An Overview of The Biological Control of Saltcedar

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Introduction

Saltcedar (*Tamarix* spp. (Tamaricaceae: Tamaricales)) is an exotic weed that has invaded many riparian areas across western North America. In the absence of natural enemies and disease causing organisms, saltcedar grows very aggressively and is highly competitive with native vegetation, especially in areas where the natural hydrology has been altered limiting stream flow during spring months when native cottonwoods and willows are seeding. Therefore, many of the nation's most productive and diverse ecological regions are being negatively affected by the invasion of this exotic invasive plant. Common methods used to control saltcedar include herbicide application, burning and bulldozing, all of which are expensive and highly detrimental to non-target flora and fauna. Although these approaches may be successful in the short run, they do not provide permanent control of the problem as the saltcedar often grows back or reinvades from surrounding areas.

Over the past decade, biological control of saltcedar has been a major research effort within the USDA-ARS. In cooperation with ARS, a consortium of scientists and land managers has field tested the use of this technology in several western states. A leaf beetle from Eurasia, *Diorhabda elongata* (Chrysomelidae: Coleoptera), has now been successfully used at several locations, where it has established reproductive populations, increased dramatically in numbers and spread extensively across saltcedar infested areas where it has caused extensive defoliation of saltcedar for multiple seasons. In many of these test locations, the leaf beetles significantly impacted saltcedar growth and development, while no non-target plants have been negatively affected. In this paper, we will primarily provide a summary of these results.

Methods And Materials

The Study Areas. Saltcedar biological control release sites have been established in at least nine different western states comprising California, Colorado, Montana, New Mexico, Nevada, Oregon, Texas, Utah and Wyoming. Some states such as California, Nevada and Texas included three or more different release sites while the other states only had a single test site. In California, initial release sites included Inyo (Owens River Valley), Monterey (along San Antonio Creek on Fort Hunter Liggett), and Yolo (Cache Creek) Counties. In Nevada release sites were established in Pershing (along the Humboldt River near Lovelock), Churchill (along the Carson River near Stillwater) and Mineral (along the Walker River near Schurz) Counties, and in Utah in Millard County along the Severe River near Delta.

Biology And Ecology Of The Saltcedar Leaf Beetle. Both adults and larvae of the saltcedar leaf beetle, *D. elongata* (Fig. 1A-D), feed on the foliage of saltcedar and the large larvae also de-bark small twigs causing the distal foliage to die. The adults overwinter and the larvae pupate under litter beneath the trees. Laboratory tests of reproductive capacity showed that beetle populations can double each 6.2 days and field cage studies showed a range of population increases but a 30-fold increase per generation was not uncommon. In Nevada and Utah, overwintered adults become active in early-May and produce two generations before they begin overwintering in September. In the more southern areas, the saltcedar growing season appears to be long enough to allow completion of 3 or possibly even 4 generations each season.

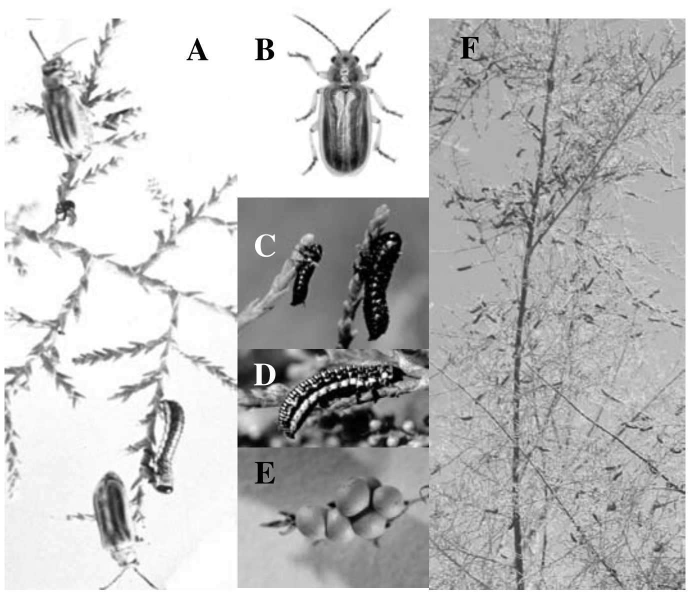


Figure 1. *Diorhabda elongata* beetles and damage to *Tamarix*: A) top to bottom adult female, 1st instar, 3rd instar, adult male all on a single stem; B) adult male; C) 1st and 2nd instars; D) 3rd instar; E) egg mass; F) moderate larval defoliation of saltcedar in a field test site.

Experimental Releases And Results In Field Cages July 1999 To May 2001. After receiving US Fish and Wildlife Service concurrence and USDA-APHIS permits, beetles from China and Kazakhstan were released into field cages during the summers of 1999 and 2000 at 10 sites in 6 states. These beetles successfully overwintered in the cages at the eight most northern sites, all north of the 38th parallel. They failed to overwinter at the two most southern sites, at Seymour, TX and Hunter-Liggett, CA both south of the 38th parallel. Here, they ceased feeding and egg-laying, and began overwintering diapause in early July but did not survive the winter. During the summer of 2000, we learned that the most probable cause of the failure to overwinter at more southern locations was the short summer daylengths, which caused premature diapause that limited egg production to early in the season and decreased overwintering survival. Laboratory studies showed these beetles required at least 14 h 45 min daylength to avoid entering overwintering diapause. Subsequently, beetles were collected from more southern locations in Eurasia and then introduced successfully into California and Texas where they are now operating effectively. Beetles from Crete, Greece were selected, as they were determined to be the most likely to succeed in areas with shorter daylengths and thus were released into southern Texas and Central California where they have established and are continuing to be monitored. Ground sampling of beetle populations and their impact on target saltcedar and adjacent beneficial species was conducted at all of the release sites for several years, however the scale of impact quickly made ground-based field sampling both difficult and expensive. Previous studies documented the effective use of remote sensing for the assessment of saltcedar infestations. In support of the overall project monitoring and assessment efforts, further remote sensing was conducted to characterize saltcedar infestations, to follow beetle establishment, impact and spread, and eventually to document the return of beneficial vegetation into areas where saltcedar has been controlled. Here we will discuss the establishment and spread of these beetles at several sites but will concentrate on local release areas in Californai, Nevada, Texas and Utah where our team has been conducting detailed assessments of this biological control program.

Results And Discussion

Releases And Results In The Open Field In Northern Areas (May 2001 To Late Summer 2005). The results of the field cage studies allowed open field releases to be conducted in multiple states during the 2001 field season. A variable number of beetles were released at the 13 different field test sites, however, in an example area near Lovelock, NV approximately 1300 beetles were released into the open field to initiate establishment and spread of these biological control agents across a wide area. At most sites, a few to moderate numbers of eggs, larvae and adults were found throughout the remainder of the summer of 2001, until late August or early September, when we assumed they had entered overwintering diapause. The most damage was at Pueblo, CO where the beetles defoliated ca. two-thirds of a rather large tree. Similar low densities of beetles were found during the spring and early summer of 2002, although they had dispersed over a wider area of ca. 50 to 100 m in radius from the release point at most study areas. Then, when large larvae of the second generation developed in mid-August, extensive damage was observed at some sites. The most spectacular damage was at the Lovelock, NV release site (Fig. 2A).

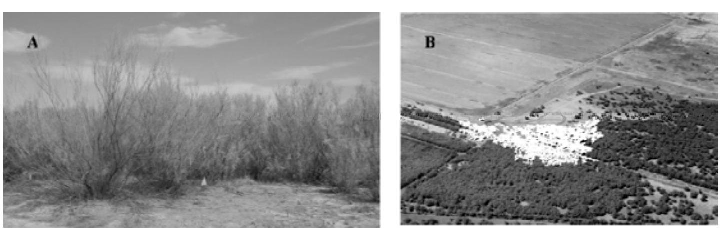


Figure 2. Saltcedar leaf beetle defoliation during midsummer 2002, one year following beetle release at Lovelock, NV. Canopy area masked with white is the highly impacted area.

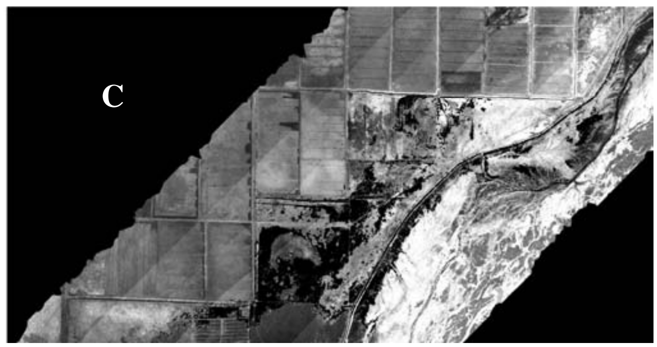
This site is located in a very large area of dense saltcedar in the floodplain of the Humboldt Sink. Essentially the only other vegetation present was a moderate stand of saltgrass growing between the saltcedar trees. Large populations of larvae (Fig 1F) were found during mid-August that rapidly defoliated the saltcedar within an area 100 m in diameter (2 acres, Fig 1B), centred at the release cage. Heavy feeding but not total defoliation had occurred in an additional concentric ring 50 m wide outside the defoliated area.

By the end of the third growing season in late August 2003, *D. elongata* had begun a rapid and dramatic defoliation of saltcedar (Fig 3A) at five of the seven release sites north of the 38th parallel. At Lovelock, NV, the beetles increased to 8 acres in early July 2003 (Fig 3B), and to ca. 500 acres by early September 2003 (Fig. 3C). By September 2003, several plants had resprouted but enough beetles had remained to defoliate this regrowth. At Delta, Utah the beetles defoliated approximately 100 acres by September 2003. At Schurz, NV the beetles dispersed beyond the monitoring area in 2002, but in 2003 they had defoliated ca. 30 acres along the Walker River. No beetle establishment was ever documented at the Stillwater release site even though it is between two other very successful release areas, however, after the first few years, no additional attempts were made. By the end of 3½ growing seasons after release (late June 2004), defoliation increased 3 to 5 fold over the amount in August 2003, to an estimated 1500A at Lovelock, 500A at Delta, 300A at Schurz. In 2005 this defoliation continued heavily in each of our test sites spreading to literally 1000s of acres in each of our Nevada and Utah test sites. By the fall of 2005 in the Lovelock, NV test area, nearly every saltcedar tree within a 65,000 acre area (not continuous saltcedar) was heavily impacted by the beetles and the spread was found to be over 100 miles along the Humboldt River and Humboldt Sink.

By early spring of 2006, many trees have been completely killed in the center of the release areas and we expect to see increasing tree death during the 2006 growing season. Although it takes substantial time for the trees to die, the defoliation has been 95 to 100% over very large areas, which has greatly reduced water usage and plant reproduction in many of the release sites. This defoliation has further opened the plant canopy and allowed other plants to begin increasing in number and size. Some of those are beneficial species, such as saltgrass, willows and seedling cottonwoods, however, other weeds such as Russian Knapweed (*Acroptilon repens*) and Tall whitetop (*Lepidium latifolium*) are increasing in number. Therefore, USDA-ARS has expanded research into revegetation and restoration research to augment previous investigations of this type conducted by the USDI Bureau of Reclamation. Currently, *Diorhabda* beetles are very widely distributed at most of our release sites in both Nevada and Utah where the local Departments of Agriculture in cooperation with USDA-APHIS have begun an area-wide redistribution effort.

Short-Daylength Beetles Discovered And Released In Southern Areas. In California, Chinese *Diorhabda* were originally released at three different locations (Owens Valley, Cache Creek and Ft. Hunter Liggett) in 2001, however, none of these releases ended in establishment due to a variety of factors including poorly adapted diapause characteristics, heavy predation by ants and other generalist predators and other factors. Once initial releases failed, the team delayed further introductions until the diapause situation was better understood and new potential germplasm

Figure 3 A. Saltcedar defoliation caused by *Diorhabda elongata* (Lovelock, NV fall 2003).
Figure 3 B. Areas appearing black are the saltcedar plants defoliated by the biological control agents in July 2003. The grey areas are the healthy non-defoliated plants. The approximate area defoliated was 8 acres.
Figure 3 C. After the 2^{nd} generation of beetles in 2003, (10 September 2003) approximately 500 acres of saltcedar had been defoliated (black area of canopy).



was available and tested. As part of a follow up study, new beetles were collected at lower latitudes in Crete and mainland Greece, and through a latitudinal gradient from Tunisia, north and east into China via our co-operators at other locations in Asia. It was felt that some of these beetles had the potential to establish south of the 38^{th} parallel and perhaps throughout the range of saltcedar in the southwestern U.S. and northern Mexico. The Crete beetles, were the first to be placed in a large outdoor cage at Temple during August 2002 and were allowed free range inside cages where they overwintered with little mortality, and began feeding and reproducing vigorously on the plants by early April. Additional host specificity testing of the Crete *D. elongata* allowed them to be permitted and released into restricted areas in Texas and California during the summers of 2003 and 2004, respectively. In California these beetles were only placed in the open field along Cache Creek where we conducted additional host specificity tests in field cages with potentially vulnerable *F. salina*. At this site, the beetles establish after the first year but did not significantly increase their populations until the summer of 2006. Currently, a significant population of Crete beetles has established and spread approximately 5 miles along Cache Creek where it has caused nearly total defoliation of saltcedar (*Tamarix parviflora*) over nearly 3.5 acres, with high numbers of adults now overwintering in the area. In Texas, the Crete beetles have followed a similar pattern where they were field released in a wide area and have become well established and are heavily defoliating saltcedar over the release area. In 2005, 2-3 acres of saltcedar were heavily defoliated with substantial populations of overwintering beetles now expanding to nearly 10 times that level of impact. We hope and anticipate that the Crete beetles will follow the same course as the Chinese beetles have done in more northern areas.

To further assess the safety of the Crete beetles to *Frankenia salina*, replicated tests were conducted in field cages in Cache Creek, CA in 2003-05 and throughout the summer of 2005 in the open field in Big Springs, TX. Under heavy defoliation pressure, planted saltcedar, athel and *Frankenia salina* were challenged with high densities of Crete beetles. In the field cages, some eggs were laid on *Frankenia*, however, under more realistic open field conditions no eggs were laid on the *Frankenia* while large numbers of eggs were laid directly on adjacent saltcedar and athel. In the case of the Texas open field studies, these plants were maintained for several weeks in areas of high beetle densities where both adult counts and levels of egg deposition were recorded on several different sampling periods in areas where background saltcedar defoliation was nearly 100%. Based on these and other supporting data, USDA-ARS has requested a more extensive field release and evaluation permit for Crete *Diorhabda* beetles to be field tested into Southern California. Since these sites are in areas near potentially susceptible *Frankenia salina* populations, we acknowledge that these beetles hold some potential risk to native *Frankenia salina.* We therefore plan to work forward in the design, testing and release of these agents with appropriate cooperators from both federal and state land management/ wildlife agencies and other potentially concerned groups to ensure that a full benefit/ risk policy discussion and consensus has been reached regarding the next steps in this biological control program. The California Department of Food and Agriculture plans to work in parallel with USDA-ARS and distribute Crete Diorhabda beetles within the state of California during the spring and summer of 2007. Initial release efforts will begin in Central and Northern California *Frankenia* testing and monitoring will be conducted to assess environmental safety.

Summary

The biological control of saltcedar has been an outstanding example of a successful biological control project. A wide number of groups have all worked cooperatively to develop, implement and assess the effectiveness of this program. The leaf beetles from China and Kazakhstan have worked extremely well across the northern tier of the U.S. and we hope that similar beetles from Crete, Greece or other more southern locations will work equally well in the southwest. The project has worked hard to clearly identify and characterize potential non-target risks to agricultural crops and native species, and is working forward in a way to document safety as we proceed. By working in a diligent and defined manner, USDA-ARS hopes that this program will be effectively operating in more southern areas of California, in the near future. Further research and monitoring is still required both to ensure safety of this and other related agents prior to final wide-spread field release and redistribution. This will be done in conjunction with plans that are now being made by CDFA teams to implement this program state-wide in a step-like fashion. Additionally, USDA-ARS and cooperators are investigating other potential natural enemies for saltcedar to use in place of the leaf beetle if the risk of release is too high, or in combination with it at other locations where additional stress on the saltcedar is needed for economic control.

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