

Overview of Saltcedar Biological Control

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***Abstract**—Biological control has successfully controlled 10 exotic, invasive weeds of rangelands and natural ecosystems in the United States since 1945, and control of others is in progress. We initiated biological control of saltcedar (*Tamarix* spp.) in 1987, using host-specific insect herbivores that regulate saltcedar populations in the Old World. We did a risk analysis, including the possible effects of biological control on the endangered southwestern willow flycatcher, (*Empidonax trailii eximius*) which had begun nesting extensively in saltcedar in Arizona. Our cooperators in France, Israel, Kazakhstan, China, and Turkmenistan tested 20 candidate control insects. Then, after quarantine testing, we released the first of these, the leaf beetle *Diorhabda elongata* Brullé from China and Kazakhstan, into field cages at 10 approved sites in 6 states in 1999 and into the open environment in May 2001. These beetles established at five sites in Nevada, Utah, Colorado and Wyoming and defoliated from 40 to 600 ha at each site by late June 2004. However, these beetles failed to establish in Texas and southern California because short summer daylengths stimulated premature diapause and failure to overwinter. In 2002, our overseas cooperators sent *Diorhabda* biotypes from four southern latitudes. After quarantine testing, we released some of these biotypes into field cages and then into the open environment at 5 sites in Texas, 2 in New Mexico, and 2 in California during late 2003 and 2004. They overwintered well, are increasing in population, and have begun defoliating saltcedar at 2 sites but have encountered heavy predation in some areas; intensive monitoring is underway. Biological control can provide self-sustaining, permanent, safe, and low cost control of saltcedars. This will allow recovery of native riparian plant communities, improved wildlife and fish habitat, reduced wildfires, increased availability of water, and increased recreational usage of parks and natural areas.*

Introduction

The invasion of river bottoms and lakeshores of the western United States by exotic, saltcedars is producing one of the worst ecological disasters in the recorded history of that region. Saltcedars, introduced in 1823, spread rapidly after the 1920s and today occupy over 800,000 ha of highly valuable land along streams and lakeshores from the central Great Plains to the Pacific and from Montana into northern Mexico. They often completely displace native plant communities, degrade wildlife habitat, and contribute to the population decline of many species of birds, fishes, mammals, and reptiles, including many threatened or endangered species (Wilcove and others 1998). They increase wildfires and soil salinity, lower water tables and reduce recreational usage of parks and natural areas. Saltcedar thickets typically use 4 to 5 acre feet of water per year that in the present drought severely reduces water available for agricultural irrigation, municipal and environmental use. They contribute to default of water agreements between states and between the U.S. and Mexico and damage parks and natural area reserves bordering the Rio Grande (Reviewed by DeLoach and others 2000).

Taxonomy and Distribution

Saltcedars (*Tamarix*: Tamaricaceae: Tamaricales) are a genus of 54 species of small trees or shrubs native only in the Old World. 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). Ten species have been introduced into the United States since 1823 as ornamentals and to control stream-bank erosion in the West. Four species and their hybrids have become serious pests in the West: *T. ramosissima*, *T. chinensis* (both widespread), *T. canariensis* (Gulf of Mexico coast), and *T. parviflora* (California) (Gaskin and Schaal 2002). All are deciduous, deep rooted, facultative phreatophytes, with pink flowers and with foliage of juniper (cedar) – like bracts. The large, evergreen tree, *Tamarix aphylla* (athel), that is a common shade tree of the Chihuahuan and Sonoran deserts, is less aggressive and is not a target for biological control.

Conventional Controls

Saltcedars are difficult to control by mechanical methods, fire or many herbicides because of their ability to resprout from underground buds and to reinvade

from their windblown seeds. Recently, “arsenal” (imazapyr) used as an aerial spray and “garlon” (triclopyr) as a cut-stump treatment provide good control (Duncan and McDaniel 1998). However, both are expensive and arsenal also kills many native plants. These controls are unsatisfactory in natural areas of mixed vegetation where the objective is to kill the invading weed and preserve the beneficial and native plants.

Biological Control

Biological control of weeds is best suited to control exotic, invasive weeds in relatively stable ecosystems such as natural areas and rangelands, by the introduction of the natural enemies (insects or sometimes plant pathogens) that regulate the weed’s abundance in its native region. The objective is to permanently reduce the weed’s abundance below the damage level, but not to eradicate it. The philosophy and methodology of biological control of weeds has been developed and reviewed by many workers (Huffaker 1957, Nechols and others 1995). This method has been used worldwide since 1865 against 133 weed species in 51 countries (Julien and Griffiths 1999). In North America, it began in 1945 and has been used against 40 exotic weeds of rangelands and natural areas. It has been highly successful in a third of the attempts (often with no additional control ever needed over wide areas) and partially successful in another third. The method also has been very safe, with only eight reported cases of non-target feeding worldwide (seven minor and temporary and one of moderate damage with stand reduction), all from agents released before testing protocols, reviews and authorization were tightened in 1965 and all predicted in the pre-release testing. The low beneficial values of saltcedar, its lack of closely related plants in the Western Hemisphere, and the large number of host-specific and damaging insects that attack it within its native distribution in the Old World, make saltcedar well suited for biological control.

Progress in Biological Control

A program of classical biological control for saltcedar, by the introduction of the *Tamarix*-specific insects that regulate its populations in its area of natural distribution in Asia and the Mediterranean area, was initiated in 1987 by one of us (DeLoach) at USDA-ARS, Temple, TX, supported from the beginning by the USDI Bureau of Reclamation. The project was joined in 1998 by the new ARS Exotic and Invasive Weeds Research Unit (ARS-Albany) organized by one of us (Carruthers).

Discovery and Testing of Control Insects

Surveys of the natural enemies of saltcedar have been made in its native geographical range for many years, as a part of the studies of the natural resources of the Soviet Union, summarized by Kovalev (1995). We began overseas exploration and testing in 1991 with our collaborators at ARS European Biological Control Laboratory (EBCL), France (Alan Kirk and Rouhollah Sobhian); Tel Aviv University, Israel (Dan Gerling); ARS Sino-American Biological Control Laboratory, Beijing and Urumqi, China (Ren Wang, Qing Guang Lu, Hongyen Chen, and Bao Ping Li); Almaty, Kazakhstan (Roman Jashenko and Ivan Mityaev); and Ashkhabad, Turkmenistan (Svetlana Myartseva). Those studies together have revealed over 300 highly specific and damaging insect species as potential biological control agents (DeLoach and others 1996).

After completing a literature review and a risk analysis, we began testing in quarantine at ARS-Temple in 1992, and at ARS-Albany in 1998. From the 20 candidate control insects investigated overseas, we tested 7 species and selected the leaf beetle *Diorhabda elongata* Brullé, from Fukang, China and Chilik, Kazakhstan as the first and most promising candidate for complete testing and release (DeLoach and others 2000).

Both adults and larvae of *D. elongata* (fig. 1a,b,c), feed on the foliage of saltcedar and the large larvae also de-bark small twigs causing the distal foliage to die. Several years of laboratory and outdoor cage testing demonstrated that *D. elongata* is unlikely to attack any non-target plants except for possibly causing slight damage to the related, native *Frankenia salina* in California but not *F. jamesii* or *F. johnstonii* in Colorado and Texas. It also might cause moderate damage to exotic athel trees (*T. aphylla*), which have some value as shade trees and windbreaks in the southernmost United States and northern Mexico; however, athel also is becoming invasive in some areas (DeLoach and others 2003, Lewis and others 2003a, John Herr, Albany and Lindsey Milbrath, Temple, manuscripts in progress).

The adults overwinter and the larvae pupate under litter beneath the trees. Laboratory tests showed that beetle populations can double each 6.2 days. Field cage studies showed a range of population increases but a 30-fold increase per generation was not uncommon. In Colorado and Wyoming, overwintered adults become active in late-April and produced two generations before they began overwintering in September. In the more southern areas, the saltcedar growing season appears to be long enough to allow completion of 4 or possibly 5 generations (Lewis and others 2003b).

Clearances and Permits

In March 1994, we submitted a petition to the Technical Advisory Group on Biological Control of Weeds (TAG) of the USDA Animal and Plant Health Inspection Service (APHIS) asking their recommendation for release of *Diorhabda elongata* into the open field.

However, the listing of the southwestern willow flycatcher as federally endangered in February 1995 required consultation with the USDI Fish and Wildlife Service (FWS). We submitted a Biological Assessment, to FWS Region 2, Albuquerque, NM in October 1997. This risk analysis revealed that the flycatcher had begun nesting extensively in saltcedar in some areas of Arizona since saltcedar had replaced the native willow habitat, but little in other areas. The effect of biological control on the other 50 threatened or endangered (T&E) species reviewed was expected to be beneficial or cause no effect. However, the harmful effects of saltcedar reduced reproductive success of the flycatcher to half of that in its native willow habitat, in heavily infested areas along the lower Colorado River and at Roosevelt Lake, AZ (DeLoach and others 2000). Recently, flycatcher populations have increased dramatically, but only in areas where the willows have increased.

In June 1998, we, with staff from several other agencies, met with FWS to discuss their requirements for approving release of the *Diorhabda* beetles. We then submitted a Research Proposal to FWS on 28 August 1998 for release of the beetles. This document included specifications as follows: a research phase in which; 1) *D. elongata* could be released only into secure field cages at 10 specified sites in different climatic zones in Texas, Colorado, Wyoming, Utah, Nevada and California, all more than 200 mi from where the flycatcher nested in saltcedar. The beetles would be monitored in the cages for one year to determine their survival, developmental biology, rate of increase, and observed damage to saltcedar and non-target plants in the cages. 2) The beetles then were to be released into the open field for a 2-year period, during which the degree and rapidity of control, rate of natural dispersal, and effects on native plant and wildlife communities would be monitored. After this combined 3-year research period, FWS and APHIS would review the research results and determine the conditions under which an Implementation Phase could be carried out in which unlimited releases could be made in specified areas. The Letter of Concurrence issued by FWS on 28 December 1998 (revised 3 June 1999), the Environmental Assessment prepared by APHIS in February 1999, the Finding of No Significant Impact (FONSI) issued on 7 July, and the APHIS permits to release in the field cages during July 1999, all contained these restrictions.

The Saltcedar Biological Control Consortium had been organized in December 1997 by one of us (DeLoach), and is co-chaired by three of us (Carruthers, Nibling, DeLoach) to help guide this process and to provide coordination between agencies and input, guidance and oversight in the research program from user and environmental organizations (Stenquist 2003). It has met annually since then and now has representatives from ca. 50 federal and state agencies, universities, and private user and environmental groups. The sister Tamarix Coalition in Grand Junction, CO and the Rio Grande Institute in western Texas were organized more recently.

Experimental Releases and Results in Field Cages: July 1999 to May 2001

After receiving FWS concurrence and FWS permits, we placed the beetles into field cages during the summers of 1999 and 2000 at 10 sites in six states. This research was coordinated by some of us at each site: for Fukang, China beetles: DeLoach at Seymour, TX; Eberts at Pueblo, CO; Kazmer at Lovell, WY and Lake Ft. Peck, MT; Knight at Lovelock, Stillwater and Schurz, NV; and Carruthers and Dudley at Bishop, Hunter-Liggett and Cache Creek, CA; and for Chilik, Kazakhstan beetles, by Greg Abbot, APHIS at Delta, UT. These beetles successfully overwintered in the cages at the eight most northern sites, all north of the 38th parallel, although only weakly so at Stillwater and Cache Creek. At the five sites where strong overwintering occurred (Pueblo, Lovell, Delta, Lovelock and Schurz), the beetles increased to large numbers during the summer and completely defoliated the plants inside the cages during both 1999 and 2000. They failed to overwinter at the two sites south of the 38th parallel, at Seymour and Hunter-Liggett. Here, they ceased feeding and egg laying, and began overwintering in early July but did not survive the winter (Lewis and others 2003b).

In laboratory and outdoor cage tests, Lewis and others (2003b) at Temple and Dan Bean at Albany showed that these beetles entered premature overwintering diapause at daylengths less than 15 h 45 min, then starved during the 8 to 9 months of often warm temperatures before spring. Maximum daylength at Seymour is only 14 hr 21 min and is even less farther south, which caused the failure to overwinter.

Releases and Results in the Open Field in Northern Areas: May 2001 to Late Summer 2004

Based on the field-cage results and additional host specificity testing (Lewis and others 2003a), we

requested and received release permits from APHIS. We released adults into the open field during May 2001 at the 6 sites where the beetles had overwintered, plus at Seymour. We released approximately 27,000 adults and larvae at Lovell, WY; 6900 adults plus many larvae at Pueblo, CO; 15,000 at Delta, UT; 3,500 at Schurz and 1,400 at Lovelock, NV; 4,400 larvae and 2000 adults at Bishop, CA; and 498 adults at Seymour, TX.

During the remainder of the summer, we found a few to moderate numbers of eggs, larvae, and adults and dispersal of only about 10 m. When large larvae of the second generation developed in mid-August 2002, we saw extensive damage at some sites. At Lovelock on 28 August, the larvae had destroyed 95 to 98 percent of the foliage of all trees within an area 100 m in diameter (1 ha), centered at the release cage. Heavy feeding but not total defoliation had occurred in an additional concentric ring 50 m wide outside the affected core area. We saw a similar area of defoliation at Pueblo. We observed heavy predation by ants at Lovell and by birds at Delta. The beetles failed to establish at Seymour.

During 2003, the beetles at Lovelock had defoliated 3.2 ha in early July, and by early September about 200 ha (total area of land infested by saltcedar, not canopy cover of the trees), along a 5 km reach of the Humboldt River (Carruthers and others, this proceedings). By September 2003, several plants had resprouted profusely from the base and occasionally from the upper branches but enough beetles had remained in the stand to defoliate this regrowth. At Schurz (Fig. 1d), the beetles had defoliated ca. 12 ha along the Walker River and at Pueblo ca. 40 ha. At Delta and Lovell, the beetles overcame bird and ant predation in 2002 to defoliate 40 ha and 6 ha, respectively by September 2003.

By the end of 3 ½ growing seasons after release (late June 2004), defoliation by the Fukang/Chilik beetles at the five northern sites had increased 3 to 5 fold over the amount in August 2003, to an estimated 600 ha at Lovelock, 200 ha at Delta, 120 ha at Schurz and Pueblo, and 40 ha at Lovell. As of late 2004, few trees have been completely killed, but we expect to see increasing whole tree death during 2005 and 2006. However, the defoliation has been 95 to 100 percent, which has reduced water usage to a very low level and has opened the canopy cover and allowed other plants to begin increasing in growth and number. Bird populations have increased at least temporarily at Lovelock, apparently because of the increased food supply (the *Diorhabda* beetles). In 2003, additional releases of the Fukang/Chilik beetles were made at Lake Fort Peck, MT by one of us (Kazmer, site manager) and at Owyhee, OR by one of us (Dudley) and E.M. Coombs, Oregon Department of Agriculture (site managers).

Short-Daylength Beetles Discovered and Released in Southern Areas

One of us (Carruthers) discovered *Diorhabda* biotypes at lower latitudes in Crete and mainland Greece, and through our cooperators at EBCL France in Tunisia and Uzbekistan and through cooperators in China at Turpan. Some of these biotypes have the potential to establish south of the 38th parallel and perhaps throughout the southern range of saltcedar in the southwestern U.S. and northern Mexico. The Crete beetles, placed in a large outdoor cage at Temple during August 2002, overwintered with little mortality and began feeding and reproducing vigorously on the plants by early April. Additional

host specificity testing of these four new biotypes of *D. elongata* from the Old World demonstrated that they also are safe to release (Lindsey Milbrath, ARS-Temple and John Herr, ARS-Albany, manuscripts in preparation), although they may feed slightly on native *Frankenia salina* in California, and they probably will moderately damage the exotic athel (*T. aphylla*) trees (fig. 1e, f) in the southern areas.

The southern-adapted Crete beetles were placed in field cages and in the open field in the southern areas during the summer of 2003 and 2004 (table 1). Populations are increasing near Big Spring, TX and at Artesia, NM and they were beginning to defoliate several saltcedar trees, as of late August 2004. However, these beetles

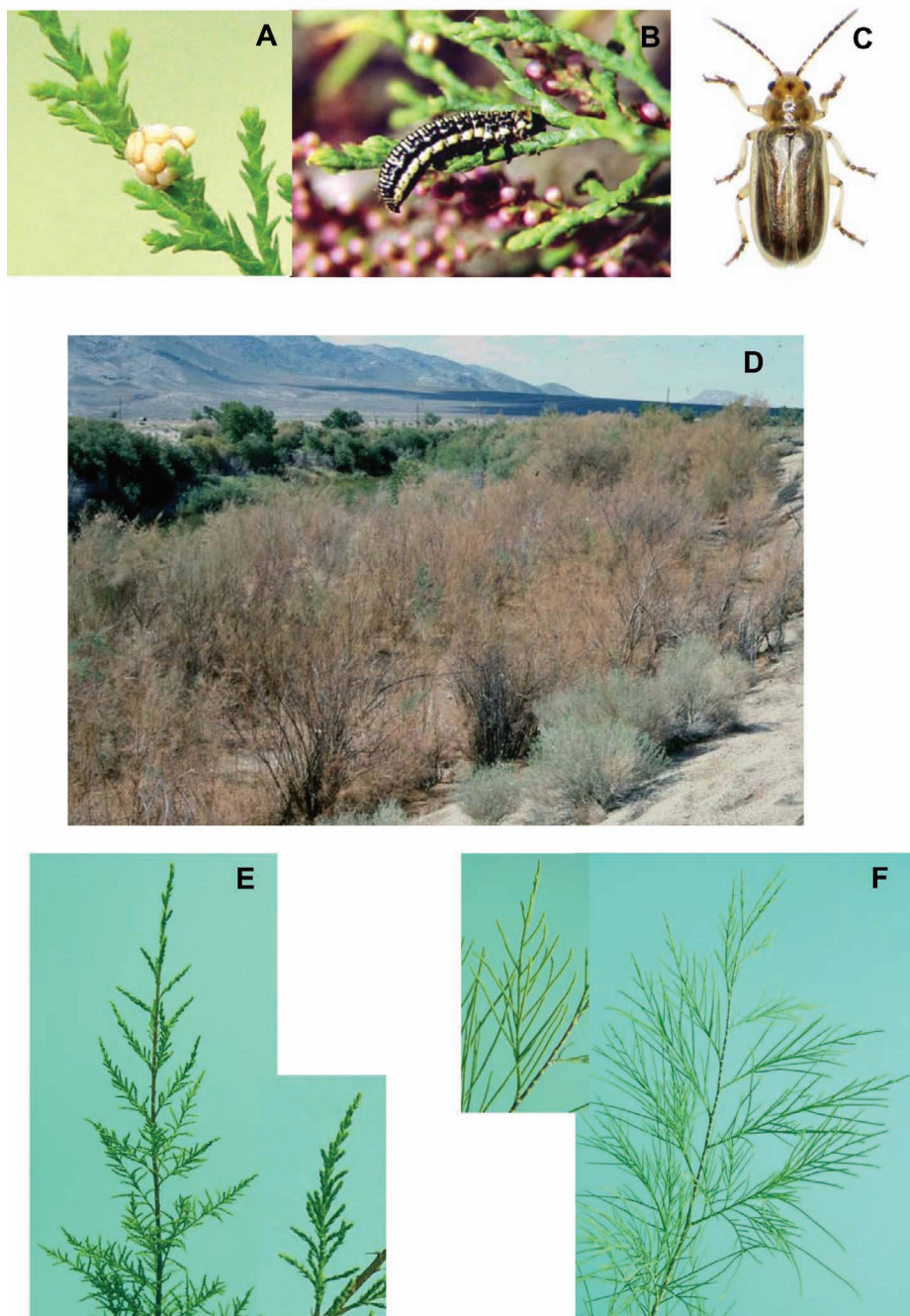


Figure 1. *Diorhabda elongata* egg mass-A; third instar larva-B; adult-C; defoliated plants at Schurz, NV, August 2003-D; foliage of *Tamarix ramosissima* or hybrid-E and foliage of *Tamarix aphylla*-F.

Table 1. Field release of southern adapted *Diorhabda elongata* biotypes in 2003 or 2004.

Approved release site	°N latitude	Origin (and latitude) of beetles: date released				
		Crete (35°20')	Tunisia (34°46')	Uzbekistan (39°55')	Turpan, China (42°57')	Posidi, Greece (39°58')
-----Released in field cages-----						
Cache Creek, CA	38°56'	22 Aug				
John Martin, CO	38°6'				May 2004	
Bishop, CA	37°5'				May 2004	
Hunter-Liggett, CA	35°57'	18 Sep 03				
Lake Merideth, TX	35°29'					May 2004
Seymour, TX	33°43'	24 Jun			20 Mar	
Artesia, NM	33°9'	13 Aug				
Lake Thomas, TX	32°36'	10 Jul			31 Jul	
Big Spring, TX	32°15'	10 Jul		20 Aug		
Brantley, NM	32°5'					May 2004
Ft. Stockton, TX	30°50'					
Candelaria, TX	30°8'					
San Jacinto SP, TX	29°45'					
Kingsville, TX	27°25'	27 Aug	13 Aug			
Zapata, TX	26°58'	5 Nov	26 Aug			
-----Released in open field-----						
Cache Creek, CA	38°56'	29 Oct				
John Martin, CO	38°6'				July 2004	
Hunter-Liggett, CA	35°57'	7 Sept				
Lake Merideth, TX	35°29'					July 2004
Seymour, TX	33°43'	14 Aug			31 Jul	
Artesia, NM	33°9'	28 Aug				
Lake Thomas, TX	32°36'	21 Aug				
Big Spring, TX	32°15'	16 Sept				
Brantley, NM	32°5'					July 2004
Kingsville, TX	27°25'	10 June 2004				

have experienced heavy predation by ladybird beetles at Cache Creek and Lake Thomas and by assassin bugs at Artesia. We are releasing large numbers into nearby subplots in an attempt to avoid or overwhelm the predators. The vigorous feeding and reproduction by these beetles, and the longer growing season allows three to five generations a year, and could result in even better control in the south than observed in the north.

Monitoring

An intensive monitoring program is being carried out as required (see Clearances and Permits, above), under monitoring plans developed by the Saltcedar Biological Control Consortium by Juli Gould for the control insects and damage to saltcedar, by Tom Dudley for saltcedar and native plant recovery, and by Larry White for bird populations (Gould and others 2000).

The basic monitoring plan specifies a 10 ha sampling circle centered at the beetle release point with 100 (now reduced to 40) permanently marked sentinel saltcedar trees within 3 concentric rings of 1, 2 and 7 ha. *Diorhabda* and other insect populations, percent defoliation, plant growth and condition are measured periodically on four marked 40 cm long branch terminals on each saltcedar

tree. Once or twice annually, the vegetation is sampled by measuring tree height and diameter, percent healthy, yellowing or dead branches, and the distance, species identification and size of three nearest neighbor trees. Also, low vegetation is measured in two 1 m² quadrats, one under and one outside the tree canopy, in which present cover of all species and of litter and bare soil is estimated. This sampling plan now seems inadequate because the beetles rapidly overflow and completely defoliate the entire sampling circle. Modifications, such as the inclusion of long transects, are being discussed.

The beetles disperse beyond the defoliated area, and are difficult to find at low densities. Our cooperators, Bob Bartelt and Allard Cossé, ARS-Peoria, IL have developed a beetle pheromone and a saltcedar extract that are very attractive to *Diorhabda* beetles over distances of 10 to 20 m. These have been effective in monitoring the dispersal of the Fukang beetles at Lovelock. (Earl Andress, APHIS, Barstow, CA, personal communication).

For monitoring birds, two riparian sampling areas are selected, one with near monotypic saltcedar and one with nearly pure native vegetation. In each area, 10 permanent point-count areas are located, each 100 m in diameter and separated from each other by 100 m. Three or more times annually during the breeding season, the

numbers of each bird species seen or heard during 5 min are counted from the center point of each circle. This allows a direct comparison between saltcedar and native vegetation, and also of populations in saltcedar before and after biological control with the native plots as a statistical control. Procedures also have been developed for monitoring butterflies, all insects, bats, other small mammals, and reptiles.

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) and of the recovery of native riparian plant communities following control although some ground truthing will still be needed. (Carruthers and others, this proceedings).

Expectations From Control

We expect biological control to gradually (over a period of 3 to 5 years) and permanently to reduce the abundance of saltcedar to below the level of economic or environmental damage, but not to eradicate it. In this situation, both saltcedar and the beetles would remain at fluctuating low population levels, the beetles always would be present to control regrowth or reinvasion, and 100 percent control (never obtained by biological or any other method) is not needed.

Under these conditions, we expect the native plant communities to reestablish naturally in most areas where depth to water table and soil salinity are not too great. This should improve wildlife habitat and allow the recovery of many species of birds and fish and some mammals and reptiles, including several threatened and endangered species. Control of saltcedar is expected to increase the amount and quality of water available for irrigated agriculture, municipalities, and the environment and to help fulfill the water rights agreements between states and between the United States and Mexico. Control also is expected to increase recreational usage of parks and wildland areas and to reduce wildfire and salinity levels.

Large-scale revegetation projects are under development by the USDI Bureau of Reclamation for areas where natural revegetation may be insufficient. Several other biological control insects are also being developed by our overseas cooperators for use in fringe climatic areas when the *Diorhabda* beetles may not provide sufficient control or where predators may limit control, or where their release may not be allowed.

Saltcedar also has invaded large areas in northern Mexico, where it is damaging natural areas and contributing to the acute water shortages along the Rio Bravo and in other areas. The U.S. program easily can be extended into Mexico at very low cost, through the participation

of Mexican scientists. However, the large, exotic, athel trees (fig. 1e, f) are valued to some degree in northern Mexico for shade trees, hedges, and windbreaks. The *Diorhabda* beetles are expected to damage athel to some extent, based on our cage studies (Lindsey Milbrath, ARS-Temple, manuscript in preparation). Open-field tests are underway at Kingsville, TX and Artesia, NM to quantify this (Patrick Moran, ARS-Weslaco, site manager). Approval of the Mexican scientists, natural areas managers, and authorities is being sought before releases are made along the Rio Grande, Texas.

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