each of 7 field cages for overwintering and release in early spring 2005 – 2 cages at Site 2a, 3 cages at Site 2c, and 2 cages at Site 1b. No life stages of Crete beetles were seen at the Higgins Ranch when monitored by Hudgeons in December.

The beetles overwintered well, emerged in large numbers in April 2005, and began advancing in large numbers through the first saltcedar strip thicket and by early July had begun defoliating it (see Fig. 20, Fig. 19C). In early July 2005, ARS declared the Crete beetles to be “established” at Big Spring, the first establishment in the program.

Uzbek Beetles. In August and September 2003, ARS brought 975 eggs and 20 adults from nursery cages at Temple and placed them in sleeve bags in Cage 2 at the Higgins Ranch. All Uzbek beetles were left in Cage 2 for overwintering (Appendix 1, Table 3).

Site 2b – Big Spring Wastewater Treatment Plant Area, 2004. On 21 July, ARS placed 200 adult Crete beetles (from the Higgins Ranch) in sleeve bags (20 adults in each of 10 bags) on branches of large, healthy, dense saltcedar trees beside a small grassy opening ca. 50 m inside the north edge of this large saltcedar-infested area (Fig. 7). The bags were removed after ca. 1 week but the beetles did not establish.

Site 2c – Buzzard’s Draw, 2003-2004. In August and October 2003, 103 Crete beetle adults, 24 firsts, 131 seconds, and 79 third instars were released into the open environment in a patch of 2-3 meter tall saltcedar trees along Buzzard’s Draw (Fig. 11, Appendix 1, Table 3). Subsequent monitoring that fall and during the spring of 2004 failed to reveal any beetles.

Another release was made in June 2004 into two of the large cages (Fig. 12) in a ca. 5 ha area of regrowth saltcedar between Buzzard’s Draw and Hwy TX 176 (Fig. 11). Beetles later released outside of the cages did not establish. During the summer of 2004, the landowner mechanically destroyed the saltcedar as required under the USDA Farm Service Agency Conservation Reserve Program. Unfortunately, ARS were not aware that the land was in the Conservation Reserve

Program and did not attempt to re-establish the site.

Releases of *Diorhabda* at Other Sites in Texas (Fig. 18).
Of the release sites, establishment varied by location, type of beetle, the presence of predators, populations and when the release sites were established. Statewide, successful establishment of the saltcedar leaf beetle, *Diorhabda* through 2007, had been achieved at three locations: the very strong establishment at Site 2a and b on the Higgins Ranch east of Big Spring (ARS), one on the Pecos River at Pecos and at Sulphur Draw (AgriLife). The three sites used the same methodologies jointly developed at Big Spring. At all of these locations, the beetles established easily and quickly, reproduced rapidly in the field, and are dispersing rapidly and defoliating saltcedars over many acres. They are now beginning to kill saltcedars defoliated for 3 years or more.

ARS, from 2004 through 2006, released Crete beetles in Texas at 7 locations from 5 cages, and 6 bags and 2 open sites – Seymour (2 cages), Big Spring/Buzzard's Draw/Lake Thomas (4 locations, 3 cages, 1 bag, 2 open field), and Kingsville area (3 locations, 5 bag releases). Of these locations, only the Big Spring Site 2a established (Fig. 18).

Our AgriLife cooperator (Knutson), during 2006 through 2008, released the Crete beetles at 23 locations in Texas – 2 in the Red River watershed, 3 in the Brazos; 12 in the Upper Colorado, 5 in the Pecos, and 3 in the Rio Grande watershed. A total of about 39,000 Crete beetles from the ARS Big Spring area were released, with up to 5,000 in three releases.

During 2007 through the present, ARS added another 18 locations with releases from 34 cages including Crete, Uzbek and Tunisian beetles, for a total of 24 locations and 48 cage/bag, open releases (Table 4).

Table 4. Releases of *Diorhabda* Beetles by ARS in Texas, 2004 to present.

Watershed	Crete Location (cages)	Uzbek Location (cages)	Tunisian Location (cages)	Total Location (cages)
Red (Wichita, Pease)		2 (8)		2 (8)
Colorado	5 (11)	1 (1)		6 (12)
Pecos		3 (5)	2 (2)	5 (7)
Rio Grande	6 (14)		5 (7)	11 (21)
Kingsville				
Total	11 (25)	6 (14)	7 (9)	24 (48)

Many of the ARS releases in Texas at first failed to establish (Seymour, Matador Wildlife Management Area near Paducah, Kingsville area, Presidio to Candelaria, and Balmorhea). ARS' experience has helped in understanding several factors that limit establishment and control, based on the different conditions at the various release sites. The purpose of including several release sites was to be able to compare the various limitations and to develop successful release procedures.

The several mile strip of saltcedar along Sulphur Springs Draw, which is north of Highway 176 and west of Buzzard's Draw, plus the simple habitat (mostly saltcedar and grass) made this a promising release site. Knutson made several releases of Crete beetles in this area during 3 years but without establishment. The area flooded during 2007 and the beetles began increasing, and partly defoliated one tree – so far the best results outside of Site 2a in the Upper Colorado watershed.

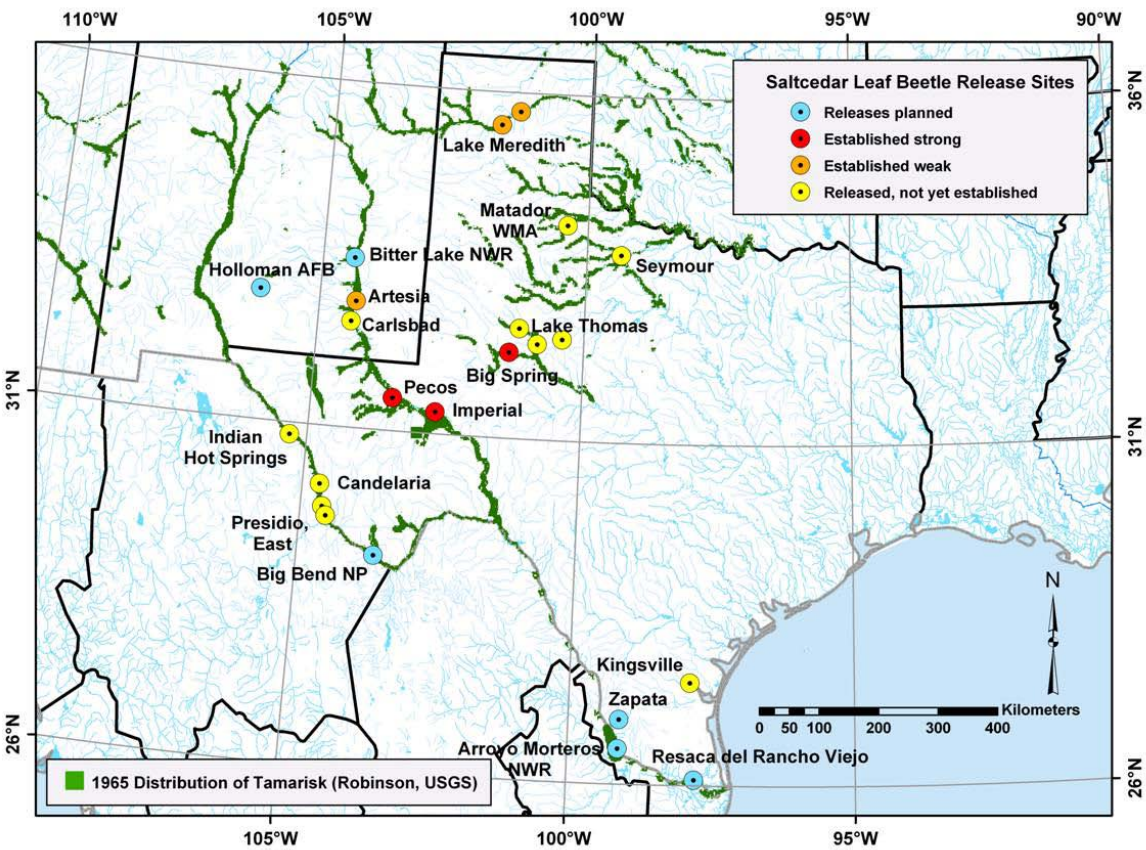


Figure 18. Releases of *Diorhabda* beetles in Texas and New Mexico through 2007 (with 1965 distribution of saltcedar).

MONITORING *DIORHABDA* BEETLE POPULATIONS, DISPERSAL, DEFOLIATION AND DEATH OF SALTCEDAR

Permanent Quadrats Along Transects – Site 2a. Seasonal Occurrence and Abundance of *Diorhabda* (Crete) Beetles

Early Season. During 2004, the Crete beetles first released by ARS on 22 April had dispersed to 20 saltcedar trees by August within a 40x75 m area near the nursery cage and had increased to high populations, defoliating a large tree (Tree #1) and two small trees (TO) and with 1–25 beetles present on 17 other trees (see Fig. 8). They overwintered well in this area under litter and in the clumps of bunch grass (living or dead), and began emerging on 28 March 2005. They increased to rather large populations of overwintered adults, then of 1st generation larvae during May and of 1st generation adults in June, before the transect monitoring began.

In 2005, *Diorhabda* beetles were monitored on 27 marked saltcedar trees from 28 March to 12 July scattered along the front edge of the 1st saltcedar strip thicket to the north and east of the nursery cage. Monitoring recorded adults, egg masses and each instar larvae counted on each tree in 2 minutes. The first overwintered adults were found on 28 March – 8 in nursery Cage #1 and 4 in saltcedar trees 15 to 90 m from the cage. A more thorough examination was made on 31 March when 15 adults were found in the cage, and 32 were found during 2-min counts in 24 trees out to 50 m from the cage (Table 5).

Table 5. Early season *Diorhabda* (Crete ecotype) populations of 27 marked trees along transects, Site 2a, Spring 2005[a].

	No. *Diorhabda*				
Date	Adults	Egg masses	Larvae	No. trees	Observations
28 March	12				Overwintered adults
31 March	47			24	Overwintered adults
27 April	59	23	0	21	Overwintered adults
11 May	19	26	177	25	Larvae mostly 1st and 2nd
24-25 May	19	11	203	28	Larvae mostly 2nd and 3rd
1 June	12	6	112	27	Larvae mostly 2nd and 3rd
14 June	134	13	70	27	New 1st gen adults. Larvae mostly 1st and 3rd
5 July	95	23	164	27	Larvae mostly 2nd and 3rd
12 July[b]					Mostly 3rd pupating.

[a]Data from Hudgeons et al. (2007), see Fig. 8.
[b]Defoliation 80-90% on 6 trees, 50-80% on 6 trees, 10-50% on 4 trees.

Occurrence of Generations. The occurrence of each generation during the season is not exact because the adult females oviposit over several weeks and so the generations soon overlap. However, based on population peaks and the expected lifespan of the adults, estimated generational occurrence from the 2006 data along the two transects in the saltcedar-athel-*Frankenia* test are as follows (Table 6):

Table 6. Occurrence of adult generations, Site 2a, 2006.

Adult generations	Range	Peak date, population
Overwintering	March–May	27 April, 59 per 2 min.
1st generation	Late May to 30 June	15 June, 10 per 1-m branch
2nd generation	1 July–1 August	15 per branch
3rd generation	1 August–10 September	25 per branch
4th generation	10 September–20 October	25 per branch

From these data, ARS concluded that the overwintering adult generation (originating from the 3rd to 5th adult generations that entered overwintering diapause during September – October 2004) began emerging in mid-March, immediately began feeding to replenish their fat reserves and egg development. They probably began mating within ca. a week, the females probably began ovipositing before ca. 10 April, and reached a peak population 31 March-27 April. The first generation of eggs and larvae reached peak populations during May. The overwintered adult population declined until ca. 14 June when the larger 1st true adult generation emerged, mated, and began ovipositing after a ca. 5-7 day pre-oviposition period while the eggs matured. The first generation females laid many eggs which produced a large larval generation that, together with the remaining adults, defoliated several trees by 12 July.

Monitoring Quadrats Along Transects, 2005. The progress of defoliation at Site 2a in 2005 was dramatically clear (Fig. 19A-C). On 21 June, no defoliation was visible (Fig. 19A); by 31 August, following the moderately large 3rd generation larvae and the large emergence of 3rd generation adults, ca. 85% of the stand had been defoliated (Fig. 19B); and by 3 October these plus 3rd generation larvae and a large emergence of 4th generation adults had defoliated 99% of the stand (Fig. 19C; 20C, F).

ARS began monitoring the 4 transects at Site 2a on 12 June 2005, ca. 10 days after the beginning of the 1st adult and 2nd larval generations, when populations were still low (Fig. 20A). However, on each later date (and especially each later adult generation) the adults dispersed farther into the stand (Fig. 16; Fig. 19B, C; Fig. 20A, D). For example, to Q1 and Q3 in T2-T4 by late June and to Q4 by late July, and began defoliating the saltcedar to 10-20% (Fig. 20A, C, D, F). By early August, they had crossed the 25 m grassy area between Q3 and Q4 (Transect 2) (Fig. 20A, D) and the 40 m grassy area between Q4 and Q5 (Transect 4) (Fig. 16) and advanced into the southwestern sector of the second, larger thicket, defoliating 1.6 acres (190 trees) by 31 August (Figs. 19A, C). A large emergence of adults on ca. 25 August, together with the large number of remaining 3rd and new 4th generation large larvae in early September, and a large emergence of 4th generation adults on ca. 19 September had defoliated 99% of the saltcedar stand by 3 October (Fig. 19; Fig, 20C, F). The beetle dispersal extended to Q6 and defoliated saltcedar 85-110 m from the origin in all 4 transects by 21 September.

Adult and larval populations remained high through August, and adults through September, with occasional higher populations in Q2 and Q3 of Transects 2 and 4 during August. Defoliation reached 80–100% by late August and remained high until the end of the season. However, egg and larval populations decreased markedly after late August (Fig. 20B, E), because the high defoliation rate severely limited their food supply (Fig. 20C, F) and also because the adult females began entering reproductive diapause and drastically reduced their rate of oviposition.

In T1 Q2; T2 Q3, 4; and T4 Q4, the beetles did not previously overwinter but invaded later in large numbers after large populations developed in the first quadrats and sometimes defoliated them very quickly. Farther out in Q5-6 the adults did not invade until early September (Fig. 20A, D) and defoliated only 10 to 40% of the saltcedar (Fig. 20C, F).

During the 2005 season, the Crete beetles advanced steadily through the first saltcedar strip-thicket from May through June. By August, they had crossed the grassy strip and advanced into the southwestern sector of the second, large thicket and by 21 September had defoliated most of the saltcedar in a 1-ha area (ca. 190 trees) (Figs. 16 and 19).

Monitoring Quadrats Along Transects, 2006. During 2006, the overwintering adult populations appeared to be much lower than in 2005 or in 2007. This possibly was caused by an unusually cold late winter when temperatures fell from a daytime high of 25°C on 18 February to highs of 2° and 0° and to lows of -5 to -7° on 17-19 February. When monitoring began in early May, a few adults and larvae were found in T2 Q7 (Fig. 21A, D) but the populations did not fully recover until mid-June. They reached high populations during July and August when the adults dispersed slowly to more distant quadrats, reaching T2 Q9 in late August and Q10 in September (Fig. 21A, Fig. 19D, E, Fig. 17). The adults and larvae both increased more rapidly at the distant quadrats in Transect 4, achieving moderate populations at Q8 (at Beals Creek) during September (Fig. 21D). However, larval populations decreased to very low numbers after mid-August in both transects but persisted longer at the more distant ones, probably because of a shortage of food in the near areas (most of the 10 ha study site had been defoliated, Fig. 17), and also because oviposition and populations of small and large larvae had decreased drastically after 21 August (Fig. 21B, E).

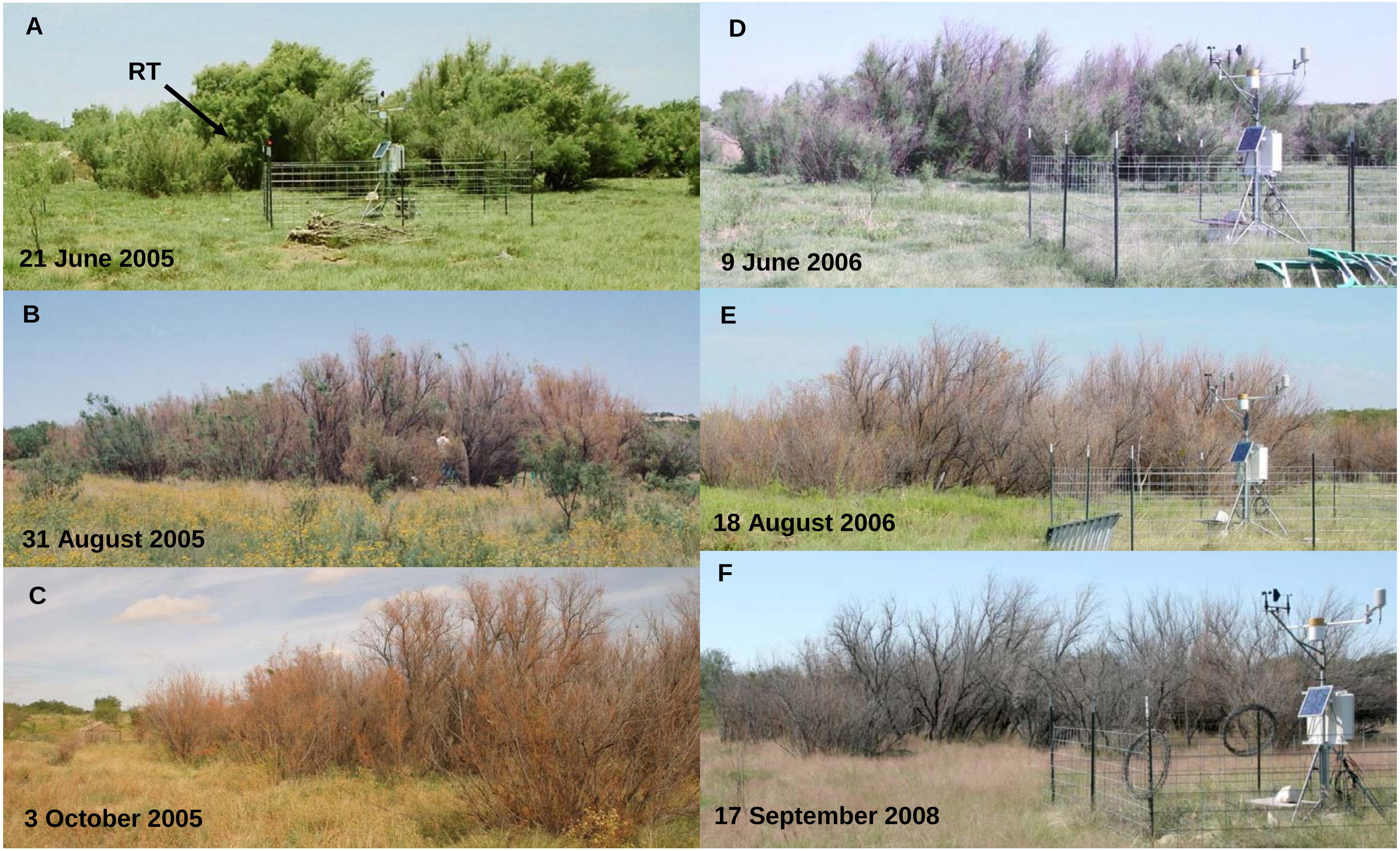


Figure 19. Defoliation of saltcedar by *Diorhabda* (Crete ecotype) from initial release (on release tree) on 22 April, 2004. Nursery cage, Tree #1 and TO are 55 to 70 m behind near border of stand on far left (see Fig. 8A): A) before defoliation; B) 90% defoliated by 3rd generation beetles; C) 99% defoliated by 4th generation beetles; D) 50% dieback/50% regrowth in spring after 2005 defoliation; E) 99% defoliation of regrowth; F) 99+% defoliation, with 90% dieback and 20% dead trees.

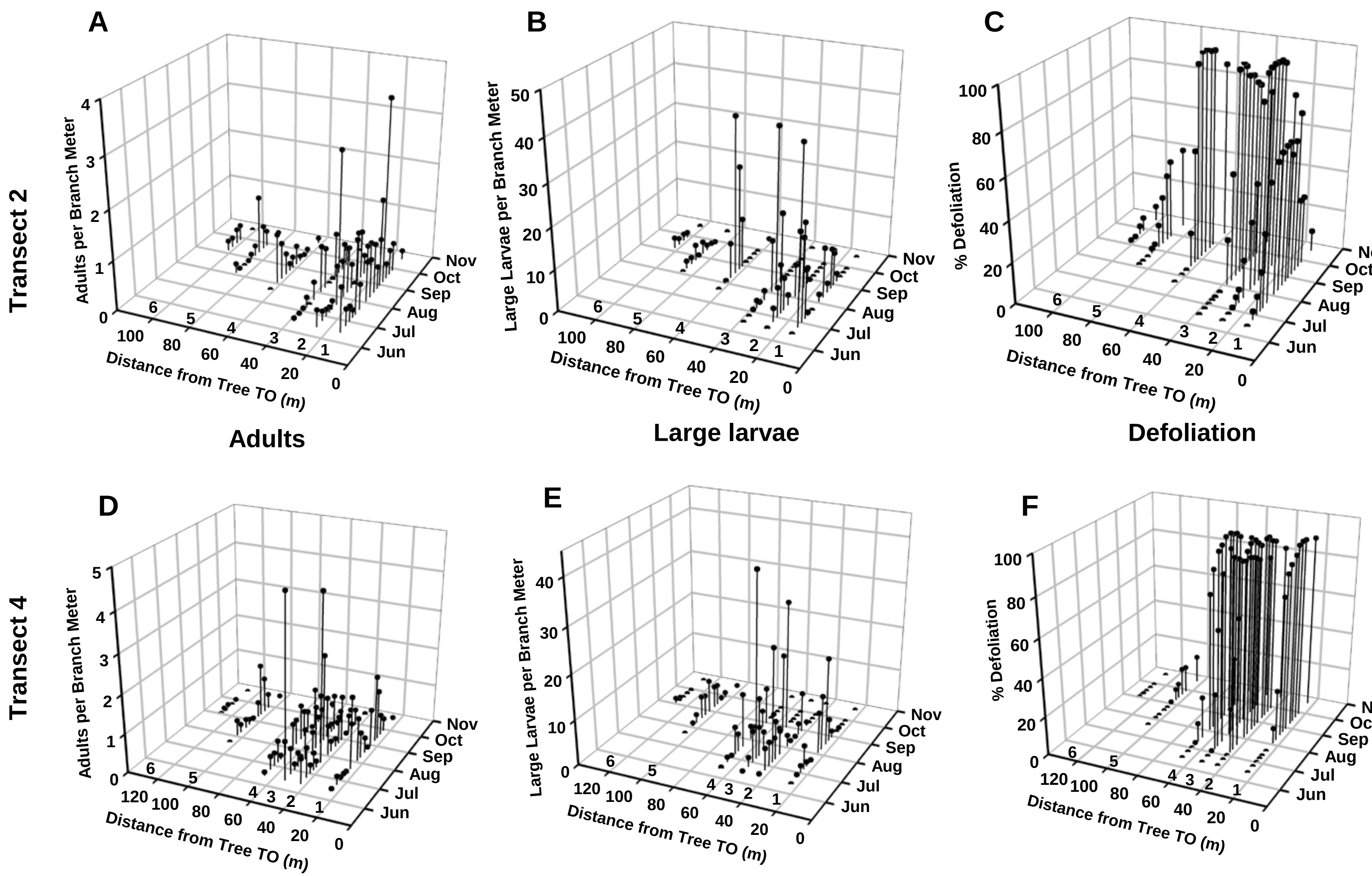


Figure 20. *Diorhabda* population, dispersal, and defoliation at Site 2a along Transect 2 (A–C) and Transect 4 (D–F): A,D) adult beetles; B,E) large 2nd and 3rd instar larvae; C,F) defoliation; quadrat numbers inside distance scale – 2005.

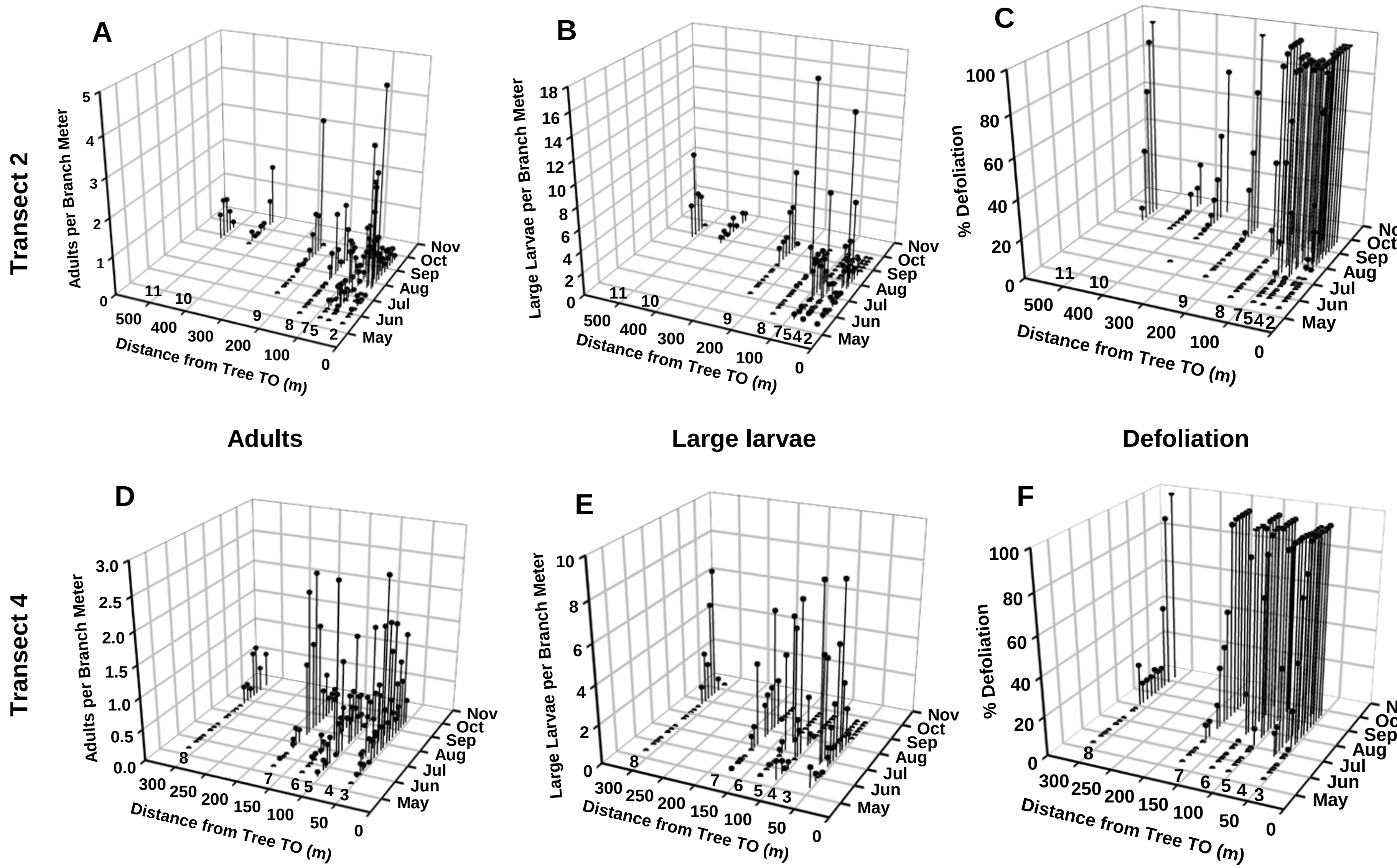


Figure 21. *Diorhabda* population dispersal and defoliation at Site 2a along Transect 2 (A–C) and Transect 4 (D–F): A,D) adult beetles; B,E) large 2nd and 3rd instar larvae; C,F) defoliation; quadrat numbers inside distance scale – 2006.

After adult dispersal from the origin (Tree #1) during 2005 and through mid-August 2006, the beetles developed a different dispersal behavior, probably in response to severe and widespread defoliation and food shortage. This involved the formation of swarms of adults on a selected few favored plants during August that then flew in mass to begin satellite colonies from just beyond the present defoliated area. The advance of the beetles through the saltcedar stand and the defoliation during 2006 is clearly documented at Site 2a.

In 2006, defoliation began along Transect 2 in Q4 and 5 in early July (Fig. 17, 19D, E) but later in Q1-4 (50% on 30 July to 9 August) as the beetles moved back into the regrowth (Fig. 21). From T2 Q4-6, the beetles moved progressively outward, producing 50% defoliation in Q7 by August, in Q8 by 6 September, and in Q9 by 27 September but the smaller population that reached Q9 achieved only 78% and those at Q10 only reached 23% defoliation by season's end (Fig. 21C, F).

Apparently, a swarm of adults from the large emergence in late August 2006, flew 300 m or more, bypassing Q9 and Q10 along Transect 2, and flew to the area around Q11 where they produced a strong satellite colony with 50% defoliation by 4 September and 100% by 20 September (Fig. 21C, F), a month earlier than in Q10. Two similar colonies established along Beals Creek (near the intersection of Transects 3 and 4 and near Q8 with the creek) after crossing the grassy strip and flying 125 to 150 m beyond Q7 (Fig. 21D-F, Fig. 17).

Monitoring 9.15 km-Long Transect 8 Along Beals Creek, 2007. Sampling began along Transect 8 along Beals Creek on 29 May 2007. The adults rapidly dispersed up and down the creek, reaching high populations of 6-8 adults per branch/min in the central area during July and August with sometimes 35 adults on same branches (Fig. 22). The population of large larvae declined rapidly after late June and never reached high numbers beyond 1000 m from the central area. The decline may have been caused because the high rate of defoliation severely reduced their food supply over a wider area after mid-June, the adult females began entering reproductive, overwintering diapause after mid-August, and/or increasing predator attacks during the summer. A visualization of Sites 1a and 1b, with the entire 9.6 km distance from Moss Lake Road to Loop 700, is presented in the aerial photographs (Fig. 23). The dispersal of beetle populations and saltcedar defoliation progressed up and down Beals Creek throughout 2007.

Saltcedar defoliation on 18 June-2 July 2007 was less widespread than beetle dispersion, but was severe (75-100%) in the 400 m section along the creek adjacent to the 10 ha original site at Site 2a (Fig. 22; Fig. 23A). However, defoliation had spread rapidly by 16-30 August (Fig. A4B) with 75-100% defoliation for 2.2 km along the creek, and with scattered defoliated trees from just below the pump station to the powerline/pipeline, a distance of 4.6 km. By 27-30 August (Fig. 23B), this 4.6 km had been severely defoliated (50-100% but mostly 75-100%) which extended 2.8 km upstream to the powerline and 1.8 km downstream to 100 m below the pump station, from the Transect 4 intersection with Beals Creek at Site 2a, plus another 3.2 km with satellite colonies, two colonies to Moss Lake Road and four to 650 m N of 11th street.

Plotting All Sample Trees. During 2006, the Crete beetles had defoliated practically all of the 20 ha study area at Site 2a and had defoliated a few small satellite areas beside the creek. ARS began sampling Transect 8 along Beals Creek on 29 May 2007; adults and larvae were present on the trees for nearly 600 m upstream and 500 m downstream but with populations of only 1 or 2 adults or larvae per 1-min count (Fig. 22). The adults rapidly dispersed up and down the creek, reaching high populations of 6-8 adults per minute in the central area during July and August, occasionally with up to 35 adults on some branches. A large 4th adult generation was seen during September from the Pump Station to Moss Lake Road dispersing outward from a few satellite trees. The population of large larvae declined rapidly after late June, for unclear reasons, and never reached high numbers beyond 1000 m from the central area (Fig. 22). Part of the reasons for the decline may have been because the high rate of defoliation severely reduced their food supply over a wider and wider area after mid-June, partly because the adult females began entering reproductive, overwintering diapause after mid-August, and possibly because of increasing predator attack during the summer.

The dispersal of beetle populations and saltcedar defoliation progressed up and down Beals Creek over the entire 9.15 km distance from Moss Lake Road to Loop 700 during 2007. *Diorhabda* beetles monitoring between 18 June and 2 July were present at low numbers from Moss Lake Road within 600 m of 11th Street with highest populations (up to 24 to 48 beetles/branch/min) along a 1 km area across from 500 to 850 m upstream from the 10 ha study area at Site 2a. By 16-30 August they had passed 11th street and were found nearly to Loop 700 (Fig. A4B), but populations had decreased substantially in the center area because the saltcedar had been mostly defoliated (Fig. 23). Also, starting July 19, the spatial frequency of monitoring was usually reduced from every tree (each 25 m) to each 2nd tree (each 50 m) to be able to cover the entire area with the personnel available.

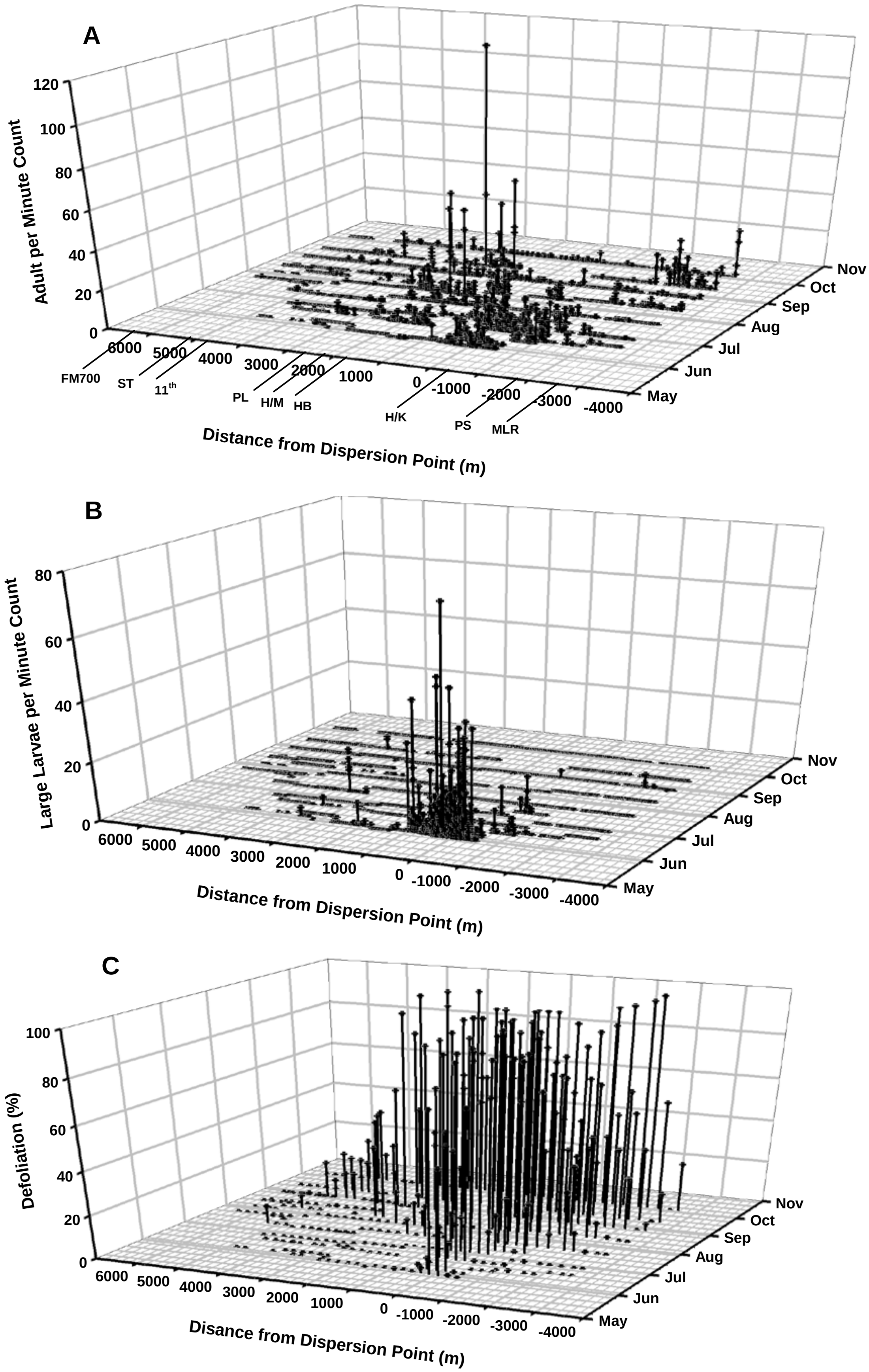


Figure 22 *Diorhabda* populations along Beals Creek - transects over distance from origin of dispersal (0) and time during 2007; Sites 2a and Site 2b: A) adult beetles, B) large 2nd and 3rd instar larvae, C) defoliation averaged over 200 m. 0 = origin of *Diorhabda* dispersal (Transect 4); Downstream: H/K = Higgins/Krampf property lines, PS = CRMWD pump station, MLR = Moss Lake Road; Upstream: HB = Higgins bridge, H/M = Higgins/Morgan property line, PL = power lines, 11th = 11th street, ST = satellite tree at Site 2b, FM700 = FM 700.

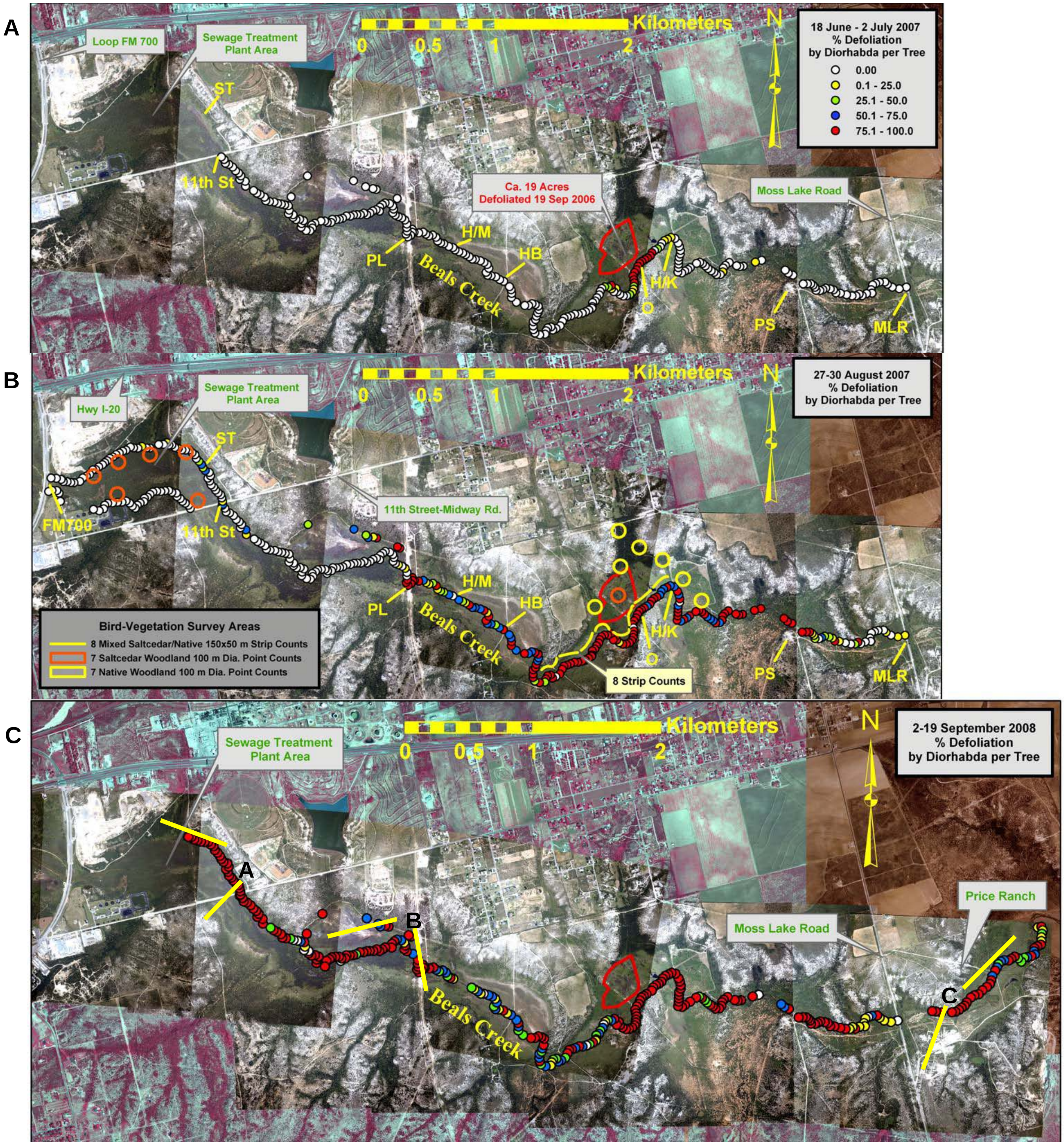


Figure 23. *Diorhabda* defoliation along Beals Creek–2007 to 2008. A) To 2 July 2007; B) To 30 August 2007, ST-Satellite tree, PL-power line/pipeline, H/M-Higgins-Morgan property line, HB-Higgins bridge, O-origin of transects, H/K-Higgins-Krampf property line, PS-CRMWD pump station, MLR-Moss Lake Road; C) To 19 September 2008 – estimate 143 acres defoliated along 6.4 miles of Beals Creek. Bird and vegetation surveys made each year in the same 100 m diameter circles and 150 X 50 m strips. (Black letters A, B, C/yellow lines=photo angle for Fig. 25A,B,C).

In the central areas (Site 2a), the beetles had almost completely defoliated all the saltcedar by mid-September 2007 and dispersed up and down the creek to other areas of green foliage; which allowed the trees to revegetate substantially during late September and October 2007. However, the beetles began returning during the summer of 2008, fed on the regrowth, and produced another generation that again defoliated the saltcedar to near 100% by mid-September 2008.

Plotting 200m Segments of the Transect. The progress of the beetle population increase, dispersal, and saltcedar defoliation during 2007 along Beals Creek can be followed in the series of 34 (2-D) graphs, one for each 200 m section (Fig. 26A, B, C; Fig. 27). The plots began at the intersection of Transect 4 with Beals Creek (Fig. 17) at Site 2a – minus plot numbers downstream and positive numbers upstream. Populations in 200 m sections along short transects 8B upslope and north of Transect 8 (Trees #3108-4041) on Morgan's property and Transect 8C southwest of Transect 8 (Trees #5034-6355) in Site 2b (Fig. 23B) are discussed in Appendix A.

Beginning at the center of dispersal (near the intersection of Transect 4 with Beals Creek, 0 to 190 m upstream) (Fig. 26A-C, monitoring Plot #12) the beetles began the year with the saltcedar still ca. 70% defoliated from October 2006 (Fig. 21F). Adults reached a small population level on 5 June and large larval peak on 22 June, and rapidly defoliated the plants after early July. Larvae reached a high peak on 19 July and adults on 7 August, defoliated the saltcedar to 100% and probably many excess adults migrated outward along the creek, after which the plants produced more regrowth. *Diorhabda* population development and saltcedar defoliation may be followed in the subsequent 34 2-D graphs as the beetles defoliate the saltcedar at progressively later dates as they move upstream or downstream from the Site 2a origin. Going upstream, they produced 50% defoliation at the 458 to 619 m segment on 10 July (Plot #14), at 1492 to 1670 m on 1 August (Plot #19) and at 2369 to 2552 m on 31 August (Plot #23). Very few larvae, adults or defoliated trees were found for the next 1700 m including the marsh on the Morgan Ranch.

Upon going downstream from the Site 2a center of dispersal (Fig. 24), the plants were 50% defoliated on progressively later dates: At -22 to -203 m (Plot #11) on 29 May, which increased to 78% on 5 June, with moderate beetle adult and larval populations; defoliation remained high until 28 August when many adults probably dispersed outward, allowing regrowth to increase to 45%. At -448 to -644 m downstream (Plot #9) population began at very low levels, produced 50% defoliation by 12 July, and again by 16 August in Plot #6. A large satellite colony was found near the pump station on 20 July (Plot #5) that reached high populations and defoliated 100% of a ca. 50 m saltcedar patch.

The beetles can defoliate saltcedar very quickly when large populations disperse into an area; for example, in Plot #14, high adult and larval populations and 10% defoliation were found 14 days after only 2 or 3 larvae or adults were found on 3 July and in Plot #19, 100% defoliation occurred only 7 days after zero adults and 4.8 large larvae per 1-min count were recorded. When defoliation occurred before 24 July, 50 to 60% regrowth occurred by October but when the plants were defoliated after 28 August, they produced little regrowth. Defoliation of 50% in Plots #4 (28 August) and #3 (25 September) occurred later as the beetles dispersed downstream, but very few reached Plot #2 and caused little or no defoliation. However, another satellite colony was found at -2533 to -2642 at Moss Lake Road with high adult (10.0) and low larval (1.5) per minute count that defoliated 50% of a a small clump of trees. Most of these adults probably dispersed across Moss Lake Road and into the neighboring Price Ranch where they overwintered.

A small satellite area at 11th Street was discovered on 31 August which produced continuing defoliation until October. A larger satellite was found in the wastewater treatment area on 10 July that produced a large adult population and 30% defoliation of two large trees by October.

Plotting Individual Trees. The details of the rapid defoliation, beetle population increase, and saltcedar increase are lost in the process of averaging the 2 to 8 sample trees (depending on the intensity of sampling) in the 200 m segments. To demonstrate this more clearly, ten individual trees were displayed in some areas of rapid increase (Fig. 27).

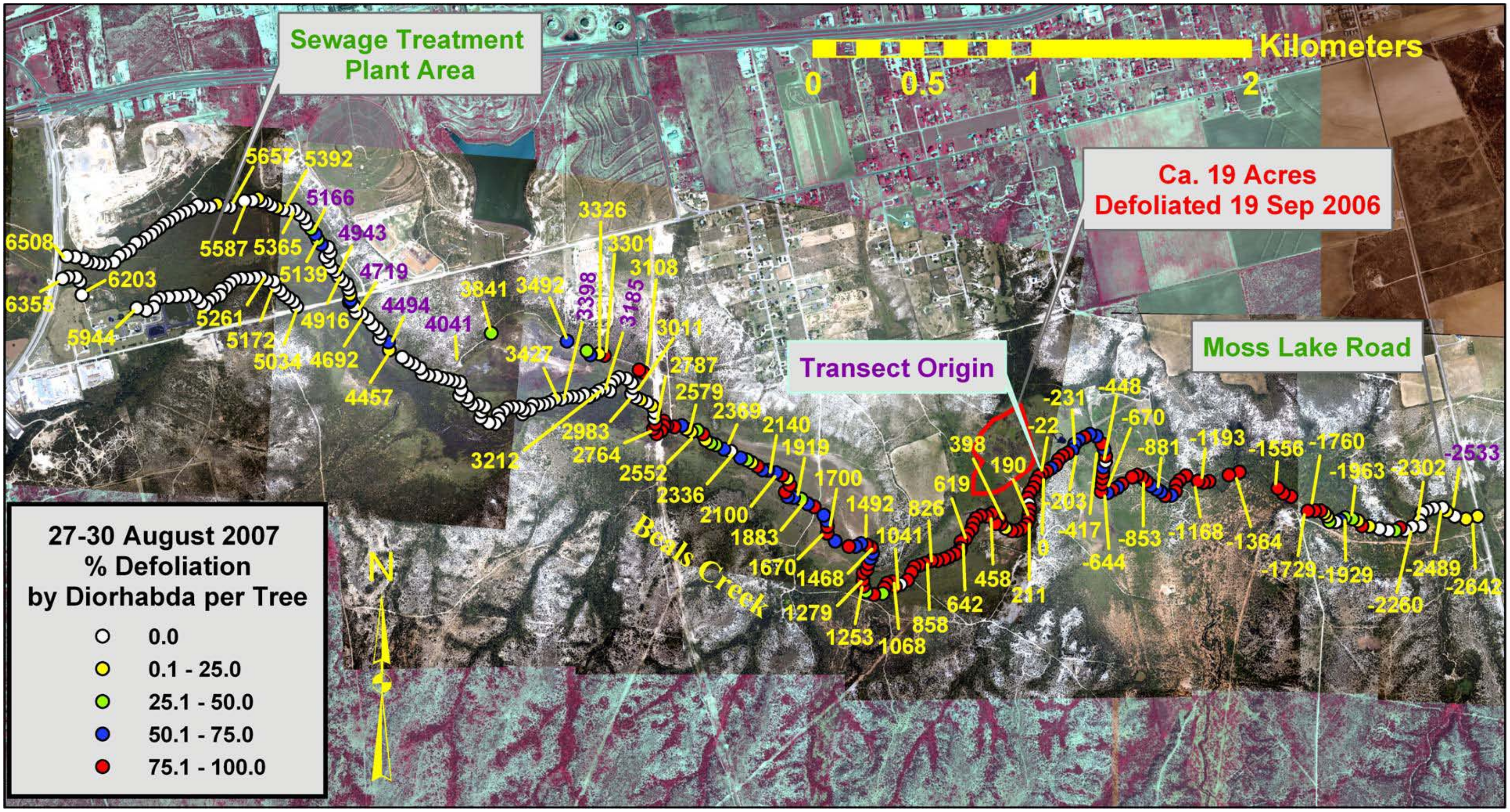


Figure 24. Key to Transect 8 distances along Beals Creek corresponding to *Diorhabda* population/defoliation graphs (Figs. 27–29) – 2007.

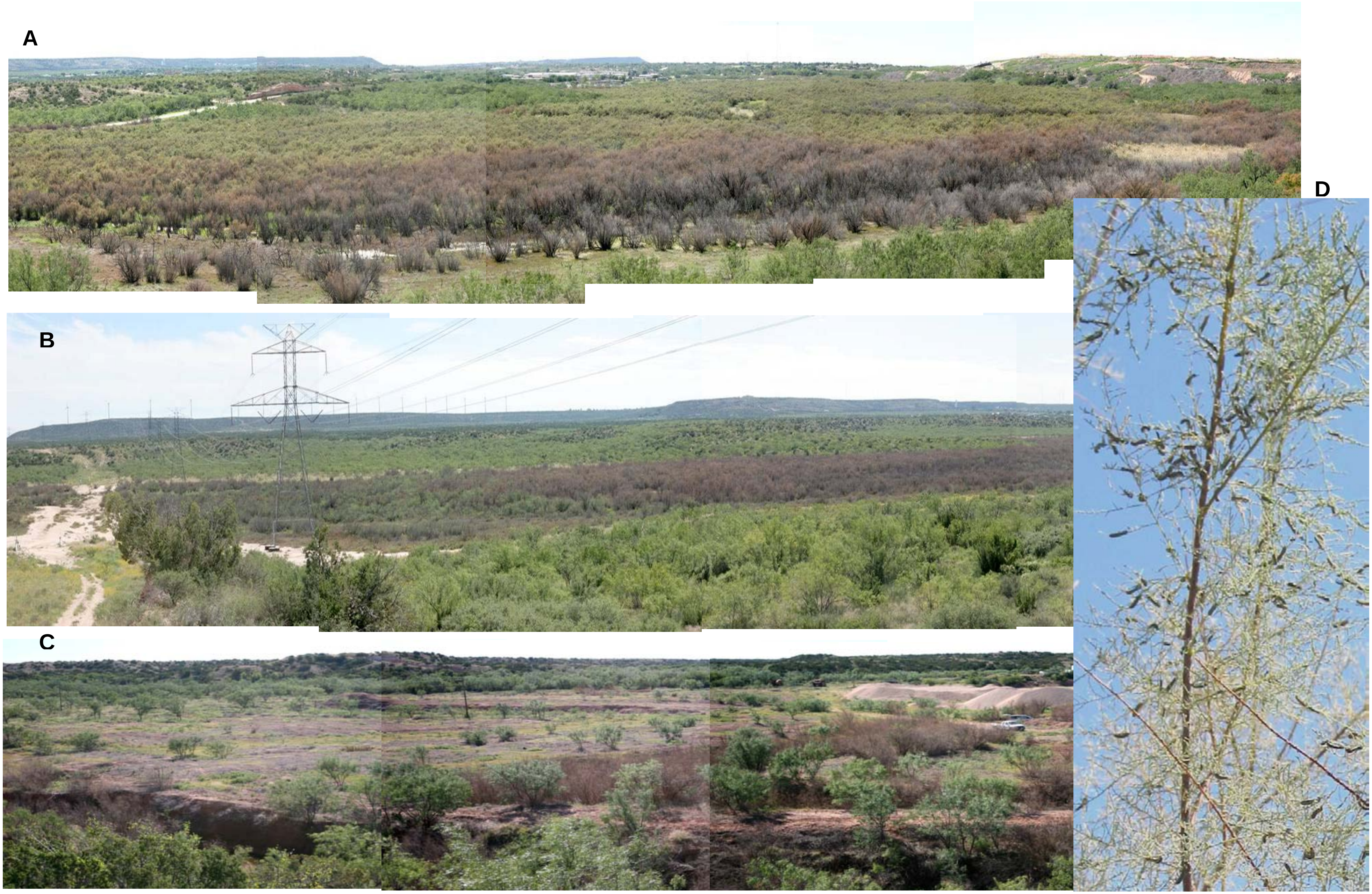


Figure 25. Defoliation of saltcedar by *Diorhabda* along Beals Creek in 2008: A) Big Spring Wastewater Treament Plant area, 17 Sep. looking west; B) Morgan property, 17 Sep. looking southwest; C) Price property, 9 Oct. looking south. D) Third instar *Diorhabda* larvae defoliating saltcedar (B lies to the southeast (left) of A, C lies to the left (east of B).

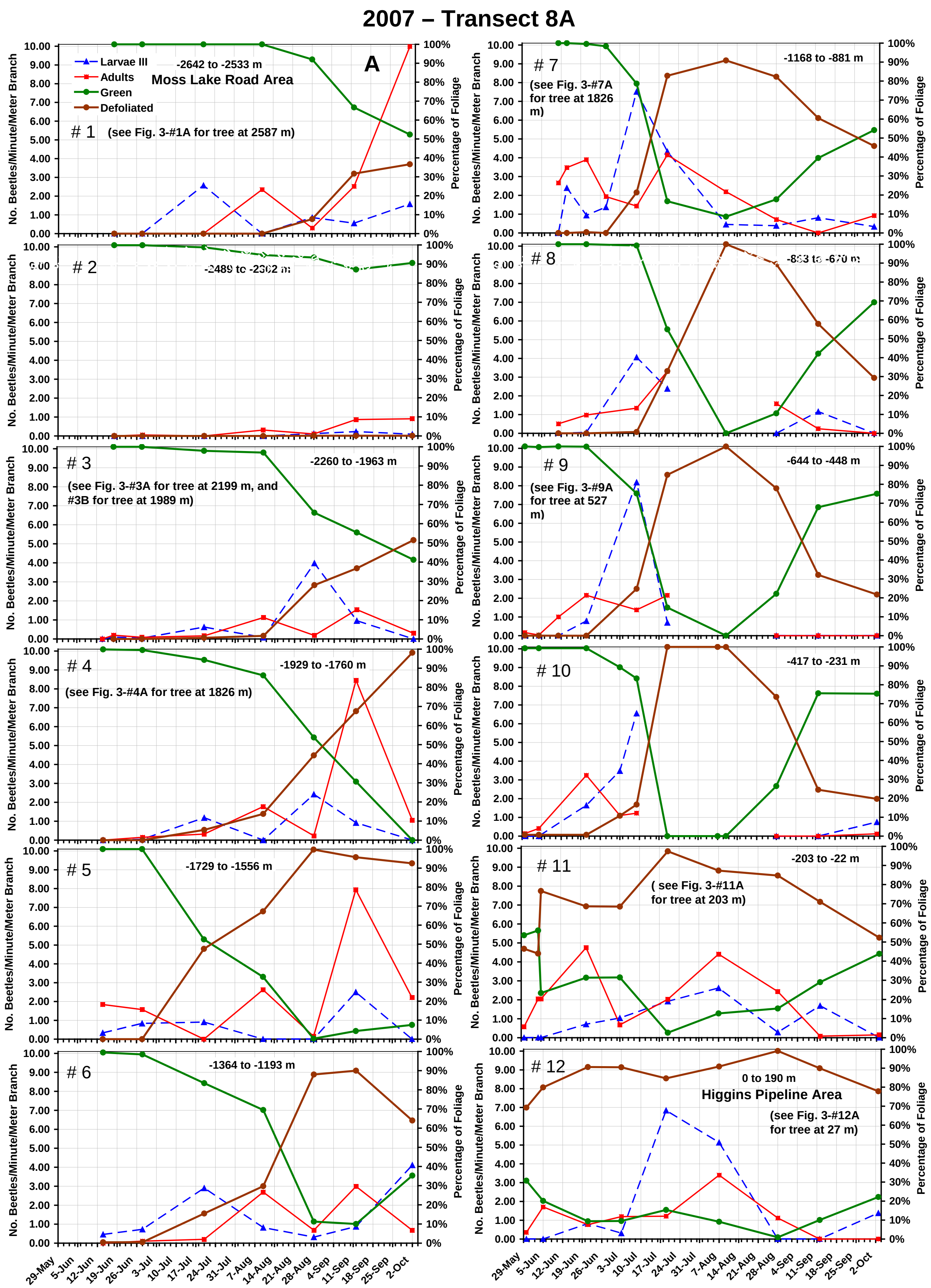


Figure 26A. Big Spring Sites 2a and 2b, main Transect 8A: Numbers of adults and 3rd instar larvae per 1 meter branch per minute count on 349 saltcedar trees for 9.00 km (5.6 miles) along entire Beals Creek area, 200 m sections, #1-12, 29 May–2 October, 2007.

2007 – Transect 8A

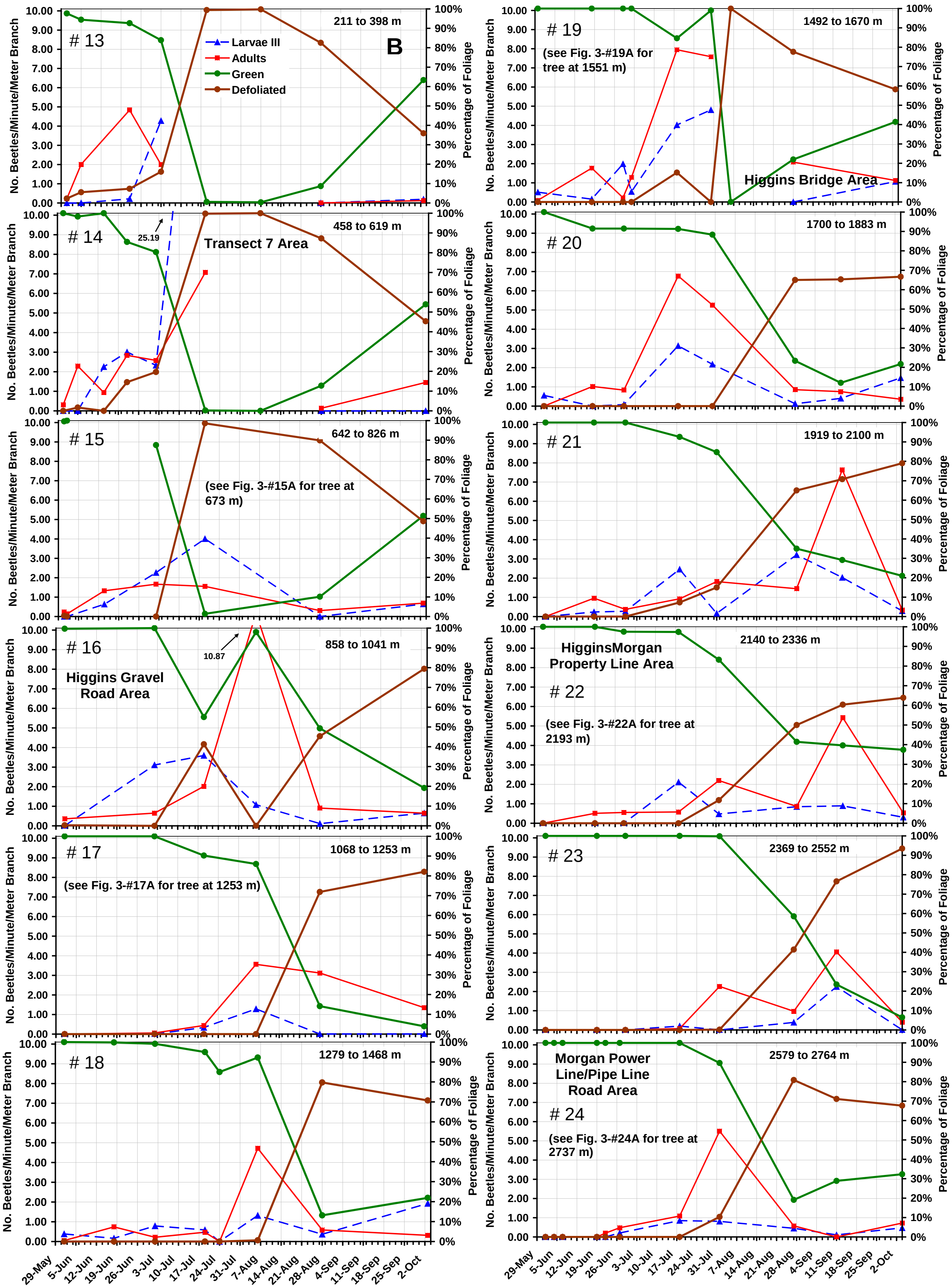


Figure 26B. Big Spring Sites 2a and 2b, main Transect 8A: Numbers of adults and 3rd instar larvae per 1 meter branch per minute count on 349 saltcedar trees for 9.00 km (5.6 miles) along entire Beals Creek area, 200 m sections, #13-24, 29 May–2 October, 2007.

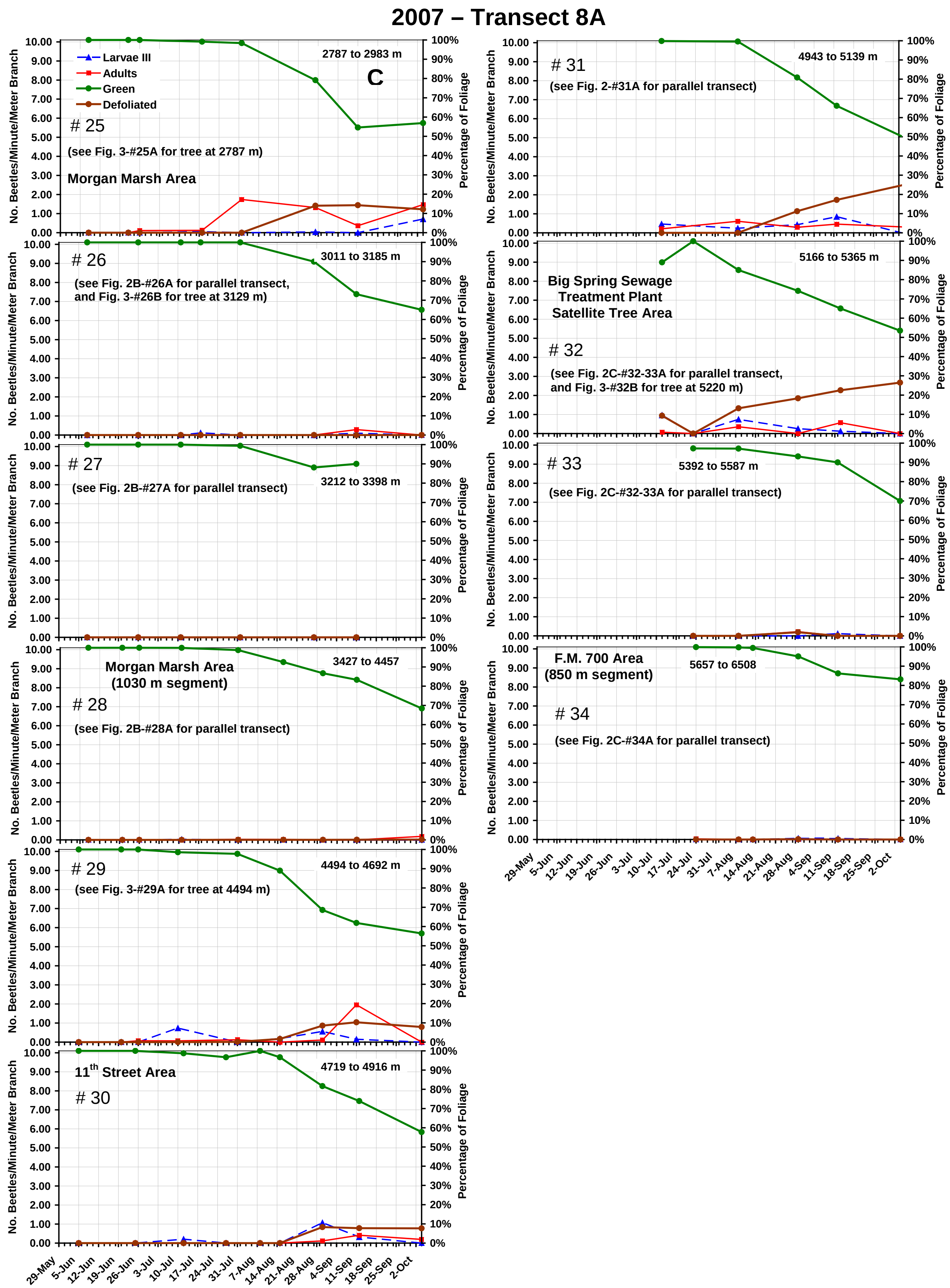


Figure 26C. Big Spring Sites 2a and 2b, main Transect 8A: Numbers of adults and 3rd instar larvae per 1 meter branch per minute count on 349 saltcedar trees for 9.00 km (5.6 miles) along **entire Beals Creek area**, 200 m sections, #25-34, 29 May–2 October, 2007.

2007 Transect 8A

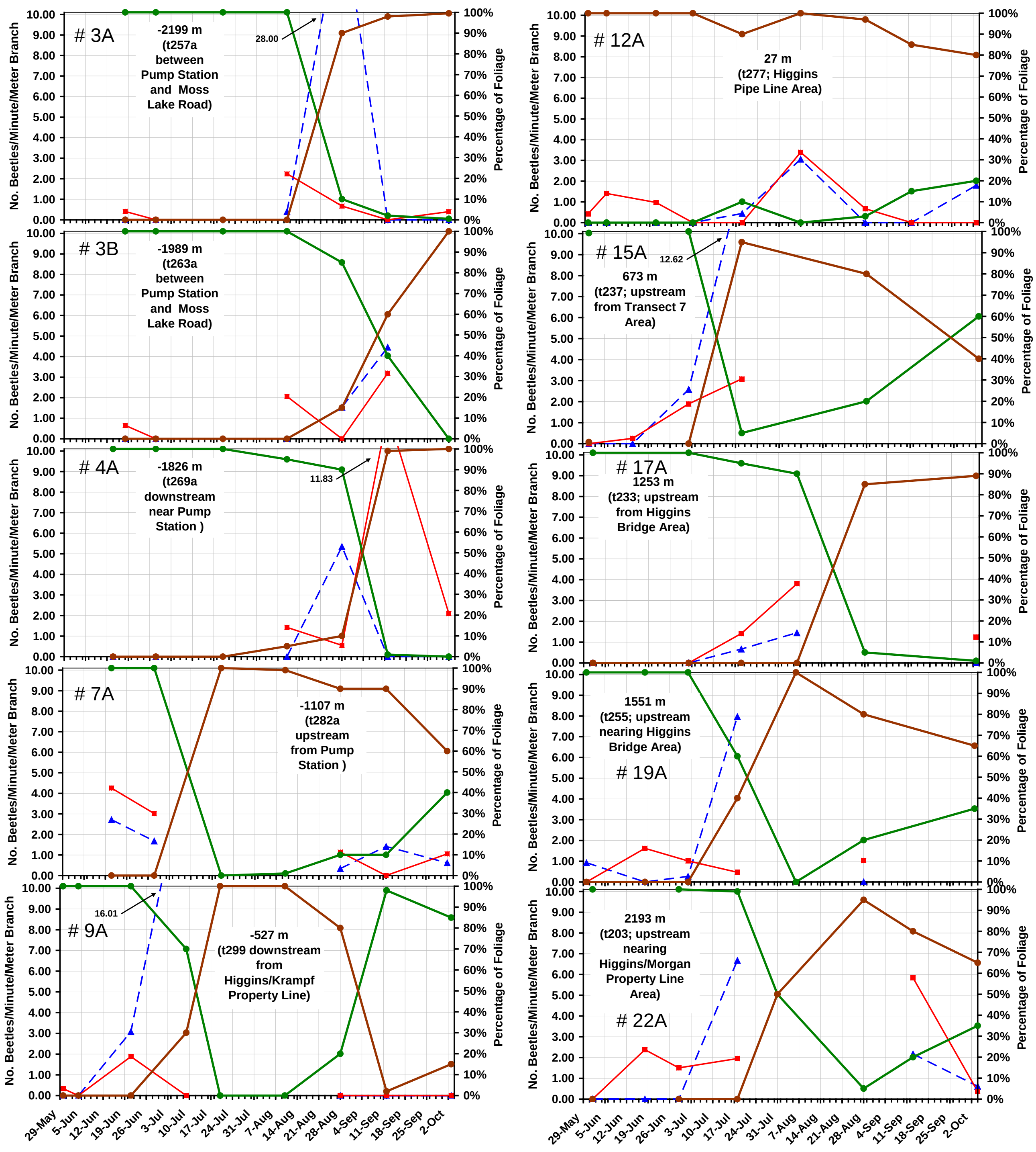


Figure 27A. Big Spring Sites 2a and 2b (ten individual trees in Plots #3-32 in Fig. 26) along Transect 8A: Numbers of adults and 3rd instar larvae per 1 meter branch per minute count along Beals Creek, 29 May–2 October, 2007.

2007 – Transect 8A

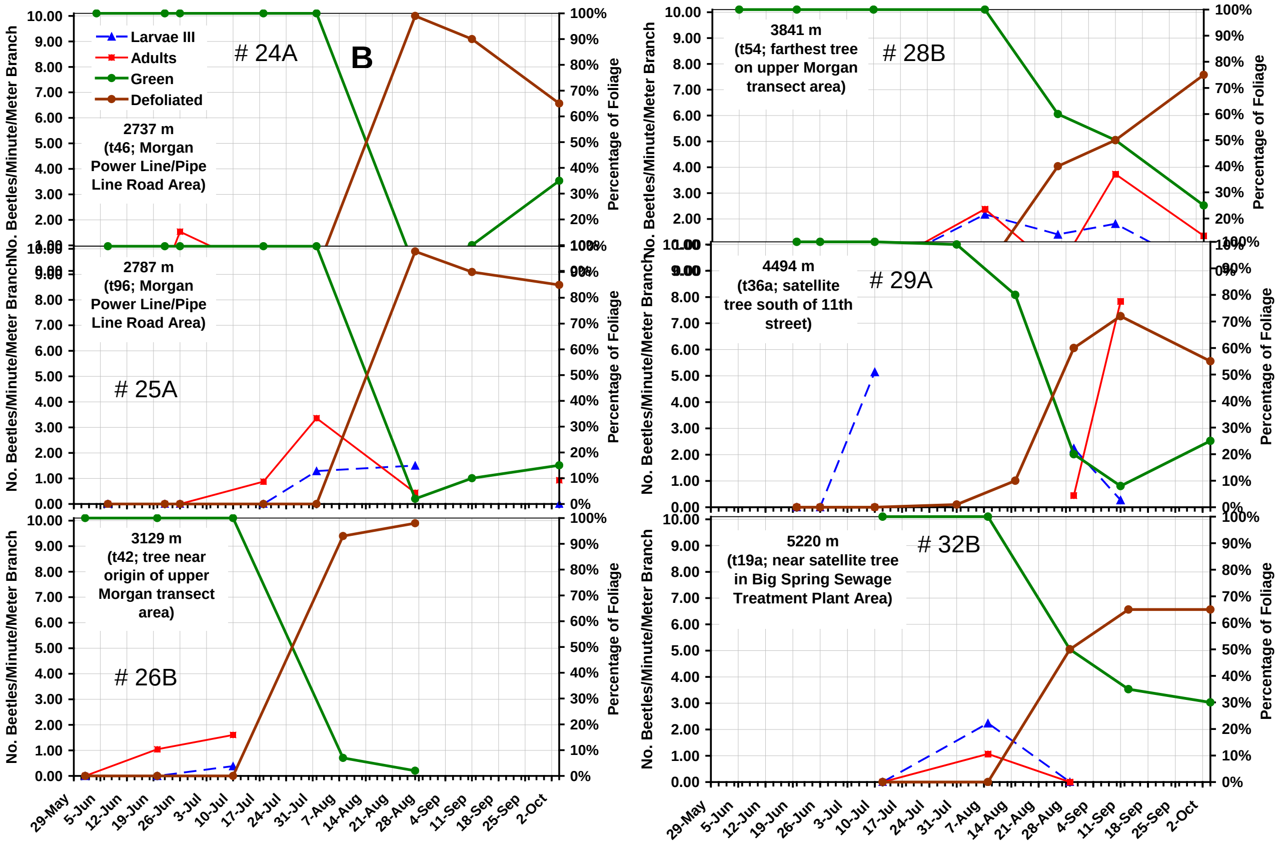


Figure 27B. Big Spring Sites 2a and 2b (six individual trees #24A-32B) along Transect 8A: Numbers of adults and 3rd instar larvae per 1 meter branch per minute count along Beals Creek, 29 May–2 October, 2007.

Saltcedar Defoliation by Crete Beetles Along Beals Creek, 2008. Preliminary analysis of the 2008 data from ground-level monitoring and low-level aerial photography revealed a large expansion of beetle dispersal and defoliated saltcedar during 2008, especially after late August. By 19 September 2008, the entire length of Beals Creek from 1.2 km east of Moss Lake Road to 0.7 km north of 11th Street had been completely defoliated (Fig. 23C).

Along Beals Creek from the central Higgins Ranch through the Morgan's Ranch, the area defoliated in 2007 (Fig. 22) refoliated substantially during early 2008, the beetles, many of which apparently had overwintered there, began defoliating the regrowth by mid-summer, increased to very large populations and migrated upstream, defoliated nearly all the saltcedar by mid-September including that in the broad marshy area (Fig. 23C) in the Morgan Ranch (Fig. 25B) not defoliated in 2007. They continued dispersing upstream, across 11th Street and into Site 2b defoliating all saltcedar in a 50-100m wide strip along the creek for a distance of ca. 0.8 km beyond 11th Street in 2008 (Fig. 23C, 25A).

Downstream from the Higgins Ranch, the beetles increased to large populations during 2008 and again defoliated essentially 100% of all the saltcedar along Beals Creek that was defoliated in 2007. They continued dispersing downstream, crossed Moss Lake Road and into the Price Ranch on the east side and as far as the saltcedar stand continued to 2 km beyond Moss Lake Road (Fig. 23C, 25C). Beyond this point the saltcedar had been sprayed with Arsenal in 2006 and little green foliage remained.

Swarming, Satellite Initiation. During the initial invasion of the overwintered adults during 2004, the beetles did not disperse uniformly to neighboring trees, but dispersed from the release tree, later reappearing 70 m away on two small trees west of the nursery cage. They defoliated these two trees then left them for large Tree #001 which they largely defoliated by the end of the season. The beetles also were found on 20 scattered trees at varying populations. In the spring of 2005, the adults spread steadily through the resident stand, but often with much higher populations on some branches than on other branches of the same tree, and on some trees more than others.

This clumped distribution pattern was clear in the saltcedar/athel test where adults and eggs were found mostly on one or two plants of a 5-plant group and few or none on the other plants of the group. This situation continued through August and September, when populations were greatly different on different plants, with 50 to several hundred adults on some plants which were defoliated probably within a few hours. ARS concluded that these population clumps were incipient swarms that continued growing into fully formed swarms, including beetles from nearby resident trees, then flew all together to green saltcedars nearby or up to 5 miles away. This, probably, is an evolved behavior of this R-strategist (high reproductive rate) beetle to escape predation.

During 2006 and 2007, these swarms developed soon after the largest annual emergence of adults during the last week of August, when defoliation of saltcedar was rapid and green foliage for food was scarce. At first, ARS detected satellite colonies along Beals Creek near the intersection of Transect 3 and near the Higgins/Krampf property line near Transect 2 (Fig. 17), both 250-300 m beyond the nearest saltcedar defoliation (Fig. 21). The defoliation at these satellites increased rapidly, indicating that a large swarm had initially arrived or that the satellite was joined by additional beetles over several days or weeks.

During 2008, the swarms and satellite initiation was more frequent and for larger distances (Fig. 28). Satellites were detected at 10 locations, from 0.5 up to 5 miles from the nearest defoliated saltcedar, and dispersed over an area of about 13x5 miles. The most western of these satellite initiation, 4.2 miles west of the nearest beetle population just west of Loop 700, consisted of one 80% defoliated medium sized saltcedar tree at the end of the I-20/Beals Creek bridge, and a few adult beetles on green trees along a 70 m nearby area with no defoliation.

The formation and maintenance of the swarms and satellite colonies is probably controlled by the aggregation pheromone produced by the males. This appears to be a very important stage in the beetle's control of saltcedar, allowing a geometric rate of increase over a large area and also allowing effective migration to other areas. Similar occurrences have been observed in Kazakhstan and at several sites in Nevada, Utah and California where the beetles defoliated saltcedar for 100 to 200 miles along streams in about 7 years.

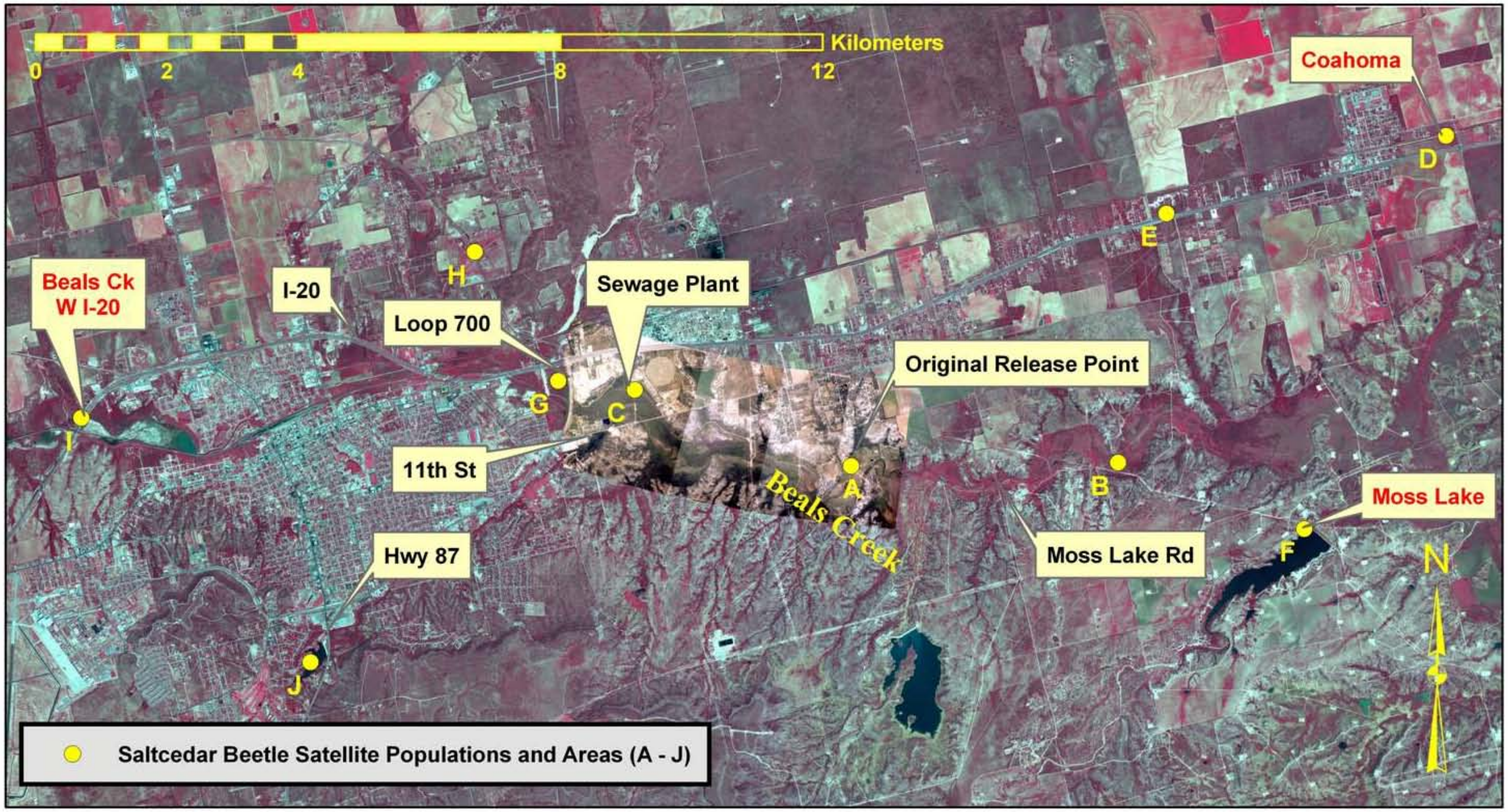


Figure 28. Satellite colonies – natural spread of saltcedar leaf beetle defoliation in and around Big Spring, Texas through October, 2008. A – Original release point for 2,200 adult *Diorhabda* (Crete ecotype) at Higgins Ranch in April–August 2004; B–C – Area of continuous near 100% defoliation from Price Ranch (B) to sewage treatment area (C), about 10.4 km (6.4 mi) along Beals Creek. Satellite populations as of October 2008 were at: D – just east of Coahoma; E – Salem Road; F – Moss Lake; G – just west city landfill off Loop 700; H – on Loop 700 north of I-20; I – Beals Creek crossing of highway I-20 on west side of city; and J – Big Spring Dora Roberts Community Center on highway 87. Distance from D to I is 21.3 km (13.2 mi).

Natural Recovery of Local Vegetation after Biological Control. Within 1 or 2 years after the saltcedar canopy was removed by *Diorhabda* feeding along Beals Creek, natural recovery of abundant and luxurious local grasses has been observed at several sites. For example, at the Higgins Ranch, the first saltcedar strip thicket was defoliated by September 2005 (Fig. 16). By September 2007 it had revegetated abundantly with alkali sacaton and cocklebur but one year later the cocklebur had disappeared, leaving only the grass (Fig. 29A-C), such as alkali sacaton, saltgrass and minor amounts of the grasses and forbs. Downstream near the CRMWD Pump Station (Fig. 23) the saltcedar was first defoliated in August/September 2007 and one year later (October 2008) it had revegetated naturally with a dense stand of vine mesquite (Fig. 29D, E).

Death of Saltcedar Trees. At Site 2a, ARS observed the first dead saltcedar trees in the summer of 2007 in the first strip thicket. This area had been defoliated twice annually for 3 years (2005-2007), with a constantly increasing amount of dead branches in the canopy. An evaluation was made of all the trees present in the strip, and 25% had no green foliage. A count during June 2009 of the second larger thicket revealed the same results – 25% apparently dead trees with no green foliage. This thicket had been defoliated twice annually for 4 years (2006-2009).

Cooperators Hudgeons and Knutson (AgriLife) found that decreasing storage of carbohydrates in saltcedar crowns was closely related to increasing defoliation over a 5 year period, which eventually would kill the trees (Hudgeons et al., 2007). Biological control is not expected to kill all the saltcedar trees, as this has never happened in any biological control of weeds project. The expectation is for the reduction in green biomass to be below the damaging level, currently varying from 70 to 98%, which already is preventing most of the damage by saltcedar.

Remote Sensing. Remote sensing of release sites was done by ARS-Weslaco from 22 November 2002 through the end of this project. The photography was made using Ektachrome 9-inch aerial photographic film from low-level, fixed-wing aircraft at altitudes between 500 and 5,000 ft to obtain detailed or broad views of the sites – the 500 ft elevation under the best conditions can have a resolution of ca. 10 cm. The sites were photographed once or twice a year, usually in September when near maximum defoliation for the year was present. The aerial photographs can be computer analyzed to obtain a measure of m^2 of defoliated saltcedar to compare with our ground-level measurements of m^2 defoliation of the quadrats but this requires geo-referencing that has not yet been done. These photographs identify the defoliated saltcedar with high accuracy but further research is needed to identify green saltcedar among other green vegetation. All the aerial photographs in this report are by Everitt and his research team at Weslaco, TX.

Previous and continuing research on remote sensing promises a good and less expensive method of monitoring the degree and extent of control (Everitt and DeLoach 1990, Carruthers et al. 2004, Ge et al. 2006) and of the recovery of native riparian plant communities following control although some ground truthing still will be needed.

Figure 29. Natural recovery of native herbaceous vegetation after defoliation of saltcedar by *Diorhabda*, A, B, C – Higgins Ranch ca. 50 m NW of weather station (see Fig. 9C): A) before herbaceous recovery, B) recovery of alkali sacaton and cocklebur, C) succession to alkali sacaton; D, E – Kramp Ranch ca. 100 m downstream from the CRMWD pump station; D) defoliated ca. 45 days before, E) recovery of mostly vine mesquite (*Panicum obtusum*) after 1 year.

Mathematical Model of *Diorhabda* Beetle Dispersal. Cooperator Dr. Joaquin Sanabria, formerly with Texas AgriLife Research at Temple, TX, and funded through TSSWCB Clean Water Act Section 319(h) Nonpoint Source grant #04-15, has developed a mathematical model that predicts the speed of dispersal after release of *Diorhabda* beetle population, and degree of defoliation and control of saltcedar over time, and dates of arrival of the beetles at given areas of interest. Such information can be of value in saltcedar management plans and for habitat changes in wildlife management areas. The model utilizes the 4-year data set of this project of monitoring *Diorhabda* populations and effects at the release site east of Big Spring, TX from 2005 to 2008 taken weekly of beetle populations per 1-m branch along transects through the 10 ha saltcedar stand or along the 9 km length of Beals Creek, plus the climate data taken at the site. The model shows the dispersal as a series of waves over time of adult and larval beetles and saltcedar defoliation extending outward across the 10 ha demonstration area original saltcedar stand and later along the 9 km transect in the infested area of Beals Creek. The model uses aspects of a newly developed Spatial Regression Model and two other models and appears to successfully display population levels at different distances and times.

Open-Field Test of Host-Plant Selection by *Diorhabda* (Crete ecotype) Beetles for Saltcedar, Athel and *Frankenia*, Higgins Ranch, 2005-2006.

The only concern regarding host specificity in the biological control of saltcedar is the possibility for non-target attack on exotic athel (*Tamarix aphylla*, family Tamaricaceae) and native *Frankenia* (family Frankeniaceae) plants (the only 2 families in the small plant order Tamaricales). Athel is a large, evergreen, non-cold tolerant tree native from North Africa to Pakistan and introduced into North America as shade trees and windbreaks in the southwestern U.S. states bordering Mexico and in northern Mexico; it is less invasive than saltcedar but probably uses more groundwater and has little wildlife value. *Frankenia* is a small genus of mostly small desert shrubs native from Chile to California and Texas with 6 species native in the southwestern U.S. and northern Mexico. Three of the species occur in the U.S. and they are not invasive or weedy but have little known positive environmental values.

Previous laboratory and outdoor caged tests at Temple and Albany, CA, completed before prior to this project, indicated that the beetles fed little to none and did not reproduce on 3 of the 4 *Frankenia* species tested (*F. jamesii*, *F. johnstonii*, and *F. palmeri*, but did feed at low levels in outdoor caged tests on *F. salina* (Lewis et al. 2003; Milbrath and DeLoabh 2006a, b; Milbrath et al. 2007).

ARS' tests also indicated that the *Diorhabda* beetles feed and reproduce slightly to moderately on athel. In outdoor caged tests with Crete beetles at Temple, larval survival and percent of total eggs laid on the three plants when together in the same cage gave a reproductive index (larval survival × % oviposition) on the three test plants as follows:

	Saltcedar	Athel	Frankenia
Larval survival (%)	81.7	75.0 (91.8%)	16.7
Oviposition (%)	25.1	11.0 (43.8%)	0.38
Reproductive index	20.5	8.2 (40.0%)	0.07

In addition, other tests in small and large outdoor cages at Temple indicated that the beetles were less attracted to athel at a distance than they were to saltcedars.

ARS concluded from these caged tests that this reproductive index, together with less attraction at a distance and additional mortality expected in the open field from predators and physical factors, would mean that athel probably would not sustain damage as shade trees or windbreaks in the desert villages in northern Mexico sufficient to impair these usages. They also concluded that *Frankenia* was unlikely to receive any damage and most likely the beetles could not even sustain viable populations on it.

Nevertheless, some concerns over safety remained among some groups (especially in Mexico) of possible non-target damage, especially to athel. Also, some concern existed about how to translate the results of caged tests to the open environment when the beetles are released. When this project began in 2004, ARS had a rare opportunity to conduct open field, uncaged host specificity tests at Big Spring to compare saltcedar, athel and *Frankenia*.

Saltcedar, athel, and *F. salina* plants were transplanted into the resident saltcedar stand at the Higgins Ranch in early June 2005 that was beginning to be invaded by the Crete beetles. In 2005, they transplanted a group of 5 near plants (35 to 50 m into the stand from the center of dispersal at Tree #1) and 5 more distant plants (at 60 to 80 m) (Fig. 30A), each one-meter diameter plot with one each of the 3 plants – athel and saltcedar about 1 m tall and *F. salina* about 20 cm tall. They counted *Diorhabda* adults, eggs, and larvae on each plant weekly (except during August) through the growing season.

In 2006, the experimental design was changed by transplanting the 3 plants into 3 plots (each 1 m diameter) at each of 4 to 6 stations 50 m apart along 2 transects out 300 to 500 m from the origin (the area to where the beetles had dispersed in 2005). At each station, 1 plot had 1 saltcedar, 1 had 1 athel, and 1 had 1 saltcedar, 1 athel, and 1 *Frankenia* plant; the plots were 7 m apart across the transect (Fig. 30B). They counted the insects and amount of defoliation of the saltcedar, athel, and *Frankenia* weekly from early June through September.

The results in 2005 showed that 34.6% of the adults but only 12.8% of the eggs were on athel and only 0.2% of the adults and no eggs were found on *Frankenia*. In 2006, 21% of the total adults were found on athel in the single plant plot and 12% in the grouped plant plot. Eggs laid were 13% on the single athel plants and 16% on the grouped athel plants (Table 8). These results confirmed the results of the outdoor caged tests at Temple and indicated that the open field was not different from that in the outdoor caged tests, and selection for *Frankenia* was vanishingly low. These tests also provided valuable information on beetle behavior, especially, in relation to the formation of swarms and migration to establish satellite colonies.

Table 7. Open-field, uncaged comparisons of numbers of adults and eggs counted on saltcedar vs. athel at Big Spring, TX, 2005 and 2006.

	Number (% of total) counted during growing season			
	Saltcedar	Athel	*Frankenia*	Total
2005		**Adults**		
Grouped	1,110 (65.14%)	590 (34.63)	4 (0.23%)	1,704 (100.0%)
		Egg masses		
Grouped	171 (87.2%)	25 (12.8%)	0	196 (100.0%)
2006		**Adults**		
Single	801 (33.2%)	508 (21.1%)	0	1,309 (54.3%)
Grouped	807 (33.5%)	295 (12.2%)	0	1,102 (45.7%)
Total	1,608 (66.7%)	803 (33.3%)	0	2,411 (100.0%)
		Eggs (individual)		
Single	638 (28.8%)	292 (13.2%)	0	930 (42.0%)
Grouped	925 (41.8%)	358 (16.2%)	0	1,283 (58.0%)
Total	1,563 (70.6%)	650 (29.4%)	0	2,213 (100.0%)

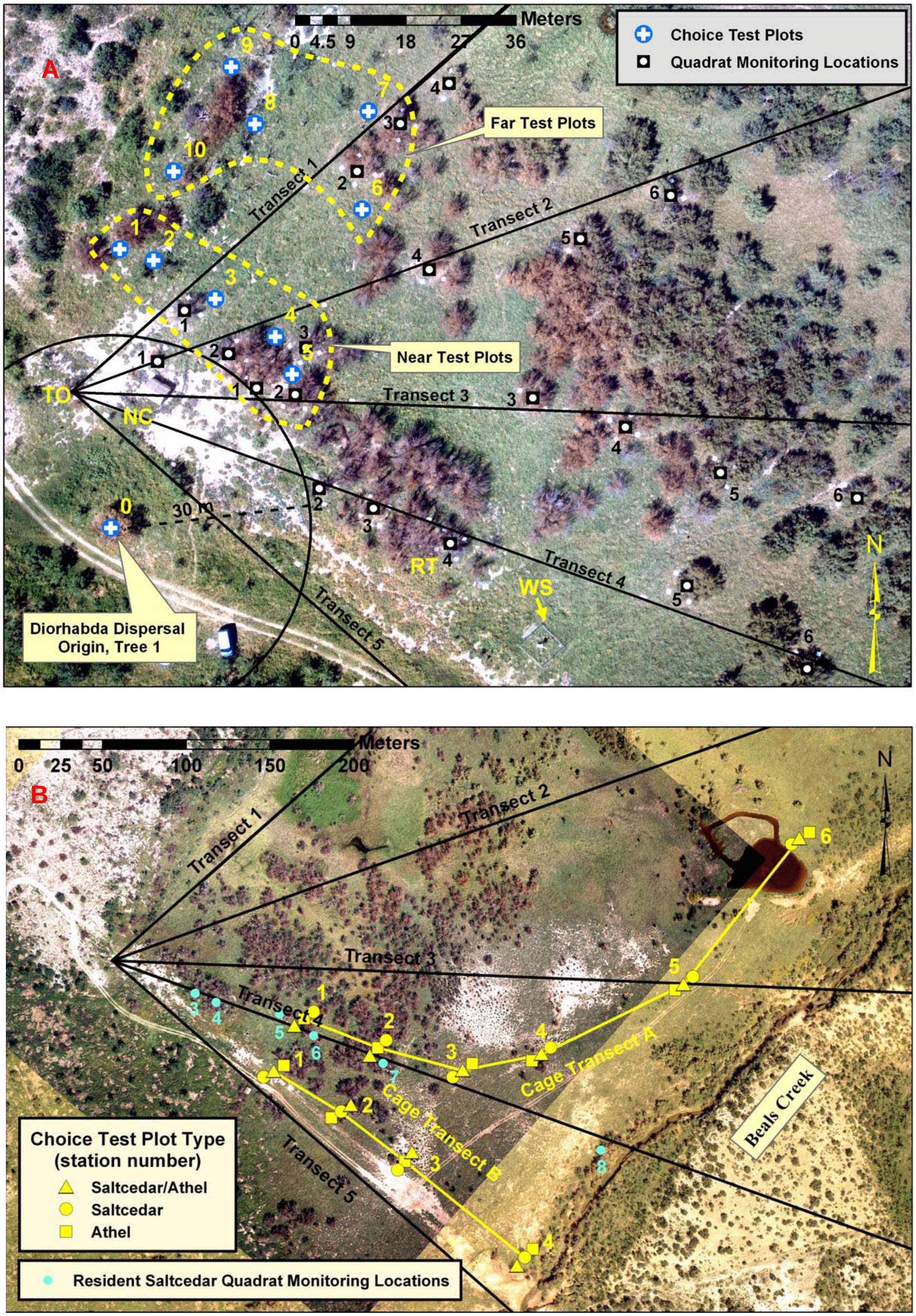


Fig. 30. Monitoring plan for open-field host selection test of athel, *Frankenia*, and saltcedar, Higgins Ranch in A) 2005 monitoring (21 September 2005) and B) 2006 monitoring (19 September 2006).

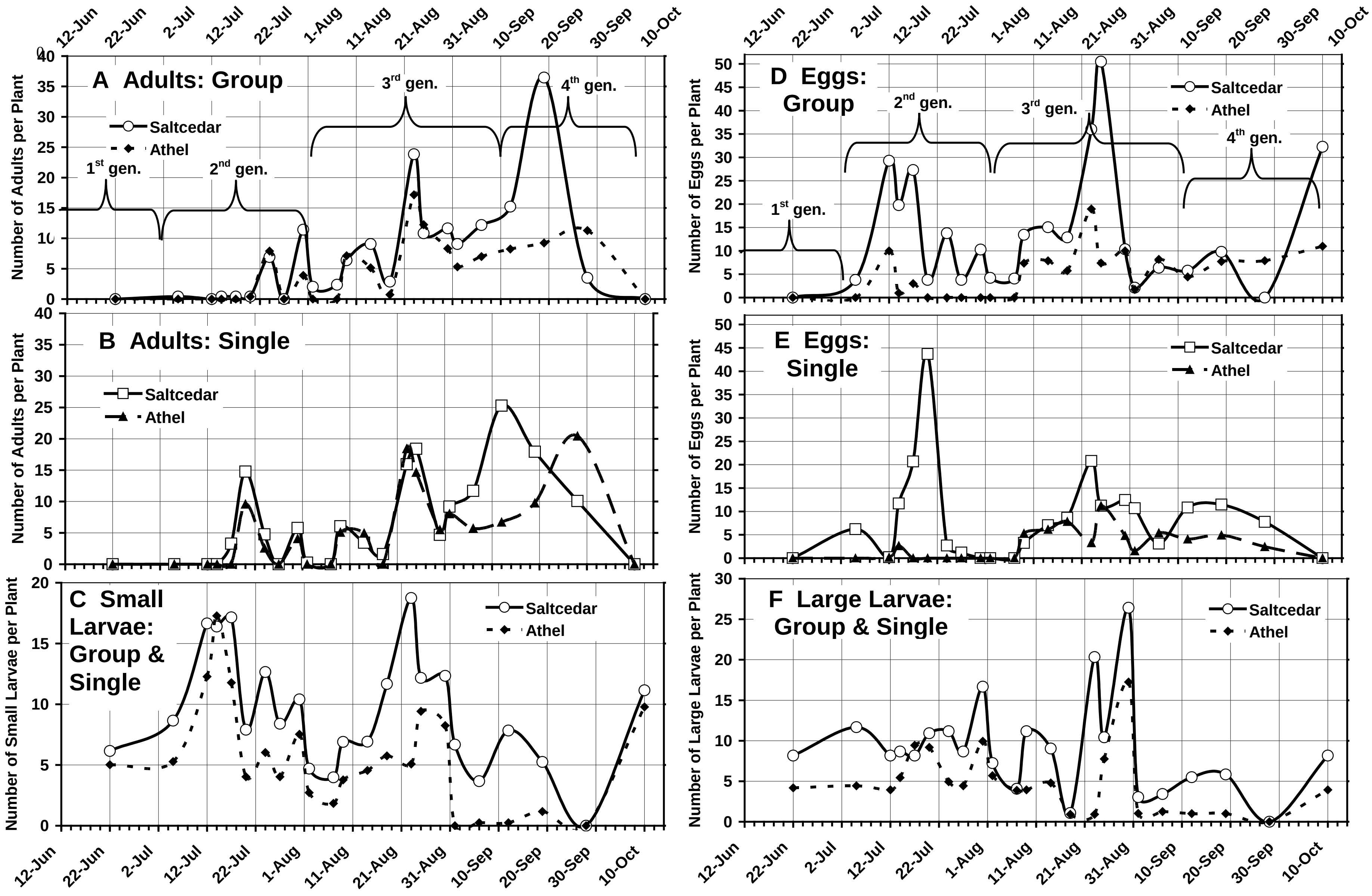


Fig. 31A. Saltcedar vs. athel: adult, egg, small larval (1st and 2nd instar), and large larval (3rd instar) populations per plant of *Diorhabda* beetles (Crete ecotype) on each date, as influenced by plant species and plot groupings (single or grouped plants per plot; groupings pooled for larvae) (from 8 stations, 4 per 2 transects [replications], zero data omitted); graphs of least squares means are from analysis of covariance models (see Fig. 11B) adjusted by the covariable of percentage green foliage. Big Spring, TX, 2006.

G Adults – Analysis of covariance

Source of Variation	Degrees of freedom	Sum of squares	*F*	*P* value
Transect	1	405.6	0.070	0.792
Date	22	702586.0	5.512	< 0.001*
Plant Species (athel vs. saltcedar)	1	22203.4	3.832	0.052
Plot Grouping	1	14096.8	2.433	0.120
Distance along Transect (Dist.)	2	35012.7	3.022	0.051
Dist.*Plant Species*Plant Grouping	4	63055.6	2.721	0.031*
% Green Foliage – Covariable	1	50639.3	8.740	0.003*
Error	213	1234084.7		

I Eggs – Analysis of covariance

Source of Variation	Degrees of freedom	Sum of squares	*F*	*P* value
Transect	1	4792.1	1.235	0.268
Date	22	305849.4	3.582	< 0.001*
Plant Species (athel vs. saltcedar)	1	42041.7	10.831	0.001*
Plot Grouping	1	23254.1	5.991	0.015*
Distance along Transect (Dist.)	2	32690.2	4.211	0.016*
Dist.*Plant Species*Plant Grouping	44	203205.5	1.190	0.210
% Green Foliage - Covariable	1	19218.8	4.951	0.027*
Error	213	826758.9		

H Small Larvae – Analysis of variance

Source of Variation	Degrees of freedom	Sum of squares	*F*	*P* value
Transect	1	1296.5	0.267	0.606
Date	22	449899.5	4.208	< 0.001*
Plant Species (athel vs. saltcedar)	1	15392.4	3.167	0.077
Plot Grouping	1	21611.5	4.447	0.036*
Distance along Transect (Dist.)	2	120093.2	12.355	< 0.001*
Dist.*Plant Species*Plant Grouping	4	13406.1	0.690	0.600
Error	206	1001189.3		

J Large Larvae – Analysis of variance

Source of Variation	Degrees of freedom	Sum of squares	*F*	*P* value
Transect	1	5720.3	1.139	0.287
Date	22	365741.1	3.311	< 0.001*
Plant Species (athel vs. saltcedar)	1	3146.3	0.627	0.429
Plot Grouping	1	4370.3	0.871	0.352
Distance along Transect (Dist.)	2	84719.0	8.438	< 0.001*
Dist.*Plant Species*Plant Grouping	4	10296.6	0.513	0.726
Error	206	1034179.5		

Fig. 31B. Saltcedar vs. athel: Analysis of variance models for adult, egg, small larval (1^{st} and 2^{nd} instar), and large larval (3^{rd} instar) populations per plant of *Diorhabda* beetles (Crete ecotype) on each date, as influenced by plant species and plot groupings (single or grouped plants per plot) (from 8 stations along 2 transects [replications]). Big Spring, TX, 2006.

FIELD ECOLOGY, BIOLOGY, BEHAVIOR

Physical Environment – Daylength. Daylength is a major factor in the adaptability of the four *Diorhabda* species/ecotypes released in the U.S. The Fukang, China/Almaty, Kazakhstan ecotype, released in May 2001, was highly successful north of the 38^{th} parallel (NV, UT, CO, WY) but never established farther south in Texas; a daylength of less than 14 hr 45 min initiates overwintering diapause in these northern beetles; maximum daylength at Seymour, TX is less than 14 hr and these beetles never overwintered in Texas. However, the more southern adapted *Diorhabda* beetles from Crete, Uzbekistan and Tunisia all have established in Texas, with the Uzbek apparently best adapted to the more northern areas, those from Crete, Greece to the central area, and those from Tunisia best in the southern areas although more precise determinations still are being investigated.

Flooding. Flooding apparently has disrupted *Diorhabda* establishment in some locations and maybe stimulated it at other sites. Summer floods along the Rio Grande, TX – at Indian Hot Springs and at Big Bend National Park (a USDI-NPS site) – washed away the cages and the beetles were not found thereafter. Some of the ARS/Rio Grande Institute/NRCS sites near Candelaria, TX have experienced short-term flooding by runoff from the hills (not by the Rio Grande) but the beetles persisted there. Flooding of half of the 400 acre establishment near Lovell, WY (where heavy ant predation had occurred for several years) was followed by a large, rapid increase of saltcedar defoliation to several thousand acres. In some cases, flooding may improve control by reducing ant populations.

A similar situation was observed at Sulphur Draw, northwest of Big Spring by Knutson. The beetles had established at very low levels but increased rapidly after a flood.

Host-Plant Compatibility. The species or hybrid of saltcedar present in the field seems to influence the degree of attraction to and damage inflicted on saltcedar by the *Diorhabda* beetles. This was confirmed in outdoor cage tests on potted plants at Temple (DeLoach et al. 2003; Lewis et al. 2003; Milbrath and DeLoach 2006a, b) where the reproductive index (% survival egg to adult X % eggs laid on each plant of all plants in the test in multiple-choice tests) was 12.4-20.5% on *T. ramosissima*/*T. chinensis* and hybrids, 8.1-11.9% on *T. canariensis*, 9.0-21.1% on *T. parviflora* and 5.6-11.9% on *T. aphylla*. In open-field uncaged tests at Big Spring, 87.5% of the eggs were laid on the local *T. ramosissima* hybrid and 12.5% on *T. aphylla* (athel). In different tests near Kingsville, both Crete and Tunisian beetles developed well and females reproduced well on both the local *T. canariensis* hybrid and athel in large nursery cages or in sleeve bags in no-choice tests but when released in the field with a choice of 3-4 m tall growing saltcedar or athel trees they were not attracted to and never established on either plant.

Plant-Insect Community. The surrounding plant (and accompanying insect) communities also may affect *Diorhabda* beetle establishment and control. The first releases, made in the Lake Thomas lakebed in August 2003 overwintered and reproduced well the following spring but then failed to establish, apparently because of severe attack by ladybird beetles and possibly also by predaceous ants (*Forelius mccooki*) that were abundant there. These predators probably were at high populations because of abundant prey insects produced on the abundant and varied plant community growing in the dry lakebed, although this has not been demonstrated. The Big

Spring (Higgins Ranch) site was chosen because the plant community consisted primarily of saltcedar and grass (probably hosting few herbivorous insects) but with a more varied plant community along the creek and where higher ant populations were sampled. Nevertheless, the beetles quickly defoliated the saltcedar by the creek, possibly because they invaded in such high numbers that they overcame any predators along the creek.

Biology. The *Diorhabda* beetles, based on the data obtained and observations made during this project, demonstrate a type "r" strategy of survival – high reproductive rate but vulnerability to attack by generalist predators. The three species/ecotypes released in Texas, from Crete, Uzbekistan and Tunisia, all have similar host plant ranges and behaviors, with minor differences. They have 4 generations per year in Texas, and feed on saltcedar from budbreak in the spring to leaf senance in autumn.

The *Diorhabda* beetles have been heavily attacked at several sites by a variety of generalist insect predators – by spiders at Balmorhea, assassin bugs at Kingsville and Artesia, NM, by ladybird beetles at Lake Thomas and Cache Creek, CA, and by ants at Lake Thomas and several other sites in Texas. Predation at Big Spring and along the Pecos River, TX has not been severe and the beetles established. In some cases, a simple ecosystem (saltcedar and grass) seems to have lower rates of predation. At many sites in Texas, ground dwelling ants appear to be the major mortality factor, probably mostly of the mostly unprotected *Diorhabda* pupae under litter in the saltcedar thickets. Predation by birds has also been observed at Delta, UT, and Lovelock, NV.

Behavior. Observations and tests by ARS and their cooperators determined that both adults and larvae of *Diorhabda* feed on the foliage of saltcedar and the females oviposit (lay their eggs) on the foliage. They also feed on the bark of small twigs causing the terminal part to die and killing much more than they consume, and producing the tan-colored dead foliage still attached to the tree for several weeks. Also, plants that revegetate after defoliation usually do not produce flowers for 1-2 years, thus halting seed production and the spread of saltcedar by wind or water-borne seeds. The larvae pupate under litter on the ground after each generation and the adults overwinter there or in bunch grass (living or dead); both are unprotected from predators, unless by chemical repellants which were not studied.

Pheromones. One of us (Lewis et al. 2003b) discovered, and our cooperators Allard Cossé, Bob Bartelt and others (USDA-ARS, Peoria, IL, Cossé et al., 2005) isolated and now have synthesized, a *Diorhabda* aggregation pheromone produced by the males, consisting of (2*E*,4Z)-2,4-heptadienal and (2*E*,4Z)-2,4-heptadien-1-ol, the ratios of which differ in the different beetle ecotypes (Cossé et al. 2005, R. Bartelt, pers. comm.). They also isolated a plant extract from saltcedar that is attractive to the *Diorhabda* beetles. The aggregation pheromone was isolated from the Fukang beetle ecotype and was attractive to those beetles in the field. It possibly could be used as an aid in monitoring or to retain adults at the release site and improve establishment. However, the Fukang pheromone was not effective for the Crete beetle, has not been tested on the Tunisian and Uzbek beetles; and the Crete beetle pheromone has not been tested. The possibility of a plant volatile caused by the beetle feeding damage also could act to concentrate migrating beetles on certain plants, but this has not been investigated.

DEMONSTRATION OF THE EFFECTS OF BIOLOGICAL CONTROL OF SALTCEDAR ON NATIVE ECOSYSTEMS

Effects on Native Plant Communities. Annually, ARS monitored vegetation species and abundance in areas of all native vegetation and in areas of near monotypic saltcedar. The Big Spring/Lake Thomas areas were monitored in all 4 years and in 2004 to 2006, transects in these areas were monitored. In 2007, monitoring began in two 14 m diameter circles within each of the bird 100 m diameter point-count circles and visually estimated the % of the circles occupied by each plant species in each of 3 strata – 0 to 0.5 m, 0.5 to 2 m, and 2.0 – 5.0 m above the ground. Bird strip counts along Beals Creek were also taken. The complete vegetation survey can be found in Appendix C.

Effects on Bird Communities. Monitoring of species diversity and abundance of all birds was done by ARS annually three times during the breeding season, generally during May and June. Where possible, 10 permanent 100-m diameter point count circles were established in nearly all native vegetation and 10 points in monotypic saltcedar stands. This is to compare the effects of saltcedar on bird populations. After biological control, surveys again will be conducted to compare native vegetation with areas where saltcedar has been controlled, and also comparing the saltcedar area before and after control. The complete bird species diversity and population surveys can be found in Appendix D.

PUBLIC EDUCATION, PUBLICATIONS AND OUTREACH

Publications, Meetings, Press Articles. Between 2004 and 2008, ARS often with other project scientists, published 26 articles in scientific journals and symposium proceedings and numerous newspaper and magazine articles were written aobut the project. The PI also presented many talks at public meetings in central and west Texas and in Mexico and led annual field days at Big Spring for the public and to High School science classes (Table 8, Fig. 32). (The complete listing is presented in Appendix B).

Table 8. Publications, meetings, public press articles.

Publications	
Journals	13
Book Chapters	3
Symposia – International, Mexico	6
Symposia – U.S. National, regional	8
Total	30
Meetings/presentations	49
Other public presentations	6
Field days – Big Spring, Presidio	17
Town meetings	11
Newspaper articles	23
Magazine articles	5
Total	141

Awards. The project has received several regional, national and international awards for the research and development of the saltcedar biological control program (Table 10).

Table 10. Project awards for development of biological control of saltcedar

Bureau of Reclamation – Certificate of Appreciation	2002
USDA – Group Honor Award	2004
ARS-Southern Plains Area Senior Research Scientist of the Year	2005
Service to America Medal – (Finalist – Science and Environment)	2007

Figure 32. Field day to observe biological control (Higgins Ranch), Big Spring, TX – 13 September 2006.

CONCLUSIONS

Monitoring began during the summer of 2004 and followed the *Diorhabda elongata* beetle populations, their dispersal, and damage to saltcedar in detail for 4 years, through the fall of 2008. The first 37 adult beetles to establish were released 55 m east of the beetle nursery cage at the southwestern corner of the 10 ha demonstration area on the Higgins Ranch along Beals Creek about 2 miles east of Big Spring, TX. These beetles apparently migrated 80 m to just west of the nursery cage and defoliated 2 small trees there by 16 July 2004. Another 171 adults were released 200 m southeast of the cage on 1 and 6 July and the remaining 2200 adults at the nursery cage on 3 and 6 August 2004. During 2004, ARS monitored the beetles through their "establishment phase", monitoring 80 trees along 8 transects using the method of 2 min. counts per tree. By 3 September a very large nearby saltcedar tree was 80% defoliated and by 3 October it was 95% defoliated, 3 other small trees were partially defoliated, and 1 to 25 beetles were found on 17 other trees. The beetles overwintered well, emerged in large numbers in April 2005, and began advancing in large numbers through the first saltcedar strip thicket and defoliating it. At this time ARS declared them to be "established".

During 2005 and 2006, the beetles were monitored through their phase of "large population increase and uniform dispersal," and saltcedar defoliation. In early 2005, quadrats were established each 20 or 50 m along 4 transects, monitoring began on ca. 10 May, and during the year 23 quadrats were monitored along 5 transects out to ca. 100 m from the transect origin (tree TO). By October, the beetles had defoliated ca. 1 ha of dense saltcedar thicket (190 trees) with intermittent grassy areas; the areas first defoliated produced regrowth which was again defoliated.

During 2006, the adults still advanced through the stand rather uniformly but more rapidly and for a greater distance, and defoliated most of the 20 quadrats along transects 2, 4 and 7 out to 300 to 500 m from the transects origin. By September, they had defoliated most of the 10 ha area. Most of the beetles were found in the advancing front of high beetle population and saltcedar defoliation. However enough remained in the stand, and some returned from the front, to again defoliate essentially all of the regrowth saltcedar. Toward the end of 2006, the beetles demonstrated the beginnings of the third phase, that of "migrating in swarms and initiation of satellite colonies," at 2 locations along the creek 125 m ahead and along the Higgins Kamph property line fence 250 m ahead of the main wave of beetles.

This "migrating swarms" phase continued during 2007 and 2008. The large beetle population, with little food remaining in the 10 ha area, began mass dispersal into the still green saltcedar trees along Beals Creek. By October, they had dispersed over a 9 km area along the Creek, downstream to Moss Lake road and to upstream Hwy Loop 700; they almost totally defoliated all the saltcedar in the central 5 km area. Also, they established several satellite colonies from a few 100's meters to 1-2 km ahead of the advancing wave of beetles.

Intensive monitoring of the beetles and defoliation continued during 2005-2007, with weekly counts of nine 1-m long branches in each quadrat of all Crete beetle adults, eggs and larvae; of all predator insects and spiders, and competitor insects (leafhoppers, scale insects and others); percent green, yellow and brown foliage on each branch and on the whole tree, and the size of the trees and total number of 1-m branches on the trees. Low-level aerial photography was made once or twice annually. In 2007 along the 9-km long transect by the creek, ARS sampled 349 trees every 2 weeks, the insects by 2-minute counts, and plant condition by visual estimation. The data was presented as beetle adult, egg and larval populations and percent defoliation in each quadrat in the main area, and in each sample tree along Beals Creek, in the form of 3-D graphs of population against both time and distance, and along the creek as a series of 2-D graphs for each 200 m section through all count dates. This is one of the most detailed monitoring programs ever conducted in a biological control of weeds program.

With this data, the detailed rate of dispersal and defoliation was demonstrated as it increased each year, and with each beetle generation during each growing season. Beetle behavior also was observed, including the highly selective choice of a few plants for oviposition, the continuing increasing populations on those same few plants through the season, the general attack on all plants as population pressures increased, the development of incipient and finally full swarms of beetles and their dispersal to found satellite colonies a few 100 m away and later up to 5 km from the main stand. This is a classical, inherent predator avoidance strategy by this beetle that seems very vulnerable to attack by ants on the ground and ladybird beetles, assassin bugs, and spiders in the trees.

The data also revealed that the adults, eggs and larvae peak very quickly, defoliate the plant (sometimes in a week or less), and then the populations fall quickly after each generation. Once the beetles reach high numbers and at isolated locations (as with the swarms) the predators cannot react quickly enough to suppress the beetle populations. The swarming/dispersal behavior indicates the presence of an aggregation phereomone that holds the swarm together which is the probable mechanism that makes the evolutionary survival strategy of predator avoidance effective.

The data also makes clear the seasonal abundance and generational structure of the Crete beetles. Adults emerge from overwintering at the end of March, feed and replenish their fat reserves, mate, develop their eggs, and oviposit over a period of a few weeks. The 1st generation larvae develop during May, pupate, and the 1st adult generation emerges in early June and oviposits until early July. Data from the transect monitoring began around 1 June and shows 4 adult generations that occur during the season.

The principal cause of failure to establish or of weak establishment both at our sites and at other locations appears to be attack by predators of various types – ladybird beetles, assassin bugs and spiders on the tree that attack adults, eggs or larvae, and/or by ants, ground beetles, small mammals etc. in the litter on the ground that attack the prepupae, pupae or overwintering adults. At Cache Creek, CA, control became successful after huge releases of beetles that overwhelmed the predators. At the Lovell, WY site, also with hight ant populations, rapid beetle increase and saltcedar defoliation (stagnated for some years) occurred soon after the lake level rose, flooding half the site, which we speculate drowned or drove out the ants (David Kazmer, ARS-Sidney, MT, personal communication). The ARS and AgriLife approach is to control the ants in the 1-2 acres around the nursery cages for 2 years, allowing a natural high increase of beetles, which then overwhelm the predators and control the saltcedar. ARS' site and those of Knutson that successfully established had low predator populations versus those that failed which had higher predator populations. Recent ant surveys and treatments in Texas and a replicated ant exclusion test near Big Spring by Knutson and Muegge may resolve these questions.

In 2005 and 2006, ARS also conducted an open-field test of adult selection and female ovipositional host selection for saltcedar, athel and *Frankenia*, in 2005 on groups of 5 near or far plants and in 2006 at 4 to 6 stations along two different transects. These tests demonstrated that the beetle adults were attacted in the ratio of 65% to saltcedar, 34% to athel and 0.23% to *Frankenia salina*. However, the females were much more discriminating in selecting an ovipositional host plant, with 85% of the eggs found on saltcedar, 15% on athel, and none on *Frankenia*. The data collected in this test reinforced and confirmed the data on seasonal abundance and generational population peaks in the quadrat/transect monitoring in the resident saltcedar stand.

Several behavioral patterns seen in the data and in the field support the hypothesis that the main governing strategy of these beetles is that of predator avoidance. First, all life stages appear to be exposed to predators, and with little protection unless from chemical repellents. The eggs and larvae are exposed on the foliage, the pupae are exposed under litter or the soil surface and made only a weak protective cell, and the adults overwinter under litter on the soil surface. The two successful sites before ant control began (Beals Creek at Big Spring, and on the Pecos River near Pecos, TX) were in locations with low predator populations (especially ants) and most of the sites that failed to establish had high predator populations (especially ants).

Second, the high peak populations of adults and larvae are very brief and last only a few days. The 2-D graphs of populations and defoliation in each quadrat, and in the 200 m and individual tree graphs from the Beals Creek transect, show very rapid population peaks and defoliation.

Third, this swarming behavior seems to be mediated by an aggregation pheromone (slightly different for each *Diorhabda* ecotype) that holds the swarm together. The aggregation pheromone has been isolated and synthesized by Cossé et al. (2005) for the China beetles but not for the Crete beetles.

Fourth, the beetles tend to congregate in swarms that then migrate together, especially observed in the saltcedar/athel/*Frankenia* open-field, host-selection test where the data was summarized separately for each small plant. From the beginning of the season, the females select 1 or 2 plants on which to lay most of their eggs from among the 4 or 5 in the group. This continues throughout the generation and the season, eventually with large numbers of adults and larvae on a few plants, increasing to swarms that can defoliate the plant in hours, that quickly move to another plant, and eventually to fly together from the nearby resident saltcedar stand as a swarm to establish a satellite colony from a few 100 m to 6 to 8 km.

Fifth, the migration of swarms to areas far from the main population center will take the beetles into areas of low predator density. Predators usually are unable to adjust to such rapid and high amplitude population changes and once they do in an area, the *Diorhabda* beetles again fly to a new area with few predators. Project cooperators, Carruthers and Herr, ,were able to establish the beetles in predator infested Cache Creek, CA by releasing more larvae and adults (ca. 200,000) than the predators could eat. The *Diorhabda* population rapidly increased, overwhelmed the predators, and within 3 years had defoliated the saltcedar over a 30-mile reach of the creek. Knowing this predator-avoidance strategy may allow the beetles to establish and control in spite of predators.

However, despite the successful control in the Beals Creek area, the establishment rate for new sites has been low. ARS have analyzed the differences between successful sites and sites that didn't establish and prepared a guide of best methods for establishing the beetles, which ARS expect will substantially improve the rate of establishment.

Nevertheless, biological control of saltcedar using the *Diorhabda* beetles now seems to be more difficult in the southern areas, below the 37th parallel in Texas, New Mexico and even in California, than in the northern desert areas in Nevada, Utah and western Colorado where biological control has been very easy and successful. But, even though it is more difficult, the success at Sites 1a and 1b along Beals Creek indicates that biological control can be very successful if done correctly. The experiences in the northern areas were highly successful with the China/Kazakhstan ecotype in Nevada, Utah, and western Colorado. It was more difficult for the beetles to establish at Lovell, Wyoming and Pueblo, Colorado and did not establish in Montana after many attempts. In the southern areas, bettle establishment was successful but difficult at Big Spring, Texas and Cache Creek, California. Beetles established but only weakly at Lake Meredith, Texas and Artesia, New Mexico and failed to establish at several sites in Texas. This indicates that each beetle ecotype probably has a definite area where it is most effective.

ARS expects the outline of best methods to obtain establishment will substantially improve both establishment and control after establishment. The success of the project along Beals Creek indicates that successful biological control in Texas is very possible, if done correctly.

The three successful establishments, two near Big Spring, and one near Pecos, Texas have several characteristics in common: 1) the lowest ant populations (except for high populations of *M. minimum* averaging 309 ants in 24 samples at Big Spring); 2) simple ecosystems – Big Spring with lush grass (a mesic area) and Pecos River saltcedar mixed with sparse grass (a desert area); 3) fewest beetles released to obtain establishment – 38 beetles at Higgins Ranch, Big Spring and 50 in each cage at Pecos and Imperial on the Pecos River. The beetles were released at these sites under what ARS consider to be the best conditions:

1) released early in the year (April – June),
2) released adults,
3) released in large cages, with beetles producing aggregation pheremones,
4) low predator populations (especially ants),
5) released in sites with simple ecosystems,
6) no sites flooded for extended periods,
7) no sites with other control methods applied (herbicides, mechanical, fire)
8) saltcedar species/hybrids attractive to the beetles,
9) daylength suitable for the beetles,
10) protection or isolation from human disturbance,
11) release additional beetles adjacent to the cages, held nearby by the pheromone in the

cages, in sufficient numbers to overcome the predators, and

12) ant control in and around the cages (1-2 acres for 2 years) allowing large population increase that could overcome the ants and other predators, and to rapidly spread and defoliate the saltcedar.

The failed sites also had some common characteristics:

1) high predator populations (especially ants and spiders),
2) some beetle ecotypes inability to adapt to the daylength or other environmental conditions, and
3) saltcedar species/hybrids not attractive to the beetles.

Suggested best methods for successful establishment. In consideration of the above site characteristics and outcomes, the following procedures are suggested:

1) Site selection. Choose a site:

a) In areas where the beetle species/ecotype is adapted to the local climate/biome: daylength, temperature extremes, moisture range, etc.,
b) Where the local saltcedar species/hybrids are attractive to and acceptable to the beetles being used (or select the beetle ecotype adapted to the local saltcedars present),
c) A simple plant community – less likely to attract a variety of insects that would produce large predator populations,
d) Areas which have the fewest predaceous ants – conduct pre-release surveys and select sites with the fewest predaceous ants,
e) A large, several acre stand of healthy saltcedar that will not be managed with herbicides, mechanical equipment, or fire for 5 years,
f) Sites secluded from public view and/or with limited access (to prevent vandalism or taking of the control beetles), and
g) Sites that are unlikely to flood – this is not completely clear since some of our sites that flooded seem not to have adversely affected the beetle populations; perhaps the floods drive out predaceous ants.

2) Releasing the beetles. Several methods may be used for placing beetles in the field that vary in effectiveness and depend on availability, time, and cost. The objective is to obtain a large population of at least a few thousand beetles together in a small area with the next generation after release.

a) **Large field cages.** This method has been the most successful, but it is also the most difficult, time consuming, and costly. Recent use of cheaper cages seems promising although some cages have flown away.
b) **Sleeve-bag cages.** This method has been used only a few times in Texas but, it has not been successful. However, at Cache Creek, California, researchers have had success releasing eggs and larvae.
c) **Release directly into the field.** This method had been used very effectively in releasing *Diorhabda* in Utah but failed to establish in the Big Spring area. Release of sufficient numbers is required to reach a critical density to produce enough aggregation pheromone to hold the group together and also to overwhelm

the local predator population. Success also depends on predator populations at the site.

d) **Numbers to release.** The number of beetles to release at a site depends greatly on predator populations. If predators (especially ants) are low, then 50 beetles in a large cage (500 or more in the next generation released) is enough. If predator populations are high, then many more may be needed. Pre-release surveys should be made to determine predator (especially ant) populations.

e) **Ant suppression.** Before establishing the cage, survey ant populations. Treat the inside of the cage and the area at least 30 m surrounding the cage with ant bait, hydromethylnon, 1 to 2 weeks before stock beetles are placed in the cages. Inspect the cage and the surrounding area for ants and repeat applications of the ant killer to control ants for 2 years at the release site.

f) **Life stage to release.** The release of adults has had the most success, especially when released into the open field. One problem with releasing larvae is that larvae must be on site for several days, then pupate under litter on the soil surface (completely exposed to predators) before producing another generation.

g) **Time of year to release.** Limited experience indicates that early releases (May and June) are more successful than later ones. The overwintering adults, after feeding for a few days, seem ready to oviposit at a high rate, and probably remain together in the same area. The 3rd and 4th adult generations during the 3rd year after release, in August and September, tend to gather in large numbers into swarms and fly either nearby or long distances to form satellite colonies. Beetle behavior may be influenced by seasonal variation in production of aggregation pheromone.

This project demonstrated the highly successful and safe biological control of saltcedar at demonstration Site 2a and 2b along Beals Creek east of Big Spring, TX. During the 4 years of the project, the leaf beetle, *Diorhabda elongata* first released in 2004, defoliated all saltcedar in the entire 10 ha demonstration area and in 2007 dispersed along 9 km of Beals Creek and defoliated 5 km of saltcedar in the central area. In the 1 ha area near the release site, that was defoliated 2 or 3 times annually for 3 years, the saltcedar canopy has been reduced by 95-98%, 25% of the trees have been killed, and the local grasses and forbs have revegetated vigorously on the former bare soil. This emerging success of this project is on par with the better of the ca. 40 biological control of weeds projects for which control agents have been released in the U.S. since 1945.

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Appendix A

ADDITIONAL CHARTS (TABLES AND GRAPHS)

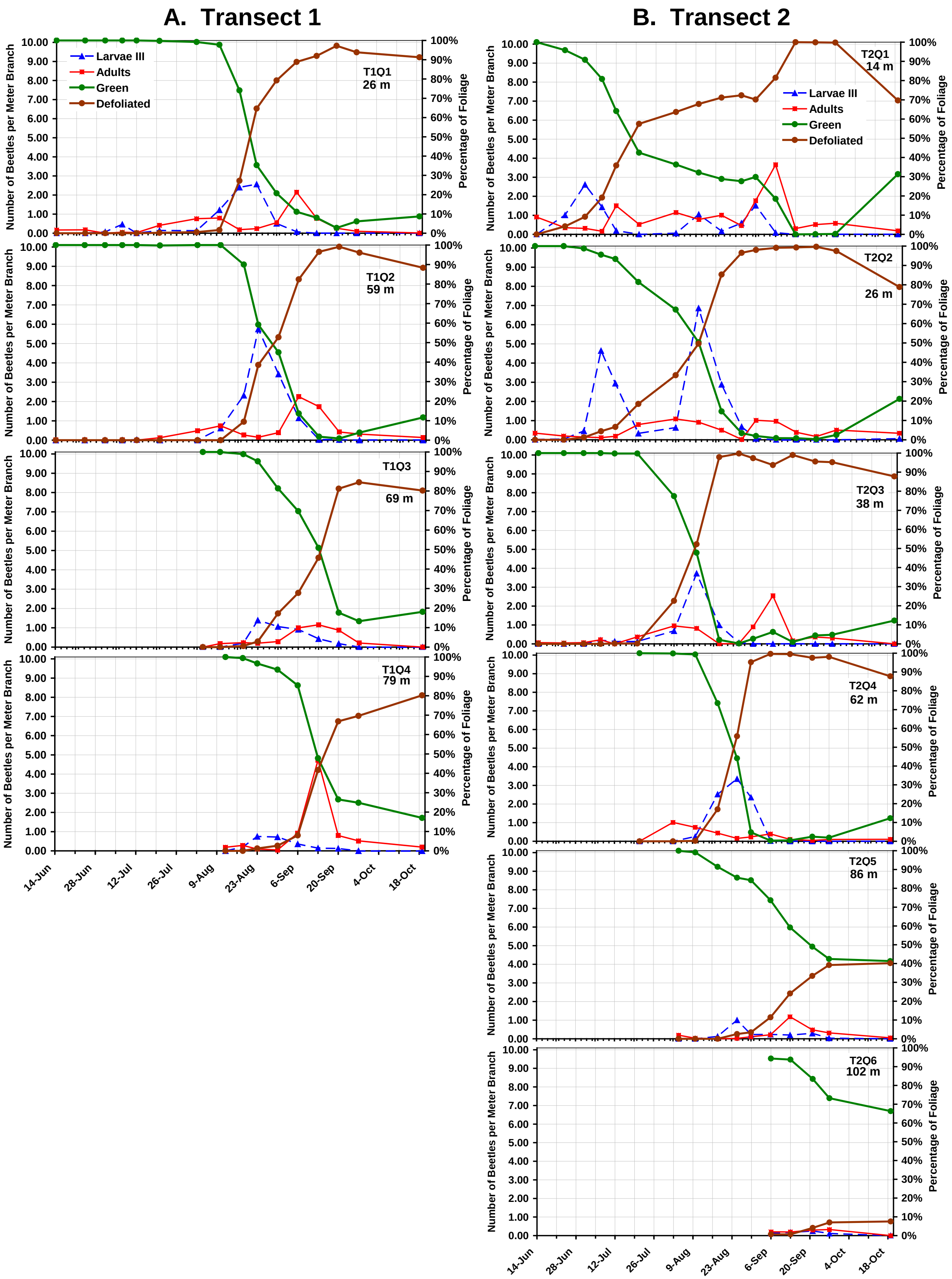

Fig. A1-A *Diorhabda* populations and percent saltcedar defoliation within each quadrat (with distance from transect origin at Tree TO) through the season, Higgins Ranch, Big Spring, TX for Transects 1 and 2 (see text Fig. 16) (quadrats along Transects 1 and 2) – 2005.

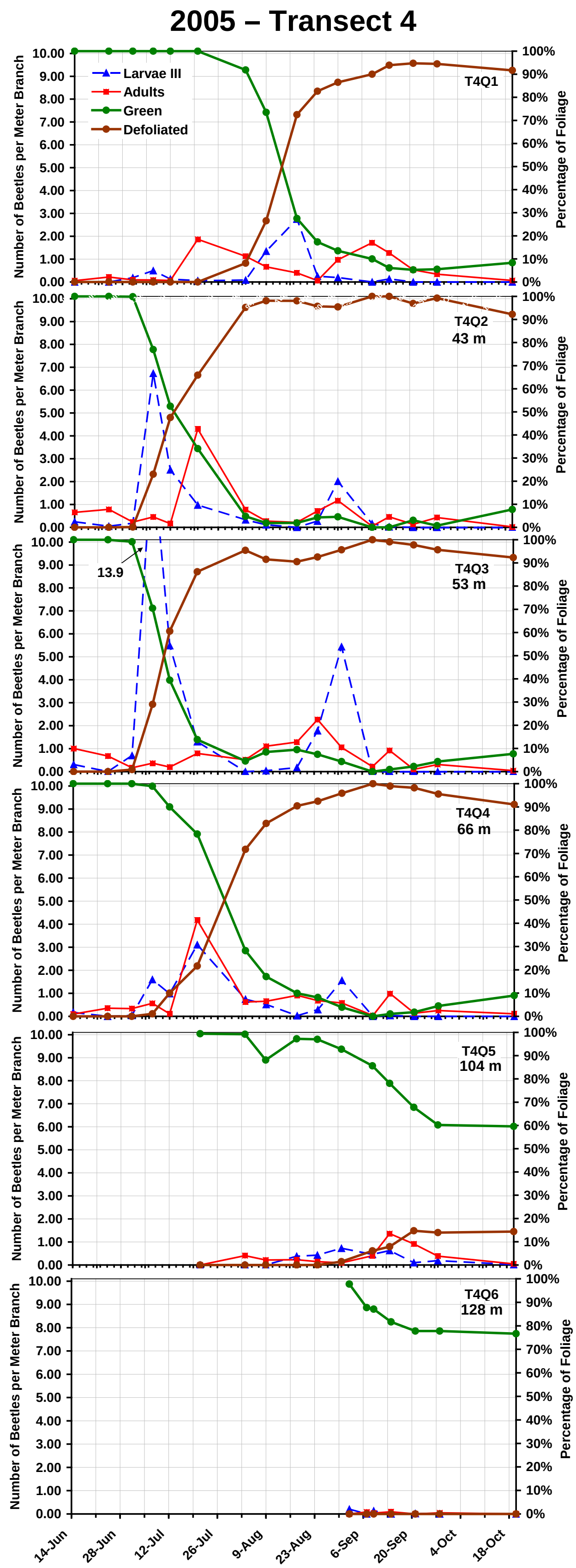

Fig. A1-B. *Diorhabda* populations and percent saltcedar defoliation within each quadrat (with distance from transect origin at Tree TO) through the season, Higgins Ranch, Big Spring, TX (quadrats along Transect 4) (see text Fig. 16) – 2005.

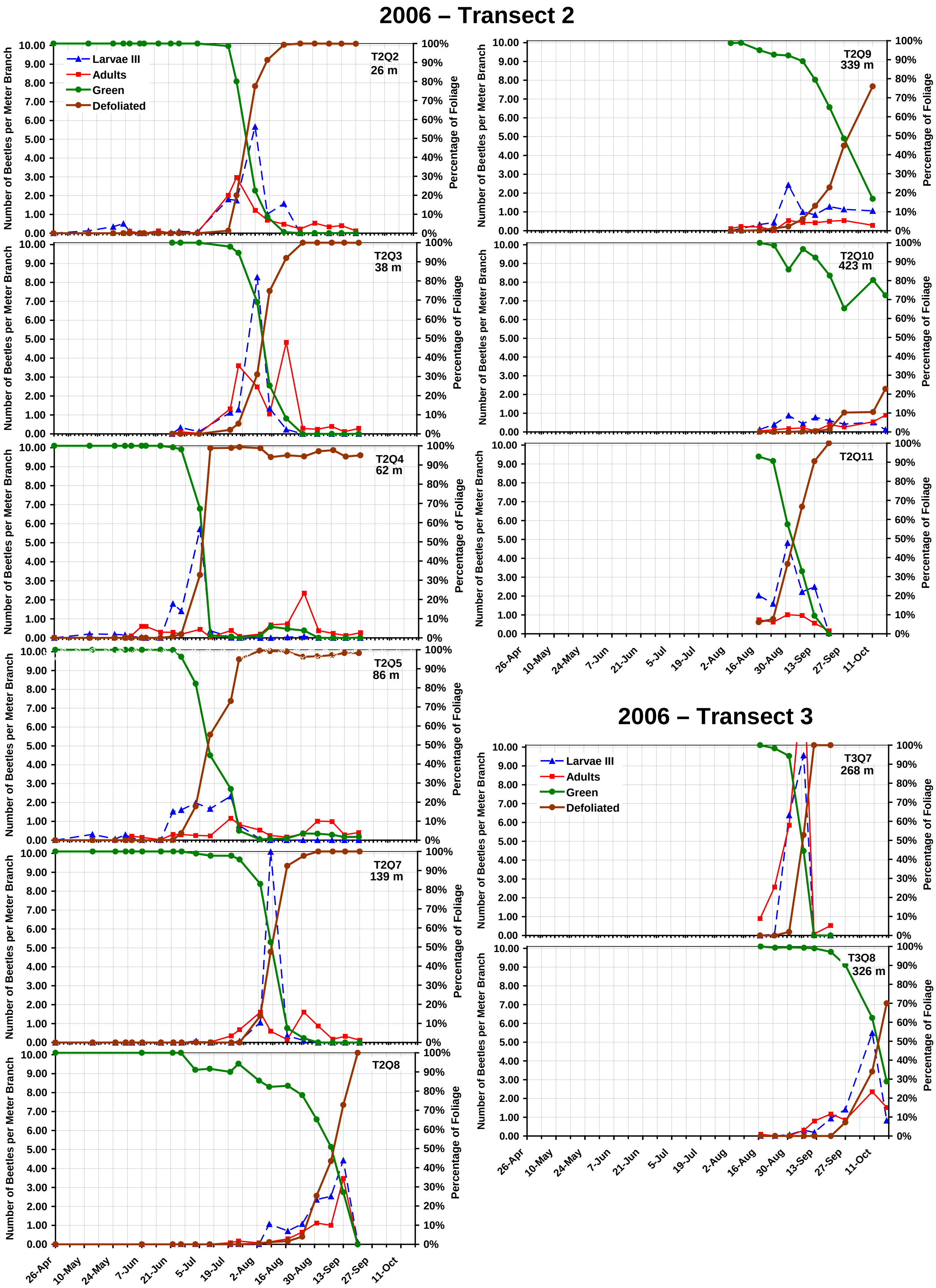

Fig. A1-C. *Diorhabda* populations and percent saltcedar defoliation within each quadrat (with distance from transect origin at Tree TO) through the season, Higgins Ranch, Big Spring, TX for (quadrats along Transects 2 and 3) (see text Fig. 17) – 2006.

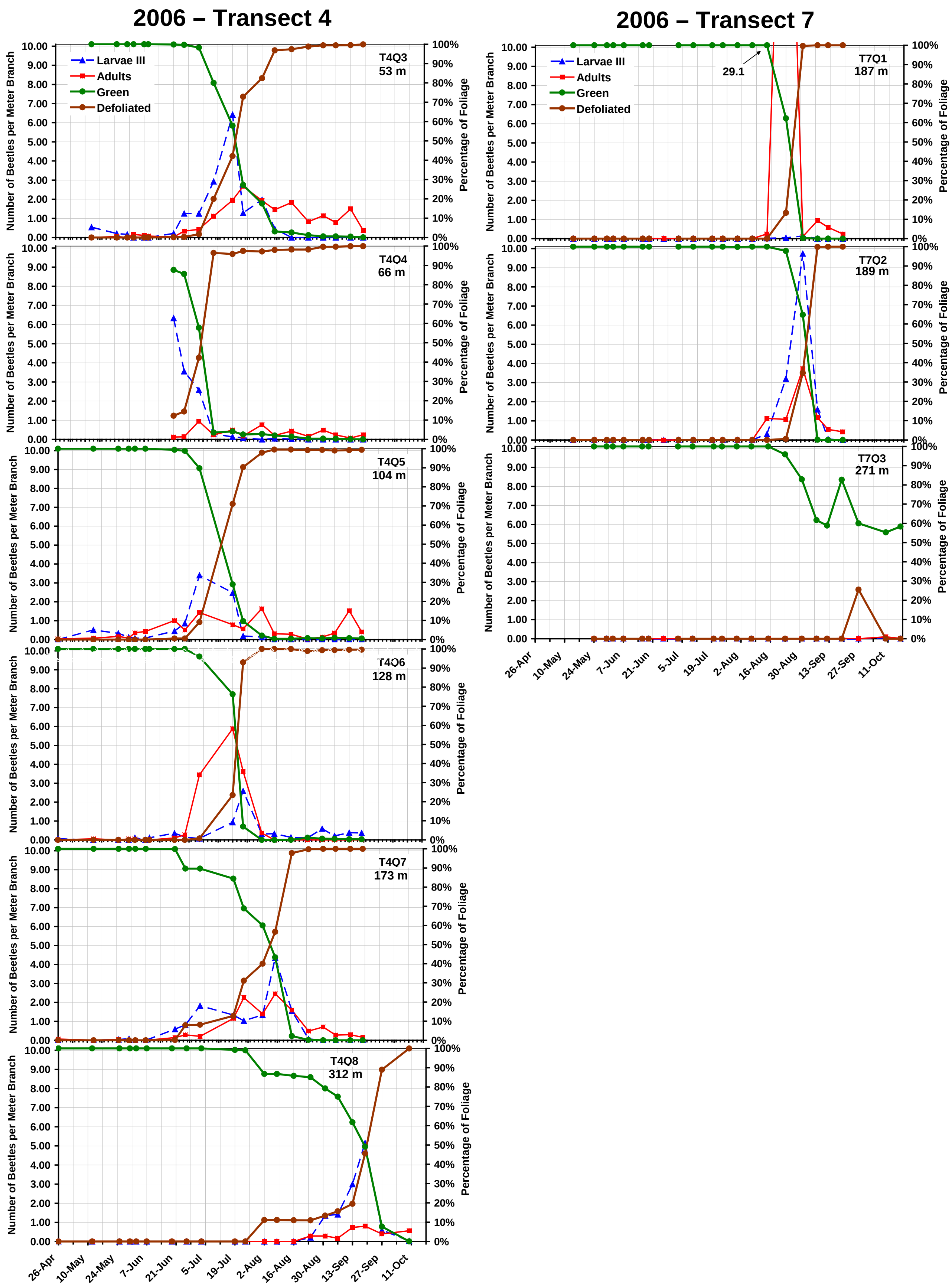

Fig. A1-D. *Diorhabda* populations and percent saltcedar defoliation within each quadrat (with distance from transect origin at Tree TO) through the season, Higgins Ranch, Big Spring, TX (quadrats along Transects 4 and 7) (see text Fig. 17) – 2006.

Short Transects

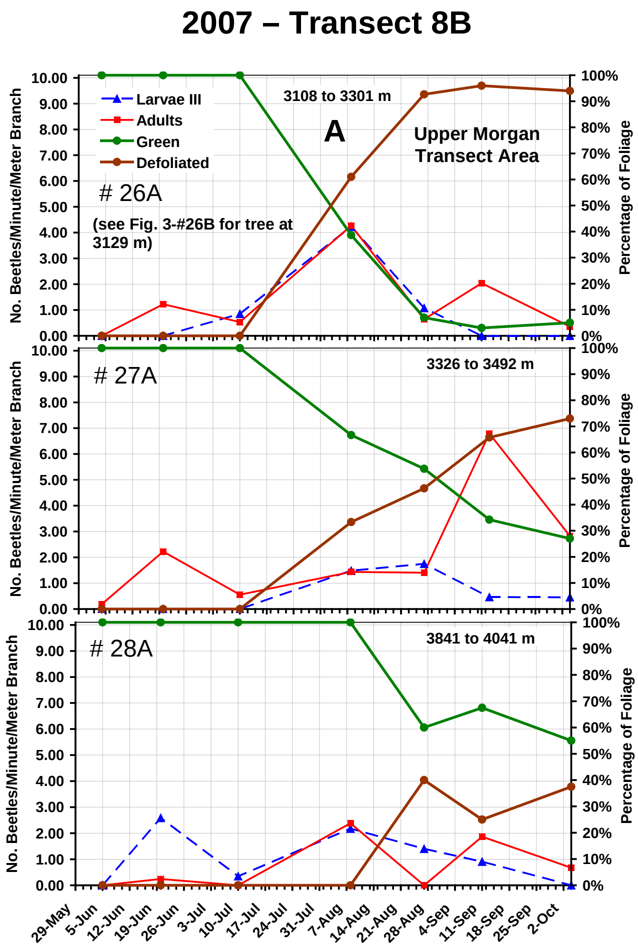

Figure A2-A.Transect 8A, B. Big Spring Site 2a and 2b (short transects). A.) Short, 933 m long, Transect 8B along field row up-slope and north of main Transect 8A, from powerline upstream; B.) Short 1,321 m long, Transect 8C upslope and southwest of main Transect 8A, 29 May–2 October, 2007.

2007 – Transect 8A

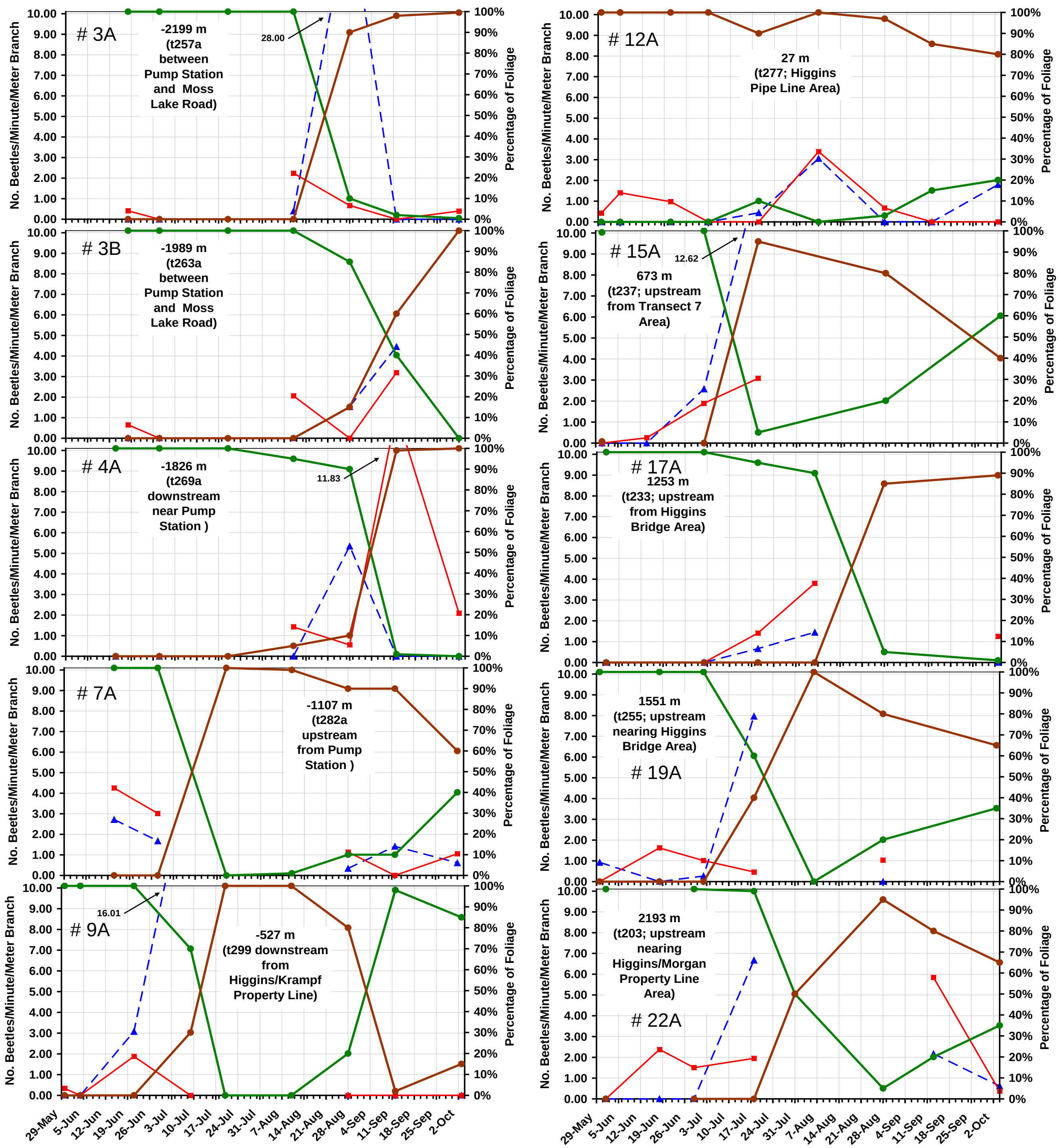

Figure A2-B. Big Spring sites 2a and 2b (individual trees #3A-22A) along Transect 8A: Numbers of adults and 3rd instar larvae per 1 meter branch per minute count along Beals Creek, 29 May–2 October, 2007.

2007 – Transect 8A

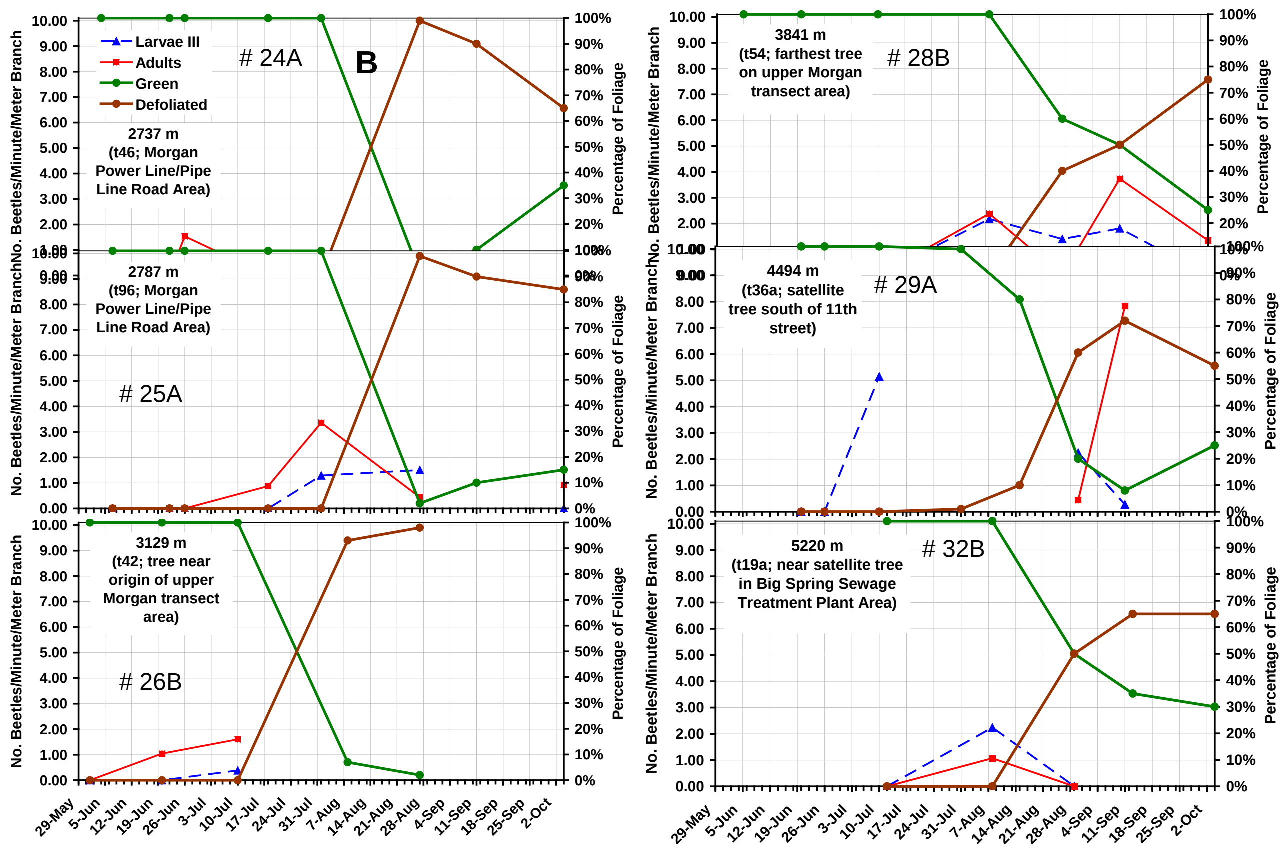

Figure A2-C. Big Spring sites 2a and 2b (individual trees #24A-32B) along Transect 8A: Numbers of adults and 3rd instar larvae per 1 meter branch per minute count along Beals Creek, 29 May–2 October, 2007.

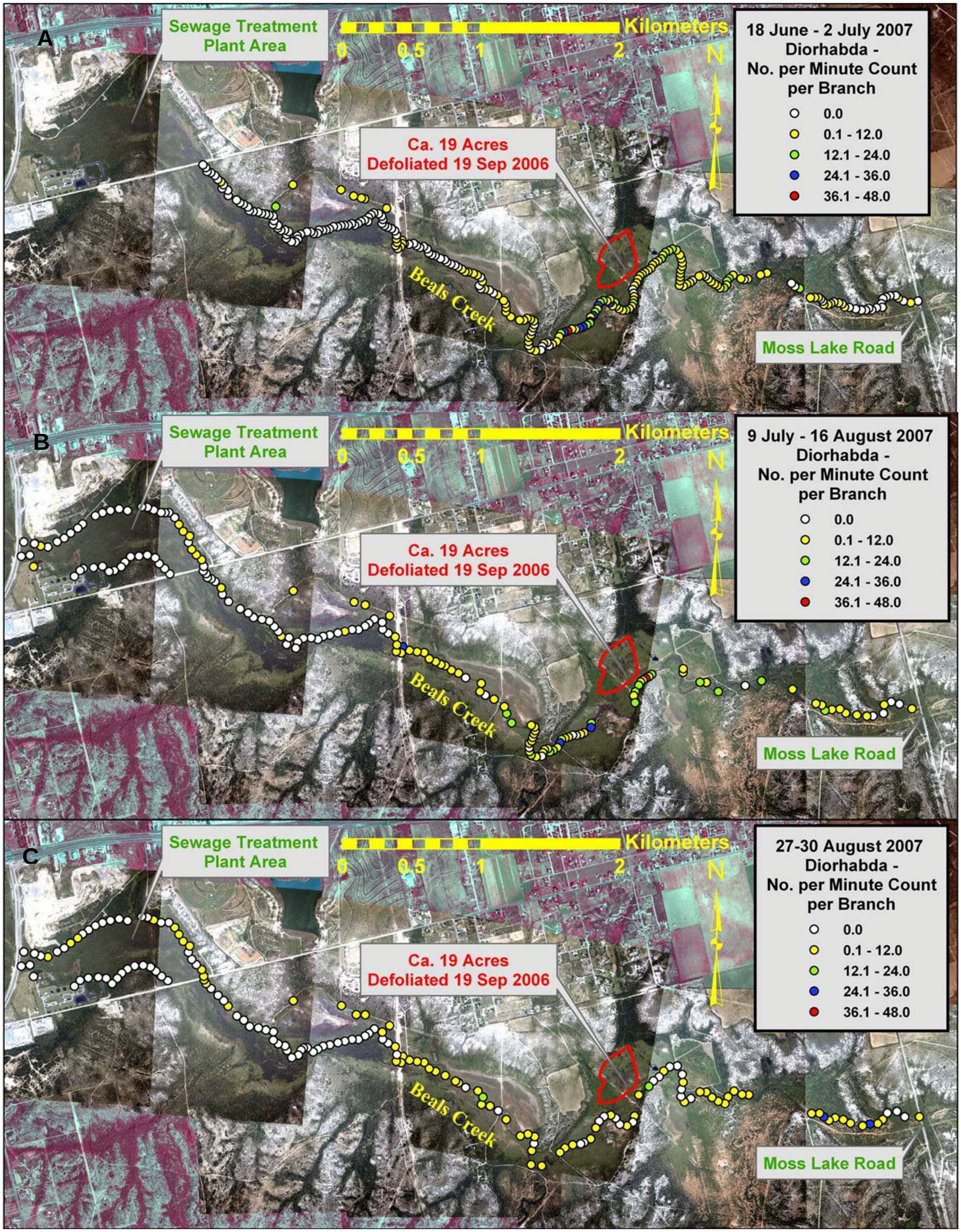

Figure A3. Population of *Diorhabda elongata* (number of all stages; egg mass counts as one): distribution along Beals Creek from (A) 18 June–2 July, (B) 9 July–16 August, and (C) 27–30 August, 2007.

Table A-1. Releases and monitoring of *Diorhabda* beetles, Big Spring area – 2003, 2004.

Date	Action: No. life stages placed in cages or released	Monitoring: Number, life stages, locations, notes
		Higgins Ranch – 2003 – Crete beetle ecotype (Site 2a)
9-10 July	100A To Higgins Cage	Higgins – erected cages 1 and 2, placed 100 adult Crete beetles in Cage 1.
29 July	447E To Higgins Cage	To Higgins, Cage 1 (from Murphy Ranch nursery cage)
8 August	Monitor	Higgins 17A 1-1st Cage 1
14 August	Monitor	Higgins 312A 1-1st larva in Cage 1 (by Knutson, Muegge)
20 August	Monitor	Higgins 182A, 20E masses, 2-3rd, some pupae in sleeve bags
28 August	Monitor	Higgins 43A, 3-1st, 21-2nd in cages.
3 September	Monitor	Higgins 72A+ 126A on cage walls, 3 e masses (52e), 48-1st, 152-2nd, 70-3rd on branches.
9-10 September	170A To Higgins cage	Erected new Cage 3 at Higgins, added 70 Crete A from Murphy nursery cages + 80A from Higgins Cage 1 to new Cage 3.
18 September	Monitor	Higgins Cage 1-3A, 1-3rd, Cage 3-9A, 39E.
26 September	Monitor	Higgins Cage 1-12A on plant, 673A on cage walls. Many leafhoppers, a few predators in cage.
30 September	Monitor	Higgins Cage 1 – 75A Crete, moved to Cage 4.
3 October	Monitor	Higgins Cage 1 – 2A, Cage 3 – 6A, 20E, 2-1st, 2-2nd. Many leafhoppers, 10 assassin bugs.
14 October	Monitor	Higgins Cage 1 – 2A on walls, plant budding, no leafhoppers. Cage 3 – 490A, 8-1st, 30-2nd, 11-3rd. Some leafhoppers, several spiders, 2 assassin bugs.
30 Oct	Monitor	Higgins Cage 1 – no beetles, tree budding out. Cage 3 – no beetles, tree budding out
		Higgins Ranch – 2004 – Crete beetle ecotype (Site 2a)
22 April	37A Released at Higgins	At original release tree (RT) near T4, Q4.
1 July	141A Released at Higgins	From Higgins Cages 1 and 2 combined, released on large tree near T7 Q2.

Table A-1 (Con't.)

6 July	30A Released at Higgins	Released near T7 Q2 from Cage 1, Higgins.
16 July	Monitor	Higgins Tree TO (future Transects Origin) – 2 small trees 95%+ defoliated, Tree #001 15% defoliated. First establishment.
3 August	Monitor	Higgins. Tree TO (still 95%+ defoliated), T-001 (54 larvae + 13 adults/1 min.), beetles dispersed 75 m from Tree RT, > 25 adults + larvae/min on 5 trees, 1-25 adults + larvae on 19 trees, none on 26 trees. Laid out 16 transects and 75 sentinel trees marked (Hudgeons and Knutson).
6 August	200A Released at Higgins	Released near Higgins Cage 2.
9 August	2,000A Released at Higgins	Removed cover from Higgins Cage 2, allowed estimated 2000A Crete beetles to disperse.
30-31 August	Monitor	Higgins Trees 001, 005 – 50-100% defoliated, TO totally resprouted, with 4 adults + 5 third instars/1 min.
2-3 September	Monitor pheromone traps	Higgins Tree #001 80% defoliated. Checked pheromone sticky traps. (Hudgeons and Knutson)
3 October	Monitor	Higgins Tree #001 – 95%+ defoliated.
September	Placed in cages	Higgins, placed Crete adults in cage and monitored.

Higgins Ranch – 2003 – Uzbek beetle ecotype

10 July	100 Adults Higgins cage	Erected Cage #2 at Higgins for Uzbeks. Placed 100 Uzbek adults in Cage 2.
20 August	600E To Higgins cage	Placed in Higgins Cage #2 (60 per bag, 10 sleeve bags), from Murphy Ranch nursery cage.
2 September	20A, 375e To Higgins cage	To Higgins Cage 3, from Temple nursery cage.
3 September	Monitor	Higgins Cage 2 – three 3rd larvae on 10 branches – many ants.
7-10 September	Monitor	Higgins Cage 2 – 143-2nd + 2-3rd in 8 sleeve bags, 2 bags none.
18 September	Monitor	Higgins Cage 2 – 15-1st, 7-2nd, 19-3rd.

Table A-1 (Con't.)

26 September	Monitor	Higgins Cage 2 – 3-3rd on walls.
3 October	Monitor	Higgins Cage 2 – 6-A, 12-3rd on sample branches, 180A in cages, many leafhoppers.
14 October	Monitor	Higgins Cage 2 – 4-A, 47A in cage, many leafhoppers.
30 October	Monitor	Higgins Cage 2 – 6A, 60A in cage, many leafhoppers.

2003 – Wastewater Treatment Plant – Crete (Site 2b)

22 April	**40A, 100E Released at Wastewater Treatment Plant**	Released at Wastewater Treatment Plant, north side, released 40A, 100E Crete beetles from Higgins cage.
21 June	**200A released**	Site 2b – Wastewater Treatment Area

2003-2005 – Buzzard's Draw – Crete beetles (Site 2c)

15 October 2003	**3A, 234L**	Monitor Higgins: 3A, 24-1st, 131-2nd, 79-3rd from Cage 4; tree 95% defoliated; **all beetles released at Buzzard's Draw**.
3 August 2004	Monitor Site 2c	Aggregation of several 100s of Crete adults.
2 September 2004	Site 2c	No adults seen.
21 October 2004	Site 2c	Cooperator Knutson established 16 transects radiating from release cage at subsite b.
June 2005	Released at Site 2c	Released from on site cages into open field at Subsite (2).

Table A-2. Releases and monitoring of *Diorhabda* beetles at Lake Thomas area Site 1A (Lakebed) and Site 1B (Murphy) – 2003, 2004[a].

Date	Action: No. life stages placed in cages or released	Monitoring: Number, life stages, locations, notes
		2003, Crete beetle ecotype
21 August	**1380A Released at Lake Thomas lakebed**	100A removed from Higgins cages to Lake Thomas, plus 1280 from Murphy cages, **released** at Lake Thomas lakebed (center of 10 ha circle).
9-10 September	**285A, 550L Released at Lake Thomas lakebed**	Found many 2nd, 3rd larvae on ground and cage walls, collected on cut branches on ground, plant defoliated, took to and **released** all adults and larvae on trees at center of 10 ha circle in Lake Thomas lakebed.
9-10 September	150A to Higgins cage	150A from Lake Thomas (Murphy nursery) to Cage 3, Higgins.
		2004, Crete beetle ecotype
ca. April 20	Monitor Site 1a	Lake Thomas Lakebed – overwintered Crete beetles laid ca. 2000 eggs plus probably many in tops of trees out of reach.
ca. early May	Monitor Site 1a	Lakebed – no eggs or larvae found, many ladybird beetle larvae present on trees.
June	**Crete released at Site 1b**	**Released** into open field at Murphy site by Hudgeons.
16 July	**Released 580A at Site 1a**	**Released** at center of 10 ha circle, in Lakebed, beetles from Murphy Ranch nursery cage.
21 July	**Released 400A at Site 1a**	**Released** at center of 10 ha circle, beetles from Murphy Ranch nursery cages.
30 August	Monitor Site 1a	Lakebed, one 3rd instar found.
September	**Released** Crete-Site 1a, 1b	**Released** Crete beetles in open field at Lakebed, in cages at Murphy Ranch.
22 October	Monitor Site 1b	Monitor 69 trees at Murphy along transects.
22 November	Site 1a	Lake level rose 12 ft.
		2004, Turpan beetle ecotype
31 July	200A to cage at Lake Thomas	Placed in cage at Lake Thomas, from Murphy Ranch nursery cage – left in cage for overwintering. Did not overwinter.

[a]All releases are in bold type.

Table 3. Exotic weeds for which biocontrol agents have been released in the United States and Canada.

Weed Species	Year Released	U.S. Agents Released	Canada Agents Released	Degree Control[a]
*St. Johnswort	45-89	6	9	S-C
Gorse	53-94	2		
*Tansy ragwort	59-69	3	5	S-C
Scotch broom	60-64	2		
*Puncturevine	61	2	2	S-C
*Alligatorweed	64-71	3		S-C
*Spurge, leafy	64-93	9	12	S-C
Thistle, Canada	66-77	3	5	
Toadflax, common	68	1	1	
*Toadflax, Dalmatian	67-86	2	1	P-S
*Thistle, musk	69-90	3	1	S-C
Thistle, milk	69	1		
*Thistle, plumeless	69-74	2	3	P-S
Starthistle, yellow	69-92	5		
*Sage, Mediterranean	69-71	2		P-S
*Waterhyacinth	72-77	3		S-C
Knapweed, diffuse	73-92	9	8	
Knapweed, spotted	73-93	11	5	
Thistle, Italian	73	1		
Thistle, slender-flower	73-90	3		
Thistle, bull	73-83	1	1	
Thistle, Scotch	73	1		
Halogeton	75	1		
*Skeleton weed	75-77	3		S
Thistle, Russian	75-77	2	2	
Spurge, cypress	76	1	9	
Knapweed, Russian	76-84		2	P
Thistle, sow	79-87		3	
*Waterlettuce	87-90	2		S-C
*Bindweed, field	87-89	2	1	S
*Hydrilla	87-90	2		P-S
*Knapweed, squarrose	88-90	3		P-S
*Melaleuca		3		P-S
*Loosestrife, purple		3		S-C
*Saltcedar	2001	4		P-S
*Salvinia, giant		1		P-S
Fern, Old Word climbing		1		
*Sodaapple, tropical		1		P-S
Peppertree, Brazilian		1 ?		P
*Waterhyacinth	1996?	1 (Mexico)		S-C
Reed, giant	2009	1		

U.S.	Canada	No. S or C
39 Species Weeds	17 Species Weeds	20 weeds
105 Species Nat. Enemies	70 Species Nat. Enemies	= 50%

APPENDIX B

PUBLIC EDUCATION AND PARTICIPATION

During this project, the following was accomplished.

	2004	2005	2006	2007	2008	2009	Total
Publications in Scientific Journals	8	1	4	9	6	2	30
Meetings Attended and Presentations Made	15	11	8	11	2	2	49
Other Recorded Public Communications	3	0	3	0	0		6
Field Days – Big Spring	1	4	6	3	3		17
Town Meetings	2	0	6	3	0		11
Newspaper Articles	4	9	5	3	2		23
Magazine Articles	0	2	2	0	1		5
Total	33	27	34	29	14	4	141

Publications

2004

1) DeLoach, C.J. 2004. Crop Protection Compendium: *T. ramosissima* [CD-ROM]. 2004 Edition. Oxfordshire, UK: CAB International.
2) DeLoach, C.J. 2004. Crop Protection Compendium: *T. parviflora* [CD-ROM]. 2004 Edition. Oxfordshire, UK: CAB International.
3) DeLoach, C.J. 2004. Crop Protection Compendium: *T. aphylla* [CD-ROM]. 2004 Edition. Oxfordshire, UK: CAB International.
4) DeLoach, C.J. and R.I. Carruthers. 2004. Biological control programs for integrated invasive plant management. In: Proceedings of the Weed Science Society of America Invasive Plant Species Workshop, February 12-13, 2004, Kansas City, MO. 2004 CDROM.
5) Knutson, A., M. Muegge, T.O. Robbins and C.J. DeLoach. Insects associated with saltcedar, baccharis and willow in west Texas and their value as food for insectivorous birds: preliminary results. Saltcedar and Water Resources in the West Symposium (2003).
6) Milbrath, L.R., J.C. Herr, A.E. Knutson, J.L. Tracy, D.W. Bean, L. Rodriguez-del-Bosque, R.I. Carruthers and C.J. DeLoach. Suitability of *Diorhabda elongata* (Coleoptera: Chrysomelidae) for biological control of saltcedars (*Tamarix* spp.) In the southern United States and northern Mexico. Proceedings of Mexican National Congress of Biological Control, Guadalajara (2003).
7) DeLoach, C.J. 2004. Research on biological control of saltcedar in the United States, with implications for cooperation with Mexico, (Plenary Talk) pp. 204-217. In: José Lorenzo Meza Garcia, Norma Elena López Leyva, Jesús Méndez Lozano, Edgardo Mondaca Cortez and Guadalupe Vejar Cota (Eds.), Memoria del XV

Curso Nacional de Control Biologico, 8-13 November 2004, Los Mochis, Sinaloa, Mexico.

8) DeLoach, C.J. 2004. Control biologico de malezas, (Workshop) pp. 116-135. In: José Lorenzo Meza Garcia, Norma Elena López Leyva, Jesús Méndez Lozano, Edgardo Mondaca Cortez and Guadalupe Vejar Cota (Eds.), Memoria del XV Curso Nacional de Control Biologico, 8-13 November 2004, Los Mochis, Sinaloa, Mexico.

2005

1) DeLoach, C.J., Knutson, A.E., Thompson, D.A. and Nibling, F. 2005. "Minutes and Research Updates". First (Organizational) meeting of the "Saltcedar Biological Control Consortium – Texas, New Mexico, Mexico Section", 29-30 March 2005, El Paso, TX, 126 p.

2006

1) Carruthers, R.I., J.C. Herr, J. Knight and C.J. DeLoach. 2007. A brief overview of the biological control of saltcedar. Proceedings of the Weed Science Society 59:128-134.
2) Everitt, J.H., C. Yang, R.S. Fletcher, C.J. DeLoach and M.R. Davis. 2004. Using remote sensing to assess biological control of saltcedar damage to two invasive plant species. Proceedings 11th Forest Service Remote Sensing Conference, Salt Lake City, UT. CD-ROM. American Society Photogrammetry and Remote Sensing 2006.
3) Everitt, J.H., D. Flores, C. Yang, R.S. Fletcher, C.J. Deloach and M.R. Davis. 2006. Using remote sensing to assess biological control damage of two invasive plant species. Submitted to Forest Service Remote Sensing Conference Proceedings (In press).
4) Herr, J.C., R.I. Carruthers and C.J. DeLoach. 2006. Comparison of laboratory and ecological host range of the saltcedar leaf beetle with respect to native non-target *Frankenia* species. In: Proceedings of the California Conference on Biological Control (pp. 148-151). 25-27 July 2006, Riverside, CA.

2007

1) Carruthers, R.I., J.C. Herr and C.J. DeLoach. 2007. An overview of the biological control of saltcedar. Proc. Weed Science Society 59:128-134.
2) DeLoach, C.J., Knutson, A.E., Moran, P.J., Michels, G.J., Thompson, D.C., Carruthers, R.I., Nibling, F. and Fain, T.G. 2007. Biological control of saltcedar (Cedro salado) (*Tamarix* spp.) in the United States, with implications for Mexico, Chapter 11, pp. 142-172 (Section II – Plenary Address). In Ricardo Hugo Lira-Saldiar (ed.), Bioplaguicidas Y Control Biológico. Simposia Internacional de Agricultura Sustentable. Centro de Investigación en Química Aplicada, Universidad Autónoma Agraria Antonio Narro, Saltillo, Coahuila, Mexico.
3) Hudgeons, J.L., A.E. Knutson, K.M. Heinze, C.J. DeLoach, T.L. Dudley, R.R. Pattison and J.R. Kiniry. 2007. Defoliation by introduced *Diorhabda elongata* leaf beetles (Coleoptera: Chrysomelidae) reduced carbohydrate reserves and regrowth of *Tamarix* (Tamaricacceae). Biological Control 43:213-221.
4) Hudgeons, J.L., Knutson, A.E., DeLoach, C.J., Heinz, K.M., McGinty, W.A. and Tracy, J.L. 2007. Establishment and biological success of *Diorhabda elongata elongata* on invasive *Tamarix* in Texas. Southwest. Entomol. 32:157-168.

2008

1) Carruthers, R.I., C.J. DeLoach, J.C. Herr, G.L. Anderson and A.E. Knutson. 2008. Saltcedar areawide pest management in the western United States, pp. 252-279, Chapter 15. In O. Koul, G. Cuperus and N. Elliott (eds.), Areawide Pest Management: Theory and Implementation. (In press)
2) DeLoach, C.J., Moran, P.J., Knutson, A.E., Thompson, D.C., Carruthers, R.I., Michels, J., Muegge, M., Eberts, D., Randall, C., Everitt, J.H., O'Meara, S. and Sanabria, J. 2008. Beginning success of biological control of saltcedars (*Tamarix* spp.) in the southwestern United States. XII International Symposium on Biological Control of Weeds, 22-27 April 2007, La Grande Motte, France. p. 535-539.
3) Everitt, J.H., Yang, C., Fletcher, R.S. and DeLoach, C.J. 2007. Mapping invasive aquatic and wetland weeds with QuickBird Satellite Imagery. Proc. Biennial Workshop on Aerial Photography, Videography, and High Resolution Digital Imagery for Resource Assessment. (Accepted September 1, 2007) (In press)
4) Everitt, J.H., Yang, C., Fletcher, R.S. and DeLoach, C.J. 2007. Mapping a riparian weed with SPOT 5 Imagery and Image Analysis. Proc. Biennial Workshop on Aerial Photography, Videography, and High Resolution Digital Imagery for Resource Assessment Proceedings. (Accepted September 1, 2007) (In press)
5) Everitt, J.H., C. Yang, R.S. Fletcher and C.J. DeLoach. 2007. Comparison of QuickBird and SPOT 5 Satellite Imagery for mapping giant reed. Journal of Aquatic Plant Management. (Accepted January 15, 2008)

2009

1) Tracy, J.L. and T.O. Robbins. 2009. Taxonomic revision and biogeography of the *Tamarix*-feeding *Diorhabda elongata* (Brulle, 1832) species group (Coleoptera: Chrysomelidae: Galerucinae: Galerucini) and analysis of their potential in biological control of Tamarisk. Zootaxa 2101:1-152.
   2)
2) Moran, P.J., DeLoach, C.J., Dudley, T.L. and Sanabria, J. 2009. Open field host selection and behavior by tamarisk beetles (*Diorhabda* spp.) (Coleoptera: Chrysomelidae) in biological control of exotic saltcedars (*Tamarix* spp.) and risks to non-target athel (*T. aphylla*) and native *Frankenia* spp. Biological Control 50:243-261.

Meetings and Presentations

2004

1) DeLoach, C.J. and R.I. Carruthers. 2004. Biological control programs for integrated invasive plant management. In: Proceedings of the Weed Science Society of America Invasive Plant Species Workshop, February 12-13, 2004, Kansas City, MO. 2004 CDROM.
2) Knutson, A., M. Muegge, T.O. Robbins and C.J. DeLoach. Insects associated with saltcedar, baccharis and willow in west Texas and their value as food for insectivorous birds: preliminary results. Saltcedar and Water Resources in the West Symposium, College Station, TX. 2003.
3) Milbrath, L.R., J.C. Herr, A.E. Knutson, J.L. Tracy, D.W. Bean, L. Rodriguez-del-Bosque, R.I. Carruthers and C.J. DeLoach. (2003) Suitability

of *Diorhabda elongata* (Coleoptera: Chrysomelidae) for biological control of saltcedars (*Tamarix* spp.) In the southern U.S. and northern Mexico. Proc. of National Congress Biological Control. Guadalajara, Mexico.

4) Attended and made oral presentations, "Alternative insects in Asia for saltcedar control" (by DeLoach), "Results of testing *Diorhabda* on *Frankenia*" (by Milbrath), and "Taxonomy of *Diorhabda elongata* beetles" (by Tracy), to the ARS Tamarix Research Planning Workshop, Albany, CA, 7-9 January 2004 (30 people attended).

5) Presented a 20 min. talk, "Traditional approach to host specificity testing in classical biological control of weeds", at the symposium, Benefits and Risks of Biological Control. Sponsored jointly by ARS and CSREES Initiative for Future Agricultural and Food Systems, Denver, CO, 26-31 January 2004 (250 people attended).

6) Presented a 20 min. talk "Saltcedar Biological Control Update" to the Texas Riparian Invasive Plant Task Force, Austin, Texas, 26 February 2004 (60 people attended).

7) Presented a 10 min. talk entitled "Identifying and prioritizing critical research gaps, data, and information needs: biological control", and presented 2 posters, and participate in planning sessions at the symposium Team Tamarix: Cooperating for Results, Albuquerque, NM, 31 March-2 April 2004 (300 people).

8) Attended meeting and made a 10 min. presentation "Need for cooperation between U.S. and Mexico on release of *Dirohabda* beetles along the Rio Grande", to the Rio Grande Institute, at Alpine, TX, 1 July 2004 (15 people including 2 scientists from Mexico).

9) Presented a 15-minute paper, "Overview of Saltcedar Biological Control" to the session Ecology, Monitoring and Management of Tamarisk, at the Monitoring Science and Technology Symposium, Denver, CO, 20-24 September 2004.

10) Attended the V Symposium on Ecology of the Chihuahuan Desert sponsored by the Chihuahuan Desert Research Institute (CDRI) and made a 15 min presentation entitled "Research on Biological Control of Saltcedar in the United States, with Emphasis on Texas and New Mexico" at Sul Ross University, Alpine, TX, 15 October 2004 (40 people attended).

11) Presented a seminar to Department of Entomology, Texas A&M University 16 September 2004, "Biological Control of Saltcedar" (40 people attending).

12) Presented an after dinner talk, "Biological Control of Saltcedar" to the North Austin Rotary Club, 1 November 2004 (50 people attending).

13) Presented four papers as part of Section C Symposium: The Biological Control of Saltcedar (Tamarix spp.): Multidisciplinary Approaches Enhance Results, Entomological Society of America Annual Meeting, Salt Lake City, UT, 15-18 November 2004 (100 people attending) by 1) C.J. DeLoach, R.I. Carruthers, F. Nibling, A. Knutson and E. Delfosse entitled, "Use of *Diorhabda elongata* in the Biological Control of Saltcedar: An Overview", by DeLoach. 2) Presented a joint paper by J.L. Tracy, L. Milbrath and C.J. DeLoach (presented by Tracy), entitled "Taxonomy and biogeography of the

Diorhabda elongata species group: Using GIS modeling to match source populations of biological control agents to introduction sites". 3) L.R. Milbrath, "Host range testing of multiple populations of *Diorhabda elongata*". Presented a joint poster, "Release of *Diorhabda elongata* (Chrysomelidae) for biological control of saltcedar in Texas" by Allen Knutson, C.J. DeLoach, J. Hudgeons and K. Hienz. *amarix* spp.): Multidisciplinary Approaches Enhance Results, Entomological Society of America Annual Meeting, Salt Lake City, UT, 15-18 November 2004 (100 people attending).

14) Presented a seminar, "Progress in Biological Control of Saltcedar", to the joint Entomology Department, New Mexico State University/USDA Rangeland Ecology, Las Cruces, NM, 8 December 2004 (35 people attending).

15) Attended the U.S.-Mexican Border 2012 Environmental Program New Mexico-Texas-Chihuahua Water Task Force, and made a 40 min. presentation, "Biological Control of Saltcedar", with discussion of U.S.-Mexican cooperation. 9 December 2004, Cd. Juarez, Chihuahua, Mexico (35 people attending).

2005

1) Meeting with NRCS State Office, Temple, made 20 min. presentation (with Allen Knutson TAES Dallas) "Research progress and needs of Saltcedar Biological Control Program", and held discussion on these issues. 3 February 2005.

2) Discussed saltcedar biological control and attended a site visit to the Matador Wildlife Management Area, Paducah, TX regarding the MWMA's participation in the program. 16 February 2005.

3) Attended an informational meeting with Texas Department of Agriculture and other agencies on biological control of saltcedar: results and issues, 28 February 2005, Austin, TX (17 people attending).

4) Organized and led the discussion of the First (Organizational) meeting of the "Saltcedar Biological Control Consortium – Texas, New Mexico, Mexico Section". Presented an "Overview of biological control of saltcedar" (48 people attending). El Paso, TX, 29-30 March 2005.

5) Invited to attend and make a 15 min. presentation, "Update on biological control of saltcedar", to the Rio Grande Institute, 31 March – 3 April 2005, Indian Hot Springs, TX.

6) Attended the 45th Annual Meeting of the Aquatic Plant Management Society, and presented a paper, "Overview of the Saltcedar Management Program in the Southwest with Emphasis on Biological Control", by R.I. Carruthers, C.J. DeLoach, D.W. Bean and G.L. Anderson. San Antonio, TX, 10-13 July 2005. (200 people attended)

7) Attended the Annual Meeting of Cooperative Regional Project W-1185 "Biological Control in Pest Management Systems of Plants" and made a 20 min. presentation, "Progress in Biological Control of Saltcedar and Research on New Control Insects in Kazakhstan", by C.J. DeLoach and R.V. Jashenko. Cloudcroft, NM, 4-6 October 2005. (38 people attended)

8) Attended the Tamarisk Symposium of the Tamarisk Coalition and presented a paper, "Overall Bio-control program: The permitting process and Research

below the 37th parallel, including research in Kazkahstan", by R.I. Carruthers, C.J. DeLoach and R.V. Jashenko. Grand Junction, CO, 12-13 October 2005. (300 people attended)

9) Organized, chaired and made a 20 min. presentation, "Progress in Biological Control of Saltcedar in Texas", to the annual meeting of the Texas Noxious Weed Working Group, Temple, TX, 18 October 2005. (30 people attended)

10) Meet with ARS Office of International Research Programs (OIRP) in Washington about research accomplishments and future needs of the Almaty, Kazakhstan biological control research station, with Roman Jashenko, 2 November 2005.

11) Attended the first meeting of the Texas Invasive Plant Conference, served as moderator of the Research Section, and made a 20 min. presentation "Research on Biological Control of Saltcedar (*Tamarix* spp.) in Texas", by C.J. DeLoach et al., and presented a poster, "Biological Control of Saltcedar in Northwestern U.S. and in TX, NM", Lady Bird Johnson Wildflower Center, Austin, TX, 17-18 November 2005 (200 people attended).

2006

1) Attended the Southwestern Branch Annual Meeting, Entomological Society of America and made 2oral presentations, 1) "Initial success in biological control of saltcedars in Texas/New Mexico", by C.J. DeLoach, A. Knutson, T. Thompson, P. Moran and J. Michels (ca. 100 people attended); and 2) "Process involved in the import and release of exotic saltcedar", by C.J. DeLoach, 30 January – 1 February 2006 (ca. 50 people attended).

2) Organized and led discussion of the second annual meeting of the "Saltcedar Biological Control Consortium – Texas, New Mexico, Mexico Section", 2-3 March 2006, Austin, TX (47 people attending representing 19 organizations).

3) Made a 45 min. presentation, "Progress on biological control of saltcedar in northwest Texas" at the Saltcedar Biological Control Consortium – TX, NM, Mexico Section, Austin, TX, 2 March 2006 (47 people attending).

4) Made two 30 min presentations, "Progress in biological control of saltcedar" to Area Director and personnel of the USDA-ARS-Southern Plains Area the Area Director and other personnel and discussed program needs. College Station, TX, August 2006 (20 people attending) and to the new Area Director on 30 October 2006.

5) Participated in planning workshop "Saltcedar control" and made a 30 min presentation, "Biological control of saltcedar along the Rio Grande of Trans Pecos, Texas" sponsored by the *Tamarix* Control Committee (TACCO), Rio Grande Institute, Sul Ross University and USDA-NRCS, Chihuahuan Desert RC&D. Alpine, TX, 1 September 2006 (20 people attending).

6) Attended annual meeting of the Tamarisk Coalition and was junior author on 3 oral presentations: a) "Regional testing of *Diorhabda elongata* ecotypes" by P. Dalin, T. Dudley, D.C. Thompson, D.W. Bean, D. Eberts, D. Kazmer, J. Michels, P. Moran, J. Milan, C.J. DeLoach. b) "Impacts of the saltcedar leaf beetle on saltcedar (*Tamarix* spp.) water use in central Nevada", by R.R. Pattison, C.M. D'Antonio, T. Dudley, K. Allanae. c) "Upper Colorado River saltcedar management program", by A. McGinty, B. Brooks, J. DeLoach, A.

Knutson, M. Muegge and O. Thornton, Ft. Collins, CO, 3-4 October 2006 (attended by 150 people). Also was junior author on 3 posters: a) "Effects of herbivory by *Diorhabda* leaf beetles on carbohydrate reserves of Tamarisk", by J. Hudgeons, A. Knutson, K.M. Heinz, C.J. DeLoach, and T. Dudley. b) "New potential agents for tamarisk biocontrol in U.S.", by R.V. Jashenko, I.D. Mityaev and C.J. DeLoach. c) "Implementing biological control of *Tamarix* with leaf beetles in West Texas", by A. Knutson, M. Muegge and C.J. DeLoach.

7) Participated in workshop with NRCS-Alpine, Sul Ross University and Rio Grande Institute for release of beetles along Rio Grande, Alpine, TX 1-3 November 2006.

8) Invited to attend workshop with U.S. and Mexican scientists and managers on possible joint release of *Diorhabda* beetle for control of saltcedar along the Rio Grande between Texas and Chihuahua, sponsored by U.S. International Boundary and Water Commission and made a 30 min. presentation, "Biological control of saltcedar along the Rio Grande Valley, TX", El Paso, TX, 16 November 2006 (attending were 8 people from Mexico, 9 from U.S.).

2007

1) 6 February 2007 – Attended the Weed Science Society of America Annual meeting and made a 15 min. illustrated oral presentation, "Biological control of saltcedar (*Tamarix* spp.) in Texas and New Mexico", San Antonio, TX (35 people attending).

2) 10 February 2007 – Attended the "Master Naturalist Club" meeting and made a 2 hr illustrated presentation, "Progress in biological control of saltcedar in Texas", Big Spring, TX (ca. 40 people attending).

3) 6-7 March 2007 – Organized, led discussion and made a 20 min. overview of biological control of saltcedar in Texas at the Saltcedar Biological Control Consortium, 3rd Annual Meeting, El Paso, TX (55 people attending).

4) 8 March 2007 – Attended a meeting between IBWC (U.S.) and CILA (Mexico) to discuss, "Concerns related to biological control of saltcedar along the Rio Grande, Texas", made a 30 min. illustrated presentation and participated in 1 hr. discussion. Juarez, Mexico (30 people attending).

5) 20-25 April 2007 – Attended the 12th International Symposium on Biological Control of Weeds, and presented a 20 min. illustrated oral presentation, "Beginning success of biological control of saltcedar (*Tamarix* spp.) in the southwestern United States", La Grand Motte, France (200 people attending).

6) 25 June 2007 – Attended meeting and participated in the discussion between U.S. and Mexican scientists, "Discussion of Mexican concerns relative to saltcedar biological control along the Rio Grande of Texas", Cuidad Juarez, Chihuahua, Mexico (15 people attending).

7) Moran, P.J., C.J. DeLoach, J. Goolsby, A. Kirk, J.H. Everitt, C. Yang, D.F. Spencer, A. Pepper, A. Contreras-Arquieta and F. Nibling. Biological control of saltcedar and giant reed in the lower Rio Grande Basin. Texas Aquatic Plant Management Society Annual Conference, September 17-19, 2007.

8) 19-21 September 2007 – Attended the Texas Plant Conservation Conference at the Ladybird Johnson Wildflower Center in Austin, TX and made a 20 min.

presentation, "Biological control of Tamarisk" (100 people attending).

9) 13 November 2007 – Organized and attended the annual meeting of the Texas Noxious Weed Working Group, Ladybird Johnson National Wildflower Center, Austin, TX and made a 20 min. presentation, "Update on biological control of saltcedar (*Tamarix* spp.) in Texas and New Mexico" (25 people attending).

10) 4 November 2007 – Attended the Texas Invasive Plant Conference, Ladybird Johnson National Wildlife Center, Austin, TX and made a 20 min. presentation, "Progress in biological control of saltcedar (*Tamarix* spp.) in Texas" (150 people attending).

11) 9-13 December 2007 – Attended the annual meeting of the Entomological Society of America meeting, San Diego, CA and made two 15 min. presentations, 1) "Monitoring, dispersal, and impact of southern-adapted *Diorhabda* beetles along the Colorado and Rio Grande of Texas" and 2) remote Powerpoint presentation, "Taxonomy and biogeography of the *Diorhabda elongata* species group: Matching *Diorhabda* species and species climatypes to ecoregions of the western North American tamarisk invasion" by James R. Tracy who could not attend.

Other Recorded Public Communications

2004

1) Knutson, A., M. Muegge and C. J. DeLoach. 2003. Biological Control of Saltcedar. Texas Cooperative Extension Brochure.
2) 25 min. oral testimony to the House Committee on Agriculture and Livestock, Texas Legislature, 14 July 2004.
3) Participated in and organized and prepared script for his section of "Biological Control: The War on Saltcedar" DVD and tape, published by ARS Communications Division, 30 March 2004. 19 min.

2006

1) Attended presentation, to receive the award, "ARS Senior Scientist of the Year for the Southern Plains Area", Department of Agriculture, Washington, D.C., 7 February 2006.
2) Made site visit to Drs. Roman Jashenko and Ivan Mityaev, cooperating biological control of weeds laboratory, Tethys Scientific Society and Kazakhstan Academy of Agricultural Sciences. Reviewed previous research, planned future research, made two field trips of 5 days and 1 day to observe ecology of potential new insects for biological control of saltcedar and Russian olive. Almaty, Kazakhstan, 15-31 May 2006.
3) Hosted Dr. Roman Jashenko, cooperator on biological control, Tethys Scientific Society, Almaty, Kazakhstan during his site visit to Temple, discussed research plans and needs, 16-18 July 2006.

Field Days

2004

1) Attended a field day at Lovelock, NV to observe the 5000 acre defoliation of saltcedar by *Diorhabda* beetles released in May 2001. Discussed the Texas project

with the USDA National Invasive Species Coordinator and others, 19-21 July 2004.

2005

1) Participated in a site review by the Texas State Soil and Water Conservation Board and the U.S. Environmental Protection Agency. Made a 20 min. presentation and conducted a site tour, 23 May 2005, Big Spring, TX.
2) Led field tours and made 15 min. presentations of progress on biological control of saltcedar near Big Spring, TX to each of three science classes from Coahoma High School. 14 September 2005. (38 students and teachers attended)
3) Conducted a field day at Big Spring, TX including 30 min. illustrated background presentation followed by a visit to the field site. Attended by 18 persons. 22 September 2005.
4) Organized, made a 30 min. presentation, and conducted a field demonstration of biological control of saltcedar. Big Spring, TX, 19 October 2005. (21 people attended)

2006

1) Invited by the Skyline Cooperative Weed Management Area to make a 1 hour presentation, "Theory and methodology of biological control of saltcedar", Moab, UT, led discussion and joined the field trip to the Colorado River to observe 11 river miles of saltcedar controlled during 1 year after release of *Diorhabda* beetles tested at Temple, TX (attended by 250 people, all expenses paid), 22-25 August 2006.
2) Attended meeting with landowners from along the Rio Grande to sign up for release of saltcedar leaf beetle on their properties, made a 30 min presentation on the use of biological control for management of saltcedar. At Rancho Pensado, Candelaria, TX, 2 September 2006 (20 people attending) (sponsored by same group as in 12 above).
3) Participated in the "Howard County Agricultural Exposition" at Big Spring, and the "Saltcedar Beetle Field Day" that was part of the Exposition, at which he made an oral presentation at Howard College, "Biological control: risks and benefits, origin and host range testing of saltcedar beetle", (30 min., ca. 60 people attending), and at the field site made a (15 min.) presentation, "History and status of beetles" (15 min.) at the field site and conducted a guided tour of the site to observe the beetles and defoliation of saltcedar (attended by 18 people), 13 September 2006.
4) Organized and conducted two additional similar field days with the same presentation at the Colorado River Municipal Water District headquarters (attended by ca. 15 people each), each followed by a guided tour to the field site, 18 September and 18 October 2006 (attended by ca. 15 people each).

5) High school field day (2 science classes, Couhoma High School), September 20 & 21, 2006.

2007

1) 6-9 September 2007 – Hosted visiting scientists Dr. Ray Carruthers, USDA-ARS-EIWRU, Albany, CA and Dr. Bill Palmer, Alan Fletcher Research Station, Sherwood, Australia on site visits to our project on biological control of saltcedar.
2) 13 September 2007 – Organized and led a public field day at Big Spring, and presented 30 min. talk, Progress in biological control of saltcedar in Texas", at the

Colorado River Municipal Water District headquarters, and made field trip to three sites where *Diorhabda* has defoliated saltcedar along Beals Creek, two on Higgins Ranch and one at CRMWD pump station and Krampf property downstream. Texas Farm Bureau made video in field (34 people attending).

3) 19 September 2007 – Conducted Field Trip for students of two science classes at Coahoma High School to see and discuss the saltcedar biological control program at the Higgins Ranch, Big Spring, ca. 30 students and teachers attended (led by technicians James Tracy and Tom Robbins).

Field Days

2008

1) 15 September 2008 – Big Spring, TX (44 persons attending).
2) 16 September 2008 – Presidio, TX (22 persons attending).
3) 2 October 2008 – Big Spring, TX (16 persons attending).

Town Meetings

2004

1) Attended a town meeting to discuss biological control of saltcedar, Ira, Texas, 23 March 2004 (50 people).
2) Presented a public seminar, "Biological Control of Saltcedar", Alpine, TX, 1 July 2004 (35 people).

2006

1) Participated in three town meetings, made a presentation at each, "Use of biological control to manage exotic invasive saltcedars in the Upper Colorado River watershed of northwestern Texas", and led discussion with local landowners 1) at Big Spring, TX on 24 January, 2) at Robert Lee on 25 January, and 3) at Colorado City on 26 January 2006 (30 go 50 people attended each meeting).
2) Visited two Native American tribes, Zia Pueblo and Jemez Pueblo, NM, made a presentation at each, "Usefullness of biological control for managing saltcedar on Native American Tribal lands", and led discussion, together with Joseph Alderete, USDI Bureau of Reclamation, Albuquerque and David Thompson, Department of Entomology, Plant Pathology and Weed Science, New Mexico State University, Las Cruces, 1-2 May 2006 (10-15 people attending each meeting).
3) La Junta Saltcedar Control Project, Public Meeting. Description of Project on Rio Grande TX border, Tyrus Fain, Rio Grande Institute, Project Manager, Mark Donet, NRCS, Chihuahuan Desert RC&D, Co-Manager; Jack DeLoach, Chair Technical Advisor, www.riogrande.org , 3 August 2006. Candelaria, TX.

2007

1) 11-12 June 2007 – Attended two U.S. National Park Service, Public Scoping Meetings, and made a 20 min. presentation to each, "Biological control of saltcedar: methodology, use along the Rio Grande, TX and potential benefits or harm to the environment", at Alpine 11 June, 10 people, and at Terlingua, 12 June, 7 people.
2) 16 June 2007 – Public meeting with landowners/ranchers and others and made a 30 min. presentation, "Progress in biological control of saltcedar along the Rio Grande, TX", Rancho Piensado, Candelaria, TX (30 people attending).

Newspaper Articles

2004

1) Newspaper article, "6-legged critter may be best defense against saltcedar". Big Bend Sentinel 15 April 2004.
2) Farm press article: "Project aims to bug saltcedar to death using special beetles". Livestock Weekly, pp. 27-28. 13 May 2004.
3) Newsletter: "Beetles get rave reviews in West Texas debut: Small new residents could shred problem plant". The Windmill (quarterly newsletter of the Colorado River Municipal Water District), Big Spring, TX, April-June 2004, pp. 2-4.
4) Newspaper website: "Valley's water hopes may rest on insect. Researcher's beetle has chewed its way through acres of water-guzzling saltcedar in Nevada". The Desert Sun, Palm Springs, CA. http://www.thedesertsun.com/news/stories2004/features/20040803000118shtml. 9 August 2004.

2005

1) Newspaper article, "Beetle may cure saltcedar woes", 14 April 2005, Temple Daily Telegram.
2) Newspaper article, "War of the exotic species in the West", 1 August 2005, USA Today.
3) Newspaper article, "Battle of the Bug: Beetles recruited in fight to control water-guzzling tree". Lubbock Avalanche-Journal, 7 August 2005.
4) Newspaper article, "Salt cedar foes put hopes in saltcedar beetles", 11 August 2005, San Antonio Express News.
5) Newspaper article, "Finding an enemy for salt cedar", 12 August 2005, Waco Tribune-Herald.
6) Newspaper article, "Tracking the magical salt cedar beetle", 12 August 2005, Austin American-Statesman.
7) Newspaper article, "It's so different". San Angelo Standard Times, September 4, 2005.
8) Newspaper article, "Beetles used to control salt cedar". Big Spring Herald, Weekend Edition, 17-18 September 2005.
9) Newspaper article, "Bugs get a buffet". Fort Worth Star Telegram, p. B1 & B10, 27 December 2005.

2006

1) Newspaper article, "Better beetle sought for saltcedar control", Science Daily, Texas A&M University – Agricultural Publications 2(2):10-14.
2) Newspaper article, "Search for best salt cedar eating beetle continues", Temple Daily Telegram, Temple, TX, 17 July 2006, p. 2A.
3) Newspaper article, "Ranchers – bugs – fight saltcedar infestations along Rio Grande", Border Hotline News, 22 August 2006.
4) Newspaper article, "Ranchers targeting Rio Grande saltcedar infestations", Big Bend Gazette (Vol. 6, No. 9), September 2006, pp. 22-23.
5) Newspaper article "Government, landowners combine for salt cedar control project". Livestock Weekly, pp. 8-9.

2007

1) 6 July 2007 – Newspaper article, "Crete beetles could solve salt problem in Pecos River", The Monahans News 75(79):1.
2) July 2007 – Circular article: Glendinning, J., "A tiny solution to one of the Rio Grande's biggest problems? Meet the Crete beetle…", The Big Bend Gazette 7(7):4.
3) 19 August 2007 – Newspaper article, "Scientists hope beetle will mitigate salt cedar infestation", The Big Bend Sentinel, 19:1,4.

2008

1) 23 March 2008 – Newspaper article, "This beetle can save our water", Las Vegas Sun.
2) May 2008 – Newspaper article, "Will beetles take a bite out of saltcedar", The Big Spring Gazette.

Magazine Articles

2005

1) Agricultural Research Service article: "Beneficial beetles take a bite out of saltcedar". Agricultural Research pp. 4-7. April 2005.
2) Texas Parks and Wildlife article: "Mean green aliens". pp. 50-55. July 2005.

2006

1) Magazine article, "Better beetle sought for saltcedar control", AgNews – News and Public Affairs, Texas A&M University System Agricultural Program. 26 June 2006.
2) Magazine article, "Texas Cooperative Extension sets Big Spring saltcedar field day for September 13th". AgNews: News and Public Affairs, Texas A&M University System Agricultural Program, 31 August 2006. 2 pp.

2008

1) Magazine article, "Weedy New World". Zoogoer Vol. 34(3):16-23, May/June 2008.

APPENDIX C

MONITOR CONTROL OF SALTCEDAR AND EFFECTS IN THE ENVIRONMENT: Monitor saltcedar and native plant communities

Prepared by James L. Tracy

Introduction

Exotic saltcedars, primarily *Tamarix chinensis* × *T. canariensis* hybrids (*T. chinensis/T. canariensis*), are the dominant woodland species much of the Upper Colorado River basin in Texas. Native riparian woodland and marsh communities of the area, primarily honey mesquite (*Prosopis glandulosa* var. *glandulosa*) and baccharis (*Baccharis neglecta*) with isolated areas of black willow (*Salix nigra*) and plains cottonwood (*Populus deltoides*), and cattails (*Typha latifolia*) and bulrushes (*Schoenoplectus americanus*) probably provide a more diversified and valuable source of wildlife habitat compared to dense stands of saltcedar. Baseline vegetation monitoring was carried out, primarily at the Beals Creek study area, in order to document changes in vegetation percent cover that will result after about 95% reductions in saltcedar canopy following biological control. Future vegetation monitoring will be necessary to compare with these baseline data to document vegetation changes.

Methods

Beals Creek Study Area. USDA-ARS visually estimated the percent cover of vegetation at different height levels as an indicator of wildlife (especially bird) habitat quality within each of thirteen 50 m radius bird point count areas (plots) from 13–15 August, 2006 and eight 50 X 150 m bird strip count plots from 10 September–15 November, 2006 in riparian woodlands in the vicinity of Beals Creek, on the east side of Big Spring, Texas (Fig1.; see bird survey report for more detailed aerial photos of survey areas). Latitude and longitude are recorded for all plots (see bird survey report). Percent vegetation cover was also recorded in several additional plots and transects in areas of heavily beetle defoliated saltcedar, but these data are not yet summarized. Six point plots each were located in native woodland (primarily western honey mesquite) (Fig. 1A), seven point count plots in saltcedar woodland habitat (Fig. 1A, 1B), and eight strip count plots in mixed saltcedar/mesquite creekside woodland habitat (Fig. 1A). In point count areas, two 7 m radius subplots were established 25 m from the center of each plot (each subplots represents 2% of the total plot area) (Fig. 2A). In strip count areas, two 7 m radius subplots were established 50 m from the edge of each plot (Fig. 2B). Within each subplot, visual estimates were made of the composition of percentage cover for the entire subplot, including each species of plant and physical features such as bare ground, open air and surface water, similar to the procedure described in Hennings and Edge (2003). Estimates of percentage cover were made for three vegetation height layers: herbaceous layer at 0.00–0.50 m; shrub layer at 0.50–2.0 m; tree layer at 2.0–5.0 m; and, when rarely present, higher tree layers at 5.0 m increments (Fig. 3). A meter stick was sometimes used to facilitate estimation of square meters cover of plant species or physical features which was then converted to percentage total cover of the subplot (1.5 sq. m is approximately 1 percent of the area of the 154 sq. meter subplots). Subplots were sometimes divided into halves or quarters using meter tape to facilitate estimations. Percent cover data for each plot was computed from an average of the subplots. Percent frequency of occurrence of plant species among plots is also calculated.

Lake Thomas Study Area. USDA-ARS visually estimated the percent cover of vegetation at two different height levels (0.0–1.0 m and 1.0 – 10.0 m) within forty 1 X 1 m quadrats bisecting the edge of the canopy of marked saltcedar trees on the north side of Lake Thomas west of Snyder, Texas on 10 August, 2004 (Fig. 4).

Results and Discussion

Beals Creek Study Area

Herbaceous Layer (0.0–0.5 m) Percent Cover. The percent cover of the herbaceous layer of native woodland is fairly diverse (Tables 1–3; Figs. 5 and 6), with western ragweed (11%), plains bristlegrass (6%), and the exotic weed common horehound (5%) being among the common plants. In the saltcedar woodland, diversity is much lower, with highest percent cover from Mexican fireweeda (16%) and saltcedar (14%) followed by inland saltgrass (9%) and alkali seepweed (5%). Percent cover in mixed saltcedar/mesquite woodland is also more diverse than saltcedar woodland and is greatly dominated by alkali sacaton (49%) followed by saltcedar (7%). Species diversity per plot in the herbaceous layer of the native woodland (37.7 species) is much higher than in the saltcedar woodland (8.4 species) (Table 1). The Shannon-Weaver diversity index per plot of the herbaceous layer in native woodland (2.46) is also much higher than that found in saltcedar woodland (1.14) (Table 1). The total number of plant species in native woodland plots (106) is much higher than the number of species in saltcedar woodland plots (27) (Table 1).

Shrub Layer (0.5–2.0 m) Percent Cover. The percent cover of the shrub layer of native woodland is dominated by western honey mesquite (8%), western ragweed (8%), and little-leaf sumac (7%) (Table 4–5, Fig. 7). Other plants of the native woodland with percent covers from 2–5% include netleaf hackberry, lotebush, pinchot juniper, camphorweed and common sunflower. The percent cover of saltcedar woodland is dominated by saltcedar (34%). The only other plants of significance in the saltcedar shrub layer are willow baccharis and cattail, both with percent covers around 2.5%. Percent cover in mixed saltcedar/mesquite woodlands is highest in saltcedar (14%), honey mesquite (3%) and various broadleaf perennials such as common broomweed (3%) (Fig. 11). Both the number of species per plot and Shannon-Weaver Diversity Index is much higher in native compared to saltcedar woodland plots. Native woodlands have 59 species in the shrub layer compared to 15 species for saltcedar woodland (Table 4).

Tree Layer (2.0–5.0 m) Percent Cover. The percent cover of the tree layer of native woodland is dominated by honey mesquite (17%), net-leaf hackberry (9%) and gum bumelia (4%) (Table 6; Fig. 8). Other trees and shrubs of the native woodland with percent covers around 2% include little-leaf sumac, lotebush, and toothache tree. The percent cover of the tree layer in saltcedar woodland is dominated by saltcedar (47%), followed willow baccharis (1%), both of which have percent covers much higher than in native woodland. Percent cover of dead wood is also much higher in the saltcedar compared to native woodland (Fig. 8). In the mixed saltcedar/mesquite woodland, percent cover was dominated by saltcedar (15%) and honey mesquite (3%) (Fig. 12). Both species diversity per plot and the Shannon Weaver diversity indices per plot are much higher in the tree layers of the native compared to saltcedar woodlands (Table 6). Native woodlands have 15 species in the tree layer compared to 5 species for saltcedar woodland (Table 6).

Percent Frequency. Trees with the highest percent frequency in native woodland plots were western honey mesquite (100%), net-leaved hackberry (83%), and gum bumelia (50%) (Table 7). Percent frequency of saltcedar (100%) and net-leaved hackberry (14%) were highest among trees in the saltcedar woodland plots. In the mixed saltcedar/mesquite woodland plots, trees of the highest percent frequency were saltcedar (100%), honey mesquite (88%), and net-leaved hackberry (50%). Percent frequency among shrubs of native woodland plots was 67% for six species, including little-leaf sumac, Torrey wolfberry, agarito, Pinchot juniper, lotebush, and small soapweed. In contrast, willow baccharis was the single shrub found in saltcedar woodlands where it occurred at 71%. The shrub with the clearly highest percent frequency in the mixed saltcedar/mesquite woodlands was Torrey wolfberry (88%). The two vines Old-man's beard and balsam gourd only had high percent frequencies in the native woodlands where they occurred at 67%. Among grasses of native woodland plots, percent frequency of plains bristlegrass (100%) was highest followed by alkali sacaton (83%), hooded windmill (67%), and rescue grass (50%). The most frequent grasses in saltcedar woodland are alkali sacaton (43%) and plains bristlegrass (29%). In mixed saltcedar/mesquite woodland, the most frequent grasses are alkali sacaton (100%), inland saltgrass (75%), and plains bristlegrass (63%). Broadleaf herbs in native woodlands with highest percent frequencies include silverleaf nightshade (100%), spear-leaf sida (100%), western ragweed (83%), and cocklebur (83%). Percent frequencies of the annuals canela (71%) and Mexican fireweed (57%) were among the highest of broadleaved herbs in saltcedar woodland plots. In mixed saltcedar/mesquite woodland plots, the highest percent frequencies among herbs are among camphorweed (100%), silverleaf nightshade (88%), cocklebur (75%), and common broomweed (75%).

Plants for Revegetation in Saltcedar Woodlands. Following selective reduction in saltcedar canopy from biological control, the associated flora should expand and passively revegetate the areas once occupied by saltcedar. In some areas, it may be desirable to artificially revegetate certain high wildlife value plants growing commonly in nearby native woodlands but that are rare in saltcedar woodlands. Among native trees, western honey mesquite and net-leaf hackberry are the most commonly found growing associated with saltcedar and these species both have higher wildlife/livestock value than saltcedar (Table 7). Honey mesquite and net-leaf hackberry should gradually increase following biological control through increased growth of existing smaller trees and new seedlings freed from competition with saltcedar for light and water. Faster growing Great Plains cottonwood and black willow are of higher wildlife value than saltcedar, especially for bird cover and nesting, but they are localized in occurrence in native woodlands and would probably require pole propagation to spread rapidly.

Shrubs of willow baccharis and Torrey wolfberry are frequent among the saltcedar and saltcedar/mesquite woodland plots (Table 7). Following saltcedar biocontrol, willow baccharis and Torrey wolfberry should spread fairly rapidly both vegetatively and by seed. Primary grasses found in saltcedar and mixed saltcedar/mesquite woodland are alkali sacaton, plains bristlegrass, white tridens, and inland saltgrass, all of which are fair to good for grazing (Powell 1994), but only plains bristlegrass is of much value for wildlife (as a grain source; Martin *et al.* 1951). Sunflower, silverleaf nightshade, and western ragweed are the only herbs frequent in saltcedar or mixed saltcedar/mesquite woodlands of much value to wildlife or livestock (Table 7). Many herbs common in saltcedar, such as Mexican fireweed, canela, cocklebur, and camphorweed, are of poor value for wildlife or livestock.

Lake Thomas Study Area

Herbaceous Layer (0.0–1.0 m) Percent Cover. The percent cover of the herbaceous layer under saltcedar canopies is fairly diverse (Fig. 13), with frogfruit (22%), willow baccharis (8%), and the horseweed (5%) being among the common plants. Spiny aster and Bermuda grass are both around 2.5% percent cover.

Tree-Shrub Layer (1.0–10.0 m) Percent Cover. The percent cover of the tree-shrub layer of the saltcedar canopy is naturally dominated by saltcedar at 60% followed by willow baccharis at 3%. Black willows are fairly common in this area along the Colorado River.

Conclusion

Native riparian woodlands in the Beals Creek area are dominated by western honey mesquite in the shrub and tree layers with little-leaf sumac as the most common shrub. Saltcedar woodlands are dominated by saltcedar with small amounts of willow baccharis and cattail in the shrub layer. Both saltcedar and mesquite dominate the shrub and tree layers of the mixed saltcedar/mesquite woodland. Small amounts of a variety of shrubs such as Torrey wolfberry and Pinchot juniper that occur in native and mixed saltcedar/mesquite woodland habitats are apparently rare in saltcedar woodland. Shrub and herbaceous species diversities are much higher in native and mixed saltcedar/mesquite woodlands compared to saltcedar woodland. A decrease in saltcedar mixed saltcedar/mesquite woodland following biological control should allow associated native flora to spread leading to increased plant diversity and wildlife habitat value. Several of the woody species common in mixed saltcedar/mesquite woodland such as western honey mesquite and Torrey wolfberry are being used in revegetation efforts for saltcedar infested areas (Lair 2006a, 2006b). The frequency of these high wildlife value species among mixed saltcedar/mesquite is favorable for vegetation restoration along Beals Creek. Various native herbaceous species should also increase following saltcedar biological control in mixed saltcedar/mesquite woodland, such as alkali sacaton, inland saltgrass, vine mesquite, alkali seepweed, and camphorweed. Following saltcedar biological control in more monotypic saltcedar woodland, native willow baccharis is the only native woody species of notable presence likely to spread and these habitats are expected to become more dominated by native herbaceous vegetation such as Mexican fireweed, alkali sacaton, alkali seepweed, Olney's bulrush, and common cat-tail. At Lake Thomas, black willow, willow baccharis and the native herbs frogfruit, horseweed, spiny aster and Bermuda grass should benefit from saltcedar biological control.

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Table 1. Most common woody plant species in the herbaceous layer (0.0–0.5 m) in point count plots of native versus saltcedar woodland.[a]

Species	Percent Cover per Plot (mean ± SD) (range)	
	Native Woodland (n = 6)	Saltcedar Woodland (n = 7)
Trees		
Prosopis glandulosa var. *glandulosa* (honey mesquite)	3.53 ± 4.19 (0.35-11.60)	0.00 ± 0.00 (0.00-0.00)
Celtis laevigata var. *reticulata* (net-leaved hackberry)	0.94 ± 0.87 (0.00-2.30)	0.00 ± 0.00 (0.00-0.00)
Sideroxylon lanuginosum ssp. *rigidum* (gum bumelia)	0.21 ± 0.31 (0.00-0.70)	0.00 ± 0.00 (0.00-0.00)
Tamarix chinensis/T. canariensis (saltcedar)	0.00 ± 0.00 (0.00-0.00)	14.47 ± 7.01 (4.25-26.00)
Shrubs		
Rhus microphylla (little-leaf sumac)	3.67 ± 3.98 (0.00-9.90)	0.00 ± 0.00 (0.00-0.00)
Berberis trifoliolata (agarito)	2.30 ± 2.57 (0.00-6.35)	0.00 ± 0.00 (0.00-0.00)
Juniperus pinchotii (Pinchot Juniper)	1.59 ± 2.26 (0.00-6.05)	0.00 ± 0.00 (0.00-0.00)
Ziziphus obtusifolia (lotebush)	1.55 ± 1.74 (0.00-4.00)	0.00 ± 0.00 (0.00-0.00)
Dalea formosa (feather dalea)	1.00 ± 2.45 (0.00-6.00)	0.00 ± 0.00 (0.00-0.00)
Zanthoxylum hirsutum (toothache tree)	0.80 ± 1.59 (0.00-4.00)	0.00 ± 0.00 (0.00-0.00)
Chrysactinia mexicana (damianita)	0.50 ± 1.30 (0.00-3.00)	0.00 ± 0.00 (0.00-0.00)
Ephedra antisyphilitica (clapweed)	0.45 ± 0.80 (0.00-2.00)	0.00 ± 0.00 (0.00-0.00)
Koeberlinia spinosa (allthorn)	0.39 ± 0.79 (0.00-2.00)	0.00 ± 0.00 (0.00-0.00)
Lycium torreyi (Torrey wolfberry)	0.36 ± 0.42 (0.00-1.10)	0.00 ± 0.00 (0.00-0.00)
Yucca glauca (small soapweed)	0.35 ± 0.34 (0.00-0.90)	0.00 ± 0.00 (0.00-0.00)
Acacia greggii (catclaw acacia)	0.28 ± 0.60 (0.00-1.50)	0.00 ± 0.00 (0.00-0.00)
Condalia ericoides (javalinabush)	0.21 ± 0.51 (0.00-1.25)	0.00 ± 0.00 (0.00-0.00)
Atriplex canescens (four-wing saltbush)	0.17 ± 0.41 (0.00-1.00)	0.00 ± 0.00 (0.00-0.00)
Opuntia engelmannii (Engelmann's Prickly Pear)	0.10 ± 0.24 (0.00-0.60)	0.00 ± 0.00 (0.00-0.00)
Parthenium incanum (mariola)	0.10 ± 0.20 (0.00-0.50)	0.00 ± 0.00 (0.00-0.00)
Baccharis salicina (willow baccharis)	0.00 ± 0.00 (0.00-0.00)	2.24 ± 3.95 (0.00-10.85)

Table 1 (cont.). Most common woody plant species in the herbaceous layer (0.0–0.5 m) in point count plots of native versus saltcedar woodland. [a]

	Percent Cover per Plot (mean ± SD) (range)	
Species	Native Woodland (n = 6)	Saltcedar Woodland (n = 7)
Statistic	Summary Statistics per Plot (mean ± SD) (range) or over all Plots	
Number Species	37.67 ± 11.47 (23–51)	8.43 ± 3.10 (5–13)
Shannon-Weaver Diversity Index	2.46 ± 0.53 (1.57–3.18)	1.14 ± 0.48 (0.73–1.89)
Total Number of Plant Species	106	27

[a] Plants generally with at 0.1 % cover per plot. Data averaged from two to three 7 m radius subplots within 10 bird point count plots (50 m radius). Percent cover calculated from total area of plot (including bare ground). See Tables 2 and 4 for percent cover of herbaceous species and less common species of the herbaceous layer.

Table 2. Most common herbaceous plant species in the herbaceous layer (0.0–0.5 m) in point count plots of native versus saltcedar woodland.[a]

Species	Percent Cover per Plot (mean ± SD) (range)	
	Native Woodland (n = 6)	Saltcedar Woodland (n = 7)
Vines		
Clematis drummondii (Old-man's-beard)	3.34 ± 5.19 (0-13.6)	0.07 ± 0.19 (0.00-0.50)
Ibervillea lindheimeri (Balsam Gourd)	0.58 ± 1.29 (0-3.2)	0.07 ± 0.19 (0.00-0.50)
Matelea biflora (two-flower milkvine)	0.18 ± 0.43 (0-1.1)	0.00 ± 0.00 (0.00-0.00)
Perennial Grasses		
Rhizomatous-Stoloniferous Grasses		
Cynodon dactylon (Bermuda grass)	1.75 ± 4.29 (0.00-10.50)	0.01 ± 0.02 (0.00-0.05)
Digitaria cognata (fall witchgrass)	0.13 ± 0.30 (0.00-0.75)	0.00 ± 0.00 (0.00-0.00)
Panicum obtusum (vine-mesquite)	0.11 ± 0.20 (0.00-0.50)	0.00 ± 0.00 (0.00-0.00)
Distichlis spicata var. *stricta* (inland saltgrass)	0.00 ± 0.00 (0.00-0.00)	9.34 ± 24.70 (0.00-65.35)
Bunch Grasses		
Setaria leucopila (plains bristlegrass)	6.77 ± 5.21 (0.12-14.00)	0.06 ± 0.12 (0.00-0.33)
Sporobolus pyramidatus (whorled dropseed)	3.06 ± 7.49 (0.00-18.35)	0.00 ± 0.00 (0.00-0.00)
Sporobolus airoides (alkali sacaton)	2.09 ± 1.69 (0.00-4.50)	2.96 ± 5.65 (0.00-15.4)
Cenchrus spinifex (common sandbur)	1.65 ± 4.04 (0.00-9.90)	0.00 ± 0.00 (0.00-0.00)
Sporobolus cryptandrus (sand dropseed)	0.96 ± 2.35 (0.00-5.75)	0.00 ± 0.00 (0.00-0.00)
Chloris cucullata (hooded windmill)	0.80 ± 1.87 (0.00-4.63)	0.00 ± 0.00 (0.00-0.00)
Aristida purpurea var. *wrightii* (Wright's three-awn)	0.25 ± 0.61 (0.00-1.50)	0.00 ± 0.00 (0.00-0.00)
Nassella ? (unidentified grass)	0.02 ± 0.04 (0.00-0.10)	0.22 ± 0.57 (0.00-1.51)
Annual Grasses		
Chloris virgata (showy chloris)	1.17 ± 1.90 (0.00-4.40)	0.00 ± 0.00 (0.00-0.00)
Setaria verticillata (hooked bristle grass)	0.80 ± 1.96 (0.00-4.80)	0.00 ± 0.00 (0.00-0.00)
unidentified brown grass	0.41 ± 1.00 (0.00-2.45)	0.00 ± 0.00 (0.00-0.00)
Eragrostis pectinacea var. *pectinacea* (spreading love grass)	0.25 ± 0.61 (0.00-1.50)	0.00 ± 0.00 (0.00-0.00)
Bromus catharticus (rescue grass)	0.23 ± 0.39 (0.00-1.00)	0.29 ± 0.76 (0.00-2.00)
Setaria viridis (green foxtail grass)	0.01 ± 0.02 (0.00-0.05)	1.43 ± 2.45 (0.00-5.40)
Polypogon monspeliensis (rabbitsfoot grass)	0.00 ± 0.00 (0.00-0.00)	0.59 ± 1.51 (0.00-4.01)

Table 2 (cont.). Most common herbaceous plant species in the herbaceous layer (0.0–0.5 m) in point count plots of native versus saltcedar woodland.[a]

Species	Percent Cover per Plot (mean ± SD) (range)	
	Native Woodland (n = 6)	Saltcedar Woodland (n = 7)
Sedges, Rushes and Cattails		
Schoenoplectus americanus (Olney's bulrush)	0.00 ± 0.00 (0.00-0.00)	1.19 ± 1.73 (0.00-4.50)
Typha latifolia (common cat-tail)	0.00 ± 0.00 (0.00-0.00)	2.91 ± 6.16 (0.00-16.50)
Broadleaf Perennials		
Ambrosia psilostachya (western ragweed)	11.71 ± 9.91 (0.00-24.43)	0.01 ± 0.02 (0.00-0.05)
Marrubium vulgare (common horehound)	5.09 ± 7.31 (0.00-18.10)	0.00 ± 0.00 (0.00-0.00)
Rhynchosida physocalyx (spear-leaf sida)	0.33 ± 0.26 (0.10-0.80)	0.00 ± 0.00 (0.00-0.00)
Tetraneuris scaposa (plains yellow daisy)	0.33 ± 0.82 (0.00-2.00)	0.00 ± 0.00 (0.00-0.00)
Rivina humilis (pigeon-berry)	0.30 ± 0.43 (0.00-1.05)	0.00 ± 0.00 (0.00-0.00)
Solanum triquetrum (Texas nightshade)	0.26 ± 0.63 (0.00-1.55)	0.00 ± 0.00 (0.00-0.00)
Solanum elaeagnifolium (silverleaf nightshade)	0.21 ± 0.11 (0.00-0.35)	0.00 ± 0.00 (0.00-0.00)
Gymnosperma glutinosum (tatalencho)	0.17 ± 0.30 (0.00-0.75)	0.00 ± 0.00 (0.00-0.00)
Hedyotis nigricans (prairie bluets)	0.12 ± 0.29 (0.00-0.70)	0.00 ± 0.00 (0.00-0.00)
Datura wrightii (Indian-apple)	0.11 ± 0.27 (0.00-0.65)	0.00 ± 0.00 (0.00-0.00)
Suaeda moquinii (alkali seepweed)	0.03 ± 0.06 (0.00-0.15)	5.24 ± 9.00 (0.00-20.01)
Broadleaf Annuals		
Heterotheca subaxillaris (camphorweed)	5.88 ± 11.44 (0.00-28.75)	0.00 ± 0.00 (0.00-0.00)
Helianthus annuus (common sunflower)	1.83 ± 4.01 (0.00-10.00)	0.00 ± 0.00 (0.00-0.00)
Kochia scoparia (Mexican fireweed)	0.59 ± 0.98 (0.00-2.35)	16.52 ± 20.81 (0.00-45.25)
Conyza canadensis (horseweed)	0.48 ± 1.11 (0.00-2.75)	0.04 ± 0.06 (0.00-0.15)
Erigeron geiseri (basin fleabane)	0.42 ± 1.02 (0.00-2.50)	0.00 ± 0.00 (0.00-0.00)
Euphorbia dentata (horseweed)	0.10 ± 0.16 (0.00-0.30)	0.00 ± 0.00 (0.00-0.00)
Chenopodium album (lamb's-quarters)	0.06 ± 0.14 (0.00-0.35)	0.29 ± 0.76 (0.00-2.00)
Pluchea odorata (canela)	0.00 ± 0.00 (0.00-0.00)	2.01 ± 3.34 (0.00-8.91)
Xanthium strumarium (cocklebur)	0.27 ± 0.44 (0.00-1.15)	0.01 ± 0.02 (0.00-0.05)

Table 2 (cont.). Most common herbaceous plant species in the herbaceous layer (0.0–0.5 m) in point count plots of native versus saltcedar woodland.[a]

	Percent Cover per Plot (mean ± SD) (range)	
Species	Native Woodland (n = 6)	Saltcedar Woodland (n = 7)
Physical Features		
Bare Ground	22.90 ± 12.54 (5.05-37.94)	27.24 ± 20.01 (0.50-64.21)
Dead Wood	4.37 ± 3.97 (0.00-10.50)	12.80 ± 4.57 (6.85-21.75)

[a] Plants generally with at 0.1 % cover per plot. Data averaged from two to three 7 m radius subplots within 10 bird point count plots (50 m radius). Percent cover calculated from total area of plot (including bare ground). See Tables 1 and 3 for percent cover of woody species and less common species of the herbaceous layer. Ranks of means in both columns followed by the same letter are not significantly different (Two-Way Kruskal-Wallis Test; $P < 0.05$).

Table 3. Less common plant species in point count plots of the herbaceous layer (0.0–0.5 m) in plots of native versus saltcedar woodland.[a]

Species	Percent Cover per Plot (mean ± SD) (range)	
	Native Woodland (n = 6)	Saltcedar Woodland (n = 7)
Trees		
Sideroxylon celastrinum (coma)	0.02 ± 0.05 (0.00-0.13)	0.00 ± 0.00 (0.00-0.00)
Viburnum rufidulum (rusty blackhaw)	0.01 ± 0.02 (0.00-0.05)	0.00 ± 0.00 (0.00-0.00)
Shrubs		
Caesalpinia gilliesii (Bird-of-Paradise)	0.05 ± 0.12 (0.00-0.30)	0.00 ± 0.00 (0.00-0.00)
Yucca baccata (banana yucca)	0.05 ± 0.12 (0.00-0.30)	0.00 ± 0.00 (0.00-0.00)
Aloysia gratissima (whitebrush)	0.02 ± 0.04 (0.00-0.10)	0.00 ± 0.00 (0.00-0.00)
Opuntia leptocaulis (tasajillo)	0.01 ± 0.02 (0.00-0.05)	0.00 ± 0.00 (0.00-0.00)
Vines		
Cocculus carolinus (Carolina snailseed)	0.07 ± 0.14 (0.00-0.35)	0.00 ± 0.00 (0.00-0.00)
Cissus incisa (ivy tree-vine)	0.02 ± 0.03 (0.00-0.06)	0.00 ± 0.00 (0.00-0.01)
Smilax bona-nox (saw greenbrier)	0.02 ± 0.04 (0.00-0.10)	0.00 ± 0.00 (0.00-0.00)
Perennial Grasses		
Bothriochloa barbinodis (cane bluestem)	0.008 ± 0.02 (0.00-0.05)	0.00 ± 0.00 (0.00-0.00)
Chloris verticillata (tumble windmill grass)	0.008 ± 0.02 (0.00-0.05)	0.00 ± 0.00 (0.00-0.00)
prob. *Dactylis glomerata* (orchard grass)	0.008 ± 0.02 (0.00-0.05)	0.00 ± 0.00 (0.00-0.00)
Sedges and Rushes		
Schoenoplectus americanus (Olney's bulrush)	0.00 ± 0.00 (0.00-0.00)	1.19 ± 1.73 (0.00-4.50)
Broadleaf Perrenials		
Hedyotis nigricans (prairie bluets)	0.12 ± 0.29 (0.00-7.00)	0.00 ± 0.00 (0.00-0.00)
Datura wrightii (Indian-apple)	0.11 ± 0.27 (0.00-6.50)	0.00 ± 0.00 (0.00-0.00)
Polygala alba (white milkwort)	0.09 ± 0.22 (0.00-0.55)	0.00 ± 0.00 (0.00-0.00)
Physalis cinerascens (beach ground-cherry)	0.07 ± 0.08 (0.00-0.20)	0.01 ± 0.03 (0.00-0.08)
Desmanthus sp. prob. *Velutinus* (vekvet bundleflower)	0.05 ± 0.09 (0.00-0.23)	0.00 ± 0.00 (0.00-0.00)
Atriplex argentea ssp. *Argentea* (silver-scale saltbush)	0.04 ± 0.10 (0.00-0.25)	0.00 ± 0.00 (0.00-0.00)
Abutilon fruticosum (Indian-mallow)	0.03 ± 0.04 (0.00-0.10)	0.00 ± 0.00 (0.00-0.00)
Sphaeralcea lindheimeri (Lindheimer's globe-mallow)	0.03 ± 0.03 (0.00-0.05)	0.00 ± 0.00 (0.00-0.00)
unknown little gray herb	0.03 ± 0.04 (0.00-0.10)	0.00 ± 0.00 (0.00-0.00)
Chamaesyce lata (hoary euphorbia)	0.02 ± 0.04 (0.00-0.10)	0.00 ± 0.00 (0.00-0.00)
Sphaeralcea lindheimeri (Lindheimer's globe-mallow)	0.03 ± 0.03 (0.00-0.05)	0.00 ± 0.00 (0.00-0.00)
Sphaeralcea angustifolia ssp. *cuspidata* (narrow-leaf globe-mallow)	0.02 ± 0.04 (0.00-0.10)	0.00 ± 0.00 (0.00-0.00)

Table 3 (cont). Less common plant species in the herbaceous layer (0.0–0.5 m) in point count plots of native versus saltcedar woodland.[a]

	Percent Cover per Plot (mean ± SD) (range)	
Species	Native Woodland (n = 6)	Saltcedar Woodland (n = 7)
Broadleaf Perrenials (cont.)		
Thelesperma simplicifolium (slender greenthread)	0.02 ± 0.04 (0.00-0.10)	0.00 ± 0.00 (0.00-0.00)
Tiquilia canescens (shrubby coldenia)	0.02 ± 0.04 (0.00-0.10)	0.00 ± 0.00 (0.00-0.00)
Oxalis stricta (gray-green woodsorrel)	0.01 ± 0.02 (0.00-0.05)	0.00 ± 0.00 (0.00-0.00)
unidentified herb (*Eupatorium*?)	0.01 ± 0.02 (0.00-0.05)	0.00 ± 0.00 (0.00-0.00)
Viguiera dentata (sunflower goldeneye)	0.01 ± 0.02 (0.00-0.05)	0.00 ± 0.00 (0.00-0.00)
Rumex crispus (curly dock)	0.00 ± 0.00 (0.00-0.00)	0.05 ± 0.06 (0.00-0.13)
Broadleaf Annuals		
Croton capitatus var. *capitatus* (woolly croton)	0.09 ± 0.23 (0.00-0.55)	0.00 ± 0.00 (0.00-0.00)
Gutierrezia texana (Texas broomweed)	0.08 ± 0.14 (0.00-0.35)	0.00 ± 0.00 (0.00-0.00)
Salsola tragus (Russian thistle)	0.05 ± 0.12 (0.00-0.30)	0.00 ± 0.00 (0.00-0.00)
Chenopodium album (lamb's-quarters)	0.06 ± 0.14 (0.00-0.35)	0.29 ± 0.76 (0.00-2.00)
Gaura parviflora (lizard-tail gaura)	0.04 ± 0.05 (0.00-0.10)	0.00 ± 0.00 (0.00-0.00)
Hedeoma hispida (rough hedeoma)	0.04 ± 0.06 (0.00-0.15)	0.00 ± 0.00 (0.00-0.00)
Chamaesyce prostrata (prostrate euphorbia)	0.03 ± 0.05 (0.00-0.10)	0.00 ± 0.00 (0.00-0.00)
Lactuca serriola (prickly lettuce)	0.03 ± 0.04 (0.00-0.10)	0.02 ± 0.05 (0.00-0.13)
Chenopodium pratericola (thick-leaf goosefoot)	0.02 ± 0.05 (0.00-0.13)	0.00 ± 0.00 (0.00-0.00)
Chenopodium incanum (mealy goosefoot)	0.02 ± .04 (0.00-0.10)	0.00 ± 0.00 (0.00-0.00)
Paronychia lindheimeri sp. (Lindheimer's nailwort)	0.02 ± 0.04 (0.00-0.10)	0.00 ± 0.00 (0.00-0.00)
Amblyolepis setigera (huisache daisy)	0.01 ± 0.02 (0.00-0.05)	0.00 ± 0.00 (0.00-0.00)
Machaeranthera tanacetifolia (coarse vervain)	0.01 ± 0.02 (0.00-0.05)	0.00 ± 0.00 (0.00-0.00)
Sonchus sp. (sow-thistle)	0.01 ± 0.02 (0.00-0.05)	0.00 ± 0.00 (0.00-0.00)
Xanthisma texanum ssp. *drummondii* (Texas sleepy daisy)	0.004 ± 0.01 (0.00-0.03)	0.00 ± 0.00 (0.00-0.00)
Ambrosia trifida (giant ragweed)	0.00 ± 0.00 (0.00-0.00)	0.03 ± 0.07 (0.00-0.18)
Pluchea odorata (canela)	0.00 ± 0.00 (0.00-0.00)	2.01 ± 3.34 (0.00-8.91)

[a] Plants with generally less than 0.1% cover per plot. Data averaged from two to three 7 m radius subplots within 10 bird point count plots (50 m radius). Percent cover calculated from total area of plot (including bare ground). See Tables 1 and 2 for percent cover of more common woody and herbaceous species of the herbaceous layer.

Table 4. Woody plants, vines and common herbaceous species in the shrub layer (0.5–2.0 m) in point count plots of native versus saltcedar woodland.[a]

Species	Percent Cover per Plot (mean ± SD) (range)	
	Native Woodland (n = 6)	Saltcedar Woodland (n = 7)
Trees		
Prosopis glandulosa var. *glandulosa* (honey mesquite)	9.09 ± 9.64 (1.05-26.50)	0.00 ± 0.00 (0.00-0.00)
Celtis laevigata var. reticulata (net-leaf hackberry)	4.31 ± 4.31 (0.00-9.50)	0.00 ± 0.00 (0.00-0.00)
Sideroxylon lanuginosum ssp. rigidum (gum bumelia)	1.01 ± 1.60 (0.00-3.75)	0.00 ± 0.00 (0.00-0.00)
Tamarix chinensis/canariensis (saltcedar)	0.00 ± 0.00 (0.00-0.00)	34.61 ± 15.08 (7.05-52.50)
Shrubs		
Rhus microphylla (little-leaf sumac)	6.83 ± 6.75 (0.00-16.08)	0.00 ± 0.00 (0.00-0.00)
Ziziphus obtusifolia (lotebush)	3.33 ± 3.88 (0.00-9.35)	0.00 ± 0.00 (0.00-0.00)
Juniperus pinchotii (pinchot juniper)	2.83 ± 4.31 (0.00-11.00)	0.00 ± 0.00 (0.00-0.00)
Berberis trifoliolata (agarito)	2.62 ± 3.45 (0.00-7.90)	0.00 ± 0.00 (0.00-0.00)
Zanthoxylum hirsutum (toothache tree)	1.32 ± 2.40 (0.00-6.00)	0.00 ± 0.00 (0.00-0.00)
Acacia greggii (catclaw acacia)	0.81 ± 1.25 (0.00-2.50)	0.00 ± 0.00 (0.00-0.00)
Koeberlinia spinosa (allthorn)	0.53 ± 1.21 (0.00-3.00)	0.00 ± 0.00 (0.00-0.00)
Yucca glauca (small soapweed)	0.41 ± 0.81 (0.00-2.05)	0.00 ± 0.00 (0.00-0.00)
Lycium torreyi (Torrey wolfberry)	0.38 ± 0.49 (0.00-1.00)	0.00 ± 0.00 (0.00-0.00)
Atriplex canescens (four-wing saltbush)	0.33 ± 0.82 (0.00-2.00)	0.00 ± 0.00 (0.00-0.00)
Caesalpinia gilliesii (bird-of-paradise)	0.33 ± 0.80 (0.00-1.95)	0.00 ± 0.00 (0.00-0.00)
Condalia ericoides (javalinabush)	0.25 ± 0.61 (0.00-1.50)	0.00 ± 0.00 (0.00-0.00)
Dalea formosa (feather dalea)	0.17 ± 0.41 (0.00-1.00)	0.00 ± 0.00 (0.00-0.00)
Ephedra antisyphilitica (clapweed)	0.13 ± 0.22 (0.00-0.50)	0.00 ± 0.00 (0.00-0.00)
Vines		
Clematis drummondii (old-man's beard)	0.78 ± 1.01 (0.00-2.65)	0.00 ± 0.00 (0.00-0.00)
Ibervillea lindheimeri (balsam gourd)	0.08 ± 0.11 (0.00-0.30)	0.00 ± 0.00 (0.00-0.00)
Cocculus carolinus (Carolina snailseed)	0.08 ± 0.20 (0.00-0.50)	0.00 ± 0.00 (0.00-0.00)
Cissus incisa (ivy tree-vine)	0.03 ± 0.06 (0.00-0.15)	0.00 ± 0.00 (0.00-0.00)
Matelea biflora (two-flower milkvine)	0.03 ± 0.06 (0.00-0.15)	0.00 ± 0.00 (0.00-0.00)

Table 4 (cont.). Woody plants, vines and common herbaceous species in the shrub layer (0.5–2.0 m) in point count plots of native versus saltcedar woodland.[a]

Species	Percent Cover per Plot (mean ± SD) (range)	
	Native Woodland (n = 6)	Saltcedar Woodland (n = 7)
Cattails		
Typha latifolia (common cattail)	0.00 ± 0.00 (0.00-0.00)	2.74 ± 5.77 (0.00-15.45)
Broadleaf Perrenials		
Ambrosia psilostachya (western ragweed)	8.53 ± 8.56 (0.00-19.40)	0.00 ± 0.00 (0.00-0.00)
Broadleaf Annuals		
Heterotheca subaxillaris (camphorweed)	3.42 ± 5.54 (0.00-13.40)	0.00 ± 0.00 (0.00-0.00)
Helianthus annuus (common sunflower)	3.03 ± 6.38 (0.00-15.95)	0.00 ± 0.00 (0.00-0.00)
Physical Features		
Open Air	42.52 ± 14.00 (26.39-58.48)	37.60 ± 19.95 (22.50-77.40)
Dead Wood	3.31 ± 3.68 (0.00-9.35)	18.80 ± 4.17 (13.80-26.15)

Statistic	Summary Statistics per Plot (mean ± SD) (range) or over all Plots	
Number Species	19.50 ± 6.80 (10–28)	4.43 ± 1.72 (2–6)
Shannon-Weaver Diversity Index	1.96 ± 0.61 (0.84–2.48)	0.52 ± 0.42 (0.04–1.28)
Total Number of Plant Species	59	15

[a] Data averaged from two to three 7 m radius subplots within 10 bird point count plots (50 m radius). Percent cover calculated from total area of plot (including open air). See Table 5 for percent cover of herbaceous species of the shrub layer.

Table 5. Less common herbaceous plant species in the shrub layer (0.5–2.0 m) in point count plots of native versus saltcedar woodland.[a]

Species	Percent Cover per Plot (mean ± SD) (range)	
	Native Woodland (n = 6)	Saltcedar Woodland (n = 7)
Perennial Grasses		
Setaria leucopila (plains bristlegrass)	0.63 ± 0.51 (0.00-1.25)	0.00 ± 0.00 (0.00-0.00)
Cenchrus spinifex (common sandbur)	0.58 ± 1.43 (0.00-3.50)	0.00 ± 0.00 (0.00-0.00)
Sporobolus pyramidatus (whorled dropseed)	0.03 ± 0.06 (0.00-0.15)	0.00 ± 0.00 (0.00-0.00)
Chloris cucullata (hooded windmill grass)	0.02 ± 0.04 (0.00-0.10)	0.00 ± 0.00 (0.00-0.00)
Chloris verticillata (tumble windmill grass)	0.01 ± 0.02 (0.00-0.05)	0.00 ± 0.00 (0.00-0.00)
Sporobolus cryptandrus (sand dropseed)	0.001 ± 0.008 (0.00-0.02)	0.00 ± 0.00 (0.00-0.00)
Sporobolus airoides (alkali sacaton)	0.00 ± 0.00 (0.00-0.00)	0.10 ± 0.28 (0.00-0.75)
Annual Grasses		
Setaria verticillata (hooked bristle grass)	0.41 ± 1.00 (0.00-2.45)	0.00 ± 0.00 (0.00-0.00)
Chloris virgata (showy chloris)	0.27 ± 0.65 (0.00-1.60)	0.00 ± 0.00 (0.00-0.00)
unidentified brown grass	0.26 ± 0.63 (0.00-1.55)	0.00 ± 0.00 (0.00-0.00)
Bromus catharticus (rescue grass)	0.00 ± 0.00 (0.00-0.00)	0.19 ± 0.51 (0.00-1.35)
Polypogon monspeliensis (rabbitsfoot grass)	0.00 ± 0.00 (0.00-0.00)	0.14 ± 0.38 (0.00-1.00)
Sedges and Rushes		
Schoenoplectus americanus (Olney's bulrush)	0.00 ± 0.00 (0.00-0.00)	0.50 ± 0.85 (0.00-1.75)
Broadleaf Perennials		
Datura wrightii (Indian-apple)	0.17 ± 0.41 (0.00-1.00)	0.00 ± 0.00 (0.00-0.00)
Rhynchosida physocalyx (spear-leaf sida)	0.11 ± 0.27 (0.00-0.65)	0.00 ± 0.00 (0.00-0.00)
Marrubium vulgare (common horehound)	0.09 ± 0.20 (0.00-0.50)	0.00 ± 0.00 (0.00-0.00)
Gymnosperma glutinosum (tatalencho)	0.03 ± 0.06 (0.00-0.15)	0.00 ± 0.00 (0.00-0.00)
Rivina humilis (pigeon-berry)	0.03 ± 0.06 (0.00-0.15)	0.00 ± 0.00 (0.00-0.00)
Sphaeralcea angustifolia ssp. *cuspidata* (narrow-leaf globe-mallow)	0.03 ± 0.06 (0.00-0.15)	0.00 ± 0.00 (0.00-0.00)
Solanum elaeagnifolium (silverleaf nightshade)	0.02 ± 0.04 (0.00-0.10)	0.00 ± 0.00 (0.00-0.00)
unknown little gray herb	0.01 ± 0.02 (0.00-0.05)	0.00 ± 0.00 (0.00-0.00)
Viguiera dentata (sunflower golden-eye)	0.01 ± 0.02 (0.00-0.05)	0.00 ± 0.00 (0.00-0.00)

Table 5 (cont.). Less common herbaceous plant species in the shrub layer (0.5–2.0 m) in point count plots of native versus saltcedar woodland.[a]

	Percent Cover per Plot (mean ± SD) (range)	
Species	Native Woodland (n = 6)	Saltcedar Woodland (n = 7)
Broadleaf Perennials		
Solanum triquetrum (Texas nightshade)	0.004 ± 0.01 (0.00-0.03)	0.00 ± 0.00 (0.00-0.00)
Phoradendron tomentosum (mistletoe)	0.001 ± 0.002 (0.00-0.005)	0.00 ± 0.00 (0.00-0.00)
Physalis cinerascens (beach ground-cherry)	0.00 ± 0.00 (0.00-0.00)	0.02 ± 0.06 (0.00-0.15)
Suaeda moquinii (alkali seepweed)	0.00 ± 0.00 (0.00-0.00)	0.007 ± 0.02 (0.00-0.05)
Broadleaf Annuals		
Kochia scoparia (Mexican fireweed)	0.30 ± 0.47 (0.00-1.05)	1.99 ± 3.11 (0.00-8.00)
Chenopodium album (lamb’s-quarters)	0.10 ± 0.25 (0.00-0.60)	0.24 ± 0.63 (0.00-1.66)
Euphorbia dentate (toothed spurge)	0.08 ± 0.20 (0.00-0.50)	0.00 ± 0.00 (0.00-0.00)
Salsola tragus (Russian thistle)	0.03 ± 0.08 (0.00-0.20)	0.00 ± 0.00 (0.00-0.00)
Gaura parviflora (lizard-tail gaura)	0.03 ± 0.04 (0.00-0.10)	0.00 ± 0.00 (0.00-0.00)
Conyza canadensis (horseweed)	0.02 ± 0.03 (0.00-0.05)	0.03 ± 0.05 (0.00-0.10)
Gutierrezia texana (Texas broomweed)	0.02 ± 0.04 (0.00-0.10)	0.00 ± 0.00 (0.00-0.00)
Lactuca serriola (prickly lettuce)	0.02 ± 0.03 (0.00-0.05)	0.05 ± 0.11 (0.00-0.30)
Chenopodium incanum (mealy goosefoot)	0.01 ± 0.02 (0.00-0.05)	0.00 ± 0.00 (0.00-0.00)
Machaeranthera tanacetifolia (Tahoka daisy)	0.01 ± 0.02 (0.00-0.05)	0.00 ± 0.00 (0.00-0.00)
Ambrosia trifida (giant ragweed)	0.00 ± 0.00 (0.00-0.00)	0.04 ± 0.11 (0.00-0.30)
Pluchea odorata (canela)	0.00 ± 0.00 (0.00-0.00)	0.54 ± 1.33 (0.00-3.55)

[a] Data averaged from two to three 7 m radius subplots within 10 bird point count plots (50 m radius). Percent cover calculated from total area of plot (including bare ground). See Table 4 for percent cover of woody species of the shrub layer.

Table 6. Woody plants and vines in the tree layer (2.0–5.0 m) of in point count plots of native versus saltcedar woodland.[a]

Species	Percent Cover per Plot (mean ± SD) (range)	
	Native Woodland (n = 6)	Saltcedar Woodland (n = 7)
Trees		
Prosopis glandulosa var. *glandulosa* (honey mesquite)	17.39 ± 5.88 (8.75-25.55)	0.00 ± 0.00 (0.00-0.00)
Celtis laevigata var. *reticulata* (net-leaf hackberry)	9.33 ± 9.58 (0.00-23.50)	0.00 ± 0.00 (0.00-0.00)
Sideroxylon lanuginosum ssp. *rigidum* (gum bumelia)	4.29 ± 8.25 (0.00-20.75)	0.00 ± 0.00 (0.00-0.00)
Tamarix chinensis/canariensis (saltcedar)	0.00 ± 0.00 (0.00-0.00)	48.51 ± 20.57 (5.05-69.00)
Shrubs		
Rhus microphylla (little-leaf sumac)	2.24 ± 2.33 (0.00-5.50)	0.00 ± 0.00 (0.00-0.00)
Juniperus pinchotii (pinchot juniper)	2.06 ± 2.74 (0.00-6.84)	0.00 ± 0.00 (0.00-0.00)
Ziziphus obtusifolia (lotebush)	1.63 ± 2.21 (0.00-5.00)	0.00 ± 0.00 (0.00-0.00)
Zanthoxylum hirsutum (toothache tree)	1.30 ± 2.41 (0.00-6.00)	0.00 ± 0.00 (0.00-0.00)
Acacia greggii (catclaw acacia)	0.25 ± 0.61 (0.00-1.50)	0.00 ± 0.00 (0.00-0.00)
Baccharis salicina (willow baccharis)	0.00 ± 0.00 (0.00-0.00)	0.91 ± 1.41 (0.00-3.35)
Vines		
Clematis drummondii (old-man's beard)	0.10 ± 0.20 (0.00-0.50)	0.00 ± 0.00 (0.00-0.00)
Physical Features		
Dead Wood	0.68 ± 0.77 (0.00-1.75)	10.08 ± 2.51 (6.75-14.05)
Open Air	59.06 ± 16.24 (34.00-75.10)	39.62 ± 18.87 (23.00-80.90)

Statistic	Summary Statistics per Plot (mean ± SD) (range) or over all Plots	
Number Species	5.83 ± 3.37 (1–11)	1.86 ± 0.90 (1–3)
Shannon-Weaver Diversity Index	1.14 ± 0.66 (0.00–1.86)	0.13 ± 0.17 (0.00–0.44)
Total Number of Plant Species	15	5

[a] Data averaged from two to three 7 m radius subplots within 10 bird point count plots (50 m radius). Percent cover calculated from total area of plot (including open air).

Table 7. Percent frequency of trees and common shrub and herbaceous species in native and saltcedar woodland habitats and their value to wildlife and livestock.[a]

Species	Percent Frequency			Value	
	Native Woodland (n = 6)	Saltcedar Woodland (n = 7)	Mixed Saltcedar/ Mesquite Creekside Woodland (n = 8)	Wildlife Food/ Cover	Livestock Forage
Trees					
Prosopis glandulosa var. *glandulosa* (honey mesquite)	100	0	88	good	fair
Tamarix chinensis/T. canariensis (saltcedar)	0	100	100	fair	poor
Celtis laevigata var. *reticulata* (net-leaved hackberry)	83	14	50	good	poor
Sideroxylon lanuginosum ssp. *rigidum* (gum bumelia)	50	0	0	good	poor
Shrubs					
Rhus microphylla (little-leaf sumac)	67	0	13	fair	poor
Lycium torreyi (Torrey wolfberry)	67	0	88	good	fair
Berberis trifoliolata (agarito)	67	0	13	excellent	poor
Juniperus pinchotii (Pinchot Juniper)	67	0	13	poor	poor
Ziziphus obtusifolia (lotebush)	67	0	25	good	poor
Zanthoxylum hirsutum (toothache tree)	50	0	0	poor	poor
Yucca glauca (small soapweed)	67	0	0	poor	poor
Ephedra antisyphilitica (clapweed)	50	0	13	good	good
Koeberlinia spinosa (allthorn)	50	0	0	poor	poor
Baccharis salicina (willow baccharis)	0	71	13	poor	poor
Vines					
Clematis drummondii (Old-man's-beard)	67	14	0	poor	poor
Ibervillea lindheimeri (Balsam Gourd)	67	0	0	fair	poor
Perennial Grasses					
Setaria leucopila (plains bristlegrass)	100	29	63	excellent	good
Sporobolus airoides (alkali sacaton)	83	43	100	poor	fair
Chloris cucullata (hooded windmill)	67	0	25	fair	fair
Distichlis spicata var. *stricta* (inland saltgrass)	0	0	75	fair	fair
Tridens albescens (white tridens)	0	0	63	fair	fair
Annual Grasses					
Bromus catharticus (rescue grass)	50	14	25	fair	fair

Table 7 (cont.). Percent frequency of trees and common shrub and herbaceous species in native and saltcedar woodland habitats and their value to wildlife and livestock.[a]

	Percent Frequency			Value	
Species	Native Woodland (n = 6)	Saltcedar Woodland (n = 7)	Mixed Saltcedar/ Native Creekside Woodland (n = 8)	Wildlife Food/ Cover	Livestock Forage
Broadleaf Perennials					
Solanum eleagnifolium (silverleaf nightshade)	100	0	88	fair	poor
Rhynchosida physocalyx (spear-leaf sida)	100	0	13	fair	fair
Ambrosia psilostachya (western ragweed)	83	14	63	good	poor
Marrubium vulgare (common horehound)	67	0	0	poor	poor
Physalis cinerascens (beach ground-cherry)	67	14	13	good	fair
Abutilon fruticosum (Indian-mallow)	50	0	0	fair	poor
Rivina humilis (pigeon-berry)	50	0	0	good	poor
Sphaeralcea lindheimeri (Lindheimer's globe-mallow)	67	0	0	fair	fair
Heterotheca subaxillaris (camphorweed)	50	0	100	poor	poor
Broadleaf Annuals					
Helianthus annuus (common sunflower)	67	0	63	good	poor
Pluchea odorata (canela)	0	71	25	poor	poor
Kochia scoparia (Mexican fireweed)	33	57	63	poor	fair
Xanthium strumarium (cocklebur)	83	14	75	poor	poor
Gaura parviflora (lizard-tail gaura)	50	0	13	fair	poor
Gutierrezia texana (Texas broomweed)	50	0	0	fair	fair
Gutierrezia dracunculoides (common broomweed)	0	0	75	fair	fair
Conyza canadensis (horseweed)	50	43	0	fair	toxic

[a] All trees are included but other plants are included only if they have a percent frequency of at least 50% and percent cover of at least 0.1% in one woodland habitat. See Table 1 for identities of less frequent species. Values to wildlife and livestock were summarized from Martin *et al.* (1951), Vines (1960), Powell (1998), Diggs *et al.* (1999), Everitt *et al.* (1999), Everitt *et al.* (2002), USDA NRCS (2007), and USDA Forest Service (2007).

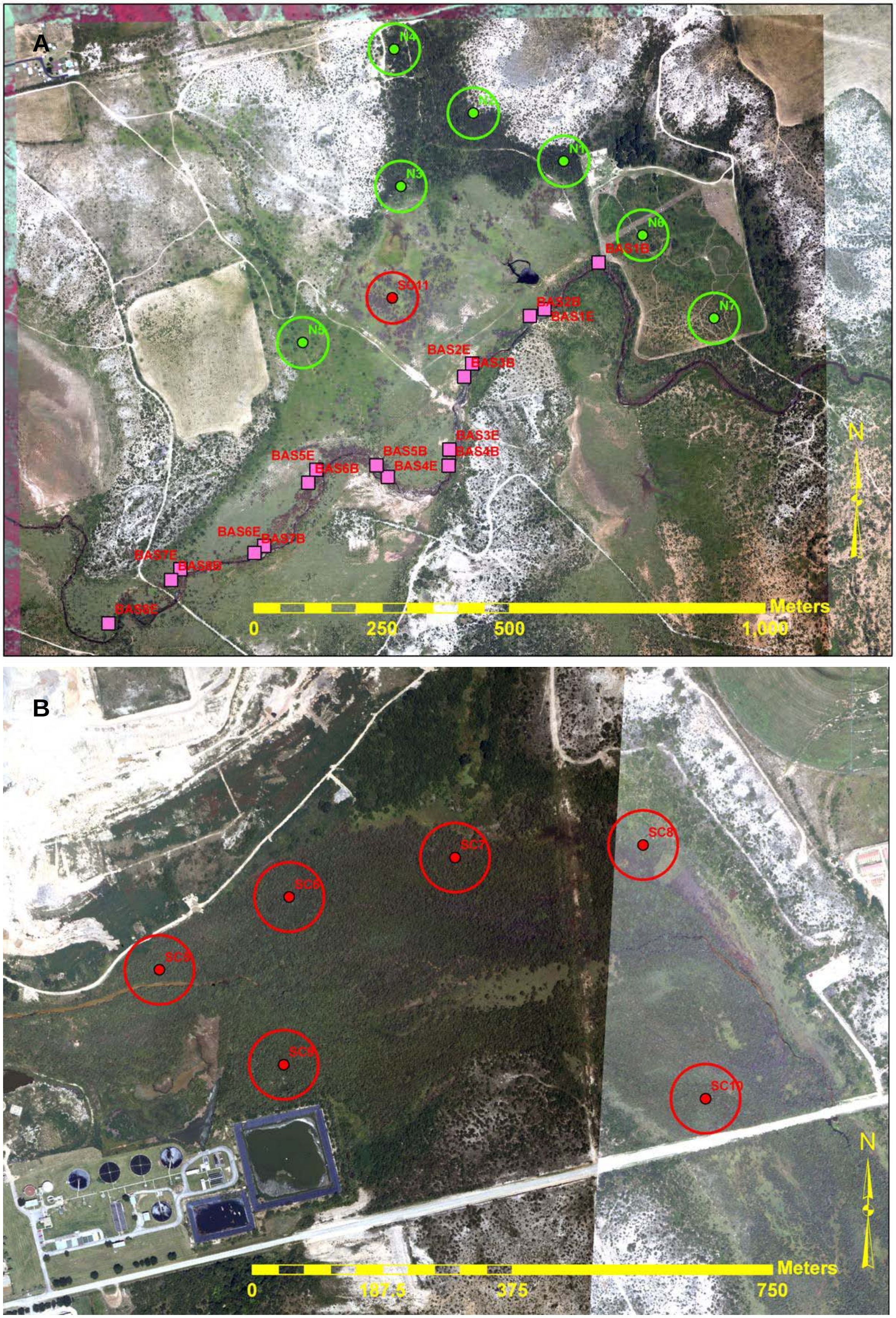

Figure 1. A) Native (green) and saltcedar (red) woodland bird point count areas (50 m radius) on Higgins Ranch near Beals Creek and mixed saltcedar/mesquite creekside woodland strip count areas (50 X 150 m areas marked by pink squares) B) Saltcedar bird point count areas (50 m radius) along Beals Creek near the Big Spring sewage treatment plant.

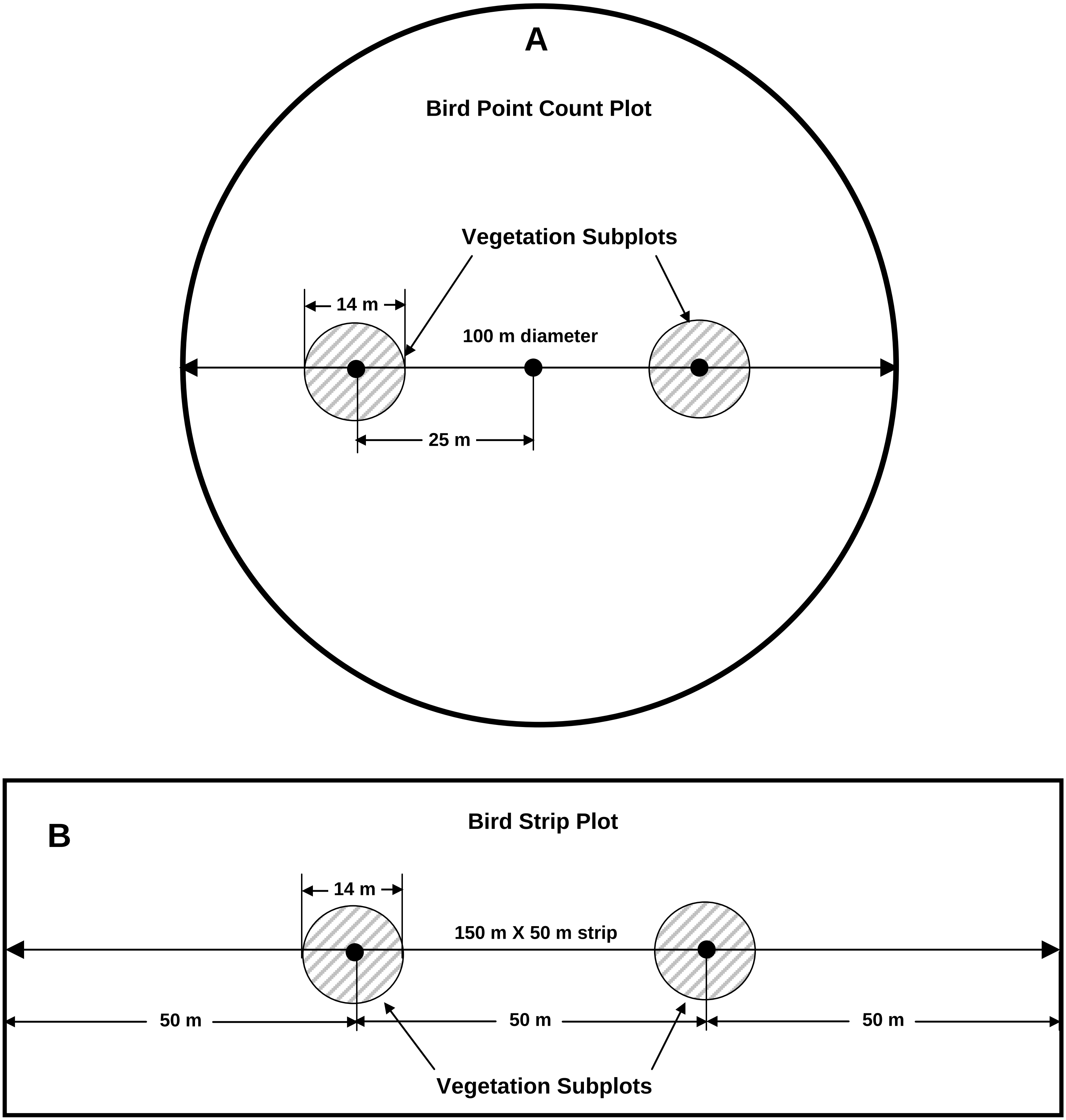

Figure 2. Placement of 7 m radius vegetation subplots within 50 m radius bird point count plots (A) and 150 m X 50 m bird strip count plots (B).

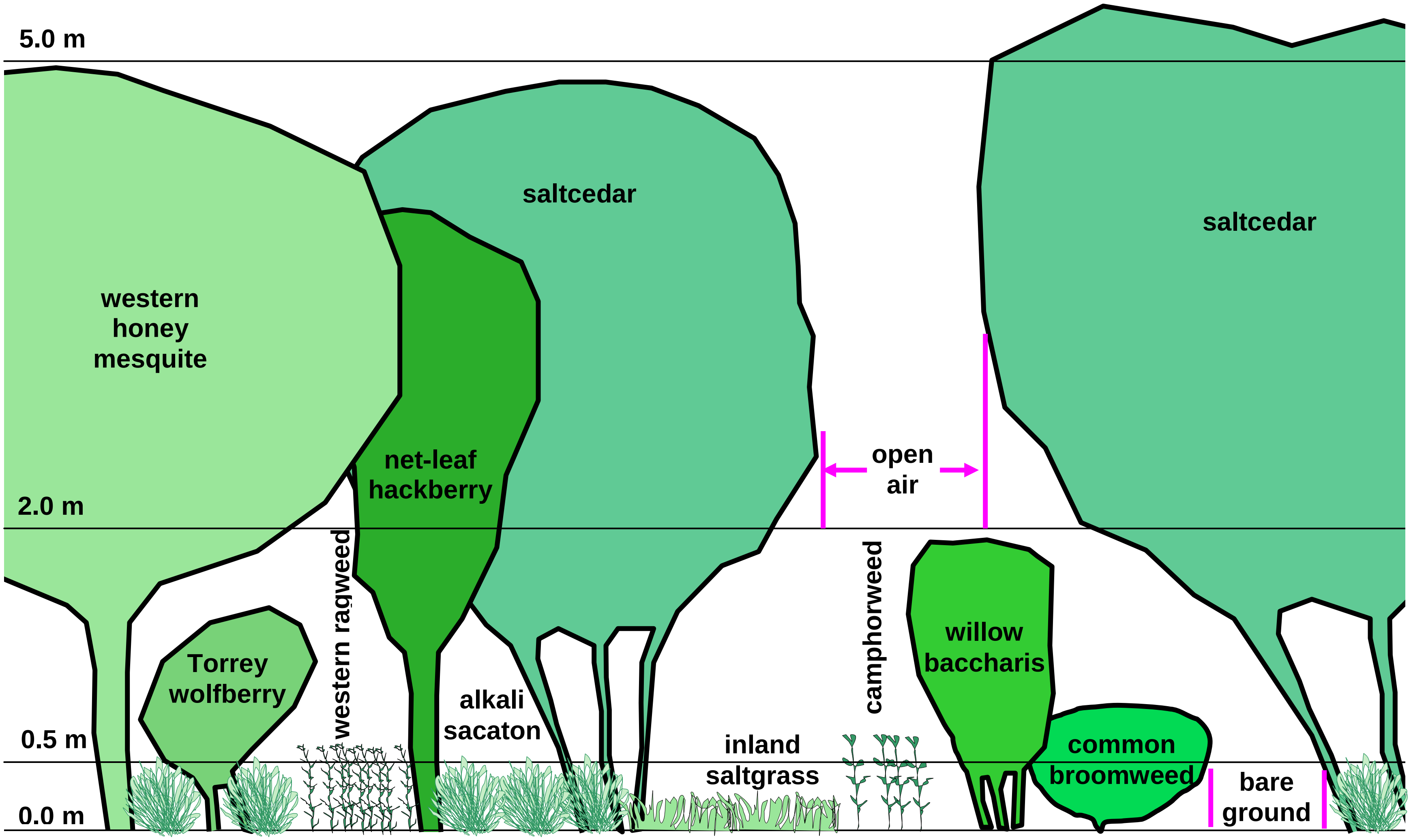

Figure 3. Common plant species and physical characteristics factored into calculating total percentage aerial cover in different height layers for 7 m radius subplots used in characterizing bird survey point and strip plots on or near Beals Creek near Big Spring, Texas.

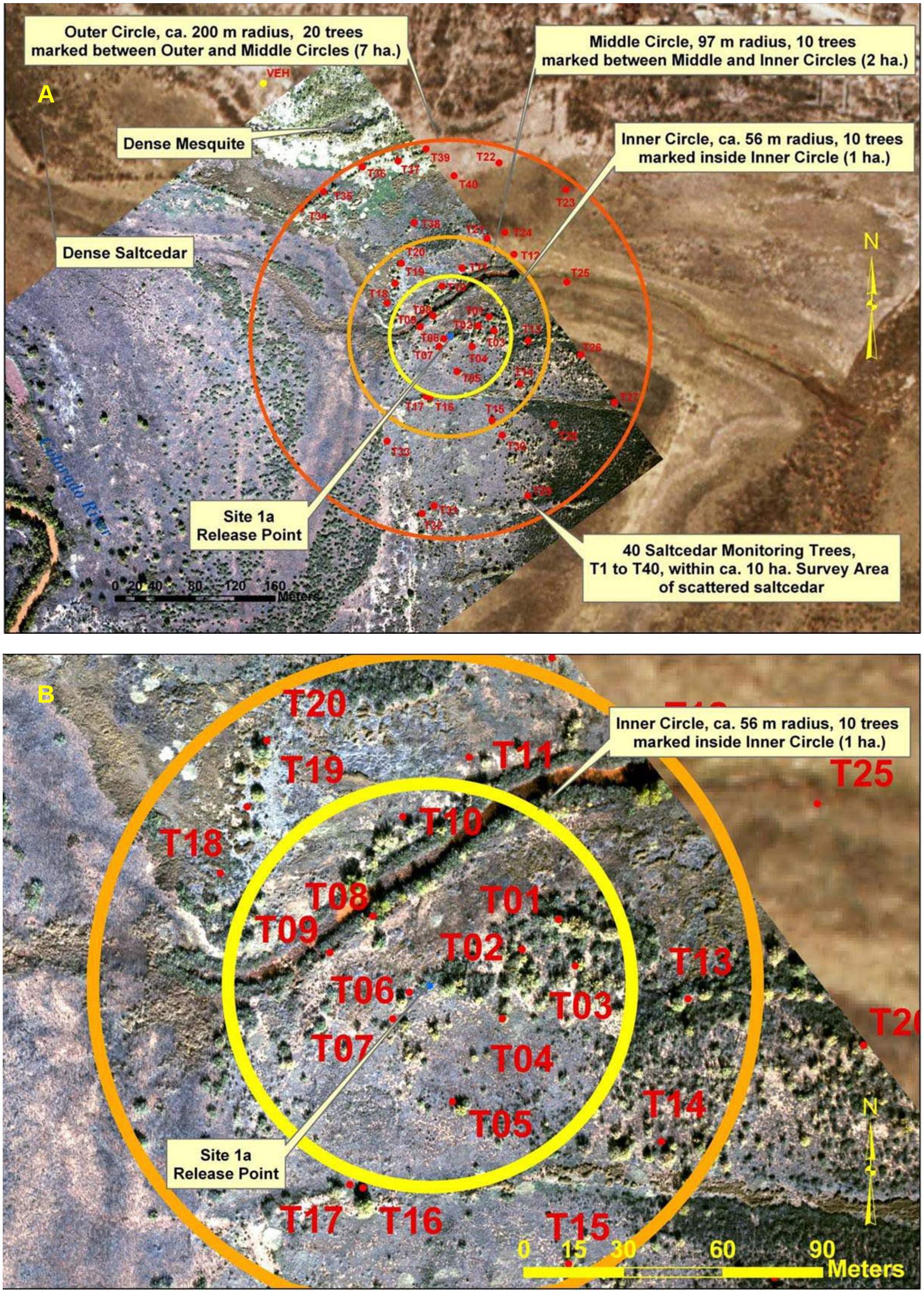

Figure 4. Location of 1 x 1 m vegetation survey quadrats bisecting saltcedar tree canopies along the northern edge of Lake Thomas, southwest of Snyder, Texas. A) Large-scale view, B) close view of center survey area.

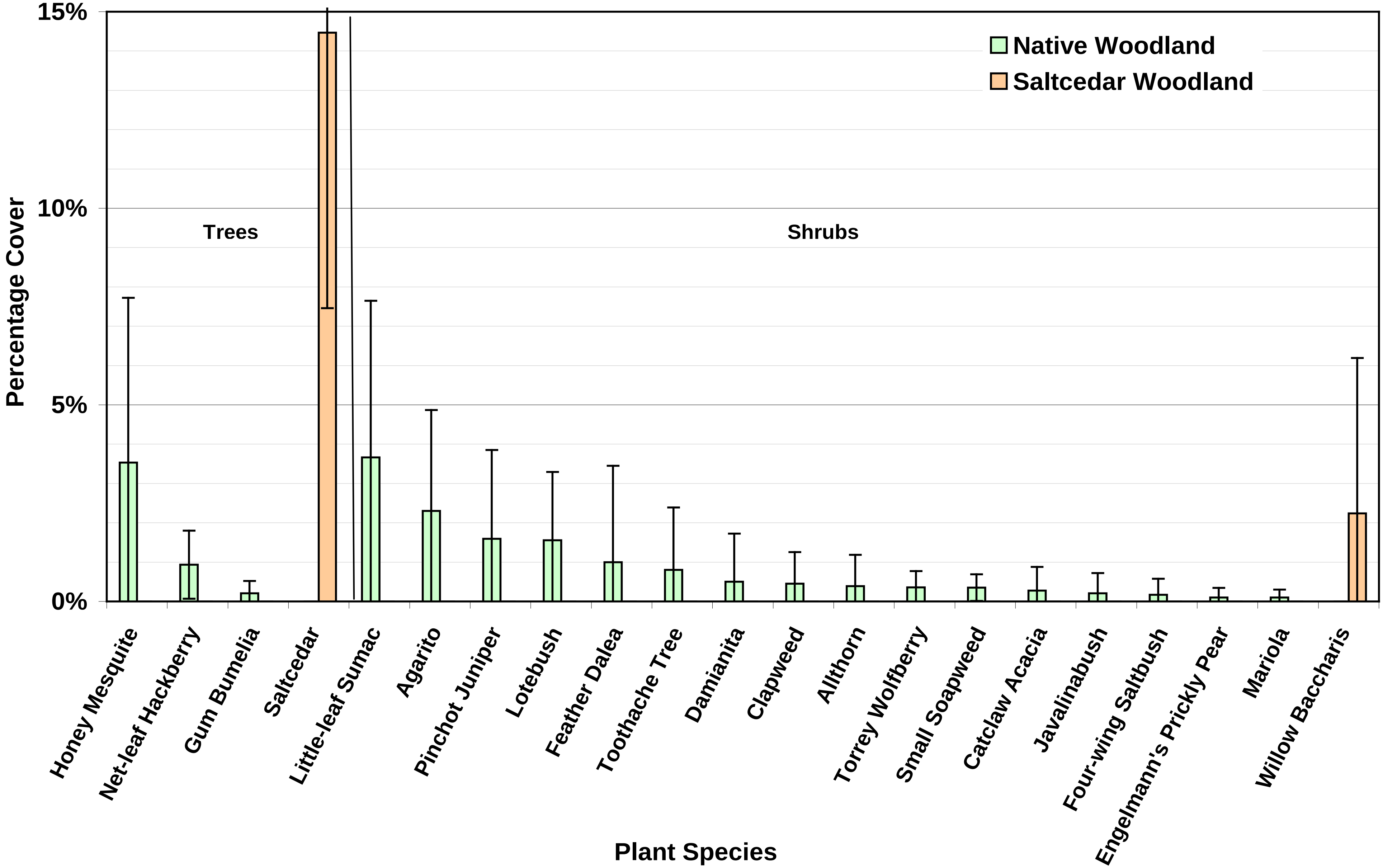

Figure 5. Most common woody plants in the herbaceous layer (0.0–0.5 m): mean (± SD) % cover of plots within point count areas of saltcedar (n = 7) versus native (n = 6) woodland along Beals Creek near Big Spring, Texas, 13-15 August 2007. (Refer to Table 1 for scientific names of plants and Table 3 for less common plants).

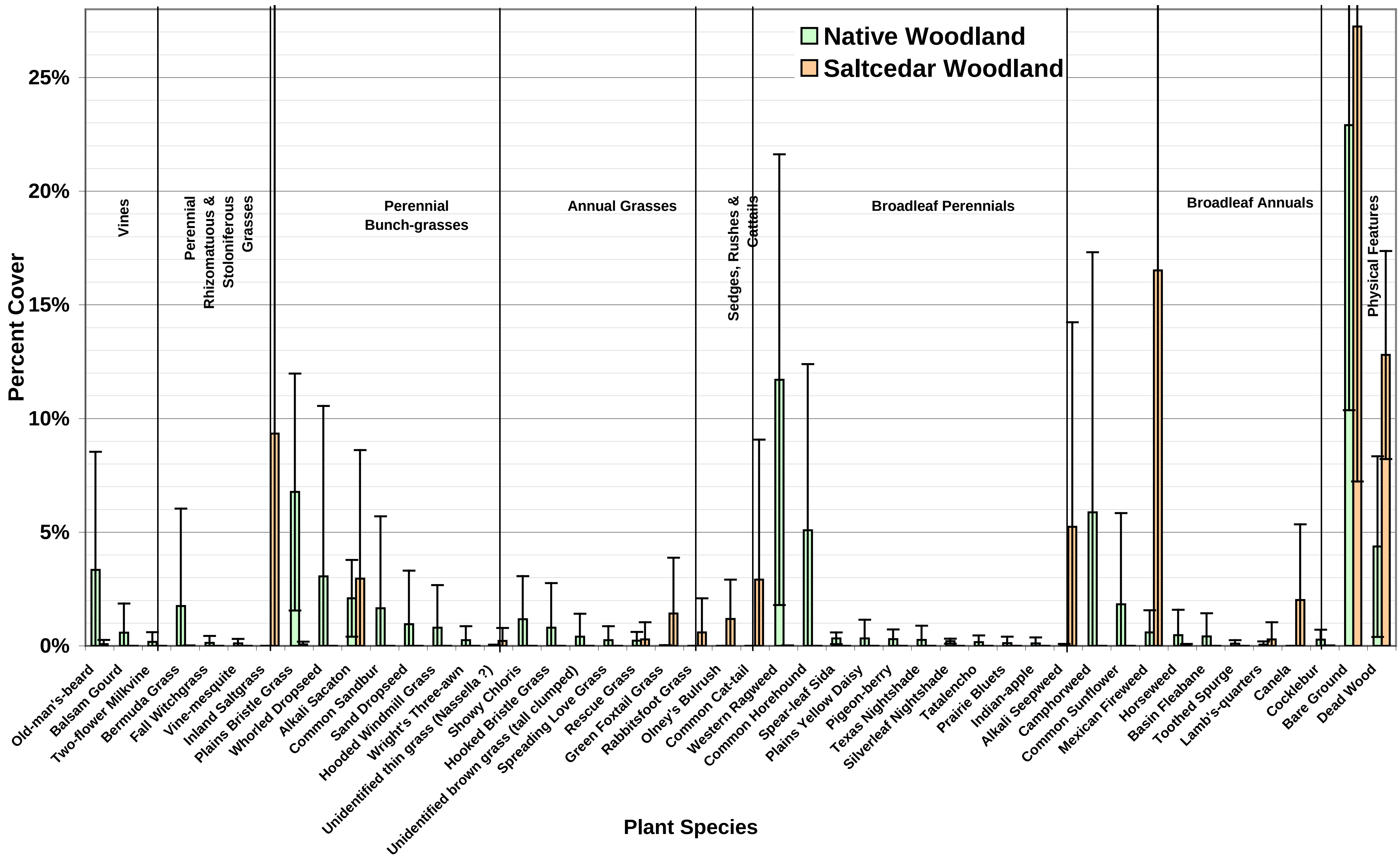

Figure 6. Most common herbaceous plants in the herbaceous layer (0.0–0.5 m): mean (± SD) % cover of plots within point count areas of saltcedar (n = 7) versus native (n = 6) woodland along Beals Creek near Big Spring, Texas, 13-15 August 2007. (Refer to Table 2 for scientific names of plants and Table 3 for less common plants).

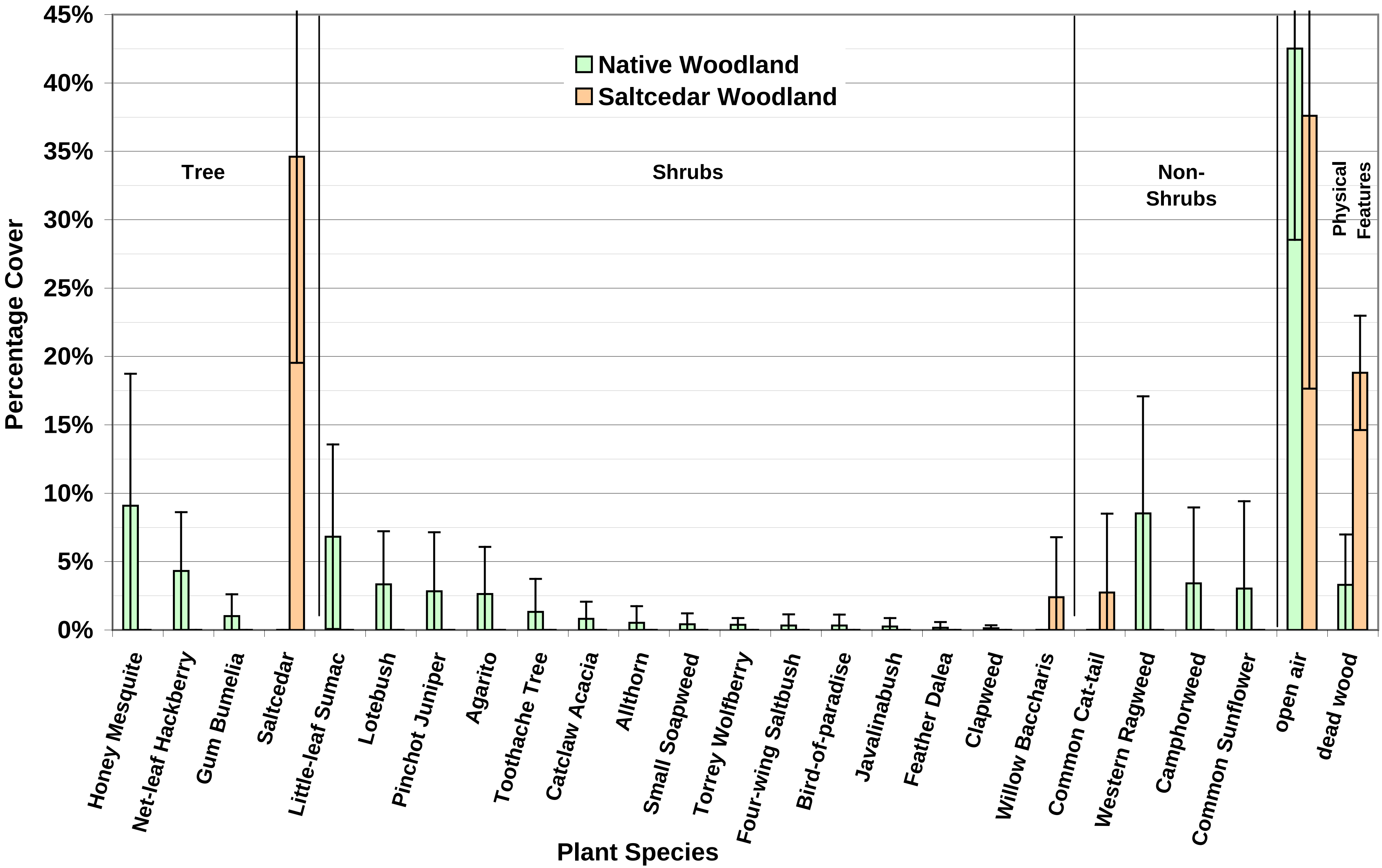

Figure 7. Plants in the shrub layer (0.5–2.0 m): mean (± SD) % cover of plots within point count areas of saltcedar (n = 7) versus native (n = 6) woodland along Beals Creek near Big Spring, Texas, 13-15 August 2007. (Refer to Table 4 for scientific names of plants and Table 5 for less common plants).

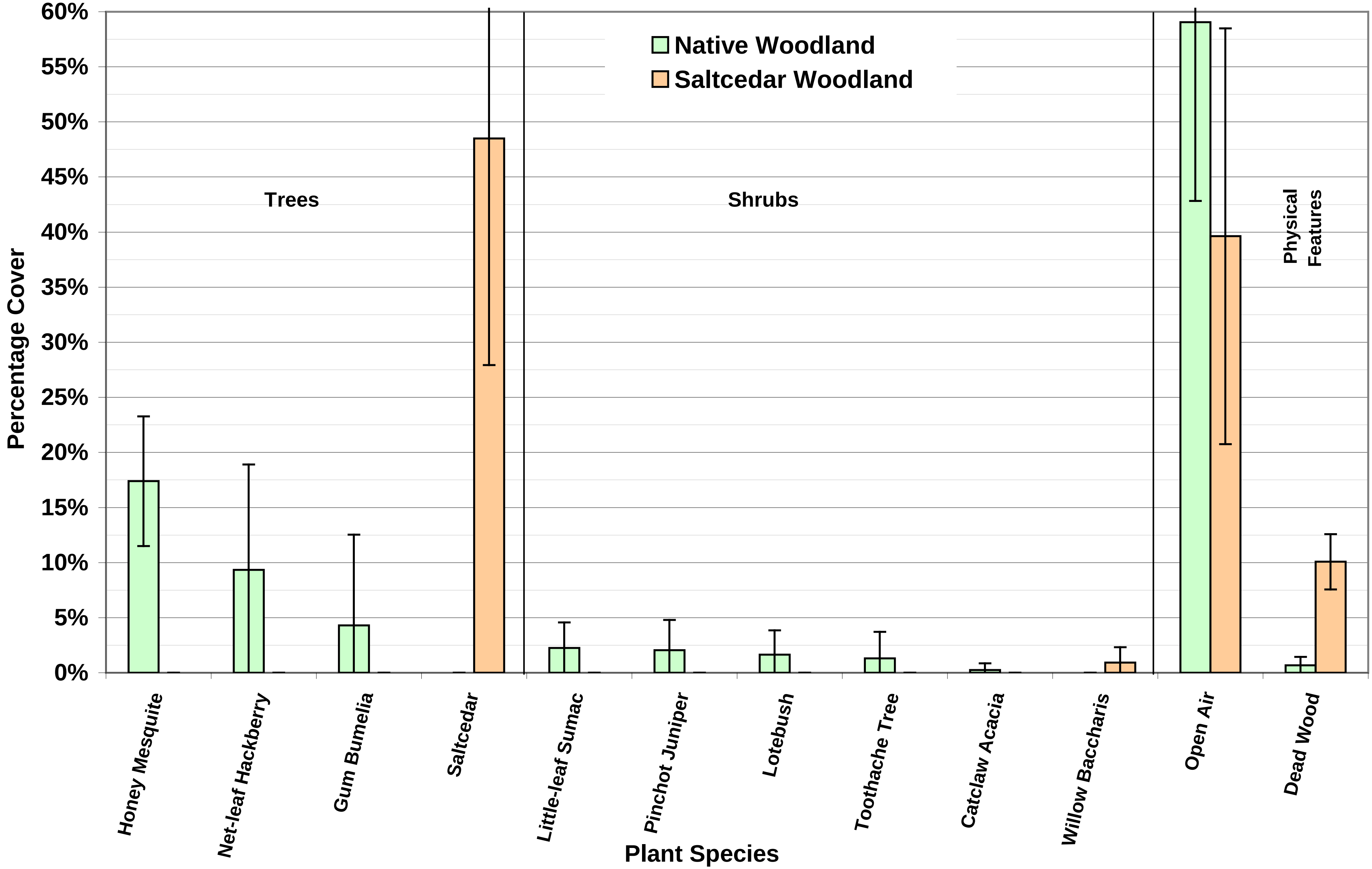

Figure 8. Woody plants in the tree layer (2.0–5.0 m): mean (± SD) % cover of plots within point count areas of saltcedar (n = 7) versus native (n = 6) woodland along Beals Creek near Big Spring, Texas, 13-15 August 2007. (Refer to Table 6 for scientific names of plants).

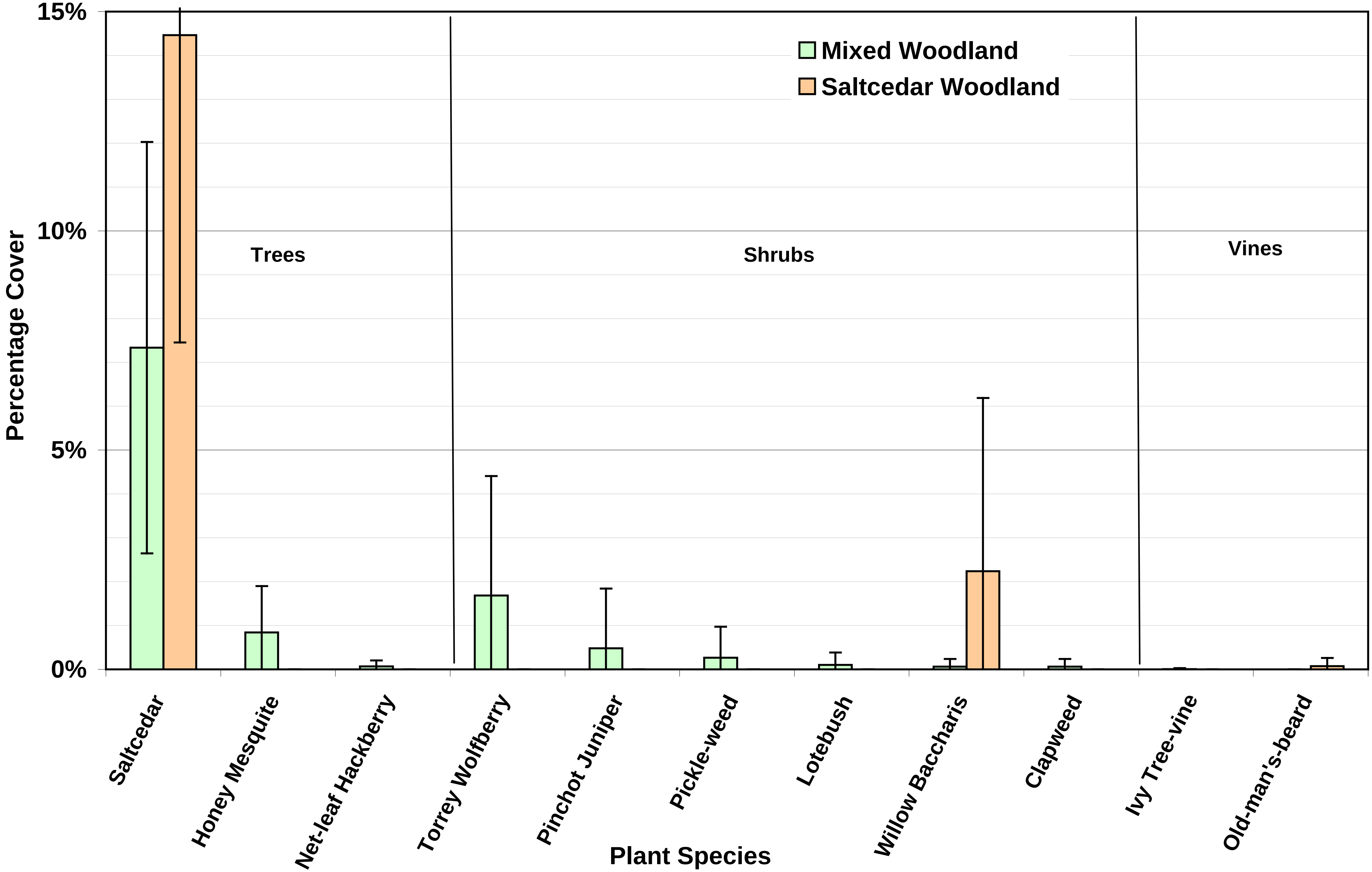

Figure 9. Most common woody plants in the herbaceous layer (0.0–0.5 m): mean (± SD) % cover of plots within point count areas of saltcedar (n = 7; 13–15 August) versus strip count areas of mixed saltcedar/mesquite creekside woodland (n = 8; 10 September–15 November) along Beals Creek near Big Spring, 2007.

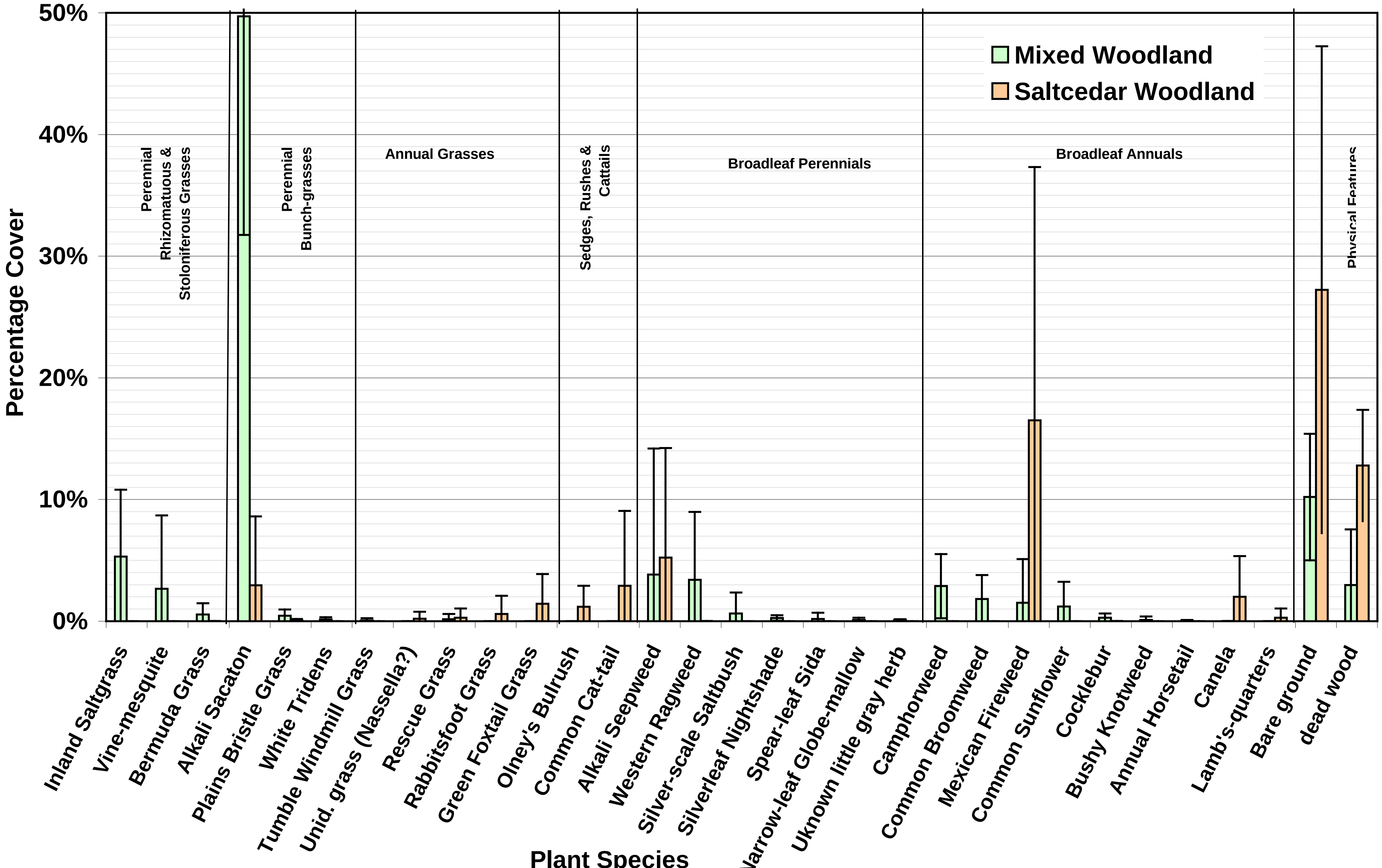

Figure 10. Most common herbaceous plants in the herbaceous layer (0.0–0.5 m): mean (± SD) % cover of plots within point count areas of saltcedar (n = 7; 13–15 August) versus strip count areas of mixed saltcedar/mesquite creekside woodland (n = 8; 10 September–15 November) along Beals Creek near Big Spring, 2007.

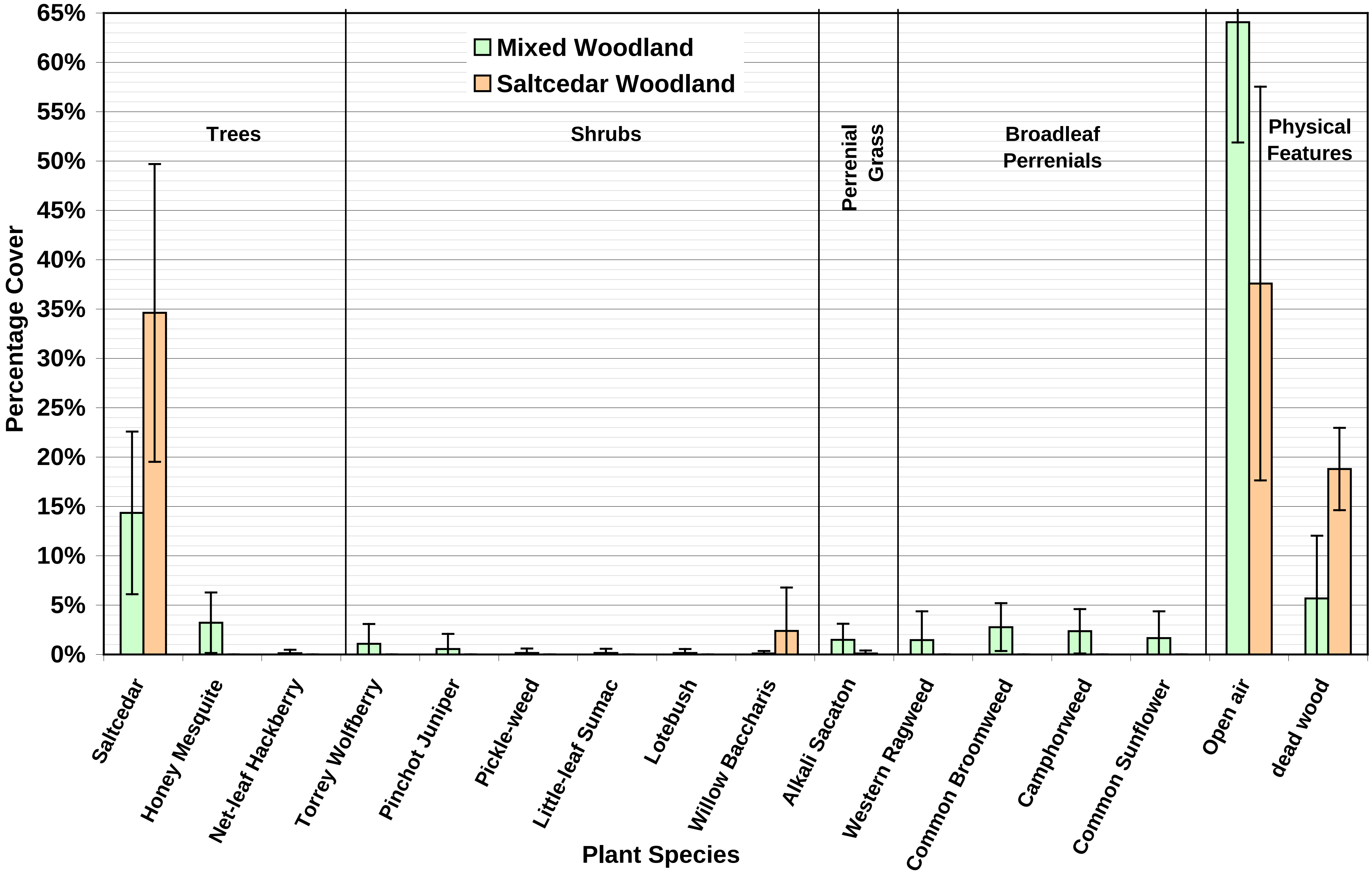

Figure 11. Plants in the shrub layer (0.5–2.0 m): mean (± SD) % cover of plots within point count areas of saltcedar (n = 7; 13–15 August) versus strip count areas of mixed saltcedar/mesquite creekside woodland (n = 8; 10 September–15 November) along Beals Creek near Big Spring, 2007.

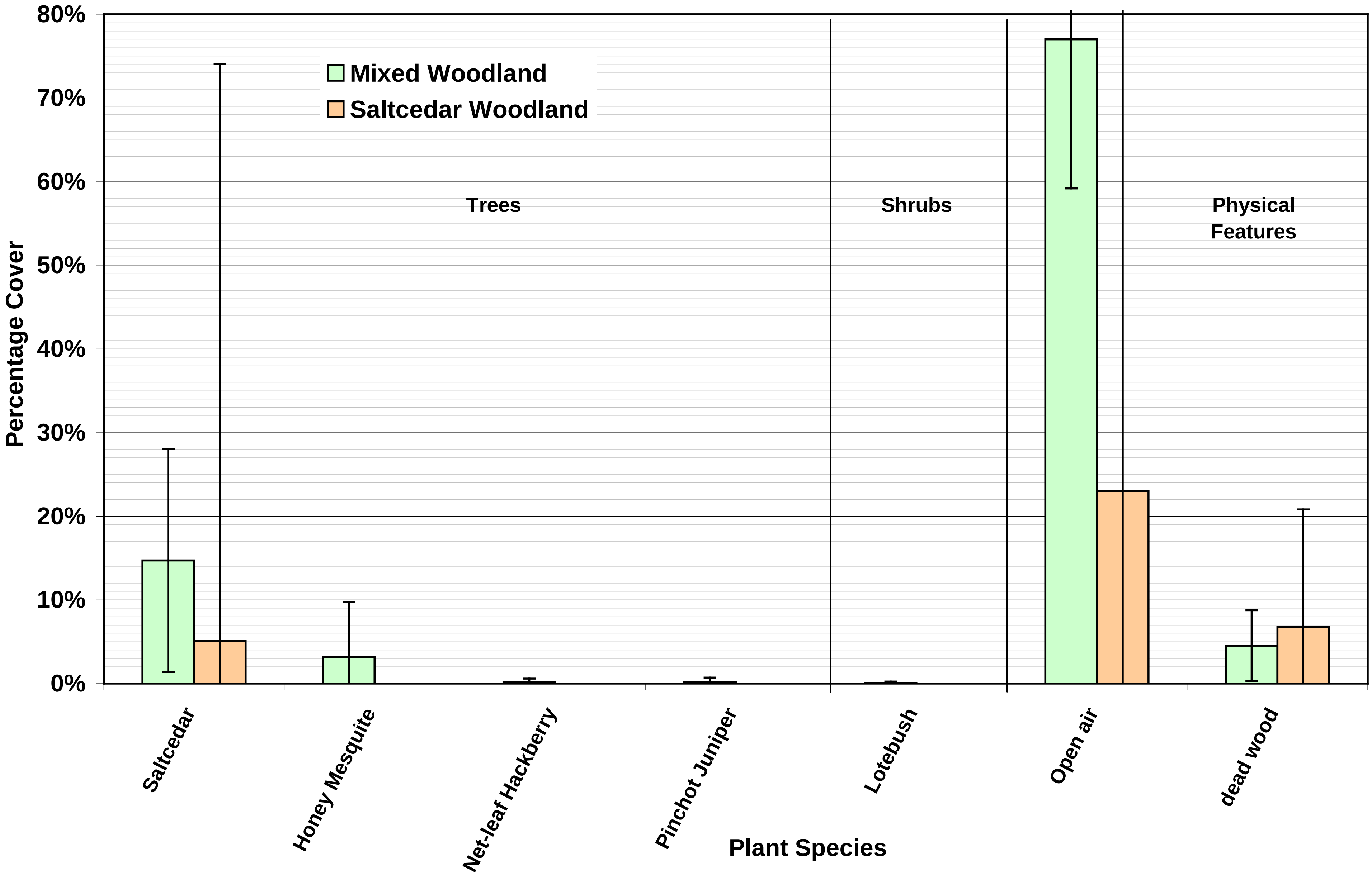

Figure 12. Woody plants in the tree layer (2.0–5.0 m): mean (± SD) % cover of plots within point count areas of saltcedar (n = 7; 13–15 August) versus strip count areas of mixed saltcedar/mesquite creekside woodland (n = 8; 10 September–15 November) along Beals Creek near Big Spring, 2007.

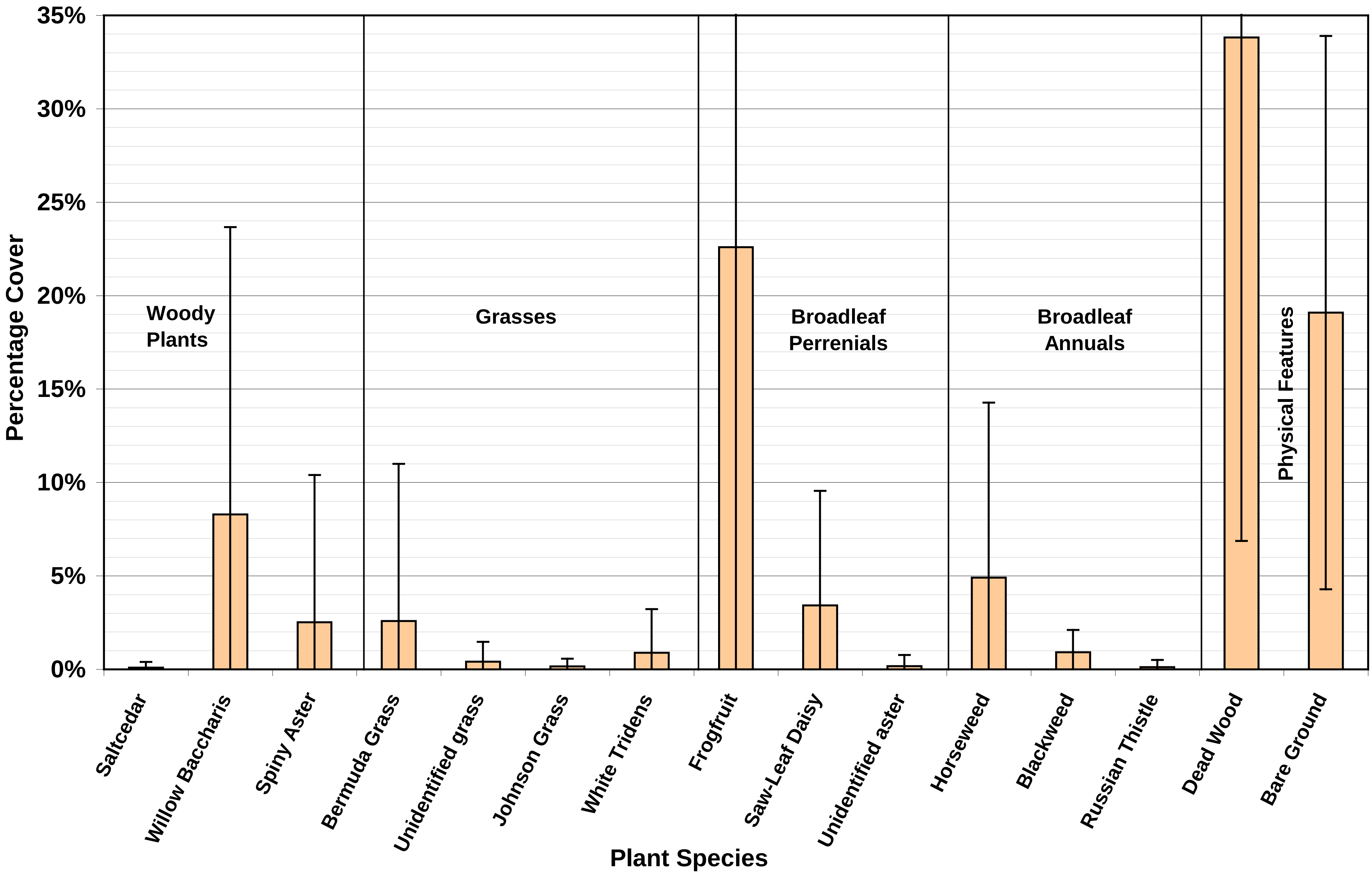

Figure 13. Plants in the herbaceous layer (0.0–1.0 m): mean (± SD) % cover of plots (n = 11) within 1 X 1 m quadrats bisecting the canopy edge of saltcedar trees along north end of Lake Thomas near Snyder, Texas, 10 August, 2004.

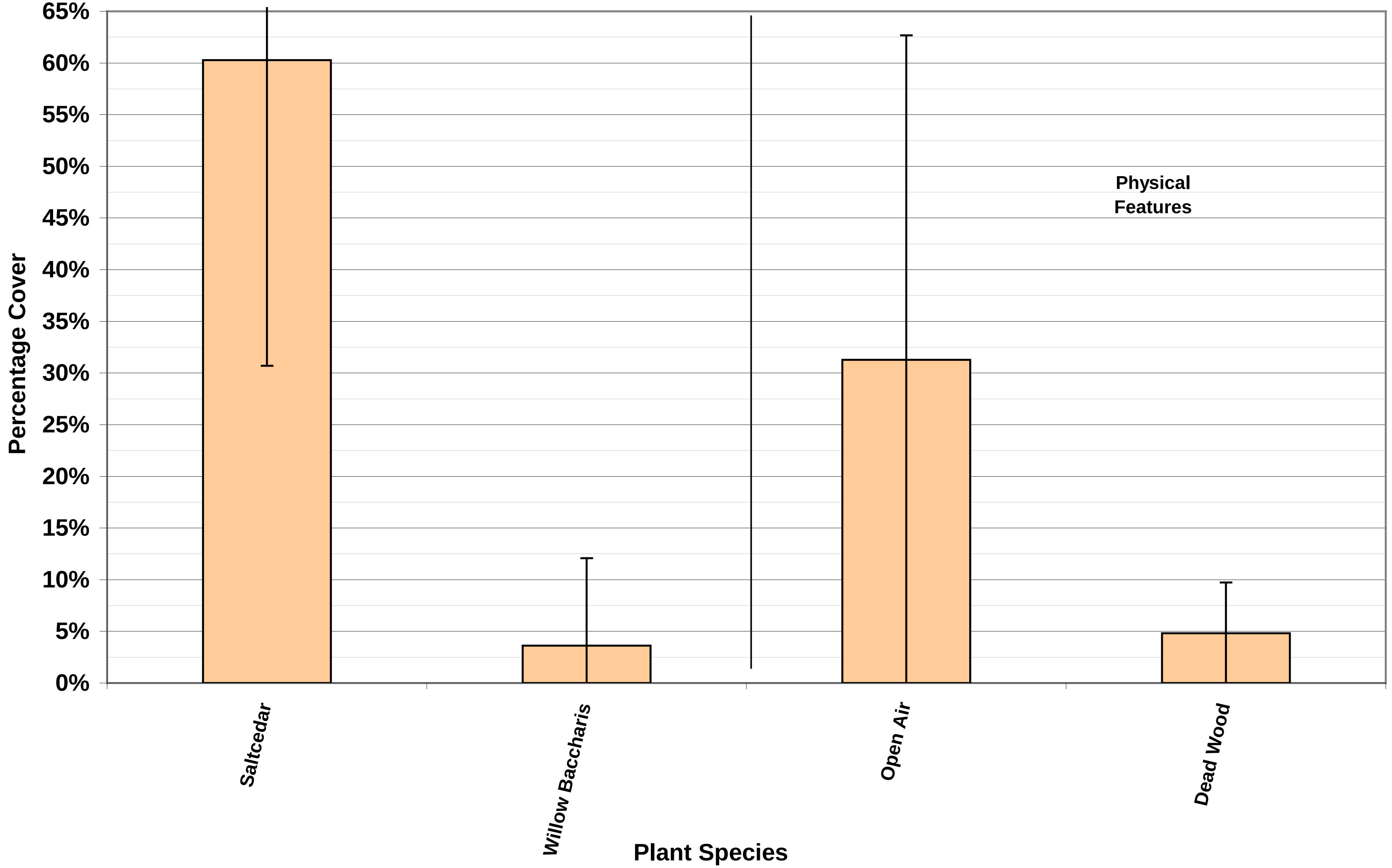

Figure 14. Plants in the tree-shrub layer (1.0–10.0 m): mean (± SD) % cover of plots (n = 11) within 1 X 1 m quadrats bisecting the canopy edge of saltcedar trees along north end of Lake Thomas near Snyder, Texas, 10 August, 2004.

APPENDIX D

MONITOR CONTROL OF SALTCEDAR AND EFFECTS IN THE ENVIRONMENT:
Annually monitor bird species diversity and populations

Prepared by
Thomas O. Robbins

Introduction and Site Descriptions. The leaf beetle, *Diorhabda elongata elongata* (Brullé), was planned for release as a biological control against saltcedar (*Tamarix chinensis* and *T. ramosissima* and hybrids) along the upper Colorado River and tributaries in Texas in spring 2004. As part of the monitoring protocol established by the U. S. Fish and Wildlife Service and the Saltcedar Biological Control Consortium, one objective was to compare wildlife populations in native plant communities versus saltcedar communities and then to monitor the effects of biological control of saltcedar on wildlife populations inhabiting the area. Birds, especially, may be affected, at first by the invasion of saltcedar and its displacement of their native plant communities and then affected by the control of saltcedar trees in riparian habitats followed by recovery of native vegetation. Our objective was to compare bird populations and species diversity in saltcedar dominated habitats versus native vegetation before and after biological control with the native vegetation plots as the statistical control.

Using aerial photography provided by USDA, ARS, Weslaco, geo-referenced against USGS Orthophoto Quads and GPS information, point count sites for bird surveys were established at sites along the Upper Colorado River above Lake Thomas in Borden County and along Beals Creek east of Big Spring, Howard County. At first, USDA-ARS did not find any suitable native vegetation areas along Beals Creek. However, large stands of mixed to near monotypic saltcedar were prevalent along Beals Creek, especially at and just below the Big Spring city wastewater treatment plant (Figs. 1, 2). Because of extended drought conditions with only occasional flooding, the water level in Lake Thomas had receded almost 5 km from the original shoreline established many years ago. The native riparian vegetation has grown considerably here with extensive stands of black willow, net-leaf hackberry, western soapberry, honey mesquite, and willow baccharis with intermixtures of broadleaved forbs and grasses. This area was chosen to establish 10 point count circles in native willow dominated vegetation (Fig. 3). However, no large stands of monotypic saltcedar were present at this location, but smaller groves of saltcedar usually mixed with grasses and forbs and some with a few honey mesquite trees were present and four saltcedar habitat point counts were established in these areas (Fig. 3).

When monitoring began in 2004, the following point counts were inaccessible and were abandoned (no data taken at these points): SC1 (saltcedar on Murphy Ranch above Lake Thomas), W3 and W6 (willow in Lake Thomas) (Fig. 3, no longer shown on map). An additional 7 point counts were established in saltcedar groves along Beals Creek east of Big Spring with 6 points located in the extensive monotypic saltcedar stand surrounding the wastewater treatment plant and one point count (SC11) on our primary research site at Higgins Ranch ca. 3.6 km farther downstream (Fig. 1). With the addition of the Higgins Ranch point count the number of saltcedar habitat point counts remained at ten. However, USDA-ARS were unable to find additional accessible sites for the native vegetation at Lake Thomas so the total point counts here were eight. The Higgins Ranch point count consisted of an open stand of saltcedar trees intermixed with inland saltgrass and alkali sacaton in a wet meadow and was located a few meters from the trees where *D. elongata* established populations in 2004. Only a portion of this count circle was defoliated in 2005, but was completely defoliated by the beetles repeatedly in 2006 and in 2007 (Fig. 10).

Methods. Each point count consisted of a circular area 100 m in diameter with a listening and viewing post in the center usually marked with flagging tape and marked by GPS. Close-up aerial photographs of two point counts, one in saltcedar habitat (SC6) at the Big Spring Wastewater Treatment Plant on Beals Creek and one in native habitat (N2) on Higgins Ranch are shown in Figures 4 and 9. USDA-ARS followed the protocol established by Larry White of Bureau of Reclamation, Denver, for monitoring birds in Colorado and New Mexico. This protocol is based on the methodologies developed by Ralph et al. (1995) which in turn is based on the previous work of Reynolds et al. (1980). An observer stands at the center point of the circle and records all birds seen or heard within a five min period. The observer moves to each point with as little disturbance as possible so that data collection can begin immediately upon arrival at the point center. All observations are taken between dawn and about 11:00 a.m. depending on weather conditions. Observations were not conducted on days with heavy rains or strong winds because of low bird activity and difficulty in making meaningful observations. Observations were not made after 11:00 a.m. on bright sunny days because bird calling declines markedly during the mid-day period. All observations were conducted during the primary breeding season for most song birds in the southern U. S. (mid-May to mid-July). Observations were repeated at each point count a minimum of 3 times during this 8 to 9 week period so that birds missed on the initial visit to a site could be noted and potentially all breeding birds in a habitat could be recorded. One difference in our point counts was the spacing between points. The protocol developed by Ralph et al. (1995) suggested a spacing of 250 m between points (150 m between circle perimeters) to avoid repeat observations. However, our habitat types were quite small. In order to acquire enough observations to obtain a statistical comparison USDA-ARS were forced to narrow the distance between points to 200 m (100 m between circles) and trust to experienced observers to separate bird observations to the delimited areas.

2006 Site Changes and Additional Site Descriptions. No bird monitoring observations were conducted in 2005 because of extensive flooding along the upper Colorado River and the long term inundation of the native vegetation site at the upper end of Lake Thomas. Lake Thomas observation sites were abandoned altogether in 2006 because of continued occasional flooding and the failure to establish a viable population of *Diorhabda elongata* beetles on the saltcedar at this location. Five native vegetation points then were established on Higgins Ranch property (Fig. 8). Four of these points were in native riparian woodlands at the mouth of sandy draws draining into Beals Creek where the vegetation consisted of very large mature honey mesquite, net-leaf hackberry, and gum bumelia trees with a dense understory of little-leaf sumac, lotebush, Pinchot juniper, and agarito along with a varied mixture of vines and herbaceous vegetation (See vegetation monitoring section). One point (N5) was located in a honey mesquite savannah ca. 80 m west of the wet meadow where *D. elongata* was released and established (Fig. 8). This area consisted of an open stand of medium to small honey mesquite trees with scattered little-leaf sumac and lotebush shrubs and a variety of herbaceous forbs and grasses. Therefore, 7 point counts were monitored in saltcedar vegetation (the same established in 2004, 6 at the Big Spring wastewater treatment plant and one at Higgins Ranch) along Beals Creek and 5 point counts in nearby native vegetation (Higgins Ranch) during 2006.

Bird Area Search Strips - Methods and Descriptions. Another addition in 2006 was the establishment of area search strips along the border of Beals Creek beginning at the southeast corner of Higgins property and going upstream approximately 1.4 km. Eight strips of mixed vegetation each 150 m long by about 50 m wide were searched for the presence of birds during the breeding season in 2006 (BAS1-BAS8)(Fig. 11). A buffer of 30 m was left between each 150 m strip so that searches were conducted in discreet units. A close-up aerial photograph of one bird area search strip (BAS2) is shown in Figure 12. As with point counts, observations were made between dawn and 11:00 a.m. and the observer walked through the unit area for a 10 min period recording all birds seen or heard within the discreet unit. If bird nests were located within the strip area, an attempt was made to identify the type and placement of the nest, the presence of eggs or chicks, the identity of the bird species involved, and to mark the nest by GPS for future reference, however, no active searches for bird nests were conducted during the census period. The vegetation bordering Beals Creek consisted of a mixed stand of saltcedar, honey mesquite, and grasses (inland saltgrass and alkali sacaton) with smaller amounts of pickleweed, willow baccharis, wolfberry, and Pinchot juniper (See vegetation monitoring section). Native point count # 5 (N5) in honey mesquite savannah was lost in late 2006 when the landowner removed most of the younger honey mesquite trees on his property. This was accomplished using an excavator where individual trees were mechanically removed with little disturbance to surrounding vegetation. The excavation of honey mesquite trees just outside the narrow band of vegetation bordering Beals Creek may have also had an influence on breeding birds counted in the area searches during the breeding season of 2007.

2007 Point Count Changes and New Site Descriptions. In preparation for monitoring birds in 2007, two new native vegetation points were established in a honey mesquite dominated field in the flood plain of Beals Creek on the neighboring property downstream from the Higgins Ranch (Fig. 8). This large field consisted of an open overstory of medium to small honey mesquite trees intermixed with broadleaved plants and a few grasses. These new points do not compare vegetatively with the other four native point counts which have no similar vegetation remaining along Beals Creek in the immediate area but do compare with N5, the point decimated in late 2006 by excavation of honey mesquite trees. Point count surveys and area searches for birds were conducted in 2007 as in 2006.

Results. Results of the bird monitoring at Lake Thomas and Beals Creek in 2004 are presented in Tables 1-3 and in Figures 5-7 . The most frequently recorded birds in native willow vegetation at Lake Thomas (n=24) (8 point counts × 3 dates) were northern cardinal, mourning dove, indigo bunting, yellow-billed cuckoo, painted bunting, and common grackle (Table 1, Figure 5). In saltcedar habitat at Beals Creek (n=21) (7 points × 3 dates), the most frequent birds were northern cardinal, mourning dove, painted bunting, common grackle, western meadowlark, and ash-throated flycatcher (Table 1, Figure 5). The saltcedar points (n=9) (3 point counts × 3 dates) at Lake Thomas were not included in this analysis. At Lake Thomas only a comparison of bird frequencies by count period between native willow point counts (n=8) and saltcedar (n=3) is shown in Figure 6 (Table 2). The most frequent birds in willow habitat were northern cardinal, common grackle, mourning dove, indigo bunting, yellow-billed cuckoo, painted bunting and orchard oriole. In saltcedar northern cardinal, yellow-billed cuckoo, painted bunting, northern bobwhite, and northern mockingbird were the most frequently recorded birds. Figure 7 shows a comparison of birds observed by count period in saltcedar at Lake Thomas (n=9) with those observed in saltcedar at Beals Creek (n=21). Several species including northern cardinal, mourning dove, painted bunting, and common grackle occurred frequently at both locations but there were habitat differences between the two sites such that several species were recorded from one site only (blue grosbeak, northern bobwhite at Lake Thomas; black-crested titmouse, western meadowlark, Bullock's oriole, brown-headed cowbird, bushtit, and curve-billed thrasher at Beals Creek). The most interesting observation was the regular frequency of yellow-billed cuckoo in saltcedar at Lake Thomas compared with almost none for the same species in saltcedar at Beals Creek. The yellow-billed cuckoo is primarily a gleaner feeding heavily on Lepidoptera larvae and other medium to large insects (ie. cicadas, katydids, crickets, grasshoppers) in the foliage of trees. The most logical explanation for the differences in frequency of yellow-billed cuckoo in saltcedar at the two sites is that extensive tracts of native vegetation surrounding the small groves of saltcedar at Lake Thomas provide ample food sources for the birds while all but one of the point counts at Beals Creek are in large stands of monotypic saltcedar where very few Lepidoptera larvae are available (USDA-ARS observed only a few generalist moth larvae – two Arctiid species and one Geometrid species – on saltcedar foliage during our studies at Beals Creek and these larvae were observed to be most frequent on broad-leaved plants growing near the saltcedar stands.) but many other insects are often present on flowers when the trees are in bloom. Species diversity (Shannon-Weaver Diversity Index, Table 1) between eight point counts in native vegetation (willow) at Lake Thomas and seven saltcedar point counts at Beals Creek showed no significant difference for 2004.

Results of bird monitoring in 2006 at Beals Creek near Big Spring are provided in Table 4 and Figure 13. These results compare the seven point counts in saltcedar (n=21) near the wastewater treatment plant with the five points in native vegetation (n=15) on Higgins Ranch downstream from there. The most frequently recorded birds in saltcedar were red-winged blackbird, common grackle, and northern cardinal and in native vegetation the most frequent birds were northern cardinal, verdin, western kingbird, and Bewick's wren. The frequency of northern cardinal in native vegetation was twice that in monotypic saltcedar. The frequency of red-winged blackbird was more than 20 times greater in saltcedar habitat than in the native vegetation. This can be explained in that these birds prefer marshy habitat for breeding and none of the native point counts occurred in this type of habitat. Along Beals Creek, marshy areas are dominated by saltcedar at the present time with small patches of cattails and Olney bulrush in places. Common grackles have a much wider range of breeding habitat but do prefer marshy riparian habitats as well (See Figures 5-7, Lake Thomas, willow habitat). Several species were recorded only in native habitat including verdin, western kingbird, Bewick's wren, northern mockingbird, Bell's vireo, Carolina wren, painted bunting, black-chinned hummingbird, curve-billed thrasher, canyon towhee, golden-fronted woodpecker, and lark sparrow. On the other hand, common yellowthroat, greater roadrunner, and great-tailed grackle were recorded only in saltcedar habitat. Common yellowthroat is another species preferring marshy habitats which are now dominated by saltcedars with intermixed small patches of cattails and bulrushes.

Bird monitoring at Beals Creek in 2007 was conducted as in 2006 with the loss of one native point count (N5, Fig. 8) and the addition of 2 new point counts in mesquite habitat downstream (N6 and N7, Fig. 8). Results of this survey for 2007 are shown in Table 6 and Figure 15. Northern cardinal was about equally frequent in native and in saltcedar habitat for this year. Other frequently recorded birds included Bullock's oriole, verdin, Bewick's wren and mourning dove in native habitat and red-winged blackbird and mourning dove in saltcedar habitat. Red-winged blackbird was the most frequently recorded bird in any habitat in 2007 and was recorded only in saltcedar habitat this year. These birds again occurred in marshy areas with some standing water or pools of water nearby and usually with cattails and bulrushes but heavily invaded by saltcedars. Other birds found only in saltcedar habitat in 2007 included blue grosbeak, bronzed cowbird, common grackle, great-tailed grackle, house sparrow, western meadowlark, and yellow-breasted chat. Birds recorded only in native habitat included verdin, black-chinned hummingbird, northern mockingbird, painted bunting, curve-billed thrasher, yellow-billed cuckoo, Carolina wren, and golden-fronted woodpecker. Overall bird frequencies were similar between 2006 and 2007, however, common grackle and northern cardinal were much lower in 2007 than in 2006. Northern cardinal occurred in saltcedar habitat at the same frequency in point counts in both 2006 and 2007, but frequency was much lower in native habitat in 2007 over the previous year (Tables 4 and 6). The species diversity results for 2006 (Shannon-Weaver Diversity Index, Table 4) indicate that there was a significantly higher diversity of species in native vegetation than in saltcedar at Beals Creek for this year. However, the results for 2007 (Table 6) indicated no significant difference in species diversity between the two habitat types along Beals Creek.

Area searches were conducted for bird occurrences along Beals Creek as described above for both 2006 and 2007. In 2006, northern cardinal, northern mockingbird, blue grosbeak, western kingbird, bushtit, lark sparrow, mourning dove, and brown-headed cowbird were the most frequent birds observed in the 150 m search strips (Table 5, Figure 14). In 2007, overall bird frequencies were much lower than those in 2006 for all bird species observed (Table 7, Figure 16). Two bird species which did not appear in 2006 but appeared in 2007 at the second and third highest observed frequencies were dickcissel and painted bunting. One dickcissel nest was observed during the second period of counting in a saltcedar tree in BAS6. The nest had been parasitized by brown-headed cowbird and was possibly preyed upon later as the nest was abandoned and contained no eggs two weeks later. A comparison of the results for these two years for each species of bird is presented in Table 8 and Figure 17. Note that the following species were statistically more frequent in 2006 than in 2007: northern cardinal, northern mockingbird, blue grosbeak, western kingbird, bushtit, lark sparrow, and brown-headed cowbird (Figure 17, signified by *). Dickcissel was the only species statistically more frequent in 2007 simply because it had not been recorded in 2006.

By July 2006, *D. elongata* beetles had reached sections of Beals Creek and had defoliated several trees in separate satellite areas as shown in Figure 19 (areas marked with red borders). This defoliation continued into October 2006 but some regrowth of foliage did occur before the onset of winter. One area of defoliation involved about 6 or 7 trees along Beals Creek between the end of Beals Creek area search strip #1 (BAS1) and the beginning of area search strip #2 (BAS2). The second area was more extensive and involved a good portion of the trees on the north bank of Beals Creek between the end of area search strip #2 and the end of area search strip #3 (BAS3)(Fig. 19). In 2007, defoliation by leaf beetles was noticed at an earlier date than in previous years, as early as 21 May. This defoliation was mainly in the same areas involving area search strips BAS2, 3, and 4, and was occurring during the breeding period for birds in the area. By 12 July, the following visual estimates of beetle defoliation were made for each area search strip count: BAS1 (nearly 100%), BAS2 (nearly 100%), BAS3 (ca. 90%), BAS4 (ca. 75%), BAS5 (ca. 85%), BAS6 (ca. 50%), BAS7 (ca. 20%), BAS8 (ca. 5%). Estimated regrowth of foliage on the defoliated saltcedar in area search strips BAS 1-6 was 25-75% by 12 October 2007. Several trees in area search strips BAS7 and BAS8 were never completely defoliated, although, they were heavily fed upon by larvae and adults of the beetles. Foliar regrowth on most of these trees should be very good for the 2008 season. The excavations of small honey mesquite trees in 2006 affected only the first three area search strips (BAS1-3). It is unknown whether or not the excavations of the honey mesquite trees or the repeated defoliation of saltcedar trees along the creek (particularly BAS2-3) in 2006 and 2007 had any effect on lowered bird frequencies in the area search strip counts during 2007. Continued monitoring in 2008 of saltcedar areas defoliated by *D.* elongata may provide the first documentation of the effects of biological control on bird populations.

Figure 10 shows the progression of defoliation of saltcedar by *Diorhabda elongata* at Higgins Ranch from 2005 through 2007 as it affected bird count point number SC11. In August 2005, defoliation reached the fringe of SC11 and by September 21, 2005 had affected only about 1/5 of the circle. Most of this section was never completely defoliated in 2005 and there was extensive regrowth by the end of the year. By August 9, 2006, more than 1/2 of SC11 was defoliated and by September 19, 2006 the entire circle was completely defoliated. It can be noted that this defoliation occurred after the breeding season for most birds was completed. In 2007, there was extensive regrowth of foliage in this area but by August 8, 2007, SC11 was again completely defoliated. Figure 18 shows the changes in frequency in bird species counted at SC11 from 2004 throuth 2007. It can be noted that there was a decline in number of species over this time period (9 species in 2004, 6 in 2006, and 5 in 2007) and that frequencies for some species declined (red-winged blackbird and western meadowlark). However, bushtit and common grackle increased in frequency between 2004 and 2006 and mourning dove increased each year through the period. Also, four species appeared in 2006 and 2007 (two each for each year) that had not been present in 2004. At the same time, four species were lost from the count (northern cardinal, ash-throated flycatcher, black-crested titmouse, and lark sparrow) after 2004.

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Reynolds, R. T., J. M. Scott, and R. A. Nussbaum. 1980. A variable circular-plot method for estimating bird numbers. Condor. 82: 309-313.

Figure 1. Layout of Big Spring, Texas, saltcedar bird survey point count locations at research sites, 2004-2007 (left, Beals Creek, Big Spring Wastewater Treatment Plant; right, Beals Creek, Higgins Ranch).

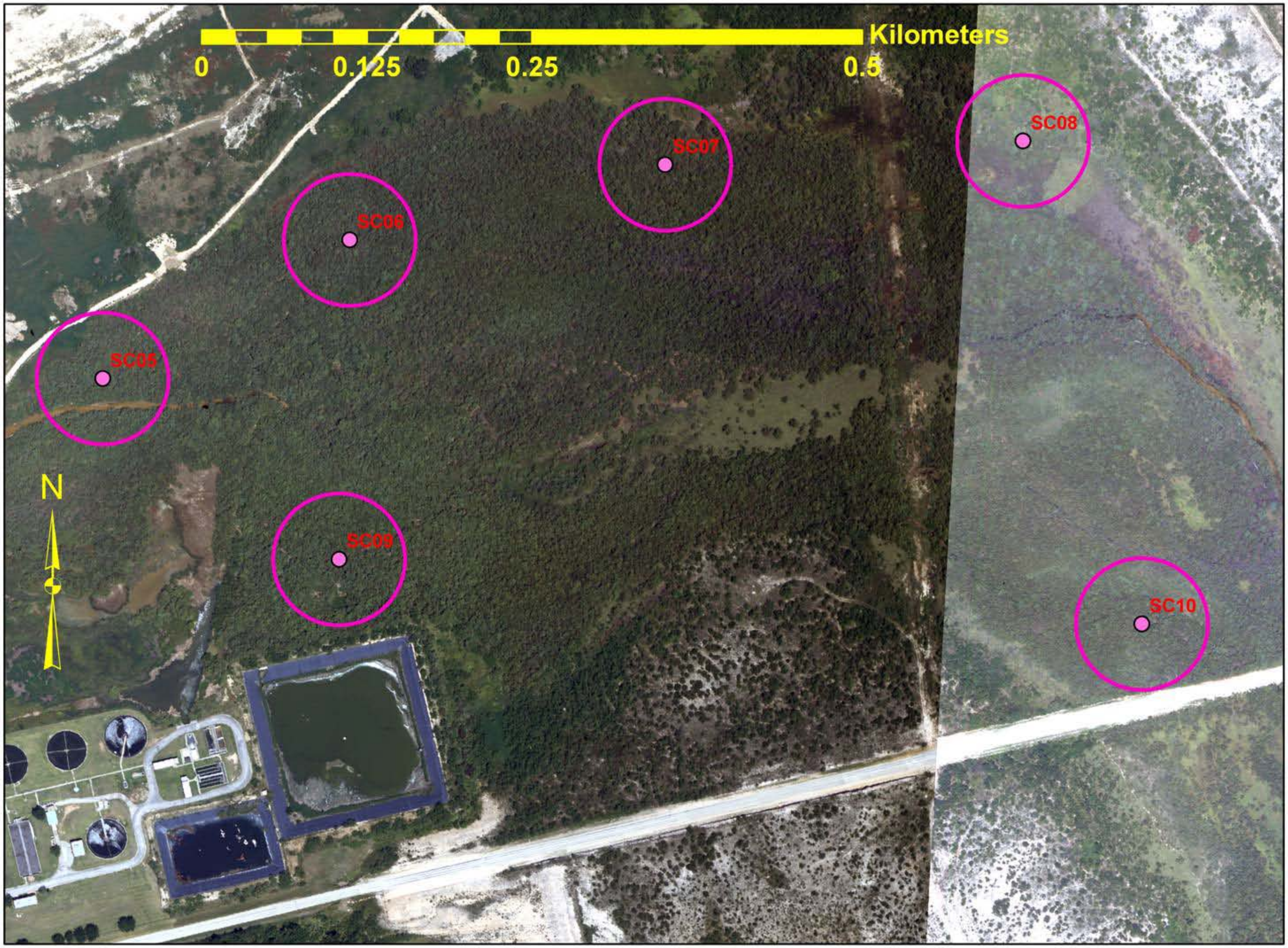

Figure 2. Layout of six bird survey saltcedar woodland point count areas (50 m radius diameter circles, numbered SCn) along Beals Creek at Big Spring Wastewater Treatment Plant, Big Spring, Texas. (Aerial photos from 8 August, 2007).

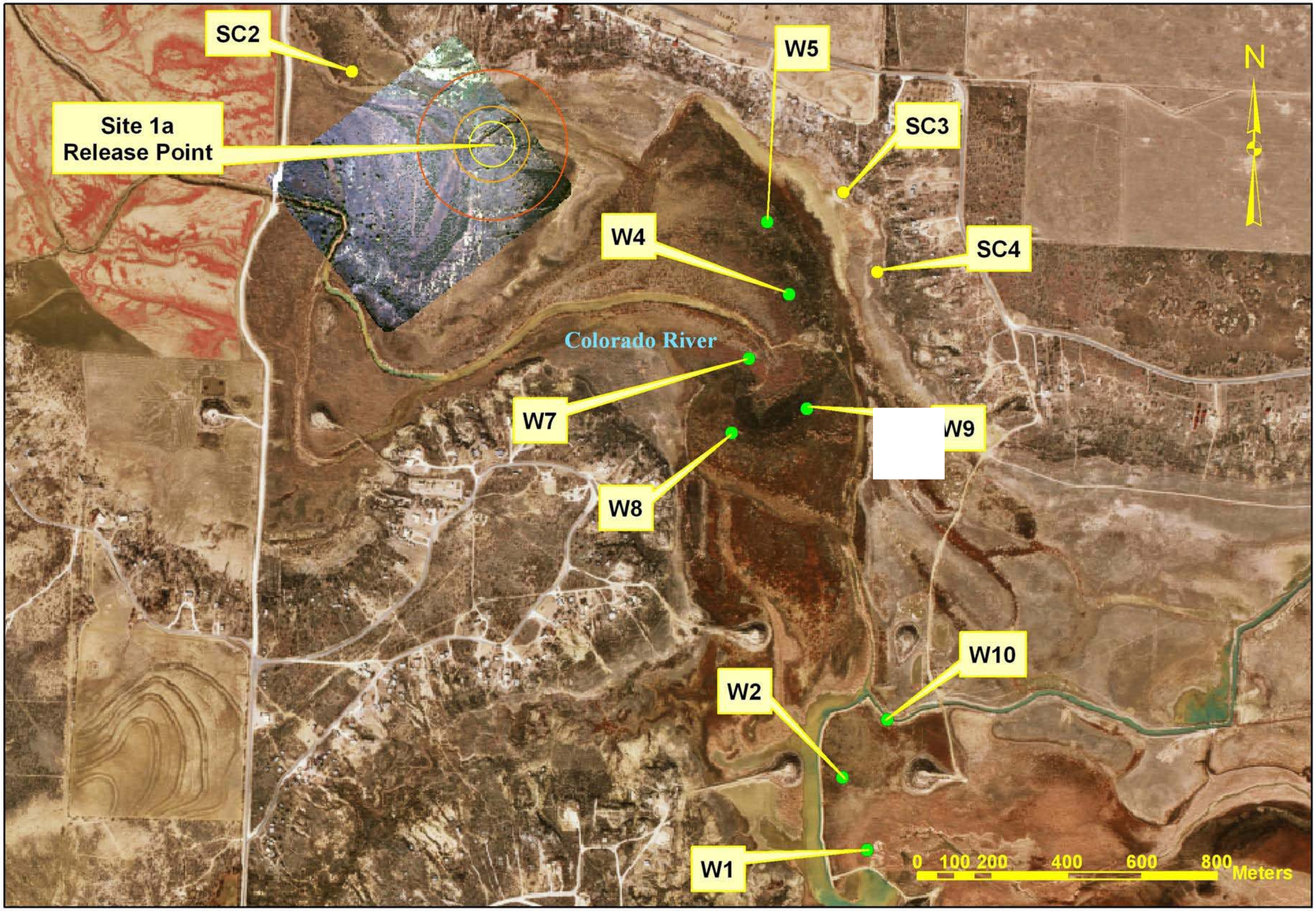

Figure 3. Layout of Lake Thomas, Texas, willow (W) and saltcedar (SC) bird survey point count locations near research site.

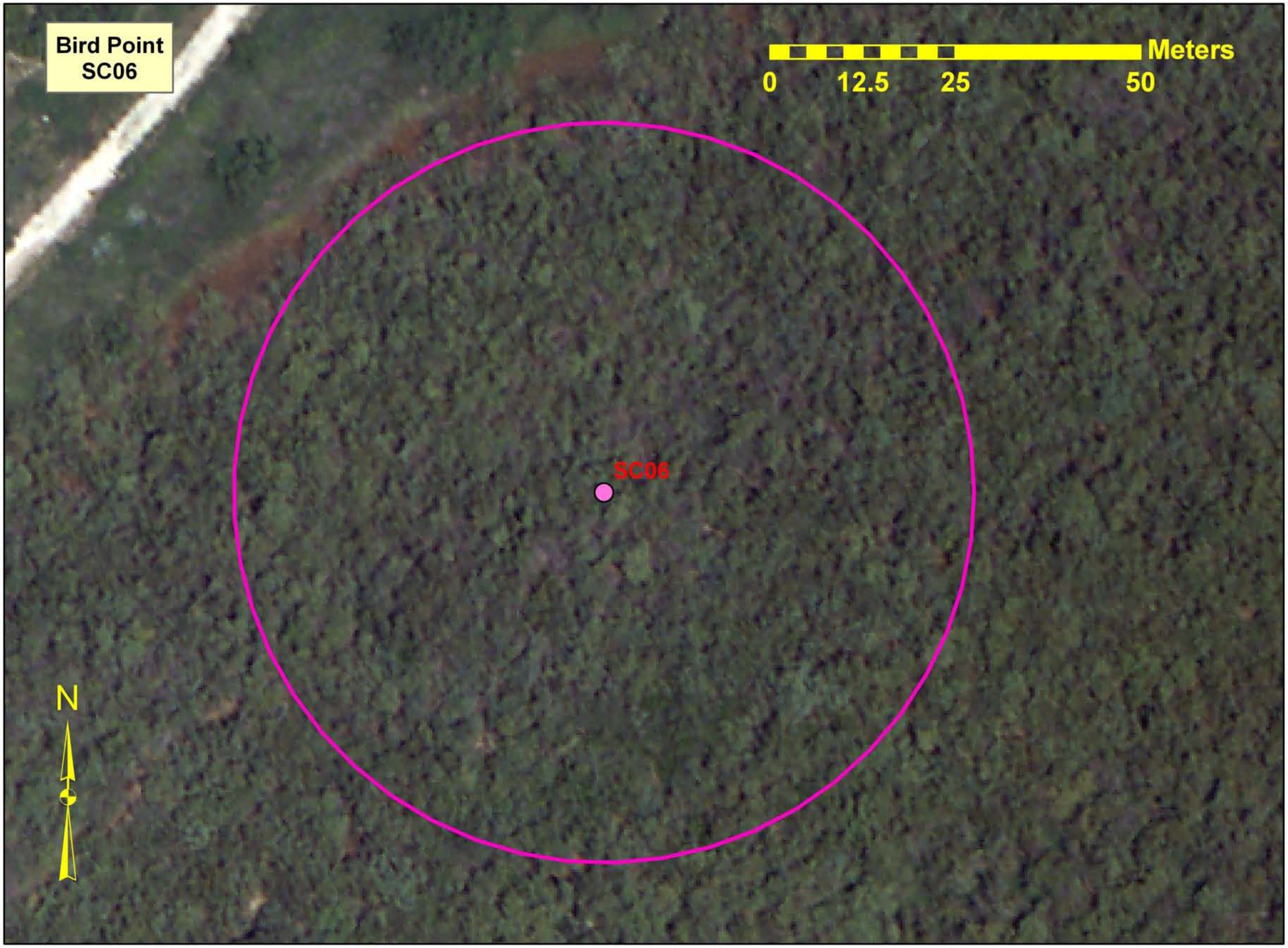

Figure. 4 Close-up of bird point count SC6 in monotypic saltcedar at Big Spring Wastewater Treatment Plant on Beals Creek.

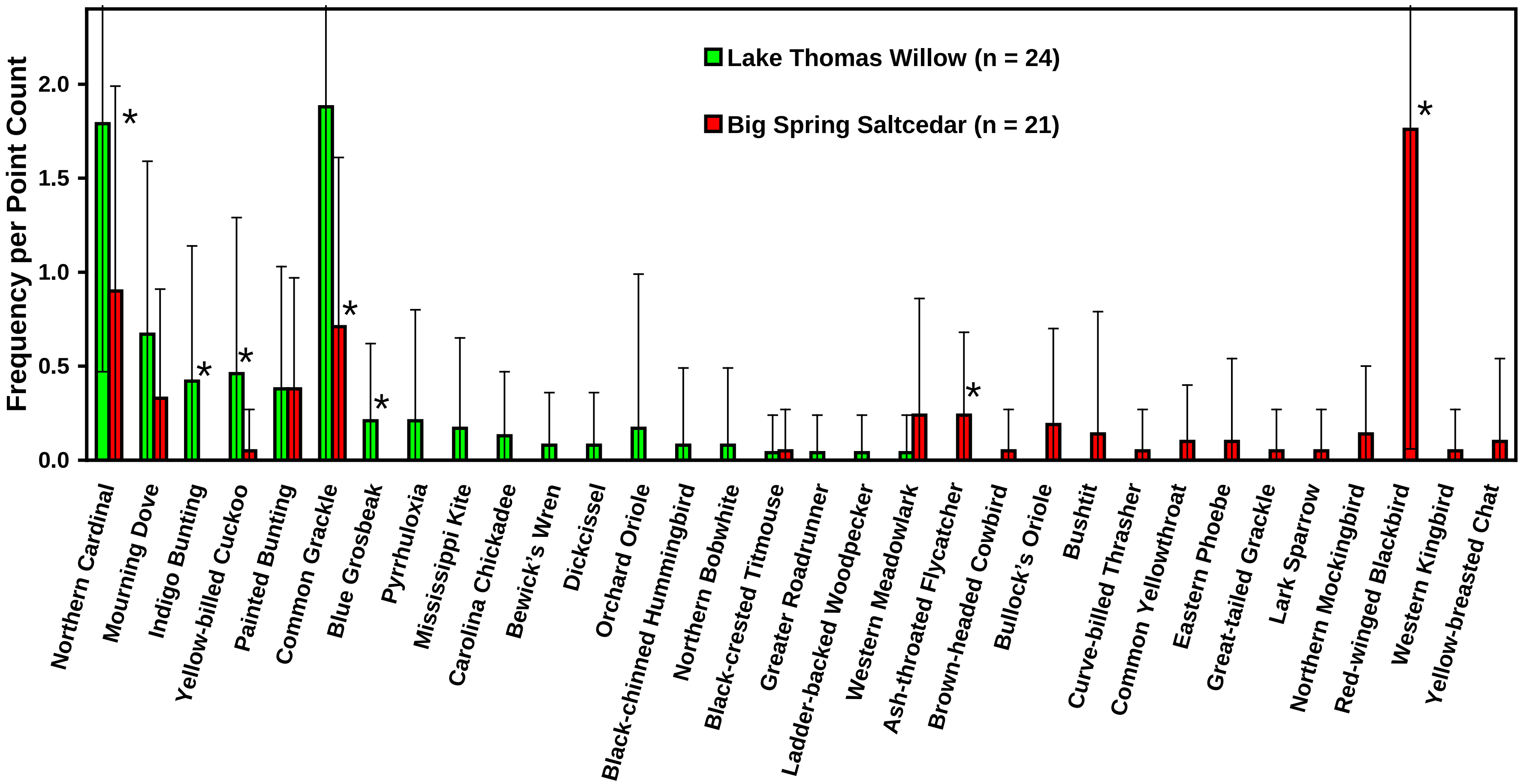

Figure 5. Bird frequency at Lake Thomas in willow (8 Point Count Stations, n=24) and at Big Spring in saltcedar (7 Point Count Stations, n=21) during the spring breeding season 2004, recorded on 17 June, 1 July, and 14 July for Lake Thomas and 3 June, 2 July, and 15 July for Big Spring. All birds seen or heard are counted during 5 min at the center point of each 50 m radius station. Mean (± SD). Habitats with significantly higher ranks for a given birds species are denoted by an asterisk near the top of the bar (P < 0.05; Three-Way Kruskal-Wallis Test). See map Figures 1 (Big Spring) and 3 (Lake Thomas) for location of point count stations.

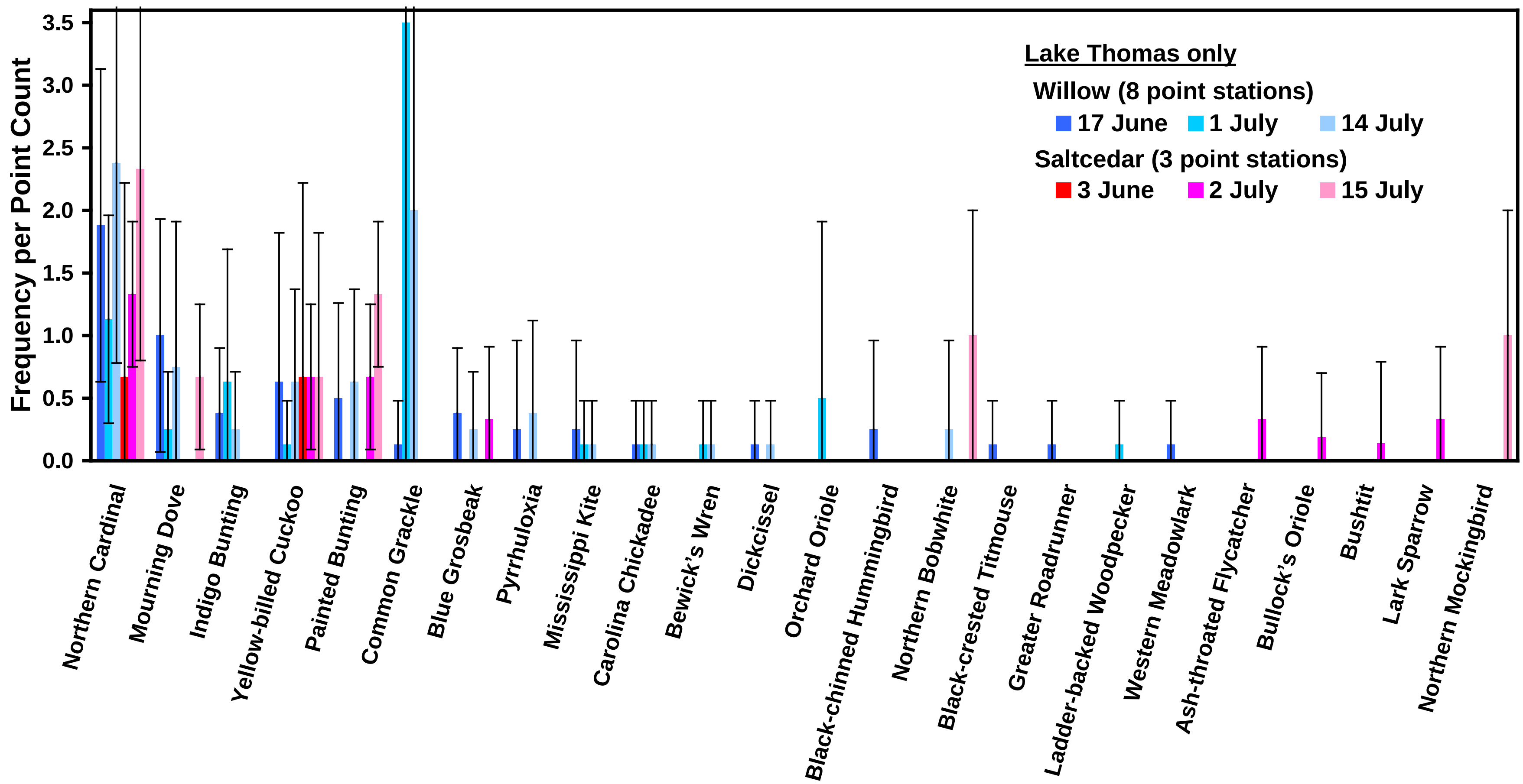

Figure 6. Bird frequency at Lake Thomas in willow (8 Point Count Stations, n=24) compared with saltcedar (3 Point Count Stations, n = 9) during the 2004 breeding season. Mean (± SD) for each bird species on each census date. (See Table 2 for summary).

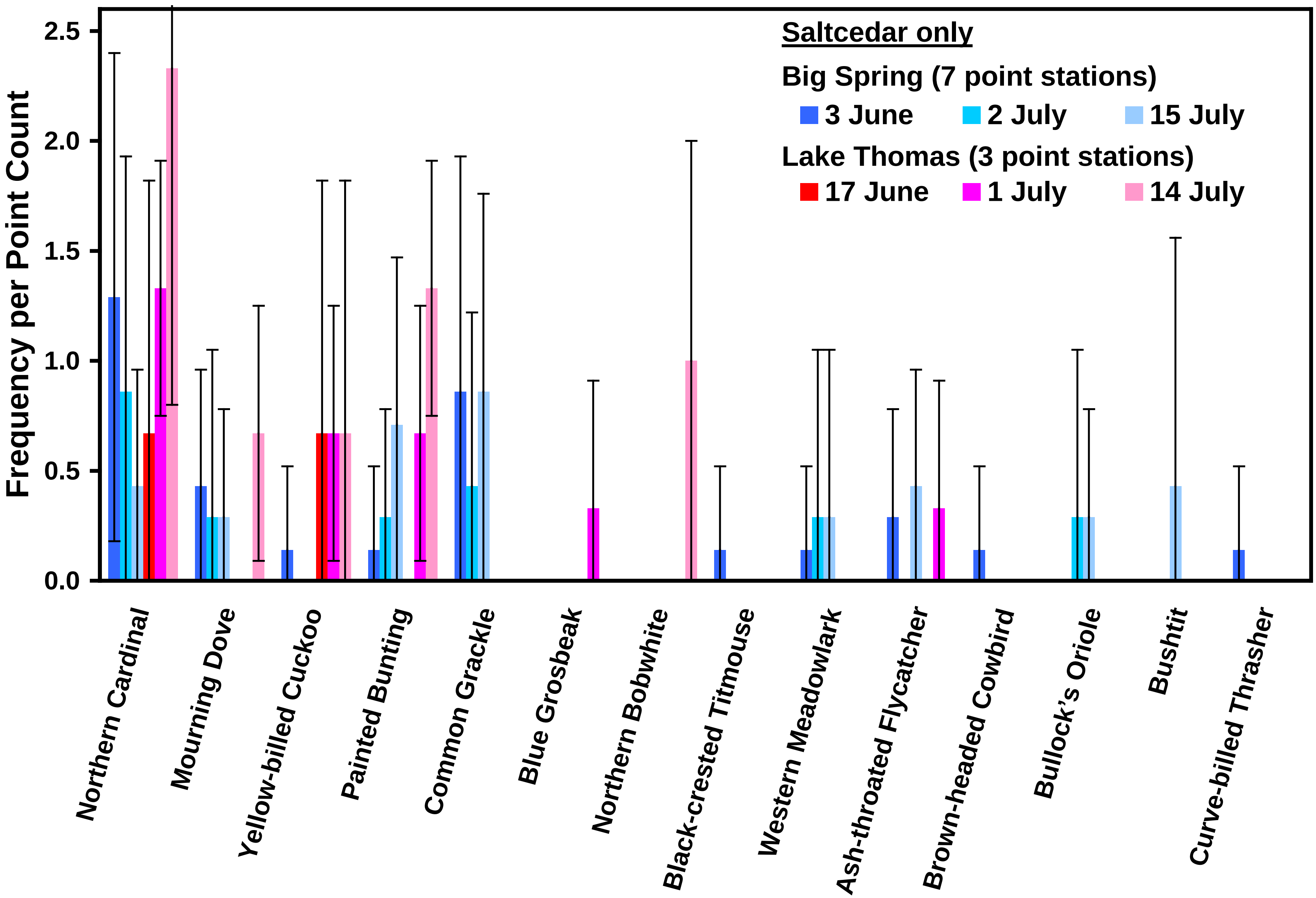

Figure 7. Bird frequency only in saltcedar at Big Spring (7 point counts, n=21) compared with Lake Thomas (3 point counts, n=9) during the breeding season 2004. Mean (± SD) for each bird species for each census date. See Table 3 for summary.

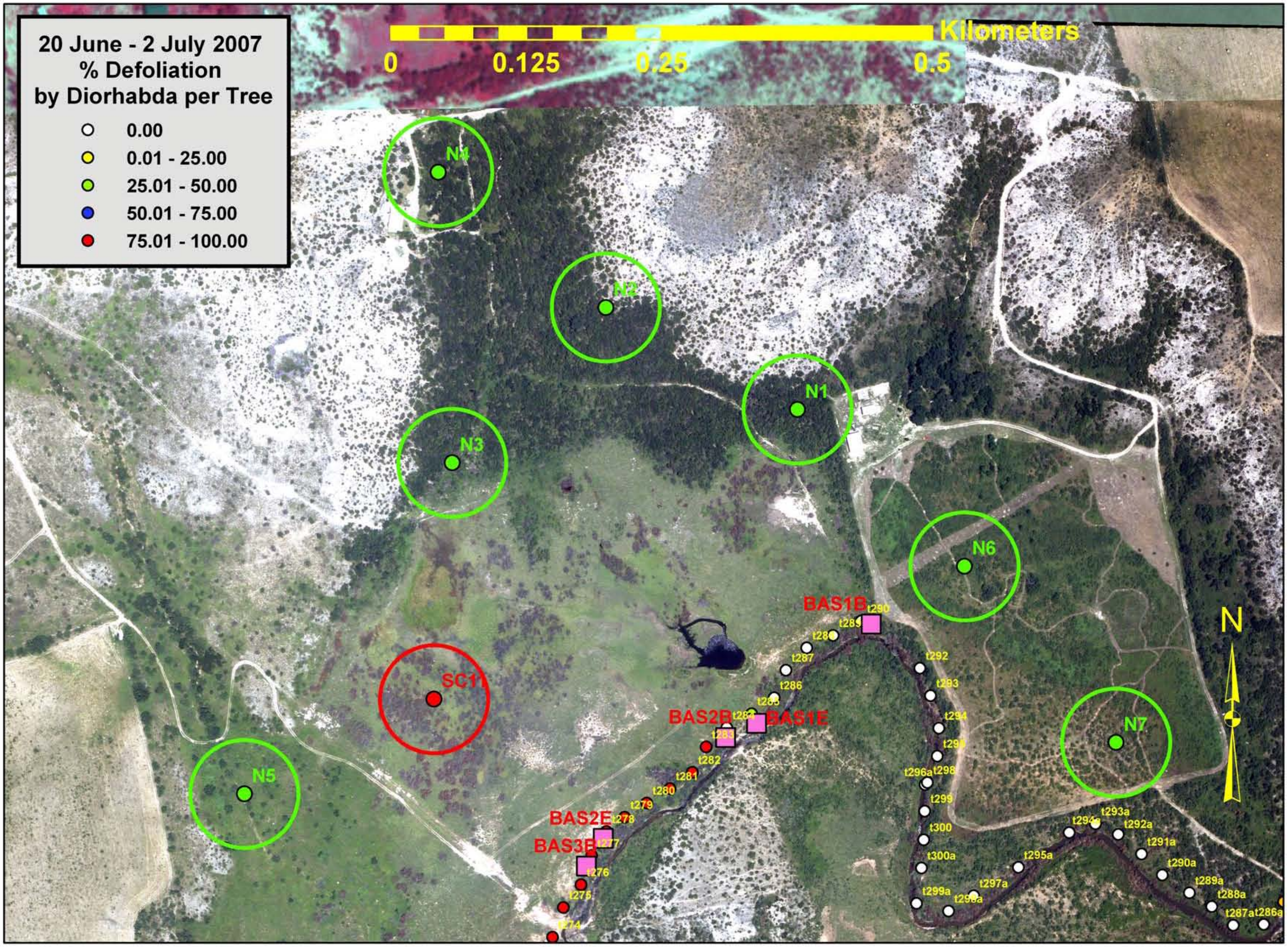

Figure 8. Layout of six bird survey native woodland (green) and saltcedar woodland (red) point count areas (50 m radius diameter circles, numbered HBPn) with 20 June–2 July, 2007 defoliation of marked saltcedar transect sample trees along Beals Creek at Higgin's Ranch near Big Spring, Texas. (Aerial photos from 8 August, 2007).

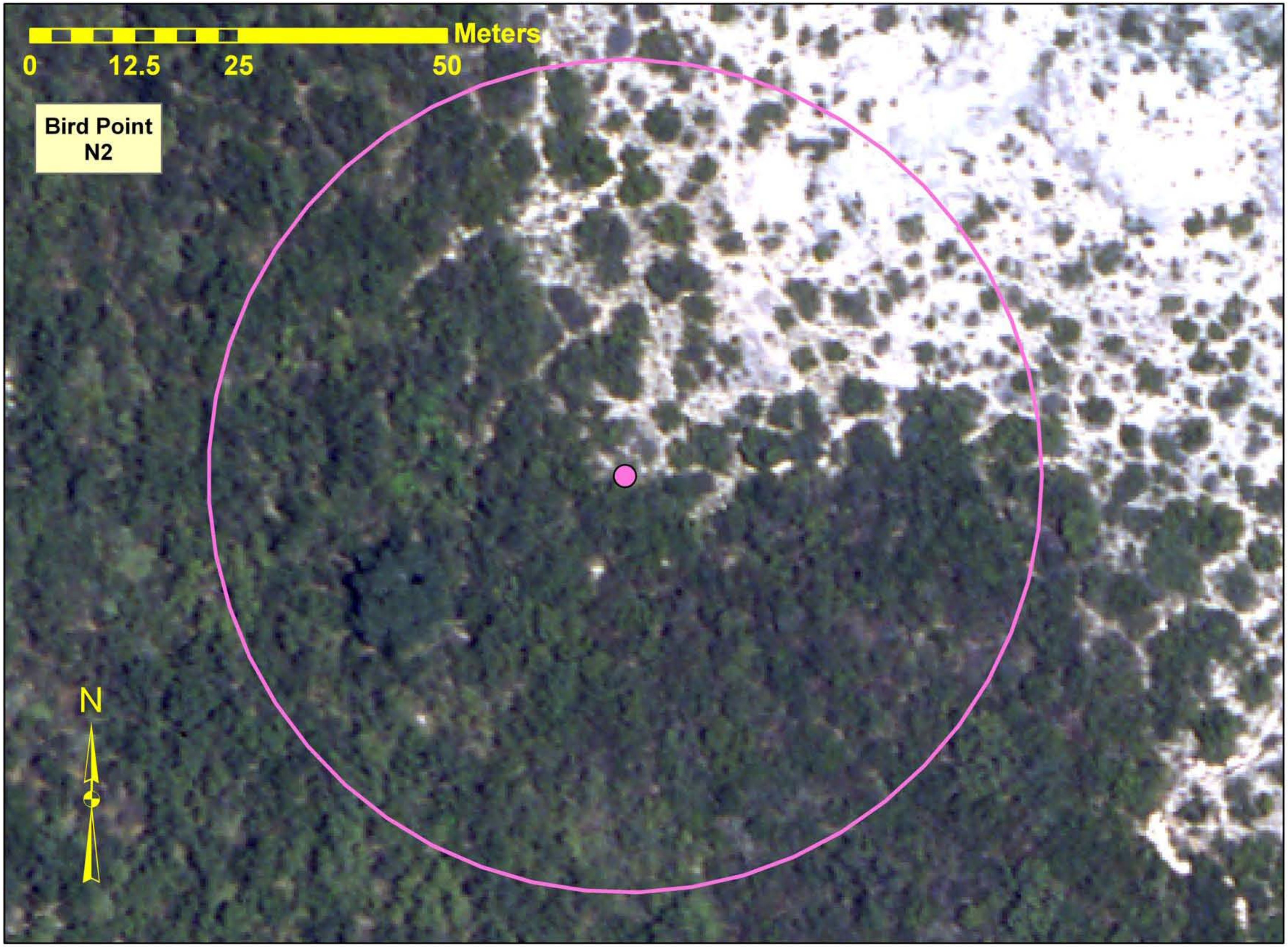

Figure 9. Native woodland bird point count area N2 (50 m radius) north of Beals Creek at Higgin's Ranch near Big Spring, Texas. (Aerial photo from 8 August, 2007).

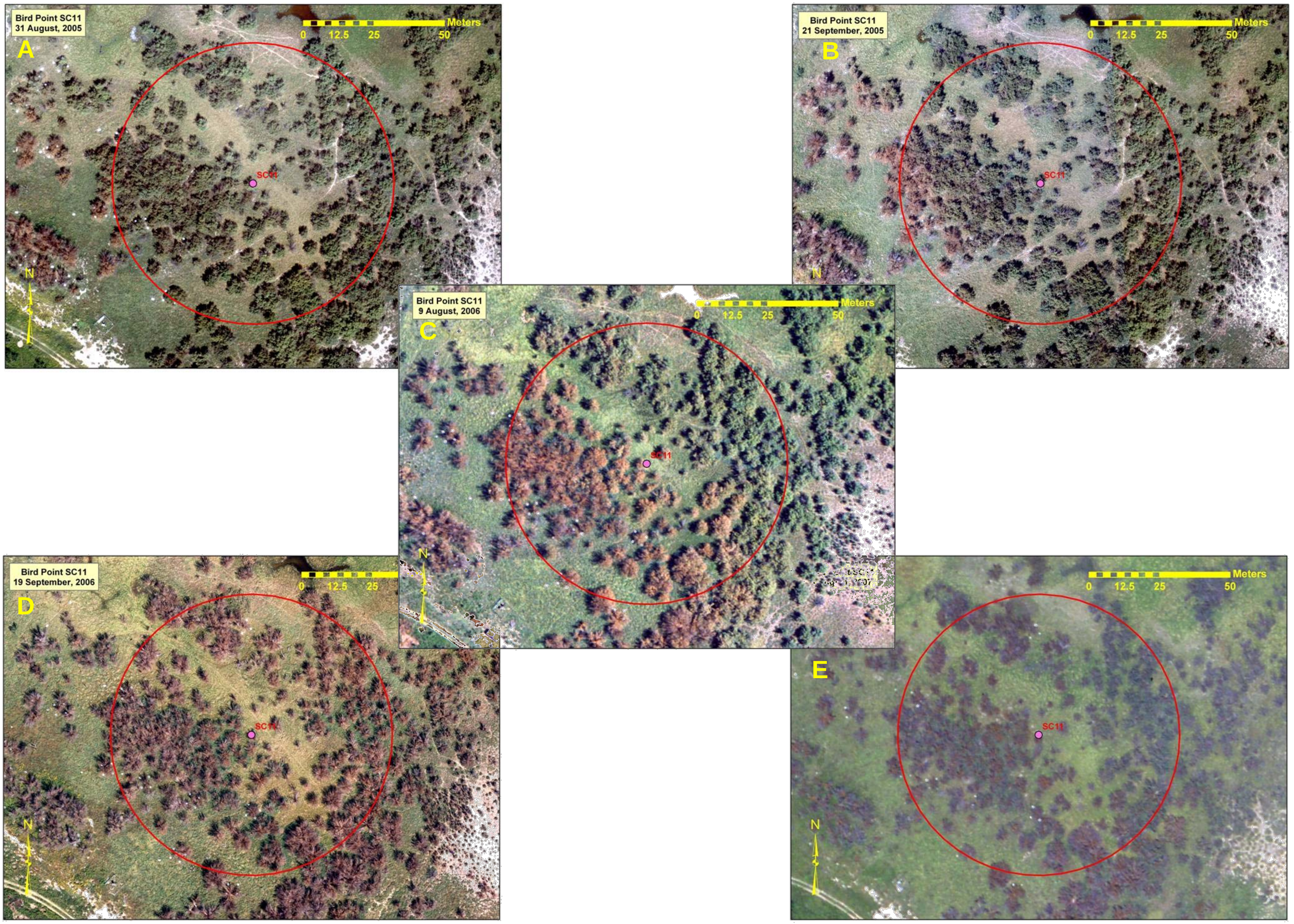

Figure 10. Saltcedar woodland bird point count area SC11 (50 m radius) near Beals Creek at Higgins Ranch, Big Spring, TX. Aerial photos from (A) 31 August, 2005; (B) 21 September, 2005; (C) 9 August, 2006; (D) 19 September, 2006; and (E) 8 August, 2007.

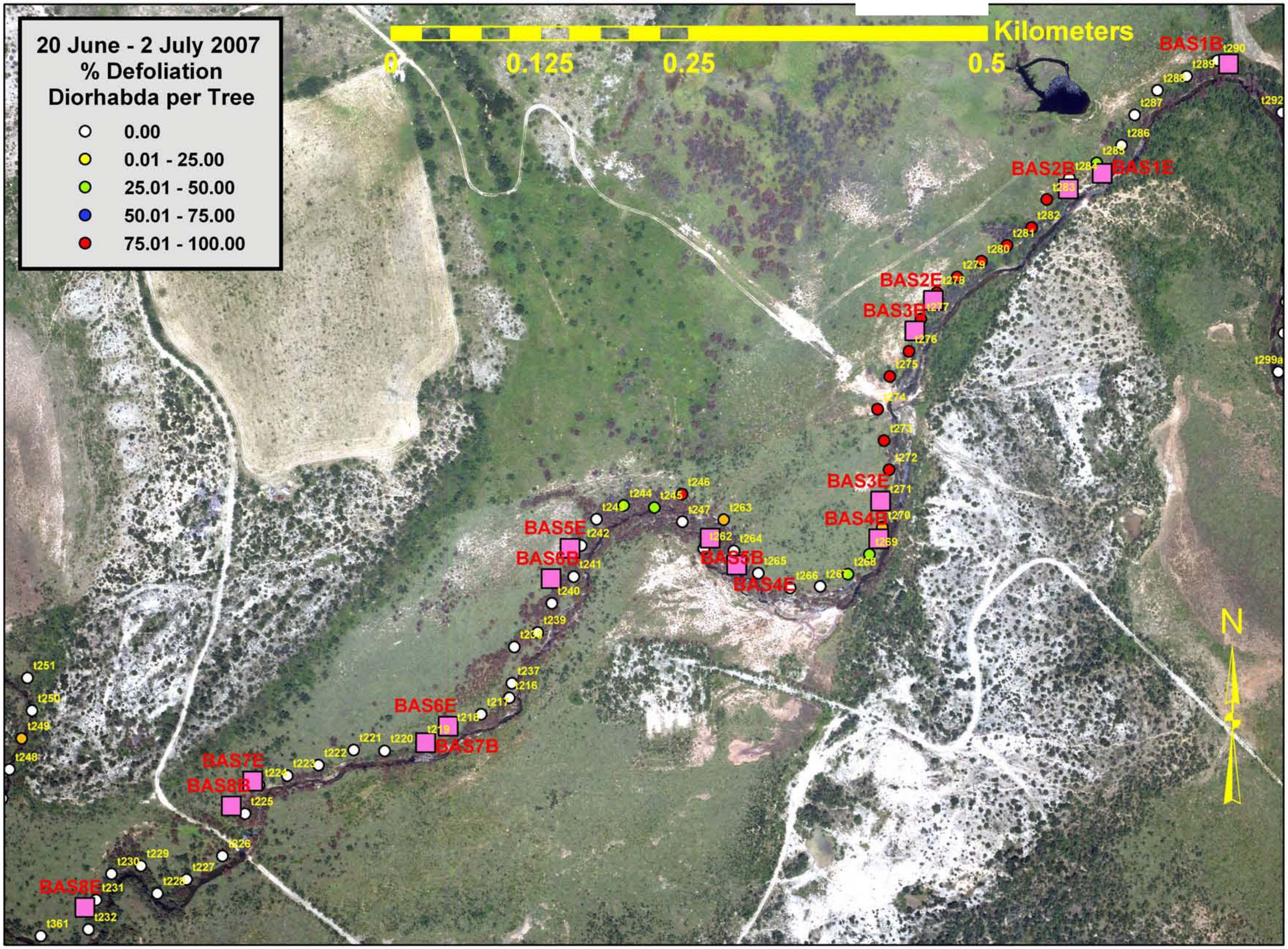

Figure 11. Layout of eight bird survey mixed woodland strip count areas (150m by 50m strips between pink squares, numbered BASn, beginning from BASnB and ending at BASnE) with 20 June–2 July, 2007 defoliation of marked saltcedar transect sample trees along Beals Creek at Higgin’s Ranch near Big Spring, Texas. (Aerial photos from 8 August, 2007).

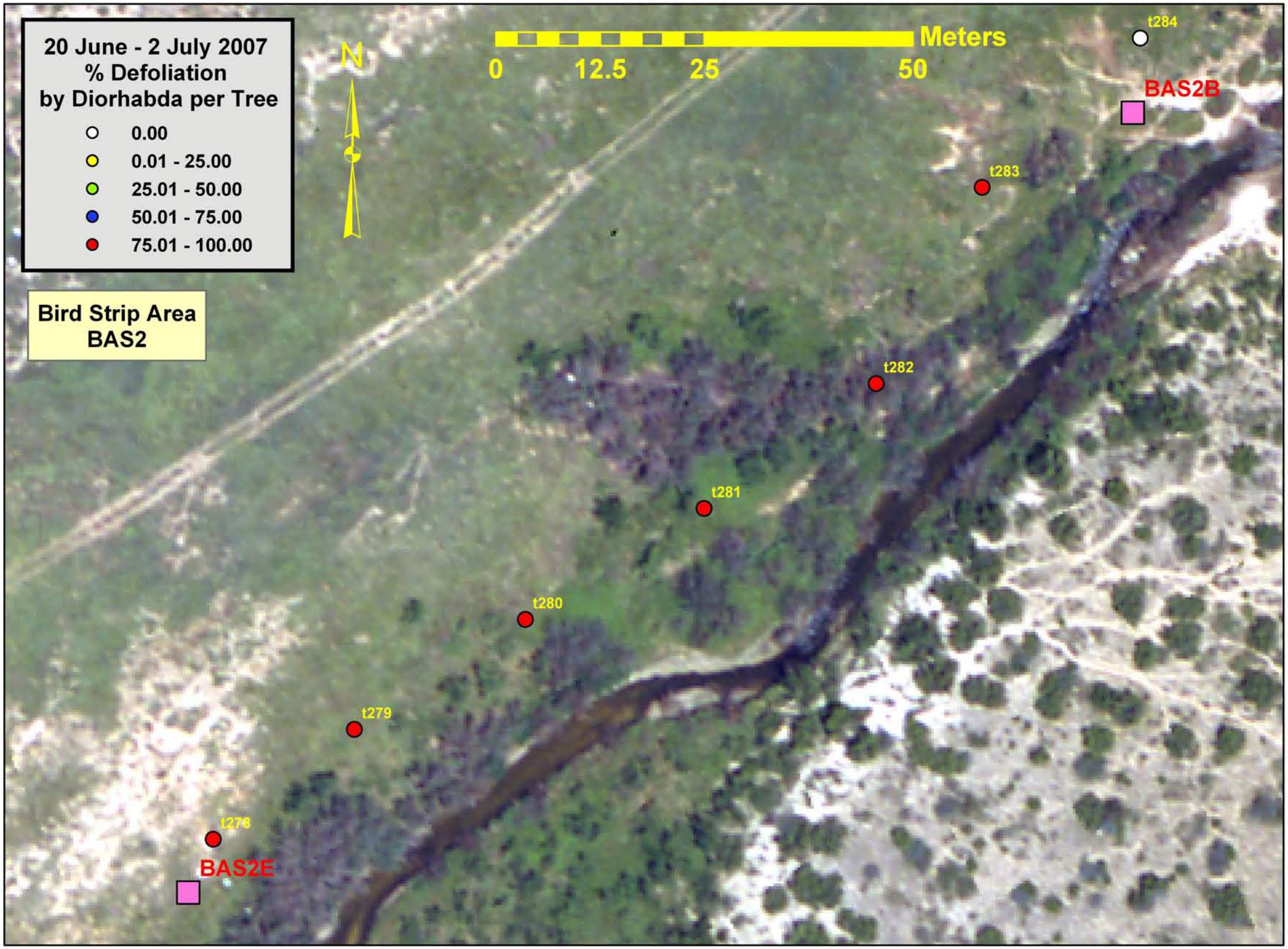

Figure 12. Mixed woodland bird survey strip count area BAS2 (150m by 50m) between pink squares with 20 June–2 July, 2007 defoliation of marked saltcedar transect sample trees along Beals Creek at Higgin's Ranch near Big Spring, Texas. (Aerial photo from 8 August, 2007).

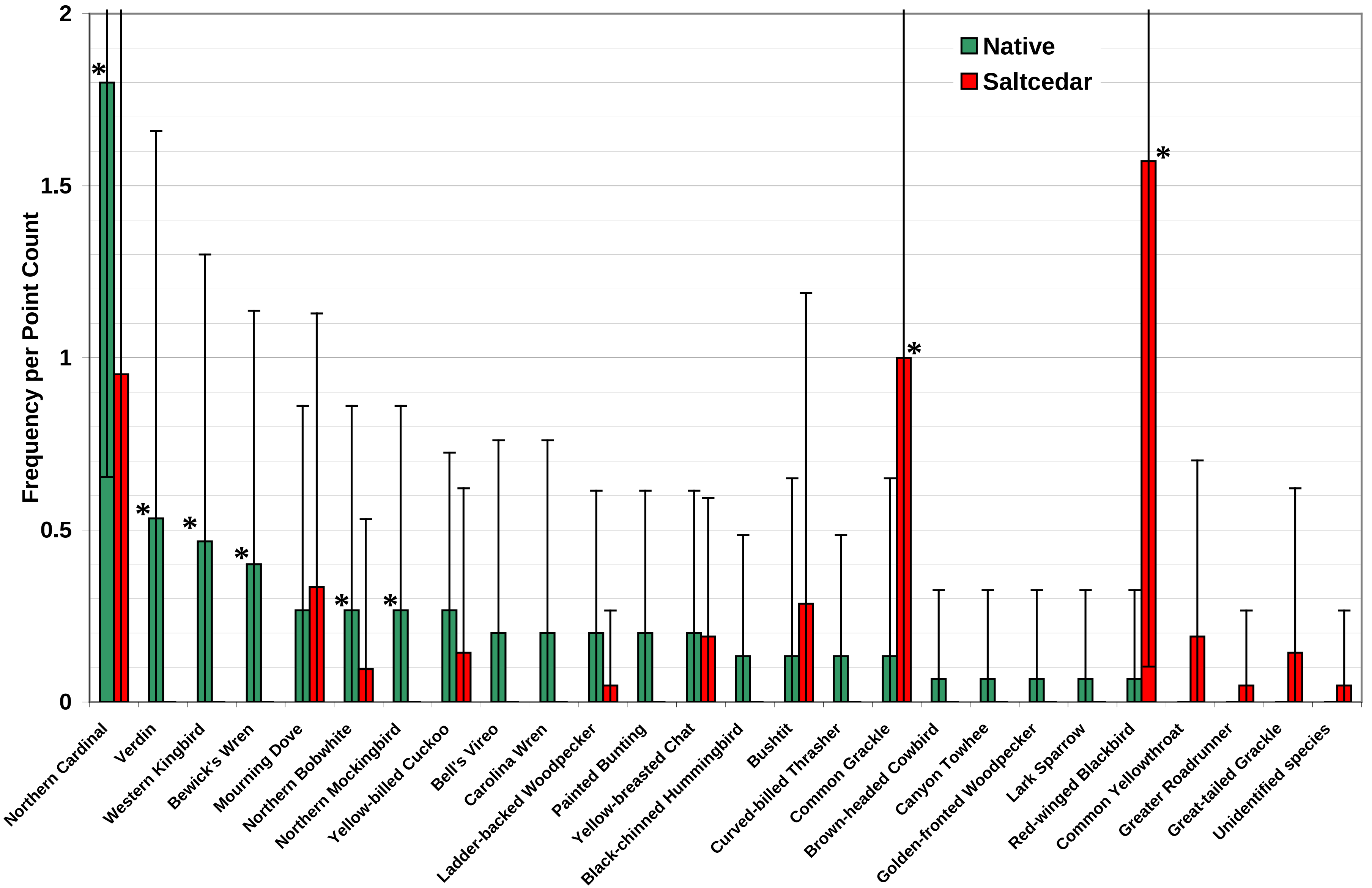

Figure 13. Mean (± SD) values for breeding bird frequency in point count surveys (n = 15, native; n = 21, saltcedar) within native versus saltcedar habitat along Beals Creek near Big Spring, Texas, spring 2006. Birds for which ranks of treatments differ significantly between habitats are denoted by an asterisk (P < 0.05; Three-Way Kruskal-Wallis Test). Data from 5–7 point count stations (50 m radius) censused 3 times (for 5 min.) during the spring breeding season (24 May, 8 June, 22 June, 2006). (Refer to Table 4 for detailed statistical analyses).

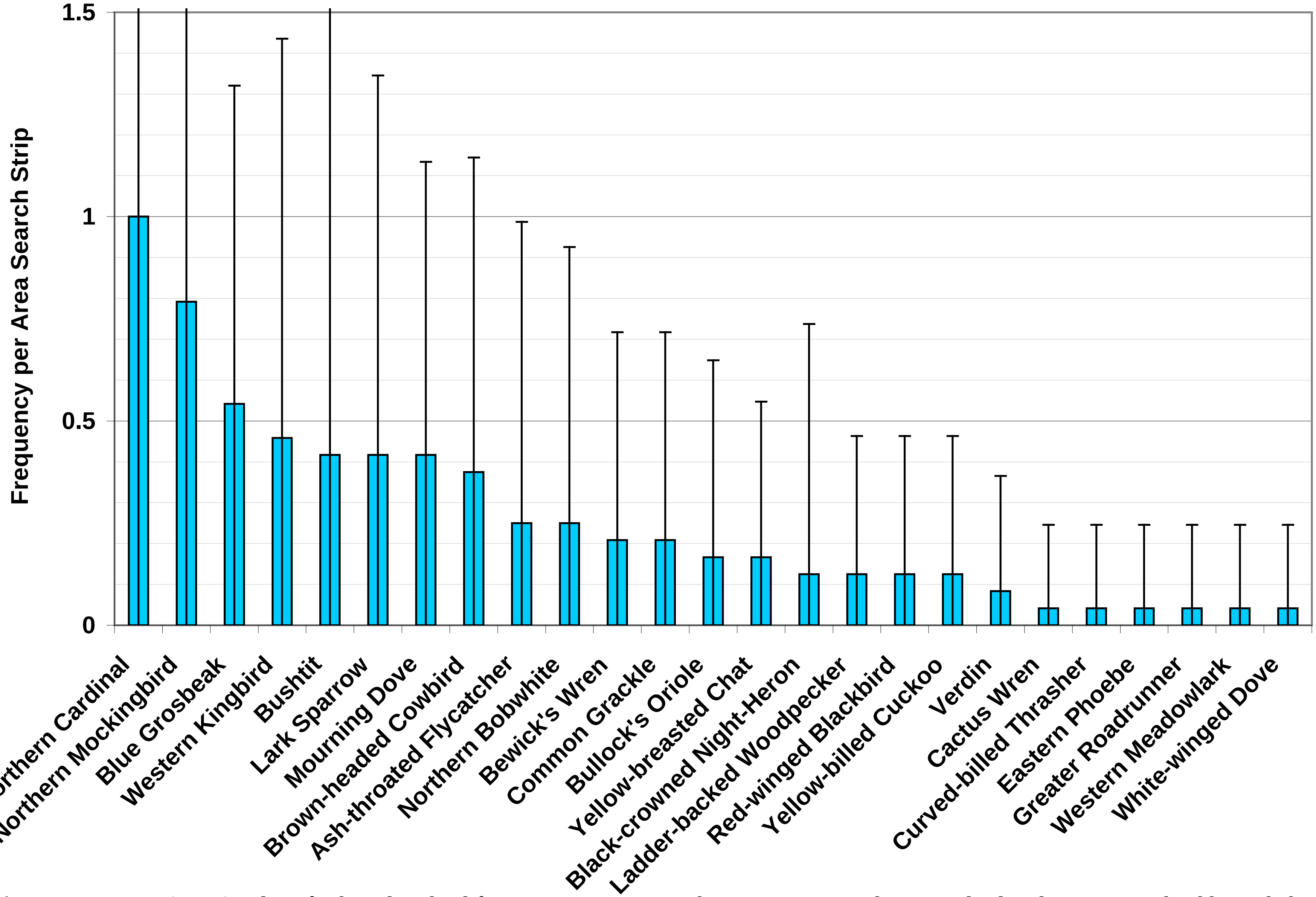

Figure 14. Mean (± SD) values for breeding bird frequency in area search strip surveys within mixed saltcedar/mesquite/hackberry habitats adjacent to the Beals Creek, near Big Spring, Texas, spring 2006. Data from 8 strips (20–50 x 150 m) censused 3 times (for 10 min.) during the spring breeding season (24 May; 9 June; 7 July, 2006). (Refer to Table 5 for detailed statistical analyses).

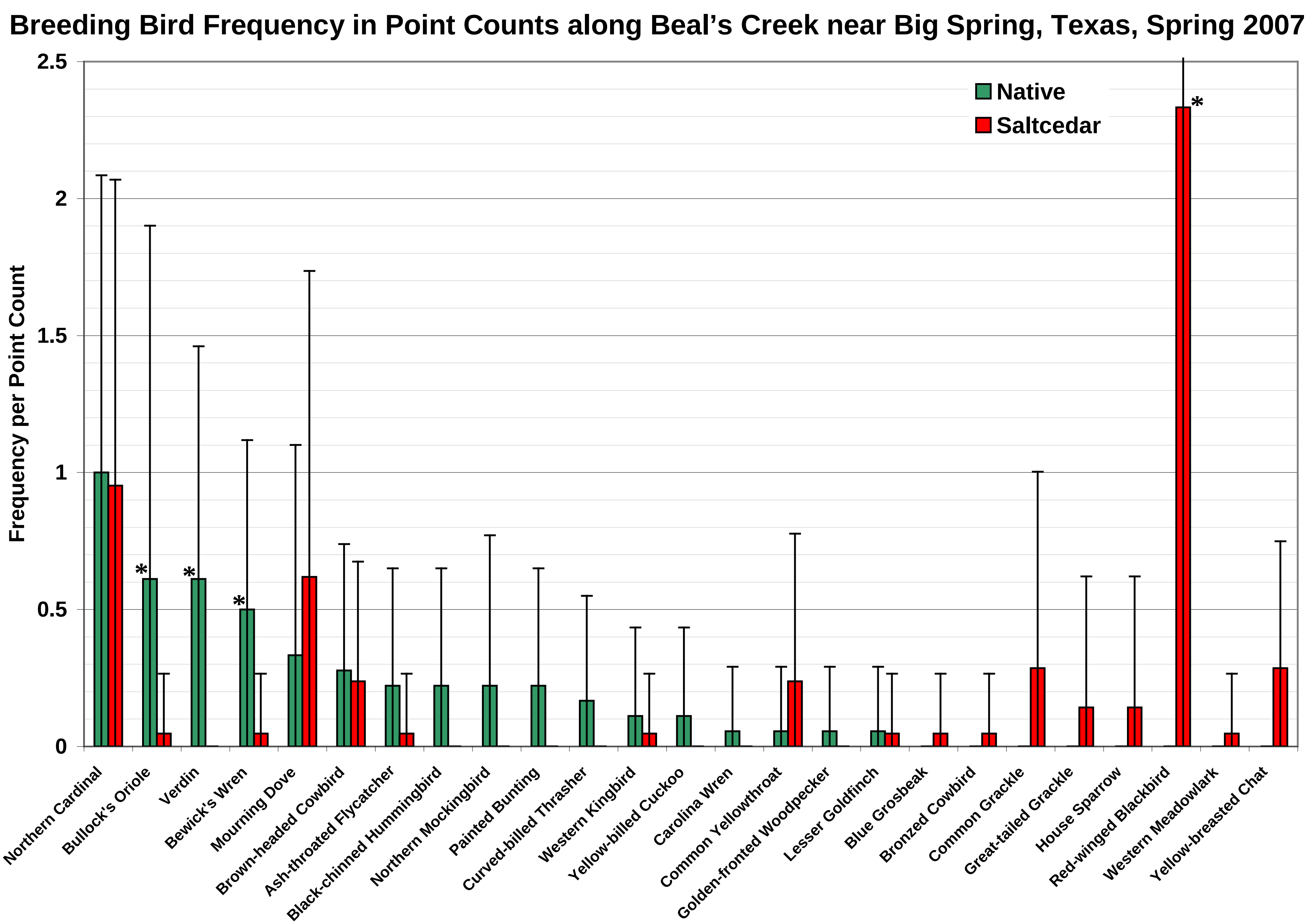

Figure 15. Mean (± SD) values for breeding bird frequency in point count surveys within saltcedar (n = 21) versus native (n = 18) habitat along Beal's Creek near Big Spring , Texas, summer 2007. Birds for which ranks of treatments differ significantly between habitats are denoted by an asterisk ($P < 0.05$; Three-Way Kruskal-Wallis Test). Data from 13 point count stations (50 m radius) censused 3 times (for 5 min.) during the spring breeding season (30–31 May; 14, 19 June; 28–29 June, 2007). (Refer to Table 6 for detailed statistical analyses).

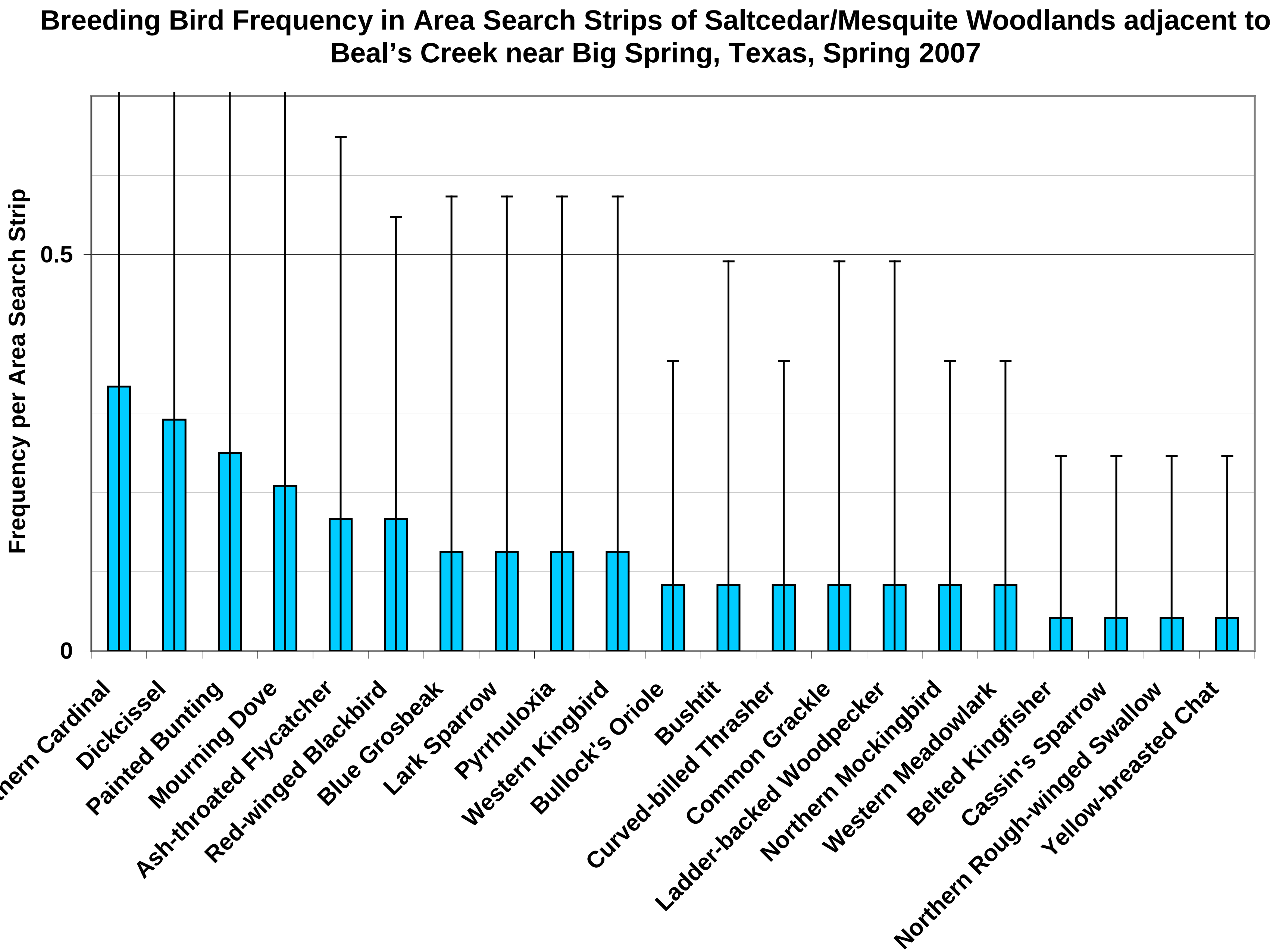

Figure 16. Mean (± SD) values for breeding bird frequency in area search strip surveys within mixed saltcedar/mesquite/hackberry habitats adjacent to the Beal’s Creek, near Big Spring, Texas, spring 2007. Data from 8 strips (20–50 x 150 m) censused 3 times (for 10 min.) during the spring breeding season (31 May; 14, 19 June; 12 July, 2007). (Refer to Table 7 for detailed statistical analyses).

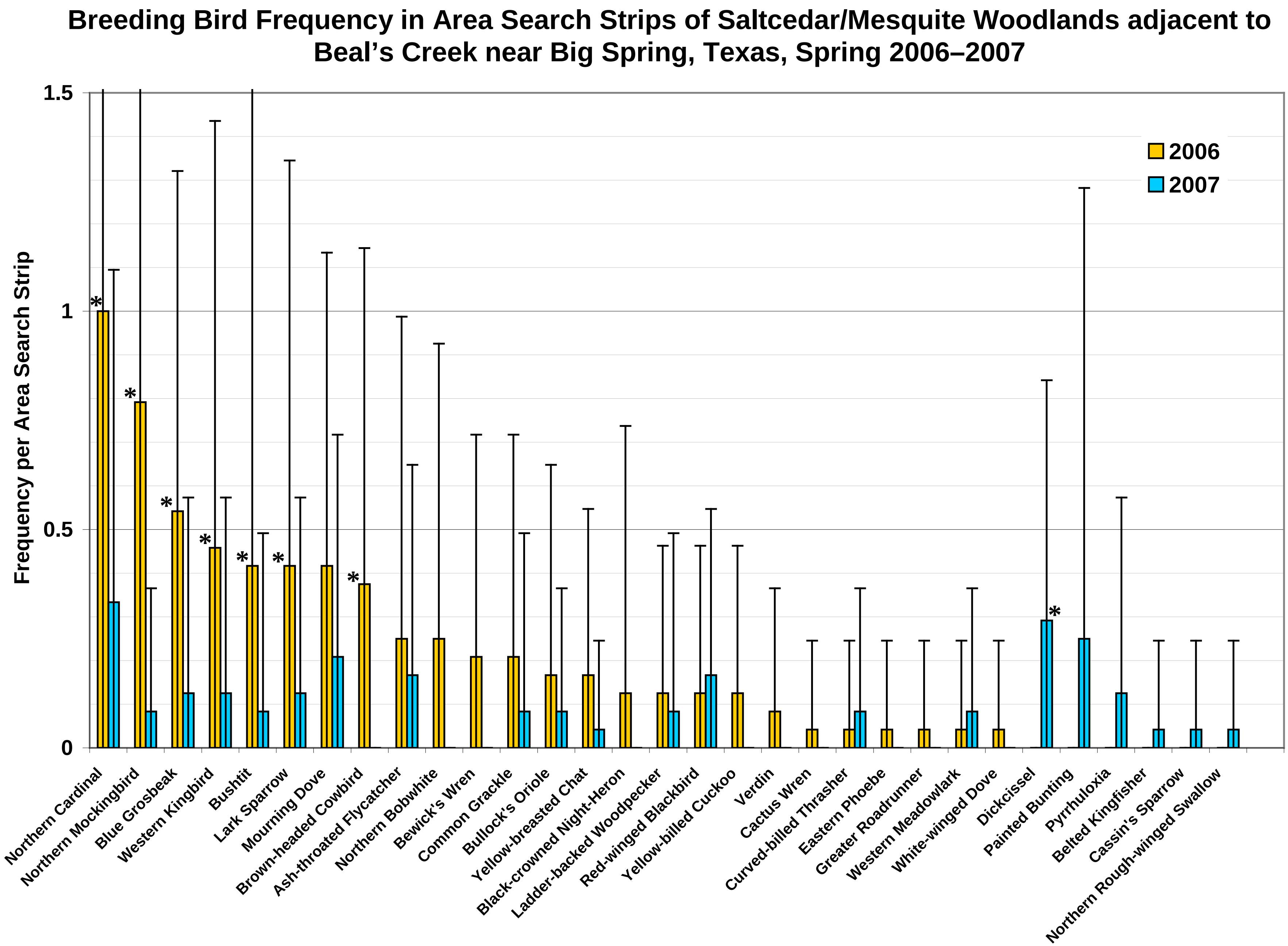

Figure 17. Mean (± SD) values for breeding bird frequency in area search strip surveys within mixed saltcedar/mesquite/hackberry habitats adjacent to the Beal's Creek, near Big Spring, Texas, spring 2006 and 2007. Data from 8 strips (20–50 x 150 m) censused 3 times (for 10 min.) during the spring breeding season for each year. (Refer to Table 8 for detailed statistical analyses).

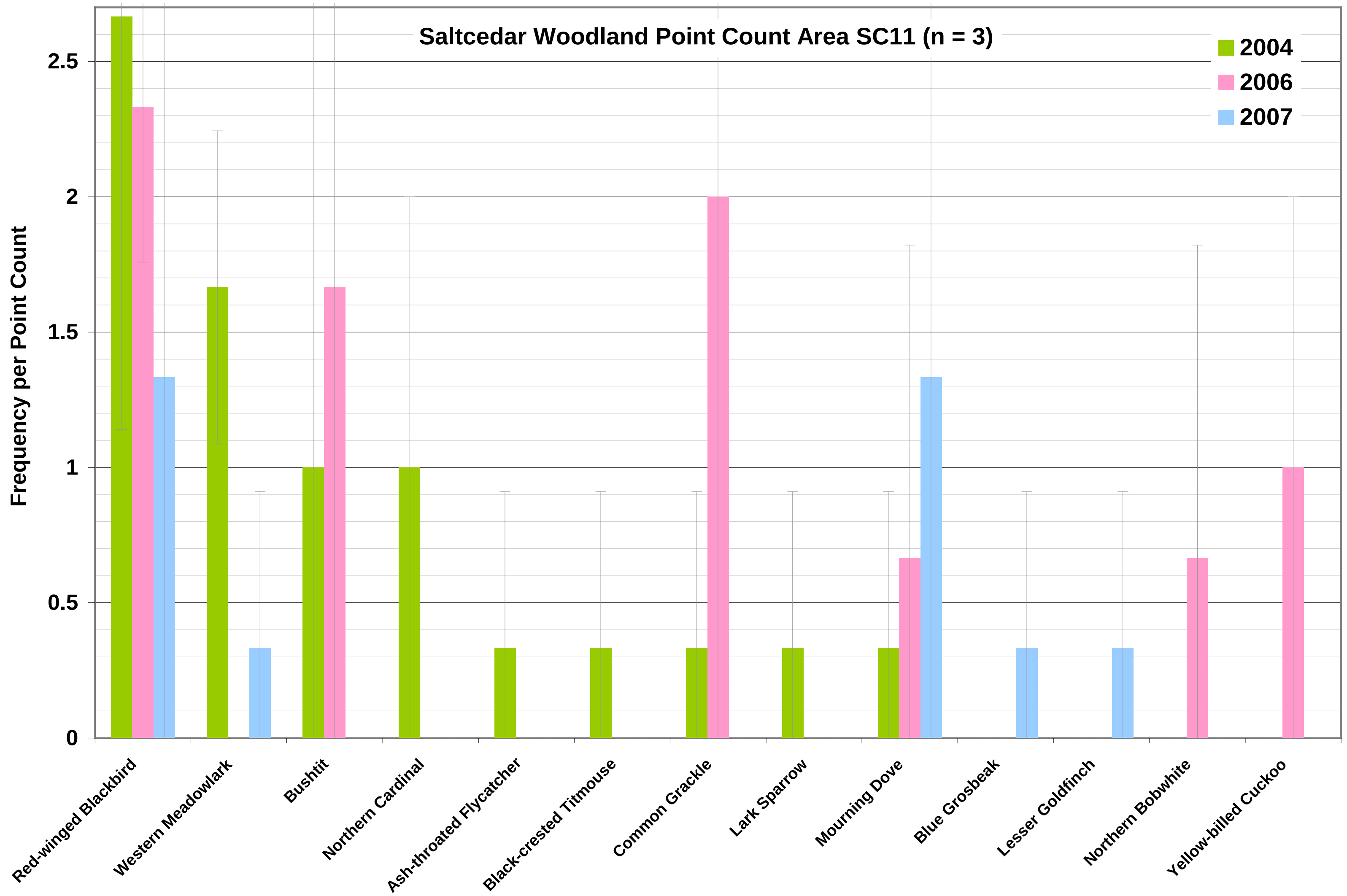

Figure 18. Breeding bird frequencies for the period 2004-2007, recorded for point count SC11, Higgins Ranch, Beals Creek, in marshy saltcedar habitat near original release point for *Diorhabda elongata*.

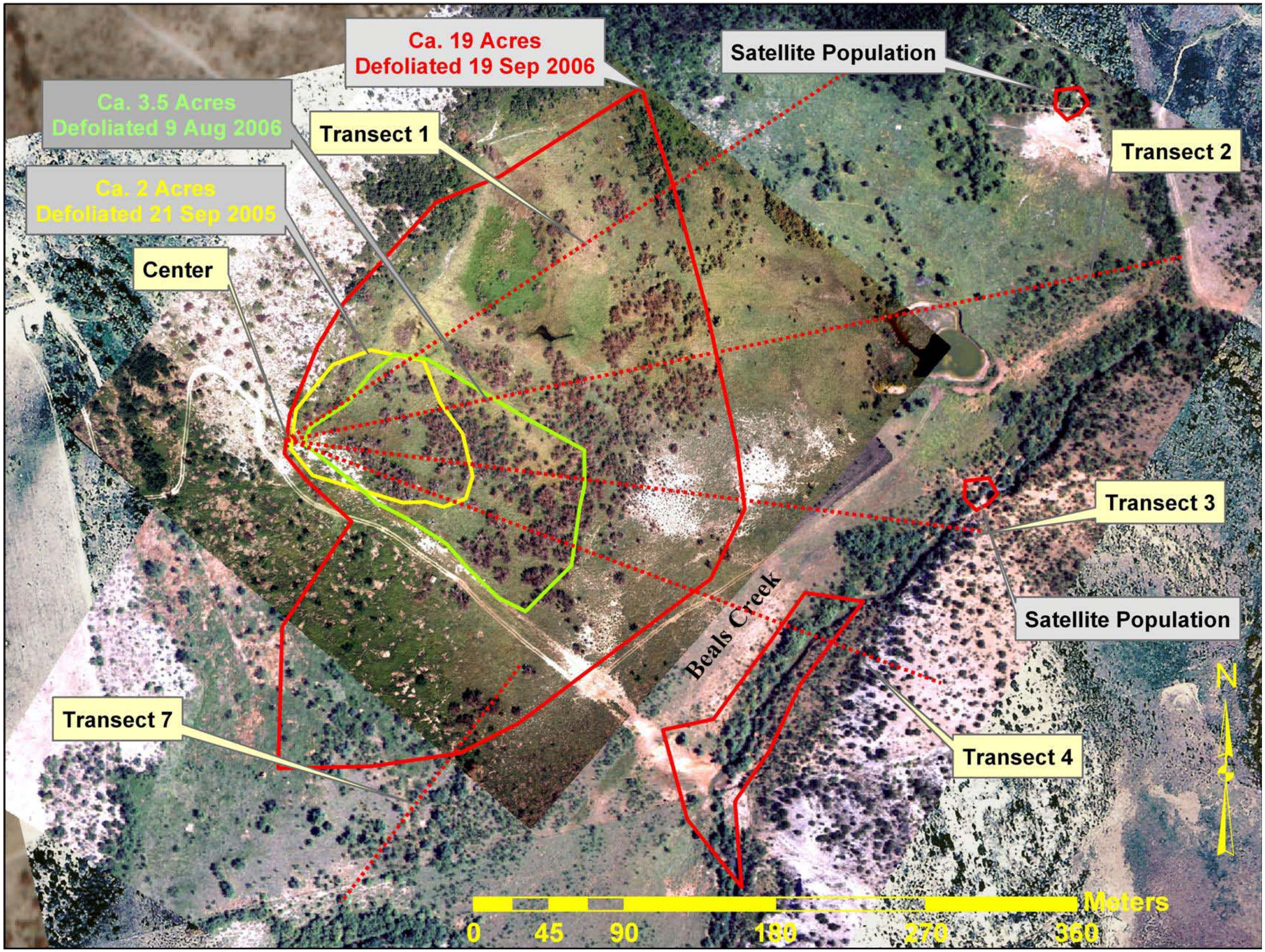

Figure 19. Layout of current survey transects for *Diorhabda* at Higgins' Ranch with areas of saltcedar defoliation by *Diorhabda* outlined for different dates. (Aerial photos are a mosaic of several dates, with the latest being 19 September 2006 in the center area.)

Figure 20. Common birds from Beals Creek bird surveys: A) Yellow-billed Cuckoo; B) Northern Cardinal; C) Painted Bunting; D) Common Yellowthroat; E) Canyon Towhee; and F) Yellow-breasted Chat.

Table 1

Breeding bird frequency for point count surveys within saltcedar versus willow habitat compared between Big Spring, Texas and Lake Thomas, Borden County, Texas, spring 2004.[a]

Species	Frequency per Point Count (n = 24,21) (mean ± SD (range))	
	Willow	Saltcedar
Northern Cardinal	1.79 ± 1.32 (0-6)a	0.90 ± 1.09 (0-3)bc
Mourning Dove	0.67 ± 0.92 (0-3)cd	0.33 ± 0.58 (0-2)def
Indigo Bunting	0.42 ± 0.72 (0-3)cde	0.00 ± 0.00 (0-0)j
Yellow-billed Cuckoo	0.46 ± 0.83 (0-3)cde	0.05 ± 0.22 (0-1)ij
Painted Bunting	0.38 ± 0.65 (0-2)de	0.38 ± 0.59 (0-2)cde
Common Grackle	1.88 ± 5.02 (0-22)ef	0.71 ± 0.90 (0-2)bc
Blue Grosbeak	0.21 ± 0.41 (0-1)efgh	0.00 ± 0.00 (0-0)j
Pyrrhuloxia	0.21 ± 0.59 (0-2)ghij	0.00 ± 0.00 (0-0)j
Mississippi Kite	0.17 ± 0.48 (0-2)ghij	0.00 ± 0.00 (0-0)j
Carolina Chickadee	0.13 ± 0.34 (0-1)ghij	0.00 ± 0.00 (0-0)j
Bewick’s Wren	0.08 ± 0.28 (0-1)hij	0.00 ± 0.00 (0-0)j
Dickcissel	0.08 ± 0.28 (0-1)hij	0.00 ± 0.00 (0-0)j
Orchard Oriole	0.17 ± 0.82 (0-4)ij	0.00 ± 0.00 (0-0)j
Black-chinned Hummingbird	0.08 ± 0.41 (0-2)ij	0.00 ± 0.00 (0-0)j
Northern Bobwhite	0.08 ± 0.41 (0-2)ij	0.00 ± 0.00 (0-0)j
Black-crested Titmouse	0.04 ± 0.20 (0-1)ij	0.05 ± 0.22 (0-1)ij
Greater Roadrunner	0.04 ± 0.20 (0-1)ij	0.00 ± 0.00 (0-0)j
Ladder-backed Woodpecker	0.04 ± 0.20 (0-1)ij	0.00 ± 0.00 (0-0)j
Western Meadowlark	0.04 ± 0.20 (0-1)ij	0.24 ± 0.62 (0-2)fghi
Ash-throated Flycatcher	0.00 ± 0.00 (0-0)j	0.24 ± 0.44 (0-1)efg
Brown-headed Cowbird	0.00 ± 0.00 (0-0)j	0.05 ± 0.22 (0-1)ij
Bullock’s Oriole	0.00 ± 0.00 (0-0)j	0.19 ± 0.51 (0-2)fghij
Bushtit	0.00 ± 0.00 (0-0)j	0.14 ± 0.65 (0-3)ij
Curve-billed Thrasher	0.00 ± 0.00 (0-0)j	0.05 ± 0.22 (0-1)ij
Common Yellowthroat	0.00 ± 0.00 (0-0)j	0.10 ± 0.30 (0-1)ghij
Eastern Phoebe	0.00 ± 0.00 (0-0)j	0.10 ± 0.44 (0-2)ij
Great-tailed Grackle	0.00 ± 0.00 (0-0)j	0.05 ± 0.22 (0-1)ij
Lark Sparrow	0.00 ± 0.00 (0-0)j	0.05 ± 0.22 (0-1)ij
Northern Mockingbird	0.00 ± 0.00 (0-0)j	0.14 ± 0.36 (0-1)fghij
Red-winged Blackbird	0.00 ± 0.00 (0-0)j	1.76 ± 1.70 (0-5)b
Western Kingbird	0.00 ± 0.00 (0-0)j	0.05 ± 0.22 (0-1)ij
Yellow-breasted Chat	0.00 ± 0.00 (0-0)j	0.10 ± 0.44 (0-2)ij

Table 1 (Cont.)

Breeding bird frequency for point count surveys within saltcedar versus willow habitat compared between Big Spring, Texas and Lake Thomas, Borden County, Texas, spring 2004.[a]

	Frequency per Point Count (n = 24,21) (mean ± SD (range))	
Species	Willow	Saltcedar
Statistic	Summary Statistics (mean ± SD (range))	
Number Birds per Point Count[b]	6.96 ± 6.29 (0-26)a	5.67 ± 2.73 (2-11)a
Number Species per Point Count[c]	3.33 ± 1.56 (0-6)a	3.29 ± 1.45 (1-6)a
Number Species per Period[d]	7.67 ± 2.31 (5-9)a	10.67 ± 2.08 (9-13)a
Shannon-Weaver Diversity Index per Period[d]	1.96 ± 0.37 (1.55-2.28)a	2.1401 ± 0.03 (2.07-2.12)a
Total Number of Bird Species	19	20

[a] Ranks of means in any rows or columns followed by the same letter are not significantly different (Three-Way Kruskal-Wallis Test; $P < 0.05$). Data from 10 point count stations (50 m radius) from 3 census periods (for 5 min. each) during the spring breeding season (3 June - 15 July, 2004).
[b] Significant habitat by species interaction precludes statistical comparison of habitat alone.
[c] Ranks of means in rows followed by the same letter are not significantly different (Two-Way Kruskal-Wallis Test; $P < 0.05$).
[d] Point count data pooled over each of n = 3 census periods. Ranks of means in rows followed by the same letter are not significantly different (One-Way Kruskal-Wallis Test; $P < 0.05$).

TABLE 2

Breeding bird frequency for point count surveys within willow versus saltcedar habitat at Lake Thomas, Borden County, Texas, spring 2004.[a]

	Frequency per Point (mean ± SD (range))					
	Willow (n = 8)			Saltcedar (n = 3)		
Species	Period 1	Period 2	Period 3	Period 1	Period 2	Period 3
Northern Cardinal	1.88 ± 1.25 (0-4)ab	1.13 ± 0.83 (0-2)bc	2.38 ± 1.60 (1-6)a	0.67 ± 1.55 (0-2)defgh	1.33 ± 0.58 (1-2)ab	2.33 ± 1.53 (1-4)ab
Mourning Dove	1.00 ± 0.93 (0-2)cd	0.25 ± 0.46 (0-1)efgh	0.75 ± 1.16 (0-3)def	0.00 ± 0.00 (0-0)h	0.00 ± 0.00 (0-0)h	0.67 ± 0.58 (0-1)bcd
Indigo Bunting	0.38 ± 0.52 (0-1)defg	0.63 ± 1.06 (0-3)defg	0.25 ± 0.46 (0-1)efgh	0.00 ± 0.00 (0-0)h	0.00 ± 0.00 (0-0)h	0.00 ± 0.00 (0-0)h
Yellow-billed Cuckoo	0.63 ± 1.19 (0-3)efgh	0.13 ± 0.35 (0-1)gh	0.63 ± 0.74 (0-2)de	0.67 ± 1.55 (0-2)defgh	0.67 ± 0.58 (0-1)bcd	0.67 ± 1.15 (0-2)defgh
Painted Bunting	0.50 ± 0.76 (0-2)defg	0.00 ± 0.00 (0-0)h	0.63 ± 0.74 (0-2)de	0.00 ± 0.00 (0-0)h	0.67 ± 0.58 (0-1)ab	1.33 ± 0.58 (1-2)ab
Common Grackle	0.13 ± 0.35 (0-1)gh	3.50 ± 7.60 (0-22)de	2.00 ± 4.28 (0-12)efgh	0.00 ± 0.00 (0-0)h	0.00 ± 0.00 (0-0)h	0.00 ± 0.00 (0-0)h
Blue Grosbeak	0.38 ± 0.52 (0-1)defg	0.00 ± 0.00 (0-0)h	0.25 ± 0.46 (0-1)efgh	0.00 ± 0.00 (0-0)h	0.33 ± 0.58 (0-1)defgh	0.00 ± 0.00 (0-0)h
Pyrrhuloxia	0.25 ± 0.71 (0-2)fgh	0.00 ± 0.00 (0-0)h	0.38 ± 0.74 (0-2)efgh	0.00 ± 0.00 (0-0)h	0.00 ± 0.00 (0-0)h	0.00 ± 0.00 (0-0)h
Mississippi Kite	0.25 ± 0.71 (0-2)fgh	0.13 ± 0.35 (0-1)gh	0.13 ± 0.35 (0-1)gh	0.00 ± 0.00 (0-0)h	0.00 ± 0.00 (0-0)h	0.00 ± 0.00 (0-0)h
Carolina Chickadee	0.13 ± 0.35 (0-1)gh	0.13 ± 0.35 (0-1)gh	0.13 ± 0.35 (0-1)gh	0.00 ± 0.00 (0-0)h	0.00 ± 0.00 (0-0)h	0.00 ± 0.00 (0-0)h
Bewick's Wren	0.00 ± 0.00 (0-0)h	0.13 ± 0.35 (0-1)gh	0.13 ± 0.35 (0-1)gh	0.00 ± 0.00 (0-0)h	0.00 ± 0.00 (0-0)h	0.00 ± 0.00 (0-0)h
Dickcissel	0.13 ± 0.35 (0-1)gh	0.00 ± 0.00 (0-0)h	0.13 ± 0.35 (0-1)gh	0.00 ± 0.00 (0-0)h	0.00 ± 0.00 (0-0)h	0.00 ± 0.00 (0-0) h
Orchard Oriole	0.00 ± 0.00 (0-0)h	0.50 ± 1.41 (0-4)fgh	0.00 ± 0.00 (0-0)h	0.00 ± 0.00 (0-0)h	0.00 ± 0.00 (0-0)h	0.00 ± 0.00 (0-0)h
Black-chinned Hummingbird	0.25 ± 0.71 (0-2)fgh	0.00 ± 0.00 (0-0)h	0.00 ± 0.00 (0-0)h	0.00 ± 0.00 (0-0)h	0.00 ± 0.00 (0-0)h	0.00 ± 0.00 (0-0)h
Northern Bobwhite	0.00 ± 0.00 (0-0)h	0.00 ± 0.00 (0-0)h	0.25 ± 0.71 (0-2)fgh	0.00 ± 0.00 (0-0)h	0.00 ± 0.00 (0-0)h	1.00 ± 1.00 (0-2)bcd
Black-crested Titmouse	0.13 ± 0.35 (0-1)gh	0.00 ± 0.00 (0-0)h	0.00 ± 0.00 (0-0)h	0.00 ± 0.00 (0-0)h	0.00 ± 0.00 (0-1)h	0.00 ± 0.00 (0-1)h
Greater Roadrunner	0.13 ± 0.35 (0-1)gh	0.00 ± 0.00 (0-0)h	0.00 ± 0.00 (0-0)h	0.00 ± 0.00 (0-0)h	0.00 ± 0.00 (0-0)h	0.00 ± 0.00 (0-0)h
Ladder-backed Woodpecker	0.00 ± 0.00 (0-0)h	0.13 ± 0.35 (0-1)gh	0.00 ± 0.00 (0-0)h	0.00 ± 0.00 (0-0)h	0.00 ± 0.00 (0-0)h	0.00 ± 0.00 (0-0jh
Western Meadowlark	0.13 ± 0.35 (0-1)gh	0.00 ± 0.00 (0-0)h	0.00 ± 0.00 (0-0)h	0.00 ± 0.00 (0-0)h	0.00 ± 0.00 (0-0)h	0.00 ± 0.00 (0-0)h
Ash-throated Flycatcher	0.00 ± 0.00 (0-0)h	0.00 ± 0.00 (0-0)h	0.00 ± 0.00 (0-0)h	0.00 ± 0.00 (0-0)h	0.33 ± 0.58 (0-1)defgh	0.00 ± 0.00 (0-0)h
Brown-headed Cowbird	0.00 ± 0.00 (0-0)h	0.00 ± 0.00 (0-0)h	0.00 ± 0.00 (0-0)h	0.00 ± 0.00 (0-0)h	0.00 ± 0.00 (0-0)h	0.00 ± 0.00 (0-0)h
Bullock's Oriole	0.00 ± 0.00 (0-0)h	0.00 ± 0.00 (0-0)h	0.00 ± 0.00 (0-0)h	0.00 ± 0.00 (0-0)h	0.00 ± 0.00 (0-0)h	0.00 ± 0.00 (0-0)h

TABLE 2 (Cont.)

Breeding bird frequency for point count surveys within willow versus saltcedar habitat at Lake Thomas, Borden County, Texas, spring 2004.[a]

	Frequency per Point Count (mean ± SD (range))					
	Willow (n = 8)			Saltcedar (n = 3)		
Species	Period 1	Period 2	Period 3	Period 1	Period 2	Period 3
Bushtit	0.00 ± 0.00 (0-0)h	0.00 ± 0.00 (0-0)h	0.00 ± 0.00 (0-0)h	0.00 ± 0.00 (0-0)h	0.00 ± 0.00 (0-0)h	0.00 ± 0.00 (0-0)h
Curve-billed Thrasher	0.00 ± 0.00 (0-0)h	0.00 ± 0.00 (0-0)h	0.00 ± 0.00 (0-0)h	0.00 ± 0.00 (0-0)h	0.00 ± 0.00 (0-0)h	0.00 ± 0.00 (0-0)h
Common Yellowthroat	0.00 ± 0.00 (0-0)h	0.00 ± 0.00 (0-0)h	0.00 ± 0.00 (0-0)h	0.00 ± 0.00 (0-0)h	0.00 ± 0.00 (0-0)h	0.00 ± 0.00 (0-0)h
Eastern Phoebe	0.00 ± 0.00 (0-0)h	0.00 ± 0.00 (0-0)h	0.00 ± 0.00 (0-0)h	0.00 ± 0.00 (0-0)h	0.00 ± 0.00 (0-0)h	0.00 ± 0.00 (0-0)jh
Great-tailed Grackle	0.00 ± 0.00 (0-0)h	0.00 ± 0.00 (0-0)h	0.00 ± 0.00 (0-0)h	0.00 ± 0.00 (0-0)h	0.00 ± 0.00 (0-0)h	0.00 ± 0.00 (0-0)h
Lark Sparrow	0.00 ± 0.00 (0-0)h	0.00 ± 0.00 (0-0)h	0.00 ± 0.00 (0-0)h	0.00 ± 0.00 (0-0)h	0.33 ± 0.58 (0-1)defgh	0.00 ± 0.00 (0-0)h
Northern Mockingbird	0.00 ± 0.00 (0-0)h	0.00 ± 0.00 (0-0)h	0.00 ± 0.00 (0-0)h	0.00 ± 0.00 (0-0)h	0.00 ± 0.00 (0-0)h	1.00 ± 0.00 (1-1)ab
Red-winged Blackbird	0.00 ± 0.00 (0-0)h	0.00 ± 0.00 (0-0)h	0.00 ± 0.00 (0-0)h	0.00 ± 0.00 (0-0)h	0.00 ± 0.00 (0-0)h	0.00 ± 0.00 (0-0)h
Western Kingbird	0.00 ± 0.00 (0-0)h	0.00 ± 0.00 (0-0)h	0.00 ± 0.00 (0-0)h	0.00 ± 0.00 (0-0)h	0.00 ± 0.00 (0-0)h	0.00 ± 0.00 (0-0)h
Yellow-breasted Chat	0.00 ± 0.00 (0-0)h	0.00 ± 0.00 (0-0)h	0.00 ± 0.00 (0-0)h	0.00 ± 0.00 (0-0)h	0.00 ± 0.00 (0-0)h	0.00 ± 0.00 (0-0)h
Statistic	Summary Statistics (mean ± SD (range))					
Number Birds per Point Count[b]	6.25 ± 3.37 (2-11)a	6.63 ± 8.28 (0-26)a	8.00 ± 6.93 (3-24)a	1.33 ± 1.15 (0-2)a	3.67 ± 0.58 (3-4)a	7.00 ± 2.00 (5-9)a
Number Species per Point Count[c]	3.75 ± 1.49 (2-6)a,b	2.50 ± 1.60 (0-5)b,c	3.75 ± 1.39 (2-6)a,b	0.67 ± 0.58 (0-1)c	3.33 ± 1.15 (2-4)a,b	4.67 ± 0.58 (4-5)a
Number Species per Period[d]		11.67 ± 1.53 (10-13)a			4.67 ± 2.31 (2-6)b	
Shannon-Weaver Diversity Index per Period[d]		1.96 ± 0.37 (1.55-2.28)a			1.34 ± 0.56 (0.69-1.69)a	
Total Number of Bird Species		19			9	

[a] Ranks of means in any rows or columns followed by the same letter are not significantly different (Three-Way Kruskal-Wallis Test; $P < 0.05$). Data from 10 point count stations (50 m radius) from 3 census periods (for 5 min. each) during the spring breeding season (3 June - 15 July, 2004).

[b] Significant habitat by species by period interaction precludes statistical comparison of habitat or habitat by species interaction alone.

[c] Ranks of means in rows followed by the same letter are not significantly different (Two-Way Kruskal-Wallis Test; $P < 0.05$).

[d] Point count data pooled over each of n = 3 census periods. Ranks of means in rows followed by the same letter are not significantly different (One-Way Kruskal-Wallis Test; $P < 0.05$).

TABLE 3

Breeding bird frequency for point count surveys within saltcedar habitat at Big Spring, Texas and Lake Thomas, Borden County, Texas, spring 2004.[a]

	Frequency per Point (mean ± SD (range))					
	Big Spring (n = 7)			Lake Thomas (n = 3)		
Species	Period 1	Period 2	Period 3	Period 1	Period 2	Period 3
Northern Cardinal	1.29 ± 1.11 (0-3)abcd	0.86 ± 1.07 (0-3)def	0.43 ± 0.53 (0-1)efghij	0.67 ± 1.15 (0-2)efghij	1.33 ± 0.58 (1-2)ab	2.33 ± 1.53 (1-4)a
Mourning Dove	0.43 ± 0.53 (0-1)efghi	0.29 ± 0.76 (0-2)hij	0.29 ± 0.49 (0-1)fghij	0.00 ± 0.00 (0-0)j	0.00 ± 0.00 (0-0)j	0.67 ± 0.58 (0-1)abcde
Indigo Bunting	0.00 ± 0.00 (0-0)j	0.00 ± 0.00 (0-0)j	0.00 ± 0.00 (0-0)j	0.00 ± 0.00 (0-0)j	0.00 ± 0.00 (0-0)j	0.00 ± 0.00 (0-0)j
Yellow-billed Cuckoo	0.14 ± 0.38 (0-1)ij	0.00 ± 0.00 (0-0)j	0.00 ± 0.00 (0-0)j	0.67 ± 1.15 (0-2)efghij	0.67 ± 0.58 (0-1)abcde	0.67 ± 1.15 (0-2)efghij
Painted Bunting	0.14 ± 0.38 (0-1)ij	0.29 ± 0.49 (0-1)fghij	0.71 ± 0.76 (0-2)def	0.00 ± 0.00 (0-0)j	0.67 ± 0.58 (0-1)abcde	1.33 ± 0.58 (1-2)ab
Common Grackle	0.86 ± 1.07 (0-2)defg	0.43 ± 0.79 (0-2)efghij	0.86 ± 0.90 (0-2)cde	0.00 ± 0.00 (0-0)j	0.00 ± 0.00 (0-0)j	0.00 ± 0.00 (0-0)j
Blue Grosbeak	0.00 ± 0.00 (0-0)j	0.00 ± 0.00 (0-0)j	0.00 ± 0.00 (0-0)j	0.00 ± 0.00 (0-0)j	0.33 ± 0.58 (0-1)efghij	0.00 ± 0.00 (0-0)j
Pyrrhuloxia	0.00 ± 0.00 (0-0)j	0.00 ± 0.00 (0-0)j	0.00 ± 0.00 (0-0)j	0.00 ± 0.00 (0-0)j	0.00 ± 0.00 (0-0)j	0.00 ± 0.00 (0-0)j
Mississippi Kite	0.00 ± 0.00 (0-0)j	0.00 ± 0.00 (0-0)j	0.00 ± 0.00 (0-0)j	0.00 ± 0.00 (0-0)j	0.00 ± 0.00 (0-0)j	0.00 ± 0.00 (0-0)j
Carolina Chickadee	0.00 ± 0.00 (0-0)j	0.00 ± 0.00 (0-0)j	0.00 ± 0.00 (0-0)j	0.00 ± 0.00 (0-0)j	0.00 ± 0.00 (0-0)j	0.00 ± 0.00 (0-0)j
Bewick's Wren	0.00 ± 0.00 (0-0)j	0.00 ± 0.00 (0-0)j	0.00 ± 0.00 (0-0)j	0.00 ± 0.00 (0-0)j	0.00 ± 0.00 (0-0)j	0.00 ± 0.00 (0-0)j
Dickcissel	0.00 ± 0.00 (0-0)j	0.00 ± 0.00 (0-0)j	0.00 ± 0.00 (0-0)j	0.00 ± 0.00 (0-0)j	0.00 ± 0.00 (0-0)j	0.00 ± 0.00 (0-0)j
Orchard Oriole	0.00 ± 0.00 (0-0)j	0.00 ± 0.00 (0-0)j	0.00 ± 0.00 (0-0)j	0.00 ± 0.00 (0-0)j	0.00 ± 0.00 (0-0)j	0.00 ± 0.00 (0-0)j
Black-chinned Hummingbird	0.00 ± 0.00 (0-0)j	0.00 ± 0.00 (0-0)j	0.00 ± 0.00 (0-0)j	0.00 ± 0.00 (0-0)j	0.00 ± 0.00 (0-0)j	0.00 ± 0.00 (0-0)j
Northern Bobwhite	0.00 ± 0.00 (0-0)j	0.00 ± 0.00 (0-0)j	0.00 ± 0.00 (0-0)j	0.00 ± 0.00 (0-0)j	0.00 ± 0.00 (0-0)j	1.00 ± 1.00 (0-2)abcde
Black-crested Titmouse	0.14 ± 0.38 (0-1)ij	0.00 ± 0.00 (0-0)j	0.00 ± 0.00 (0-0)j	0.00 ± 0.00 (0-0)j	0.00 ± 0.00 (0-0)j	0.00 ± 0.00 (0-0)j
Greater Roadrunner	0.00 ± 0.00 (0-0)j	0.00 ± 0.00 (0-0)j	0.00 ± 0.00 (0-0)j	0.00 ± 0.00 (0-0)j	0.00 ± 0.00 (0-0)j	0.00 ± 0.00 (0-0)j
Ladder-backed Woodpecker	0.00 ± 0.00 (0-0)j	0.00 ± 0.00 (0-0)j	0.00 ± 0.00 (0-0)j	0.00 ± 0.00 (0-0)j	0.00 ± 0.00 (0-0)j	0.00 ± 0.00 (0-0)j
Western Meadowlark	0.14 ± 0.38 (0-1)ij	0.29 ± 0.76 (0-2)hij	0.29 ± 0.76 (0-2)hij	0.00 ± 0.00 (0-0)j	0.00 ± 0.00 (0-0)j	0.00 ± 0.00 (0-0)j
Ash-throated Flycatcher	0.29 ± 0.49 (0-1)fghij	0.00 ± 0.00 (0-0)j	0.43 ± 0.53 (0-1)efghi	0.00 ± 0.00 (0-0)j	0.33 ± 0.58 (0-1)efghij	0.00 ± 0.00 (0-0)j
Brown-headed Cowbird	0.14 ± 0.38 (0-1)ij	0.00 ± 0.00 (0-0)j	0.00 ± 0.00 (0-0)j	0.00 ± 0.00 (0-0)j	0.00 ± 0.00 (0-0)j	0.00 ± 0.00 (0-0)j
Bullock's Oriole	0.00 ± 0.00 (0-0)j	0.29 ± 0.76 (0-2)hij	0.29 ± 0.49 (0-1)fghij	0.00 ± 0.00 (0-0)j	0.00 ± 0.00 (0-0)j	0.00 ± 0.00 (0-0)j

TABLE 3 (Cont.)

Breeding bird frequency for point count surveys within saltcedar habitat at Big Spring, Texas and Lake Thomas, Borden County, Texas, spring 2004.[a]

	Frequency per Point Count (mean ± SD (range))					
	Big Spring (n = 7)			Lake Thomas (n = 3)		
Species	Period 1	Period 2	Period 3	Period 1	Period 2	Period 3
Bushtit	0.00 ± 0.00 (0-0)j	0.00 ± 0.00 (0-0)j	0.43 ± 1.13 (0-3)ghij	0.00 ± 0.00 (0-0)j	0.00 ± 0.00 (0-0)j	0.00 ± 0.00 (0-0)j
Curve-billed Thrasher	0.14 ± 0.38 (0-1)ij	0.00 ± 0.00 (0-0)j	0.00 ± 0.00 (0-0)j	0.00 ± 0.00 (0-0)j	0.00 ± 0.00 (0-0)j	0.00 ± 0.00 (0-0)j
Common Yellowthroat	0.14 ± 0.38 (0-1)ij	0.14 ± 0.38 (0-1)ij	0.00 ± 0.00 (0-0)j	0.00 ± 0.00 (0-0)j	0.00 ± 0.00 (0-0)j	0.00 ± 0.00 (0-0)j
Eastern Phoebe	0.29 ± 0.76 (0-2)hij	0.00 ± 0.00 (0-0)j	0.00 ± 0.00 (0-0)j	0.00 ± 0.00 (0-0)j	0.00 ± 0.00 (0-0)j	0.00 ± 0.00 (0-0)j
Great-tailed Grackle	0.14 ± 0.38 (0-1)ij	0.00 ± 0.00 (0-0)j	0.00 ± 0.00 (0-0)j	0.00 ± 0.00 (0-0)j	0.00 ± 0.00 (0-0)j	0.00 ± 0.00 (0-0)j
Lark Sparrow	0.00 ± 0.00 (0-0)j	0.14 ± 0.38 (0-1)ij	0.00 ± 0.00 (0-0)j	0.00 ± 0.00 (0-0)j	0.33 ± 0.58 (0-1)efghij	0.00 ± 0.00 (0-0)j
Northern Mockingbird	0.43 ± 0.53 (0-1)efghi	0.00 ± 0.00 (0-0)j	0.00 ± 0.00 (0-0)j	0.00 ± 0.00 (0-0)j	0.00 ± 0.00 (0-0)j	1.00 ± 0.00 (1-1)abc
Red-winged Blackbird	2.71 ± 1.50 (0-4)abc	0.86 ± 1.21 (0-3)defgh	1.71 ± 1.98 (0-5)bcde	0.00 ± 0.00 (0-0)j	0.00 ± 0.00 (0-0)j	0.00 ± 0.00 (0-0)j
Western Kingbird	0.00 ± 0.00 (0-0)j	0.00 ± 0.00 (0-0)j	0.14 ± 0.38 (0-1)ij	0.00 ± 0.00 (0-0)j	0.00 ± 0.00 (0-0)j	0.00 ± 0.00 (0-0)j
Yellow-breasted Chat	0.00 ± 0.00 (0-0)j	0.29 ± 0.76 (0-2)hij	0.00 ± 0.00 (0-0)j	0.00 ± 0.00 (0-0)j	0.00 ± 0.00 (0-0)j	0.00 ± 0.00 (0-0)j
Statistic	Summary Statistics (mean ± SD (range))					
Number Birds per Point Count[b]	7.43 ± 2.57 (4-11)a	3.86 ± 1.35 (2-6)b,c	5.71 ± 2.98 (2-11)a,b	1.33 ± 1.15 (0-2)c	3.67 ± 0.58 (3-4)b,c	7.00 ± 2.00 (5-9)a
Number Species per Point Count[c]	4.14 ± 1.35 (2-6)a	2.29 ± 1.11 (0-3)b	3.43 ± 1.40 (2-6)a,b	0.67 ± 0.58 (0-1)b	3.33 ± 1.15 (2-4)a,b	4.67 ± 0.58 (4-5)a
Number Species per Period[d]		10.67 ± 2.08 (9-13)a			4.67 ± 2.31 (2-6)b	
Shannon-Weaver Diversity Index per Period[d]		2.10 ± 0.03 (2.07-2.12)a			1.34 ± 0.56 (0.69-1.69)b	
Total Number of Bird Species		20			9	

[a] Ranks of means in any rows or columns followed by the same letter are not significantly different (Three-Way Kruskal-Wallis Test; $P < 0.05$). Data from 10 point count stations (50 m radius) from 3 census periods (for 5 min. each) during the spring breeding season (3 June - 15 July, 2004).
[b] Significant habitat by species by period interaction precludes statistical comparison of habitat or habitat by species interaction alone.
[c] Ranks of means in rows followed by the same letter are not significantly different (Two-Way Kruskal-Wallis Test; $P < 0.05$).
[d] Point count data pooled over each of n = 3 census periods. Ranks of means in rows followed by the same letter are not significantly different (One-Way Kruskal-Wallis Test; $P < 0.05$).

Table 4. Breeding bird frequency for point count surveys within saltcedar versus native habitat at Beals Creek, Big Spring, Texas, spring 2006.

Species	Frequency per Point Count (mean ± SD (range))[a]	
	Native (n=15)	Saltcedar (n=21)
Northern Cardinal	1.80 ± 1.15 (0-4)a	0.95 ± 1.07 (0-2)c
Verdin	0.53 ± 1.13 (0-4)d	0.00 ± 0.00 (0-0)e
Western Kingbird	0.47 ± 0.83 (0-2)d	0.00 ± 0.00 (0-0)e
Bewick's Wren	0.40 ± 0.74 (0-2)d	0.00 ± 0.00 (0-0)e
Yellow-billed Cuckoo	0.27 ± 0.46 (0-1)d	0.14 ± 0.48 (0-2)de
Mourning Dove	0.27 ± 0.59 (0-2)d	0.33 ± 0.80 (0-3)d
Northern Bobwhite	0.27 ± 0.59 (0-2)d	0.10 ± 0.44 (0-2)e
Northern Mockingbird	0.27 ± 0.59 (0-2)d	0.00 ± 0.00 (0-0)e
Painted Bunting	0.20 ± 0.41 (0-1)de	0.00 ± 0.00 (0-0)e
Ladder-backed Woodpecker	0.20 ± 0.41 (0-1)de	0.05 ± 0.22 (0-1)e
Yellow-breasted Chat	0.20 ± 0.41 (0-1)de	0.19 ± 0.40 (0-1)de
Carolina Wren	0.20 ± 0.56 (0-2)de	0.00 ± 0.00 (0-0)e
Bell's Vireo	0.20 ± 0.56 (0-2)de	0.00 ± 0.00 (0-0)e
Black-chinned Hummingbird	0.13 ± 0.35 (0-1)de	0.00 ± 0.00 (0-0)e
Curve-billed Thrasher	0.13 ± 0.35 (0-1)de	0.00 ± 0.00 (0-0)e
Common Grackle	0.13 ± 0.52 (0-2)de	1.00 ± 2.19 (0-8)b
Bushtit	0.13 ± 0.52 (0-2)de	0.29 ± 0.90 (0-4)d
Lark Sparrow	0.07 ± 0.26 (0-1)e	0.00 ± 0.00 (0-0)e
Red-winged Blackbird	0.07 ± 0.26 (0-1)e	1.57 ± 1.47 (0-6)a
Canyon Towhee	0.07 ± 0.26 (0-1)e	0.00 ± 0.00 (0-0)e
Brown-headed Cowbird	0.07 ± 0.26 (0-1)e	0.00 ± 0.00 (0-0)e
Golden-fronted Woodpecker	0.07 ± 0.26 (0-1)e	0.00 ± 0.00 (0-0)e
Common Yellowthroat	0.00 ± 0.00 (0-0)e	0.19 ± 0.51 (0-2)de
Great-tailed Grackle	0.00 ± 0.00 (0-0)e	0.14 ± 0.48 (0-2)de
Greater Roadrunner	0.00 ± 0.00 (0-0)e	0.05 ± 0.22 (0-1)e
Unidentified species	0.00 ± 0.00 (0-0)e	0.05 ± 0.22 (0-1)e
Statistic	Summary Statistics per Point Count (mean ± SD (range))[b]	
Number of Birds	6.13 ± 2.23 (3-10)a	5.05 ± 2.89 (1-11)a
Number of Bird Species	4.13 ± 1.46 (2-7)a	2.62 ± 1.16 (1-5)b
Shannon-Weaver Diversity Index	1.30 ± 0.33 (0.69-1.91)a	0.77 ± 0.47 (0.00-1.55)b
	Summary Statistics over all Point Counts[c]	
Total Number of Bird Species (number unique to habitat)	22 (13)	13 (4)

[a] Data from 5 and 7 point count stations (50 m radius) in native and saltcedar woodland, respectively, from 3 census periods (for 5 min. each) during the spring breeding season (24 May; 8 June; 22 June 2006). Ranks of means in any rows or columns followed by the same letter are not significantly different (Three-Way Kruskal-Wallis Test; $P < 0.05$). Significant habitat by species interaction precludes statistical comparison of habitat alone.
[b] Ranks of means in rows followed by the same letter are not significantly different (Two-Way Kruskal-Wallis Test; $P < 0.05$).
[c] Total of 26 bird species found in both habitats with 9 species in common between habitats.

Table 5. Breeding bird frequency for area search strip surveys within mixed saltcedar/ mesquite/hackberry habitats adjacent to the Beal's Creek, near Big Spring, Texas, spring 2006.

Species	Frequency per Area Search Strip (n = 24) in Woodland (ca. 20 to 50 m width by 150 m length) (mean ± SD (range)) [a]
Northern Cardinal	1.00 ± 1.14 (0-3)
Northern Mockingbird	0.79 ± 1.22 (0-5)
Blue Grosbeak	0.54 ± 0.78 (0-2)
Western Kingbird	0.46 ± 0.98 (0-3)
Bushtit	0.42 ± 1.67 (0-8)
Lark Sparrow	0.42 ± 0.93 (0-4)
Mourning Dove	0.42 ± 0.72 (0-2)
Brown-headed Cowbird	0.38 ± 0.77 (0-2)
Ash-throated Flycatcher	0.25 ± 0.74 (0-3)
Northern Bobwhite	0.25 ± 0.68 (0-2)
Bewick's Wren	0.21 ± 0.51 (0-2)
Common Grackle	0.21 ± 0.51 (0-2)
Bullock's Oriole	0.17 ± 0.48 (0-2)
Yellow-breasted Chat	0.17 ± 0.38 (0-1)
Black-crowned Night-Heron	0.13 ± 0.61 (0-3)
Ladder-backed Woodpecker	0.13 ± 0.34 (0-1)
Red-winged Blackbird	0.13 ± 0.34 (0-1)
Yellow-billed Cuckoo	0.13 ± 0.34 (0-1)
Verdin	0.08 ± 0.28 (0-1)
Cactus Wren	0.04 ± 0.20 (0-1)
Curve-billed Thrasher	0.04 ± 0.20 (0-1)
Eastern Phoebe	0.04 ± 0.20 (0-1)
Greater Roadrunner	0.04 ± 0.20 (0-1)
Western Meadowlark	0.04 ± 0.20 (0-1)
White-winged Dove	0.04 ± 0.20 (0-1)

	Summary Statistics per Area Count (mean ± SD (range))		
	Period (n = 8)[b]		
Statistic	1	2	3
Number of Birds	10.88 ± 6.81 (4-23)a	4.75 ± 3.15 (1-10)b	3.88 ± 1.64 (2-7)b
Number of Bird Species	6.38 ± 3.07 (2-11)a	3.25 ± 1.83 (1-6)b	2.50 ± 1.20 (1-5)b
Shannon-Weaver Diversity Index [c]	1.61 ± 0.52 (0.56-2.13)a	0.97 ± 0.59 (0.00-1.70)b	0.76 ± 0.42 (0.00-1.48)b

	Summary Statistics over all Area Counts
Total Number of Bird Species	25

[a]Ranks of means in column are not significantly different (Two-Way Kruskal-Wallis Test; P < 0.05). Data from 8 area search strips (150 m length by 20-50 m width) from 3 census periods (for ca. 10 min. each) during the spring breeding season (24 May; 9 June; 7 July, 2006).
[b]Ranks of means in rows followed by the same letter are not significantly different (One-Way Kruskal-Wallis Test; P < 0.05).
[c]Area search strip data pooled over each of n = 3 census periods.

Table 6. Breeding bird frequency for point count surveys within saltcedar versus native habitat on Beals Creek near Big Spring, Howard County, Texas, spring 2007.

	Frequency per Point Count (mean ± SD (range)) [a]	
Species	Native (n = 18)	Saltcedar (n = 21)
Northen Cardinal	1.00 ± 1.08 (0-4) a	0.95 ± 1.12 (0-3) a
Red-winged Blackbird	0.00 ± 0.00 (0-0) c	2.33 ± 3.07 (0-11) a
Verdin	0.61 ± 0.85 (0-3) b	0.00 ± 0.00 (0-0) c
Bewick's Wren	0.50 ± 0.62 (0-2) b	0.05 ± 0.22 (0-1) c
Mourning Dove	0.33 ± 0.77 (0-3) bc	0.62 ± 1.12 (0-4) b
Yellow-breasted Chat	0.00 ± 0.00 (0-0) c	0.29 ± 0.46 (0-1) bc
Brown-headed Cowbird	0.28 ± 0.46 (0-1) bc	0.24 ± 0.44 (0-1) bc
Bullock's Oriole	0.61 ± 1.29 (0-4) b	0.05 ± 0.22 (0-1) c
Ash-throated Flycatcher	0.22 ± 0.43 (0-1) bc	0.48 ± 0.22 (0-1) c
Black-chinned Hummingbird	0.22 ± 0.43 (0-1) bc	0.00 ± 0.00 (0-0) c
Painted Bunting	0.22 ± 0.43 (0-1) bc	0.00 ± 0.00 (0-0) c
Common Grackle	0.00 ± 0.00 (0-0) c	0.29 ± 0.72 (0-3) c
Common Yellowthroat	0.06 ± 0.24 (0-1) c	0.24 ± 0.54 (0-2) bc
Northern Mockingbird	0.22 ± 0.55 (0-2) bc	0.00 ± 0.00 (0-0) c
Curved-billed Thrasher	0.17 ± 0.38 (0-1) bc	0.00 ± 0.00 (0-0) c
Western Kingbird	0.11 ± 0.32 (0-1) c	0.05 ± 0.22 (0-1) c
Yellow-billed Cuckoo	0.11 ± 0.32 (0-1) c	0.00 ± 0.00 (0-0) c
Great-tailed Grackle	0.00 ± 0.00 (0-0) c	0.14 ± 0.48 (0-1) c
House Sparrow	0.00 ± 0.00 (0-0) c	0.14 ± 0.48 (0-1) c
Carolina Wren	0.06 ± 0.24 (0-1) c	0.00 ± 0.00 (0-0) c
Lesser Goldfinch	0.06 ± 0.24 (0-1) c	0.05 ± 0.22 (0-1) c
Golden-fronted Woodpecker	0.06 ± 0.24 (0-1) c	0.00 ± 0.00 (0-0) c
Blue Grosbeak	0.00 ± 0.00 (0-0) c	0.05 ± 0.22 (0-1) c
Bronzed Cowbird	0.00 ± 0.00 (0-0) c	0.05 ± 0.22 (0-1) c
Western Meadowlark	0.00 ± 0.00 (0-0) c	0.05 ± 0.22 (0-1) c
Statistic	Summary Statistics per Point Count (mean ± SD (range))[b]	
Number of Birds	4.83 ± 2.73 (0-9) a	5.62 ± 3.76 (0-16) a
Number of Bird Species	3.66 ± 2.20 (0-8) a	2.90 ± 1.26 (0-5) a
Shannon-Weaver Diversity Index	1.08 ± 0.66 (0.00-2.04) a	0.87 ± 0.38 (0.00-1.61) a
	Summary Statistics over all Point Counts	
Total Number of Bird Species (number unique to habitat) [c]	17 (8)	17 (8)

[a] Data from 6 and 7 point count stations (50 m radius) in native and saltcedar woodland, respectively, from 3 census periods (for 5 min. each) during the spring breeding season (30–31 May; 14–19 June; 28 June 2006). Ranks of means in any rows or columns followed by the same letter are not significantly different (Three-Way Kruskal-Wallis Test; $P < 0.05$). Significant habitat by species interaction precludes statistical comparison of habitat alone.
[b] Ranks of means in rows followed by the same letter are not significantly different (Two-Way Kruskal-Wallis Test; $P < 0.05$).
[c] Total of 25 bird species found in both habitats with 9 species in common between habitats.

Table 7. Breeding bird frequency for area search strip surveys within mixed saltcedar/ mesquite/hackberry woodland adjacent to the Beals Creek, near Big Spring, Texas, spring 2007.

Species	Frequency per Area Search Strip (n = 24) in Woodland (ca. 20 to 50 m width by 150 m length) (mean ± SD (range)) [a]		
Northern Cardinal	0.33 ± 0.76 (0-3)		
Dickcissel	0.29 ± 0.55 (0-2)		
Painted Bunting	0.25 ± 1.03 (0-5)		
Mourning Dove	0.21 ± 0.51 (0-2)		
Ash-throated Flycatcher	0.17 ± 0.48 (0-2)		
Red-winged Blackbird	0.17 ± 0.38 (0-1)		
Blue Grosbeak	0.13 ± 0.45 (0-2)		
Lark Sparrow	0.13 ± 0.45 (0-2)		
Pyrrhuloxia	0.13 ± 0.45 (0-2)		
Western Kingbird	0.13 ± 0.45 (0-2)		
Bullock's Oriole	0.08 ± 0.28 (0-1)		
Bushtit	0.08 ± 0.41 (0-2)		
Curve-billed Thrasher	0.08 ± 0.28 (0-1)		
Common Grackle	0.08 ± 0.41 (0-2)		
Ladder-backed Woodpecker	0.08 ± 0.41 (0-0)		
Northern Mockingbird	0.08 ± 0.28 (0-1)		
Western Meadowlark	0.08 ± 0.28 (0-1)		
Belted Kingfisher	0.04 ± 0.20 (0-1)		
Cassin's Sparrow	0.04 ± 0.20 (0-1)		
Northern Rough-winged Swallow	0.04 ± 0.20 (0-1)		
Yellow-breasted Chat	0.04 ± 0.20 (0-1)		
	Summary Statistics per Area Count (mean ± SD (range))		
	Period (n = 8)[b]		
Statistic	1	2	3
Number of Birds	1.13 ± 0.83 (0-2)b	3.63 ± 1.41 (2-5)a	3.25 ± 3.54 (0-11)ab
Number of Bird Species	1.00 ± 0.76 (0-2)b	2.63 ± 1.30 (1-5)a	2.25 ± 2.12 (0-6)ab
Shannon-Weaver Diversity Index [c]	0.52 ± 0.59 (0.00-1.61) (n = 24)		
	Summary Statistics over all Area Counts		
Total Number of Bird Species	21		

[a]Ranks of means in column are not significantly different (Two-Way Kruskal-Wallis Test; $P < 0.05$). Data from 8 area search strips (150 m length by 30-50 m width) from 3 census periods (for ca. 10 min. each) during the spring breeding season (31 May; 19 June; 12 July, 2007).
[b]Ranks of means in rows followed by the same letter are not significantly different (One-Way Kruskal-Wallis Test; $P < 0.05$).
[c]Area search strip data pooled over each of n = 3 census periods.

Table 8. Breeding bird frequency for area search strip surveys within mixed saltcedar/ mesquite/hackberry woodland adjacent to the Beals Creek, near Big Spring, Texas, spring 2006–2007.

	Frequency per Area Search Strip (n = 24) in Woodland (ca. 30 to 50 m width by 150 m length) (mean ± SD (range)) [a]	
Species	2006	2007
Northern Cardinal	1.00 ± 1.14 (0-3)a	0.33 ± 0.76 (0-3)c
Northern Mockingbird	0.79 ± 1.22 (0-5)ab	0.08 ± 0.28 (0-1)d
Blue Grosbeak	0.54 ± 0.78 (0-2)b	0.13 ± 0.45 (0-2)d
Western Kingbird	0.46 ± 0.98 (0-3)c	0.13 ± 0.45 (0-2)d
Bushtit	0.42 ± 1.67 (0-8)c	0.08 ± 0.41 (0-2)d
Lark Sparrow	0.42 ± 0.93 (0-4)c	0.13 ± 0.45 (0-2)d
Mourning Dove	0.42 ± 0.72 (0-2)c	0.21 ± 0.51 (0-2)cd
Brown-headed Cowbird	0.38 ± 0.77 (0-2)c	0.00 ± 0.00 (0-0)d
Ash-throated Flycatcher	0.31 ± 0.87 (0-3)cd	0.19 ± 0.40 (0-1)cd
Northern Bobwhite	0.25 ± 0.68 (0-2)cd	0.00 ± 0.00 (0-0)d
Bewick’s Wren	0.21 ± 0.51 (0-2)cd	0.00 ± 0.00 (0-0)d
Common Grackle	0.21 ± 0.51 (0-2)cd	0.08 ± 0.41 (0-2)d
Bullock’s Oriole	0.17 ± 0.48 (0-2)cd	0.08 ± 0.28 (0-1)d
Yellow-breasted Chat	0.17 ± 0.38 (0-1)cd	0.04 ± 0.20 (0-1)d
Black-crowned Night-Heron	0.13 ± 0.61 (0-3)d	0.00 ± 0.00 (0-0)d
Ladder-backed Woodpecker	0.13 ± 0.34 (0-1)d	0.08 ± 0.41 (0-2)d
Red-winged Blackbird	0.13 ± 0.34 (0-1)d	0.17 ± 0.38 (0-1)cd
Yellow-billed Cuckoo	0.13 ± 0.34 (0-1)d	0.00 ± 0.00 (0-0)d
Verdin	0.08 ± 0.28 (0-1)d	0.00 ± 0.00 (0-0)d
Cactus Wren	0.04 ± 0.20 (0-1)d	0.00 ± 0.00 (0-0)d
Curve-billed Thrasher	0.04 ± 0.20 (0-1)d	0.08 ± 0.28 (0-1)d
Eastern Phoebe	0.04 ± 0.20 (0-1)d	0.00 ± 0.00 (0-0)d
Greater Roadrunner	0.04 ± 0.20 (0-1)d	0.00 ± 0.00 (0-0)d
Western Meadowlark	0.04 ± 0.20 (0-1)d	0.08 ± 0.28 (0-1)d
White-winged Dove	0.04 ± 0.20 (0-1)d	0.00 ± 0.00 (0-0)d
Dickcissel	0.00 ± 0.00 (0-0)d	0.29 ± 0.55 (0-2)c

Painted Bunting	0.00 ± 0.00 (0-0)d	0.25 ± 1.03 (0-5)cd
Pyrrhuloxia	0.00 ± 0.00 (0-0)d	0.13 ± 0.45 (0-2)d
Belted Kingfisher	0.00 ± 0.20 (0-1)d	0.04 ± 0.20 (0-1)d
Cassin's Sparrow	0.00 ± 0.00 (0-0)d	0.04 ± 0.20 (0-1)d
Northern Rough-winged Swallow	0.00 ± 0.00 (0-0)d	0.04 ± 0.20 (0-1)d

Table 8 (cont.). Breeding bird frequency for area search strip surveys within mixed saltcedar/ mesquite/hackberry woodland adjacent to the Beal's Creek, near Big Spring, Texas, spring 2006–2007.

	Summary Statistics over all Area Counts	
Statistic	2006	2007
Total Number of Bird Species (number unique to habitat) [b]	25 (10)	21 (6)
	Summary Statistics per Area Count (mean ± SD (range)) (n = 48) [c]	
Number of Birds	4.58 ± 4.51 (0-23)	
Number of Bird Species	3.00 ± 2.43 (0-11)	
Shannon-Weaver Diversity Index	0.81 ± 0.67 (0.00-2.13)	

[a] Ranks of means in columns are not significantly different (Three-Way Kruskal-Wallis Test; $P < 0.05$). Data from 8 area search strips (150 m length by 30-50 m width) from 3 census periods (for ca. 10 min. each) during the spring breeding seasons of 2006 and 2007. Significant differences seen among the three census periods for each bird species (Three-Way Kruskal-Wallis Test; $P < 0.05$) are not tabulated.
[b] Total of 31 bird species found in both years with 15 species in common between years.
[c] Ranks of means of differing years and census periods are not significantly different (Two-Way Kruskal-Wallis Test; $P < 0.05$). Data pooled over each of the three census periods for the two years.