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Biological control programme against saltcedar (*Tamarix* spp.) in the United States of America: progress and problems

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Abstract. Invading saltcedar (*Tamarix ramosissima*) from central Asia has become the most damaging weed of native riparian ecosystems of the western United States of America. Classical biological control is the method of choice for control in these areas where the native flora and fauna should not be harmed. At least 25 genera of insects have co-evolved with the genus *Tamarix* in central Asia, with over 300 species host-specific to the genus. We are testing 15 of these species in France, Israel, China, Turkmenistan, and Kazakhstan. Six species have been introduced into quarantine at Temple, Texas for final testing. Two species, the mealybug *Trabutina mannipara* from Israel and the leafbeetle *Diorhabda elongata* from China, have received preliminary approval for release. The other 13 species also appear suitable for release. However, final release permits await resolution of conflicts of interest that involves the endangered southwestern subspecies of the willow flycatcher, *Empidonax traillii extimus*, that now nests in the saltcedar that has displaced its native nest-trees.

Introduction

Saltcedars are mostly deciduous, small trees or shrubs in the genus *Tamarix*, family Tamaricaceae. They have attractive, small pink flowers in racemes that are insect pollinated and small, wind-blown seeds. The foliage consists of small, cedar-like bracts (Baum 1978; Liu 1987). They are phreatophytes that mostly grow along streams and lakes where the water table is 1-6 m deep. They can utilize saline groundwater by excreting the excess salt through glands in the leaves (Waisel 1972).

Ten species of *Tamarix* were introduced into the United States of America, beginning in 1837 (Baum 1967; Crins 1989). They were planted in the southeast but they are only minimally naturalized there. In the arid west, one species, *Tamarix ramosissima* Ledeb., was widely planted as an ornamental, for windbreaks and to stabilize streambanks and it became naturalized by 1910. Populations of *T. ramosissima* exploded during the 1930s and by the 1950s it occupied large areas of bottomlands and was recognized as the worst weed of western riparian areas (Robinson 1965; Turner 1974). The identity of the major weedy species of the West is still uncertain (Crins 1989) and may differ slightly from any of the Old World species. Specimens that we collected from several large, weedy infestations from western Texas to California and Wyoming were all recently identified as *Tamarix ramosissima* Ledeb. by B.R. Baum. The *Tamarix chinensis* Lour. referred to in North American reports is probably not *T. chinensis*, which is native only in eastern China.

The somewhat beneficial athel, *Tamarix aphylla* (L.) Karst., is planted for windbreaks and shade in southern Arizona, New Mexico, Texas and northern Mexico, and usually is not weedy. It is evergreen and grows to 20 m high with a 1 m trunk diameter. The damage caused by saltcedar and its beneficial values in the USA were reviewed by Horton and Campbell (1974) and DeLoach (1990, 1991).

Recent human-induced changes in riparian ecosystems, combined with the intrinsic biological characteristics of saltcedar, provide it with great competitive advantages over native plants. These are: (i) dams on rivers in the western USA have altered the natural spring flood-cycle, preventing seedling establishment of cottonwoods (*Populus* spp.) but allowing that of saltcedar; (ii) this flood prevention has halted the annual leaching of salt from the soil, while salt continues to accumulate through the excretions of saltcedar's foliar salt glands; (iii) frequent fires kill only the top growth of saltcedar which rapidly regrows, yet fires completely kill even large cottonwoods; (iv) livestock-grazing is very destructive to young cottonwoods and willows but damages saltcedar only slightly; (v) most herbicides and mechanical controls are more destructive to native vegetation than to saltcedar; and (vi) growth of native trees is restrained by native insects and pathogens but saltcedar is not damaged by these.

The genus *Tamarix* originated in central Asia where it is one of the oldest and most dominant plant genera. Its 54 species occur naturally in Spain and Morocco, southern Africa, India, China, and Mongolia (Baum 1978). *Tamarix ramosissima* is the most widespread, abundant, and variable species. Its range extends from eastern Turkey to central China and Mongolia, above the 8ºC isotherm (Kovalev 1995). *Tamarix aphylla* is also widespread, from northern Africa to India, but below the 8ºC isotherm. The family Tamaricaceae includes only the genus *Tamarix* and the small genera *Myricaria* (Eurasia) and *Reaumuria* (central Asia). The order Tamaricales includes only one other family, the Frankeniaceae. The genus *Frankenia* is native in Australia and South America, with a few species in Asia. Six *Frankenia* species are native in the southwestern USA and northern Mexico, three of which are rare (Whalen 1987). Cronquist (1981) places all these in one isolated family group in his order Violales. Most species are adapted to xeric climates and saline soils. This taxonomic isolation of the genus *Tamarix* implies that many insect species may have evolved with it in Asia and that these insects are unlikely to attack other plants in North America.

The easiest modification that would affect the ecology of saltcedar and reduce its abundance would be to introduce the insects from the Old World that control populations of *Tamarix* species there. We plan to introduce insects that: (i) are capable of feeding on and damaging saltcedar; (ii) will not harm *Frankenia* species or other native vegetation; and (iii) do not feed on athel, or at least do not cause significant damage to it. In addition, we would choose insects that do not directly reduce pollen and nectar used by honeybees, at least until native 'honey-plants' begin replacing saltcedar.

Natural enemies of *Tamarix* species in Eurasia

Kovalev (1995) listed 25 insect genera that have co-evolved with and are completely or mostly specific to the genus *Tamarix*. Their host plants sometimes included the genus *Myricaria* or rarely *Reaumuria* (that do not occur in North America), but never the genus *Frankenia*. Most of these insects could be candidates for biological control. In faunistic studies, 59 species of insects that attack *Tamarix* species were listed in Kazakhstan (Mityaev 1958), 52 in Georgia (Lozovoi 1961), 105 in central Asia (Sinadskii 1968), and 92 in Italy (Zocchi 1971). Kovalev (1995) reviewed these and other records and listed 325 species from the former Soviet Union that fed only on plants in the family Tamaricaceae, 75% of which were specific to *Tamarix* species and most of which attack *T. ramosissima* but probably not *T. aphylla*. Other surveys specifically identified potential biocontrol agents for introduction into the USA; 220 species were listed from Israel, Turkey, Iran, and western India (Gerling and Kugler 1973), 26 from Turkey (Pemberton and Hoover 1980) and 190 from Pakistan (Habib and Hassan 1982). Also, between 1991 and 1993, we collected about 75 species in China that are still being identified.

Insects exert heavy pressures on *Tamarix* species in central Asia. Kovalev (1995) quoted the Russian researcher Rusanov as saying that in the tamarisk brakes in middle Asia he "sometimes could not find and collect even a small amount of intact tamarisk fruit and seeds because of the depredations of weevils in the tribe Corimaliini. Other insect species also cause damage there.

Candidate insects for introduction and release

At present, we are testing 15 insect species as candidates for introduction. Two species have preliminary approval for release (noted as *** below), while three are being tested in quarantine and two are approved for introduction into quarantine in the USA (** below), overseas testing has been completed on three species (* below) and five species are still being tested elsewhere.

Trabutina mannipara (mealybug)***

The genus *Trabutina* contains five species, including species formerly assigned to *Naiacoccus*, all restricted to the genus *Tamarix* (Danzig and Miller in press). *Tamarix mannipara* (Hemprich and Ehrenberg) was the first insect species that was tested. The biotype that was tested is known only from deciduous *Tamarix* species from the Dead Sea and Sinai areas in Israel, but other biotypes occur in central Asia. We never collected *T. mannipara* from *T. aphylla*.

The adult female of *T. mannipara* is wingless and excretes a tough waxy egg sac that gradually encloses her and in which she lays eggs. After hatching, the nymphs remain in the egg sac for a few days, then disperse onto the surrounding branches and plants. This species is bi- or tri-voltine.

In quarantine at Temple, nymphs survived only on *Tamarix* species among 14 genera of Violales and two habitat associates (willow and cottonwood) that were tested. Populations from the first to the second generations increased 4-20 times on various tamarisk accessions but decreased on *T. aphylla*. The waxy nymphs covered young twigs and eventually killed several of the test plants. Several parasitoids and a predaceous drosophylid fly attack *T. mannipara* in Israel but do not attack first-instar nymphs, so they can easily be separated from cultures before field-release. The adult females are strongly tended by ants in the field. In Israel, *T. mannipara* is known only from areas warm enough for citrus to grow. In the USA this zone extends from Phoenix and Tucson, Arizona to the lower Rio Grande Valley of Texas. Thus, this mealybug is safe for release, being restricted in host range, climatic tolerance and dispersal ability.

Diorhabda elongata (leaf beetle) ***

Seven species of *Diorhabda* are recorded from Eurasia. *Diorhabda elongata* Brullé occurs from France to Mongolia and China, where it attacks only *Tamarix* spp., mostly along the river banks. It is common everywhere and causes appreciable damage (Lopatin 1977). In China, where *Tamarix* spp. are planted to stabilize sandy soils in deserts, the beetle must be treated with insecticides to prevent it from defoliating and killing the plants.

In quarantine tests at Temple, larvae fed only on the Tamaricaceae and almost entirely on the genus *Tamarix*. In tests using potted plants, only two adults developed from 106 neonate larvae on *Frankenia* species; both were deformed and unable to reproduce. However, survival was the same on *T. aphylla* as it was on *T. ramosissima*. Ovipositional host-selection tests were inconclusive because adults brought from China in 1992-1994 laid only a few eggs. However, in multiple-choice tests at Beijing and Hohhot, using potted plants (six replicates of 100 adults each; 841 eggs laid), only 25% as many eggs were laid on the two *T. aphylla* from the USA as on the four *T. ramosissima* accessions. In a smaller no-choice test at Ashgabat, also using potted plants, females laid 12.7 eggs each per day on *T. ramosissima* and none on *T. aphylla*. If released, *D. elongata* may damage *T. aphylla* slightly, if at all. We have reared no parasites from larvae or adults collected in China, but *Tetrastichus* n.sp. were reared from last-instar larvae in Turkmenistan. In China, Sha (1991) reported three generations, with adults overwintering, but in Turkmenistan, it overwinters as full-grown larvae. This indicates possible biotype differences.

Psectrosema spp. (gall midges) **

Three new species of *Psectrosema* were found to induce small stem and leaf-tip galls on *Tamarix* spp. in France. *Psectrosema nigrum* Gagné was most abundant from April to early June. Two additional species, *Psectrosema album* Gagné and *Psectrosema acuticorne* Gagné, were more abundant in July and August. These midges were heavily parasitized and were preyed upon by a nabid. In France, outdoor host-range tests, conducted under infested trees, showed that both species attacked the local *T. gallica* and the *T. ramosissima* from the USA, but neither attacked *T. aphylla*.

Coniatus tamarisci (weevil) **

Adults and larvae of at least 14 species of *Coniatus* feed on buds and shoots of *Tamarix* species from

France to China. They feed almost exclusively on the genus *Tamarix*, including *T. ramosissima*, and rarely on the genera *Myricaria* or *Reaumaria*. They sometimes occur in large numbers and cause heavy damage (Sinadskii 1968). At Montpellier, *C. tamarisci* F. produced most larvae on *T. ramosissima* accessions from Texas and Wyoming, less on the natural host, *T. gallica*, a few on the genus *Myricaria*, and none on *T. aphylla*, *Frankenia* species, or other plant genera.

Ornativalva spp. (gelechiid moths) **

Ornativalva is a genus of 14 species whose host range is entirely restricted to the genus *Tamarix*. The genus occurs from Spain and Algeria across central Asia to India and Mongolia. In most species, the larvae have at least a weak leaf-tying behaviour, though some live in galls of other insects. Most have 4-5 generations per year. We found *Ornativalva* sp. commonly throughout northern China. In the laboratory at Hohhot, the larvae developed as well on several USA accessions of *T. ramosissima* as on the local *T. austromongolica*, and about half-as-well on *T. aphylla* and *Myricaria* species. In quarantine at Temple, 38% of the neonate larvae of *O. grisea* Sattler collected from *T. chinensis* south of Tienjin in eastern China developed to adults, 30% on *T. chinensis* from Cangzhou, 11% on *T. ramosissima* from Seymour, Texas, and none on three other *Tamarix* species, *T. aphylla*, or on the two *Frankenia* species that were tested.

Colposcenia and *Diaphorina* spp. (psyllids) **

These genera apparently are specific to the genus *Tamarix*. They form 'brushy-tip' galls, about 2 cm long by 1 cm in diameter, from the enlarged foliage bracts, densely arrayed on the dwarfed terminal twig. We have seen them throughout China, Kazakhstan and Turkmenistan, and often at very high populations on groups of plants. Kovalev (1995) listed 20 species of *Colposcenia* from the genus *Tamarix*, many of them on *T. ramosissima*, and none are known to attack *T. aphylla*. At Hohhot, field-collected galls from *Tamarix austromongolica* Nakai contained up to 20 or more nymphs, some of which transferred when placed on potted laboratory plants. Female adults oviposit between the leaf bracts on growing terminals. The eggs hatched in 12 days and nymphs lived 28 days. In quarantine at Temple, nymphs on galls brought from China in 1994 transferred and produced over 300 adults on *T. ramosissima*, but these did not reproduce and host-range testing could not be done. The rearing methods need refinement. At Almaty, adults oviposited on new shoots in spring and the developing nymphs produced galls. Adults emerged in July and produced a second generation which did not produce galls. The third-instars overwinter.

Corimalia tamarisci (weevil) *

Kovalev (1995) reported 36 species of the tribe Corimaliini (Apionidae) on *Tamarix* species from the Mediterranean to Mongolia including, two species of *Allomalia*, 27 of *Corimalia*, three of *Hypophyes*, and four of *Titanomalia*. He proposed that the latter genus should contain excellent biocontrol agents because they form galls in fruits or on stems and heavily damage *Tamarix* species. Host-range tests and studies of the biology of *Corimalia tamarisci* (Gyrll.) are being undertaken at Montpellier. The insects produce ovary-galls which sterilize the flowers. Both saltcedar and athel are suitable hosts. The damage caused by *C. tamarisci* could slow the spread of *Tamarix* species but would not prevent nectar and pollen production for honeybees, or negate the value of the trees for shade.

Agdistis tamaricis (plume moth) *

Agdistis tamaricis (Zell.) occurs from the Mediterranean to Pakistan. It is oligophagous on the genera *Tamarix* and *Myricaria* and is trivoltine in Israel. Its host range was tested and its biology was studied at Tel Aviv. In seven collections, during the summer of 1995, from an area where both saltcedar and athel occurred side by side, 22 larvae were collected from the native saltcedars (*T. nilotica* (Ehrenb.) Bge., *T. palaestina* Bertol, and *T. tetragyna* Ehrenb.) but none from athel, though a few were found on athel at other locations. In multiple-choice tests in 1 m^2 cages, moths laid three times as many eggs on the Israeli saltcedar and five times as many on USA accessions of *T. ramosissima* as on athel. When the larvae hatched they completely defoliated *T. ramosissima* from Kansas but feeding on athel was not noticeable.

Cryptocephalus spp. (leaf beetles) *

Cryptocephalus is a large genus that contains several species that attack the genus *Tamarix* in Israel and from the Caucasuses to Mongolia and China (Lopatin 1977). The species of *Cryptocephalus* that occur in Israel have been reviewed and biological and host-range studies have been conducted on

Cryptocephalus sinaita moricei (Pic.) which occurs around the Dead Sea (V. Chikatunov unpublished). In multiple-choice tests in 1 m^2 outdoor cages, 38% of the eggs produced adults on *T. ramosissima* from Kansas and 27% on the natural host, *T. nilotica*. Only 17% of larvae (from the second-instar onwards) produced adults on *T. aphylla* and the duration of the larval stages was twice as long on *T. aphylla*. In nature, *C. sinaita moricei* probably completes its development only rarely on *T. aphylla*.

Other natural enemies

Seven other species of insects are being tested, all of which appear suitable for introduction to the USA. Larvae of two gelechiid moths form stem galls about 20 mm long by 9 mm in diameter on young stems of *Tamarix* species, which often kill the distal part of the stem. They occur in an area which extends from France to Israel and China. The biology and host-range of the univoltine *Parapodia sinaica* Frauenfeld is being studied at Montpellier. *Amblypalpis olivierella* Rag. causes similar damage (Lupo and Gerling 1984) and sometimes is a prolific pest of *Tamarix* species from Israel to Kazakhstan.

The range of *Trabutina serpentina* (Green) extends from Israel to western China. In laboratory tests at Tel Aviv, nymphs developed well on the local *Tamarix* species and on USA accessions of *T. ramosissima*, but only 20% as many survived on *T. aphylla*. It sometimes reaches high populations near the Dead Sea, but is rare on *T. aphylla* in nature. *Trabutina crassispinosa* Borchs. is similar in appearance to *T. mannipara* but is probably more cold tolerant. It is being tested, together with the scale *Adiscodiaspis tamaricicola* (Mal.), at Ashgabat and at Almaty.

In China, the cerambycid, *Asias halodendri* (Pallas) was collected from *T. chinensis* south of Tienjin. This species is abundant in stems, often killing them to ground-level. The species is reported in literature from several fruit trees but not from the genus *Tamarix*. We are conducting tests to determine if it may be a sibling species that is specific to the genus *Tamarix*. Few stem-borers are known from *Tamarix* species that do not attack *T. aphylla* and this could be a very valuable agent if it is host specific.

Several other insect species listed by Mityaev (1961), Sinadskii (1968), Gerling and Kugler (1973), and Kovalev (1995) could be candidates for introduction. Most of the genera discussed above have other species that may be just as promising. Stem-damaging insects include the gall midge, *Psectrosema noxium* Marik. which is very damaging in Kazakhstan (Mityaev 1961) and China, and several species of buprestids (though they also damage *T. aphylla*). Few cerambycids attack the genus *Tamarix* but the oligophagous *Hesperophanes heydeni* Back. (Kovalev 1995) is promising. Among the most damaging species may be the root-galling weevil *Liocleonus clathratus* Oliv. Other foliage feeders include the leaf beetles *Stylosomus* species, the weevils *Geranorhinus* species, and moths of several families.

Many sucking insects are damaging and abundant in Asia and are probably host specific, especially the scale *Circodiaspis sinensis* Tang, the twig-galling mealybug *Acanthococcus orbiculus* Mat., leafhoppers of the genera *Opsius*, *Tamaricades*, and *Tamaricella*, cixiids of the genus *Duilius (= Hemitropis* and *Bitropis)* , and mirids of the genus *Tuponia*.

Plant pathogens are little known from the genus *Tamarix*. At Montpellier, a *Fusarium* sp. was isolated from seeds in the field and *Trichothecium* sp. was isolated from dying branches. At Montpellier, seedling establishment is rare when compared with the high rate in the USA.

Plans to release and concerns about endangered species

In March 1994, we submitted petitions to the technical advisory group (TAG) in the USA to release the mealybug *Trabutina mannipara*, from Israel, and the leaf beetle *Diorhabda elongata*, from China. In December, TAG recommended to APHIS (US Department of Agriculture) that both could be released. Accordingly, APHIS-PPQ began preparation of the Environmental Assessment (EA) (as required under the National Environmental Policy Act) to obtain final approval and permits for release.

However, the southwestern subspecies of the willow flycatcher, *Empidonax traillii extimus* Phillips, was placed on the endangered species list in February (U.S. Fish and Wildlife Service 1995). In some areas of Arizona, the flycatcher is now nesting in saltcedar, since its natural nest trees, willows (*Salix* spp.), have been displaced by saltcedar. Concern has been expressed that the soil now may have become so saline as a result of dam construction and the salinifying effect of saltcedar itself, that if saltcedar were removed, other vegetation would not return. Approval of the EA awaits a resolution of the questions involving the flycatcher.

Soil salinity in bottomlands may have increased substantially during the past 50 years, but by what amount is poorly documented. Some areas apparently always have been saline. A survey of 7596 ha at four sites on the lower Colorado River, (presently covered with 80-100% saltcedar) showed that 45% of the area could be re-vegetated with screwbean mesquite (*Prosopis pubescens* Bentham) which is relatively salt tolerant and honey mesquite (*Prosopis glandulosa* Torrey) while 45% could be re-vegetated with quailbush (*Atriplex lentiformis* (Torr.) Wats.), but only 10% was suitable for cottonwoods (*Populus* spp.) and willows, which provide the best wildlife habitat (Bureau of Reclamation 1995). Re-vegetation attempts during the 1970s and 1980s, using primarily cottonwoods, were not very successful because of high soil salinity, drought, improper planting, grazing by cattle and wildlife, insect attack, or lack of irrigation. Re-vegetation using screwbean and honey mesquite, on the Gila River near Tacna, Arizona, was successful (Pinkney 1992).

The willow flycatcher apparently does not nest in *Tamarix* species below 625 m. At the higher elevations nesting in *Tamarix* species is less frequent and less successful than in native vegetation. Therefore, the widespread replacement of native riparian vegetation by saltcedar is probably a major factor in the loss and modification of willow flycatcher habitat (U.S. Fish and Wildlife Service 1995). One factor that is thought to contribute to the low success rate of willow flycatcher nests in saltcedar is the probable limited availability of desirable insect food (U.S. Fish and Wildlife Service 1995). It may feed on pollinating insects, but very few other native insects occur in saltcedar. The leafhopper, *Opsius stactogalus* Fieb., probably introduced from Asia with the original tamarisk importations, acts as a biocontrol agent (Liesner 1971), although without providing sufficient control. *Opsius stactogalus* could be an important food source for the flycatcher. Other insects that could be introduced in the future would provide more food for the flycatcher and other species of birds as well, thus making saltcedar a more valuable plant at the time that native cottonwoods and willows are permitted to increase.

Nine species of rare birds (Hunter 1984) and at least five other endangered or threatened animals are being harmed by the saltcedar invasion (Anonymous 1995). Common birds, mammals and reptiles also are severely impacted by saltcedar. In the winter months, when food is limited and other factors affecting survival are critical, bird densities and the number of species in saltcedar are only 39%, and 48%, respectively, of the average density and number of species found in cottonwood, willow, honey mesquite, and screwbean mesquite (Anderson *et al.* 1977). In some areas, saltcedar causes springs to dry up, causing wildlife to die or forcing them to other areas (Comrack 1988).

The presumption that biological control will suddenly 'eradicate' saltcedar, leaving a vast void in the plant community and leaving wildlife and birds with no habitat is incorrect. Biocontrol has never eradicated a weed in the more than 700 projects undertaken worldwide (Julien 1992). Nearly always, the weed remains at least as a common, or sometimes abundant, member of the plant community. We do not expect to achieve more than 80% control of *Tamarix* spp. using introduced insects. However, biological control has greatly improved the natural ecosystem and the native plant and animal communities in many projects, including several in the USA (including Hawaii) and Canada (Huffaker and Kennett 1959; Kelleher and Hulme 1984; DeLoach 1991, 1996; Buckingham 1994; Rees *et al.* 1996). Biological control has never caused any significant damage to native plant communities, or to rare species, even in those few cases where a small amount of non-target feeding occurred on some plants (Turner *et al.* 1987; Funasaki *et al.* 1988; Harris 1988; Turner and Herr this Volume). In most cases, control has required 5-10 years, giving ample time for the natural vegetation to return.

Anderson and Ohmart (1984), after intensive studies of the lower Colorado River over several years, concluded that a management plan to improve avian habitat should include three components: (i) above-average foliage density and diversity and above-average numbers of cottonwood and willow trees; (ii) mistletoe as food for frugivores; and (iii) elimination of saltcedar. Experimental removal of saltcedar on the lower Colorado River resulted in increased growth of willows (Busch and Smith 1995) and control by insects should act similarly. Biological control will not 'eliminate' saltcedar but, if successful, would reduce it sufficiently so that native plants would return and that wildlife habitat, including that of rare or endangered species, would improve substantially.

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