PHILOSOPHY AND USAGES OF BIOLOGICAL CONTROL OF WEEDS
(For recent reviews and citations of original references, the reader is referred to DeLoach 1981, DeLoach 1991, and DeLoach 1997).

Definition and action of biological control. For the purposes of this discussion, I define biological control as the planned use of undomesticated organisms (usually insects or plant pathogens) to reduce vigor, reproductive capacity, or density of target plants. It excludes cultural controls (grazing management, crop rotation, transgenic manipulation of crops, etc.) and natural control (the action of organisms without human direction). It acts to tip the competitive advantage back in favor of the native species, even though the weed is still present. Biological control seeks not to eradicate the target species but to reduce its density below the economic threshold or below some biological threshold, so that other controls are not needed or, at least, so that damage and the use of other controls are reduced. Biological control of weeds has neither eradicated a target species from an ecosystem nor made rare plants more rare.

Approaches to biological control of weeds. Three major approaches are available in biological control. First, the introduction of foreign control agents, often call the “introductory” or the “classical” approach, has been much the most used and the most successful. The approach is to find insects or sometimes plant pathogens near the origin or within the natural range of the
target weed that can reduce its population. These organisms are tested to insure that they do not harm other plants and then are released in the field. The agents need to be released at only one or a few sites; they reproduce and spread on their own and actively seek out the weed. The only cost is that of the research. Introduction is permanent and self-sustaining, and it controls the weed in all areas, including those hard to reach by ground equipment. Because of low cost, the method is suitable for controlling weeds in natural areas or in areas of low economic return such as rangelands. Many weeds have been controlled completely or substantially in most of the infested area by only one control agent, although often additional agents are needed to obtain control in fringe climatic zones where that control agent is not adapted. A disadvantage is that the released agent is likely to control the weed in all areas, thus damaging target species in areas where it is valued (e.g., landscape plantings). The area treated or the duration of treatment can be limited only with difficulty, if at all. Before beginning a program, agreement should be reached that control in all areas is acceptable.

The second approach, called “augmentation” was developed since the 1960s. It seeks to increase effectiveness of phytophagous organisms already in an area, whether native or previously introduced. The methods include increasing the number of biotic suppressants attacking the weed by distributing insects from areas of surplus or from laboratory colonies grown on host plants or artificial diets, producing an inundative effect by using plant pathogens as “bio-herbicides”, and using insecticides to reduce parasites or predators attacking the biocontrol agent. Augmentation has the advantage of having few or no conflicts of interest because reared insects or bio-herbicides applied will spread only a very short distance from where applied, so limited areas can be treated and control can be discontinued at will. A disadvantage is that all infested areas must be treated periodically. Mass production of insect herbivores in sufficient numbers to control weeds is expensive and probably not practical except in high-value crops. However, plant pathogens often can be produced at costs competitive with herbicides. These have been used effectively in a few cases such as control of northern joint-vetch (Aeschynomene virginica) in Arkansas rice fields and of strangler vine (Morrenia odorata) in Florida citrus groves.
In the third approach, called “conservation”, methods used are the adjusting of cultural practices to preserve natural enemies of weeds and the preserving of alternate host plants or refuges for these enemies.

**Control of exotic vs. native weeds.** The causes of a native plant becoming weedy are wholly or partly different from the causes of introduced plants becoming weedy. Native plants become weedy because of environmental changes brought about by humans, for example, overgrazing, creation of disturbed areas, increased landscape fragmentation, increased atmospheric CO$_2$, and possibly (though not demonstrated) reduction in populations of insects or other organisms that formerly controlled the plant. Introduced plants become weedy primarily because of the absence of natural enemies, as well as some of the above factors.

**Native weeds.** Control of native weeds historically has been considered more difficult than control of introduced weeds because of the difficulty in finding host-specific control agents, the higher probability of many closely related non-target plants, and the greater use of the weed by native animals. Control of only a few native rangeland weeds has been successfully attempted: prickly-pear cactus (*Opuntia tricantha*) in the Caribbean, other prickly-pear species (*O. littoralis* and *O. oricola*) on Santa Cruz Island off California, and manuka weed (*Leptospermum scoparium*) in New Zealand.

Most environmentally oriented groups today argue against the concept of biological control of native weeds as a general principle. However, some are very invasive and damaging, often in agricultural and sometimes in natural ecosystems, and today are hundreds of times more abundant than before European settlers arrived. Examples are mesquite (*Prosopis glandulosa*), junipers (*Juniperus*), snakeweeds (*Gutierrezia*) and poison ivy (*Toxicodendron*). A very successful biocontrol program would be unlikely to reduce these even to their pre-Columbian abundance. No programs to control native weeds are being considered today.

**Exotic weeds.** The great majority of the successful cases of biological control have been of invasive, exotic weeds. Most of the most serious weeds of North America are introduced, invasive, exotic plants from other countries. The classical approach is appropriate for several of
these weeds, is feasible, and has a high probability of success if the target weeds are selected with care (it is not appropriate for some weeds), and if used with caution, proper procedures, and under established regulations (see below).

Classical biological control has been applied against 133 weed species, using more than 350 control organisms, in 51 countries since 1865. Worldwide, only eight examples of damage to non-target plants are known, none of which has caused serious economic or environmental damage and the majority of which were temporary and all were anticipated by routine testing before release. In North America, biological control has been used against some 40 weed species since 1945, with about one third being completely or substantially controlled and another third being partially controlled. The philosophy and methodology of biological control of weeds has made dramatic improvements since the early 1960s and has developed into a broadly based, logical science as outlined by Huffaker (1957, 1964) and others. Improvements in the concepts of host-specificity testing, test plant selection and natural enemy selection have resulted in both greater efficiency and greater safety. Intensive monitoring of weed biological control projects now is required in ARS projects for several years after control is initiated. Regulatory direction and oversight were provided by the USDA Working Group on Natural Enemies (WGNE) in the 1960s, later broadened to the TAG in the 1970s and strengthened in the 1990s; the National Environmental Policy ACT (NEPA) of 1969, and the Endangered Species Act (ESA) of 1973.

To be feasible, the weed and its close relatives should not have overriding beneficial values, and host specific control agents should exist somewhere within the native range of the weed that can be introduced. Biological control has been most successful against introduced weeds, and weeds of relatively stable ecosystems such as natural areas or rangelands where very high specificity, low costs, and permanent control are needed to control the weed without harming the native species.

Throughout the history of biological control, the “introductory” or “classical” approach has been used mostly in relatively stable ecosystems, for example, rangelands, pastures, natural areas, and aquatic sites, and almost entirely to control exotic weeds. It has been used mostly to control herbaceous broadleaf plants or shrubs or sometimes annuals and biennials. Control of
Control of weeds in crops has been attempted only rarely with introduced control agents. Three factors make such control in crops difficult: (1) disturbance from agricultural activities is likely to kill the biological control agents; (2) several species of weeds in a crop usually need control, and the biological control of only one would not reduce conventional controls needed for others; and (3) rapid control is needed to prevent crop damage. However, methods can be envisioned to circumvent these difficulties. Given that the greatest losses occur in crops, biological control in this system deserves further investigation. The opportunities and problems associated with biological control of crop weeds were reviewed by Charudattan and DeLoach (1988).

We do not propose that the risk of biological control is zero. However, other control methods also entail risks although the risks may be different. We deal with a range of risks in selecting target weeds – from very slight, to small, to moderate, to too severe to attempt biological control. However, to hold a requirement of zero risk is unrealistic and actually may be harmful to the ecosystems we are attempting to improve. This would end the use of biological control altogether and force reliance on other more harmful and expensive control procedures. The minute risk of damage that might be produced by biological control must be weighed against the great known damage caused by the weed, and the risk from the no-action option of allowing this damage to continue (Pimentel et al. 1992, Pimentel 2000). These dangers are revealed by surveys in Australia showing that more than 50 plant species are endangered because exotic, invading weeds out-compete them (Bell 1983) and in Germany showing that 89 of 581 rare plants are declining because of herbicidal applications to control weeds (Sukopp and Trautmann 1981). In the United States, Stein and Flack (1996) estimated that approximately 400 of the 972 federally listed threatened and endangered species of plants and animals are at risk primarily because of competition with and predation by non-native species. Wilcove et al. (1998)
estimated that 48% of 56 periled birds and 30% of 641 species of plants in the continental United States are imperiled because of alien species.

Of the 40 North American weeds for which biological control has been attempted (control insects released in the field) some 12 cases have provided substantially or complete control. Projects that already can be classified as successful are: St. Johnswort (*Hypericum perforatum*), puncturevine (*Tribulus terrestris*), tansy ragwort (*Senecio jacobaea*), alligatorweed (*Alternanthera philoxeroides*), waterhyacinth (*Eichhornia crassipes*), waterlettuce (*Pistia stratiotes*), musk thistle (*Carduus nutans*), skeletonweed (*Chondrilla juncea*), Mediterranean sage (*Salvia aethiopis*), leafy spurge (*Euphorbia esula*), purple loosestrife (*Lithrum salicaria*), and field bindweed (*Convolvulus arvensis*). Four new projects that are achieving very promising control in the field and seem poised to provide excellent control over wide areas are: Melaleuca (*Melaleuca quinquenervia*), saltcedar (*Tamarix* 4 spp. and hybrids), hydriilla (*Hydrilla vertiillata*), yellow starthistle (*Centaurea solitialis*).

**EXAMPLE: BIOLOGICAL CONTROL OF SALTCEDAR**

(For recent reviews the reader is referred to DeLoach et al. 1996 and 2000, and for original research the reader is referred to DeLoach et al. 2003, Lewis et al. 2003a and b, and DeLoach et al. 2004).

**Need for Biological Control**

**Invasion and damage.** The invasion of river bottoms and lakeshores of the western United States by exotic, invasive saltcedars (*Tamarix* spp.), deciduous shrubs or small trees, from the Old World, is producing one of the worst ecological disasters in the recorded history of that region. Saltcedars rapidly invaded after the 1920s and today occupy over 2,000,000 acres 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 some 40 species of threatened or endangered species. 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 and municipal use. They contribute to default of water agreements between states and between the U.S. and Mexico and damage natural area reserves bordering the Rio Grande.

**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. Ten species have been introduced into the United States since 1823 as ornamentals and to control streambank 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). 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 its windblown seeds. Recently, “arsenal” (imazapyr) as an aerial spray and “garlon” (triclopyr) as a cut-stump treatment provide good control. 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 damaging level, but not to eradicate the weed. This method has been used worldwide since 1865 against 133 weed species in 51 countries. 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 8 reported cases of
non-target feeding worldwide (7 minor and 1 of moderate damage), all before testing protocol 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 an almost “ideal” weed for biological control.

**Research Progress**

**Discovery and testing of control insects.** Surveys for natural enemies have been made in Italy, Israel, Iran, India, Pakistan, and Turkey. These searches, together with extensive ecosystem studies in the former Soviet Union and by some of us in China, have revealed over 300 highly specific and damaging insect species as potential biological control agents. Research began by ARS at Temple, Texas, in 1986, with a thorough review of the literature and risk analysis. We conducted overseas explorations for and tested insect natural enemies through cooperators in France, Israel, Turkmenistan, China and Kazakhstan from 1991 to the present time. Testing in quarantine began at Temple in 1992, and at Albany, California, in 1998. Some 20 candidate biological control insects are under investigation overseas and 7 species in quarantine at Temple, and Albany. The leaf beetle *Diorhabda elongata*, was selected as the first and most promising candidate for release and the testing of its host specificity (safety), biology and ecology have been completed.

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

However, the listing of the southwestern willow flycatcher as federally endangered in February 1995 required consultation with FWS and the preparation of a Biological Assessment, which we submitted to FWS Region 2 (Albuquerque, New Mexico) in October 1997. This analysis revealed that the flycatcher utilized saltcedar extensively for nesting habitat in some
areas of Arizona but little in other areas. However, the harmful effects of saltcedar reduced reproductive success of the flycatcher to half of that in its native willow habitat. We then submitted a Research Proposal to FWS on 28 August 1998 for release of the beetles. It specified a research phase in which; 1) *D. elongata* could be released 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 southwestern willow flycatcher nests in saltcedar. The beetles were to be carefully monitored in the cages for one year to determine their overwintering ability, mortality factors, rate of increase, and damage to saltcedar and non-target plants in the cages, and, 2) the beetles then could 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 3-year research period, FWS, ARS and APHIS would review the research results and determine the conditions under which the Implementation Phase could be carried out in which the beetles could be released at will in specified areas. A Letter of Concurrence was issued by FWS on 28 December 1998 (revised 3 June 1999) and an Environmental Assessment was prepared by USDA-APHIS in February 1999. APHIS issued a Finding of No Significant Impact (FONSI) on 7 July and permits to release in field cages during July 1999.

Meanwhile, the Saltcedar Biological Control Consortium was organized in December 1997 to provide coordination between agencies and input, guidance and oversight in the research program from user and environmental organizations. It has met annually since then and now has representatives from some 50 federal and state agencies, universities, and private user and environmental groups.

**Biology and ecology of the saltcedar leaf beetle.** Both adults and larvae of the saltcedar leaf beetle 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. 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 2 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 3 or possibly even 5 generations.

**Experimental releases and results in field cages: July 1999 to May 2001.** We placed beetles from Fukang, China, into field cages during July and August 1999 at seven sites: near Seymour, TX; Pueblo, CO; Lovell, WY; Lovelock and Schurz, NV; and near Bishop, and on Hunter-Liggett Military Base, CA. Beetles from Chilik, Kazakhstan were placed in cages near Delta, UT. During the spring of 2000, beetles from Fukang also were placed in cages at Stillwater National Wildlife Refuge near Fallon, NV and at Cache Creek near Woodland, CA. 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 six sites where strong overwintering occurred (Pueblo, Lovell, Delta, Lovelock, Schurz and Bishop), 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 most southern sites, at Seymour and Hunter-Liggett, both south of the 37th parallel (the northern border of Oklahoma, New Mexico, and Arizona). Here, they ceased feeding and egg-laying and began overwintering 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 Seymour and Hunter-Liggett was the short summer daylengths, which caused premature overwintering, then starvation during the 8 to 9 months before spring. Daylength near the origin of these beetles at Fukang (44°17′ N) and Chilik (43°33′ N latitude) reaches a maximum of 15 h 30 min. Maximum daylength at Seymour (33°35′ N) is only 14 h 21 min and at Temple (31°10′ N) is only 14 h 10 min. Laboratory studies at Albany showed these beetles required at least 14 h 45 min daylength to avoid entering overwintering diapause.

**Releases and results in the open field in northern areas: May 2001 to early fall 2003.** The results of the releases into field cages and of the additional testing results of *D. e. deserticola* were submitted to APHIS on 25 August 2001 requesting releases into the open field. APHIS issued release permits, and we released 400 adults into the open field at the 6 sites where the beetles had overwintered during May 2001.
Additional releases were made during the remainder of the year as excess beetles were produced in the cages. Altogether, we released approximately 27,000 adults and larvae at Lovell, WY (six nursery cages had been established there); 6900 adults plus many larvae at Pueblo, CO; 15,000 at Delta, UT (from nine cages); 3,500 at Schurz, NV; 1,650 at Lovelock, NV; 4,400 larvae and 2000 adults at Bishop, CA; and 498 adults at Seymour, TX.

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 no more were found and we assumed they had entered overwintering diapause. The most damage was at Pueblo, where the beetles defoliated ca. two-thirds of a rather large tree to which they had flown, about 30 ft from the tree on which they had been released.

Similar 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. Then, when large larvae of the second generation developed in mid-August, we saw extensive damage at some sites. The most spectacular damage was at the Lovelock, NV, release site (Fig. 1F, G & H). 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 large and some medium-sized larvae were found on 13 August that were rapidly defoliating the trees. On 28 August, the larvae had destroyed 95 to 98% of the foliage of all trees within an area 100 m in diameter (2 acres), centred at the release cage. Heavy feeding but not defoliation had occurred in an additional concentric ring 50 m wide outside the defoliated area.

The second most severe damage was at Pueblo, CO (Fig. 1I). Nearly complete defoliation was seen on ca. 25 trees in the centre of the release area, with heavy feeding but not total defoliation out to 50 m from the release point. At Lovell, WY, the beetles produced substantial feeding damage but not complete defoliation. The most obvious reason for the low amount of damage was heavy predation by ants, which were abundant at this release site.
At Delta, UT, we found few beetles and no feeding damage at the release site. However, on 1 August 2002, we observed a large swarm of 800+ adult beetles flying about and mating among the larger trees. By 22 August, these had produced many large instar larvae. However, while we observed, a flock of towhee birds descended upon and devoured most of the larvae.

At Bishop, CA, we did not find noticeable damage to plants after release into the open, although defoliation inside the cages had been complete. Two factors seemed to reduce the effectiveness of the beetles. First, we observed some predation by ants and second, about half the adults entered diapause in early summer and probably did not survive the winter.

At Schurz, NV the beetles had increased well in the cages, defoliated the plants, and overwintered in the cages. However, we found few beetles in the open field. Beetles at Cache Creek, CA, and Stillwater NWR reproduced poorly in the cages and were not released in the open. At Cache Creek, the beetles were intended to control *Tamarix parviflora*, which may be a somewhat less acceptable host plant for them. At Seymour, Texas, the beetles were replenished in the cages, reproduced well, and 498 first generation adults were released into the open on 13 and 26 June, but apparently did not produce a second generation and none were found the following year.

By the end of the third growing season in late August 2003, the Fukang/Chilik biotype of *D. elongata* had begun a rapid and dramatic defoliation of saltcedar at five of the seven release sites north of the 38th parallel. At the best site (Lovelock, NV), the beetles had defoliated 2 acres of a dense stand of saltcedar in early September 2002 (Fig. 1H), which increased to 8 acres in early July 2003, and to 480 acres by early September 2003, along a 3 mile reach of the Humboldt River (Fig. 2). 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 Pueblo, the beetles were confined to one tree during 2001, had dispersed within a 100m radius of the release point during 2002, and defoliated ca. 100 acres of saltcedar by September 2003. At Delta and Lovell, the beetles overcame bird and ant predation in 2002 to defoliate 75 acres and 23 acres respectively by September 2003. At Schurz, the beetles apparently had dispersed beyond the monitoring area in 2002 and were not found but in 2003
they had defoliated ca. 35 acres along the Walker River. Little is known yet about the rate of kill of the plants but we expect to find many dead plants during 2004. In the northern area, the beetles failed to establish only at Stillwater NWR, NV, and at Cache Creek and Bishop, CA.

In summary, beetles released at sites north of the 38th parallel where daylength exceeds 14 hr 45 min at least into mid-August, and where predation from ants or birds was not severe, reproduced well during the first 3 years in the open field and promise to provide good to excellent control of saltcedar. At an intermediate site at Bishop, California, beetles overwintered in the cages but could not overcome predation in the open field and could not establish. At sites south of the 37th parallel, where daylength did not reach 14 hr 45 min, the beetles failed to overwinter, did not become established, and promise no control.

**Short-daylength beetles discovered and released in southern areas.** We and our overseas cooperators have discovered beetles with daylength requirements of only 10 to 13 hr at lower latitudes in Crete and mainland Greece, and in Tunisia, Uzbekistan, and China. These beetles probably can 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 and allowed free range inside the cage, 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. These were placed in field cages in the southern areas during the summer of 2003, the Crete beetles at five sites in Texas and at one site in New Mexico, and the Tunisian, Uzbekistan, and Turpan, China biotypes at one or two locations each in Texas. The Crete beetles were released into the open field at Seymour, Lake Thomas, and Big Spring, Texas and at Artesia, New Mexico and the Turpan beetles also were released at Seymour. The Crete beetles also were released at Hunter-Liggett in September and at Cache Creek in October 2003. The vigorous feeding and egg laying by these beetles, especially of those from Crete, and the longer growing season in the south that allows 3 to 5 generations a year, could allow even better control in the south than in the north.
**Monitoring.** An intensive monitoring program is being carried out as required by the Research Proposal to FWS of 28 August 1998 and by ARS and other cooperating agencies. Two years of baseline data now has been compiled from the various release sites on the beetle populations, dispersal, mortality factors, and effects on saltcedar and non-target plants; on the present vegetation density and composition; and on wildlife populations (bird species, butterflies, small rodents and bats). Also, differences in insect species, life stages, and abundance between saltcedar and native riparian trees and shrubs, is being measured. The monitoring is by far the most time-consuming and expensive part of the project but it is essential to understanding the effects of control on native ecosystems. Previous and continuing research on remote sensing promises a good and less expensive method of monitoring the degree and extent of control and of the recovery of native riparian plant communities following control.

**Expectations from Control**

We expect biological control to gradually (over a period of 3 to 4 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 of windblown or waterborne seeds, and 100% control (never obtained by biological or any other method of control) is not needed. This is the situation obtained in all other successful biological control of weeds projects.

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 of plants and animals. Successful control of saltcedar also is expected to substantially increase the amount and quality of water available for irrigated agriculture and municipal use 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, to reduce wildfires, and to allow the gradual reduction of salinity levels of surface soils in presently infested areas.
Large-scale revegetation projects are under development by the USDI Bureau of Reclamation for areas where natural revegetation may be insufficient. Also, several other biological control insects are being developed by our overseas cooperators in Kazakhstan, China, Israel and France for use in fringe climatic areas when the *Diorhabda* beetles may not provide sufficient control or where predation, especially by ants, may limit control.

The above preliminary results indicate that the program on biological control of saltcedar has a high probability of providing good control of saltcedar over much of the infested area of the United States. 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 through the cooperation of Mexican scientists, and at very low cost.
REFERENCES CITED


