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Progress and Problems in Introductory Biological Control of Native Weeds in the United States

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Introduced and native plants become weedy from different causes: introduced weeds primarily because of a lack of natural enemies and native ones because of environmental or habitat changes. A native weed selected for biological control must have closely related species (same genus) native in another region where natural enemies can be found; these enemies will be "new associates" and necessarily will not be species-specific in host range. The potential of several important native weeds of western U.S. rangelands, humid pastures, crops, and natural areas are evaluated based on the damage caused, beneficial values, closely related plants, geographical distribution of the genus, and natural enemy potential. Ten to 20 important native weeds of western rangelands, 9 of crops, 6 of humid pastures, and 4 of natural areas have known or potential natural enemies from South America and others have potential enemies on other continents; 15 of these weeds have good overall biological control potential and others could have with more explorations for control agents. We have tested 2 Argentine insects to control snakeweed (*Gutierrezia*), 3 others are being tested, and others have potential for testing. Two have been tested in quarantine in the U.S. One (the stem-boring weevil *Heilipodus ventralis*) has been released in the field but a variety of problems so far has prevented its establishment. Biological control of properly selected native weeds seems hardly less feasible than for introduced weeds.

Introduction

Nearly all of the major weeds on southwestern U.S. rangelands are native species and a few are major pests in the northwest and central areas. Native weeds are among the most serious crop pests, some native species are serious pests in humid-area pastures, and a few species in "natural" areas cause serious human health problems. Traditional thought holds that biological control of native weeds is more difficult than for introduced species (Huffaker 1964) and could involve serious risks to the ecosystem (Turner 1985). Planned introductions to control native weeds have been attempted only twice, both times on small islands and both highly successful (Julien 1987). Biological control of native weeds of southwestern U.S. rangelands has been the major effort at our laboratory for the past 15 yrs (DeLoach 1981, DeLoach *et al.* 1986). This is the first attempt at biological control of native weeds in a continental area anywhere in the world. Although we have yet to control our selected target species, we have made substantial progress in both the theoretical and practical aspects. Biological control of properly selected native weeds seems hardly less feasible than for introduced weeds. Here, I attempt to bring together the rationale for introducing foreign control agents to control native weeds and to evaluate the major potential target weeds in rangelands, pastures, crops and natural areas of the United States.

Theory of Biological Control of Native Weeds

Causes of Weediness

"A weed is any plant that interferes with the management objectives for a given area of land (or body of water) at a given point in time" (James *et al.* 1991). Introduced plants become weeds primarily because they were introduced without the complement of insects, mites and pathogens that regulated their population within their area of natural distribution. The chance occurrence of an underexploited habitat, together with the innate aggressiveness of the weed, also plays an important role in some cases. Native plants obviously become weedy for different reasons, since they have long been present together with their natural enemies. Many native species have increased in abundance to become weedy since the European settlers arrived. An obvious modifying force in the rate and direction of weed increase is human caused habitat or environmental change. Vegetation change is also a natural ongoing process. The perception of whether such changes are good or bad depends on human values.

Recent investigations at our laboratory indicate that the 30% increase in atmospheric CO_2 during the last 125 yrs may be a major factor in the worldwide replacement of grasslands by woody plants (Mayeux *et al.* 1991). The probable mode of action is the differential utilization of the CO_2 by plants with a C4 carbon metabolic pathway (warm-season grasses) compared with that of plants with a C3 pathway (cool-season grasses and many woody plants). At the CO_2 levels of 125 yrs ago, C4 plants utilized CO_2 more efficiently than did C3 plants. However, C3 plants respond to increasing CO_2 levels more rapidly than do C4 plants. At today's CO_2 levels, woody plants have a competitive advantage over grasses, an advantage that will continue increasing into the future as CO_2 levels in the atmosphere continue to rise.

Rangelands and Pastures. In southwestern rangelands, the development of the livestock grazing industry beginning in the early 1800's introduced an important new environmental influence (Buffington and Herbel 1963). The early cattle producers often stocked their ranges in accordance with the grass present in normal years. When droughts came, the livestock rapidly consumed the available grass, leaving the ranges severely denuded. The more unpalatable woody and poisonous plants survived and increased. Some brush species have seeds pre-adapted to spread by cattle. Fencing of the ranges confined the livestock continuously in the same areas, resulting in the destruction of native grasses that were adapted to only periodic grazing by the migratory herds of buffalo. Water wells with windmills allowed cattle to range much further from natural water sources, denuding ranges and spreading weed seeds to new areas. Concurrent with the increase in livestock grazing was a great effort to suppress rangeland fires that destroyed fences, homes and barns and killed cattle. In the past, large fires frequently swept vast areas of grasslands, killing young woody plants but not the grass, which quickly regrew from the crowns.

Crops. In cultivated crops, native plants with weedy tendencies also have increased because of habitat change, but the mechanisms are different. Mechanical cultivation creates a habitat ideal for plants adapted to disturbed areas. Cultivation reduces competitors of the weed and kills pupae of weed-feeding insects in the soil. Pesticides used to control insect pests of the crop also kill the natural enemies of the weed. Over time, several weeds have evolved mechanisms to escape mechanical controls (Gould 1991). The high cost of mechanical control has made herbicidal control more cost efficient but under this regime perennial weeds are gaining in importance. Genetic resistance of weeds to herbicides began to appear in the 1960's and by 1991 was reported in 84 weed species (Gould 1991). Most herbicides are broad spectrum and often cannot be used post emergence to control a weed closely related to the crop, such as grasses in corn and sugarcane, sidas in cotton, and sicklepod and hemp sesbania in soybeans. A major source of groundwater pollution is from herbicides used to control a few species of crop weeds, some of which are possible biological control targets (Soper and King 1989).

Natural areas. A great increase in density of any weed species in natural areas may be harmful by decreasing plant diversity, by competing with rare or endangered species (Harris 1988) (though this degree of increase is rare among native weeds) or by increasing human health problems. When native plants do become weedy in natural areas, the problem is also caused by habitat or biological change. In some areas, disturbed areas and edges have increased greatly, allowing plants such as poison ivy and ragweeds to increase. In some areas, dense stands of rangeland weeds that existed before the natural area was established still persist. In other areas, overgrazing by feral donkeys, horses and pigs (or deer) creates weedy situations as does overgrazing in rangelands.

Difficulties and Concerns with Controlling Native Weeds

One solution to native weed problems argued by proponents of the equilibrium or climax theory would be to restore the habitat to its original condition (by eliminating livestock grazing, re-initiating wildfires, etc.), since habitat change was the cause of native plants becoming weedy. However, long-term (50 yrs or more) experiments in excluding all livestock show no indication of a decrease in brush once it is established. Also, the termination of livestock production on rangelands or the reversion of cropland to the natural forests are not in the best national interest. A meaningful reduction in atmospheric CO_2 would necessitate a conversion to energy sources other than fossil fuels or a massive reduction in energy consumption or possibly fertilizing the oceans with iron to cause phytoplankton to utilize more CO_2, a procedure with unknown consequences.

Whatever the causes of brush increase, they seem to be general and widespread in effect. Biological controls also are area- or region-wide control systems and are ideally suited to counteract the area- or region-wide displacement of grasslands by brush. Biological controls using introduced agents are the only control methods that can provide positive benefit-cost ratios in low-value-per-unit-area situations such as natural areas and rangelands, are sufficiently specific not to harm non-weedy plants, and do not pollute the environment. The criteria for selecting a weed as a target for biological control are that the weed should: 1) cause sufficient actual or potential damage to justify the cost of the program; 2) have little beneficial value; and 3) have natural enemies somewhere in the world capable of producing control. Selection, or a ranking of several weed species, depends on an optimization of these 3 factors (DeLoach 1981).

A major concern with biological control of a native weed has been that a drastic reduction in abundance could have dire and unforeseen consequences within the food chains of organisms that feed on the weed, with consequences that could approach ecosystem collapse. Johnson (1985) demonstrated that these concerns are in large measure groundless. Predictions of ecosystem collapse are based on the Clementsian theory of a delicately balanced climax vegetation, stable in species composition across time. Mainstream plant ecological thought no longer supports this theory. Overwhelming evidence indicates that the Gleasonian concept of a dynamic ecosystem, in which species composition is constantly changing, much more closely portrays the real world. In such a system, ecosystem goods and services lost as 1 species declines are replaced as other species increase. We propose that each target native weed species should be examined carefully to determine the degree to which other important species depend on it. If such dependency is small, then the weed can be controlled without fear of damage to the ecosystem. An important point is that only those native plants are considered for biological control that have increased greatly above their pre-European settlement density. The objective of control is not eradication but to reduce the abundance of the weed below the threshold where it causes more damage than benefit.

Another concern, related to that above, is that native weeds are of more value in the plant community and that more animal species depend on them than on introduced weeds. However, in some cases, introduced plants are better adapted, more productive and provide more goods and services than do some native plants (Johnson 1985). It is true, however, that in many cases more animal species are adapted to the native plants than to the introduced weeds that displaced them. This is especially true with insect species and also with some birds but mammals normally use a broad range of food plants. The less than 100% effectiveness of biological control probably would leave enough plants for the dependent animals.

Native weeds often may be closely related to more species of beneficial plants or non-weedy native plants than are introduced weeds. The number of related plants depends more on the site of origin of the weed genus and family than on the origin of the species itself. For example, native weeds such as snakeweeds (*Gutierrezia*; Asteraceae) are related to plants in several other native composite genera, while the invading saltcedar (*Tamarix*; Tamaricaceae) has no relatives in that family that are native. Weeds with closely related beneficial species demand highly specific control agents. This makes native weeds more difficult to control biologically. However, these relationships must be examined on a case-by-case basis. Some native weeds do not have beneficial close relatives or sufficiently host-specific control agents can be found. The problem is made more difficult with native weeds because of the necessity of using control agents from plants closely related to the weed (new associates) for biological control, which by definition, are not species-specific in host range. Nevertheless, new associates may be sufficiently host- specific and may even attack only the target weed in the new country. Another problem is that the new associate may not readily attack the target weed.

Native weeds seldom have been targets for introductory biological control. Only 4 successful cases have been recorded (Wilson 1964, Julien 1987). Two cases were accidental: control of manuka weed (*Leptospermum scoparium* Forst.; Myrtaceae) in New Zealand in the 1940s by the introduced mealybug *Eriococcus orariensis* Hoy (Homoptera: Eriococcidae); and control of Bermuda cedar (*Juniperus bermudiana* L.; Cupressaceae) by the introduction of two scale insects. Two cases were planned: 1) the control of pricklypear cactus, *Opuntia stricta* (Haworth) (Cactaceae) on the Caribbean island of Nevis by *Cactoblastis cactorum* (Bergroth) (Lepidoptera: Pyralidae); and 2) the control of pricklypear (*Opuntia spp.*) on Santa Cruz Island, California in the 1960s. Although these cases were all highly successful, they were all on islands, where biological control apparently is easier.

The many cases of desirable native plants being destroyed by invading exotic insects or pathogens amply demonstrate that introductory biological control of native weeds is feasible in a continental area. Such cases in natural areas are the "control" of the American chestnut, *Castanea dentata* (Marsh) Borkh. (Fagaceae), the American elm, *Ulmus americana* L. (Ulmaceae), various oak (*Quercus*) species (Fagaceae) and dogwood, *Cornus floridana* L. (Cornaceae). Cases in crops are grapes in Europe by the grape phylloxera, *Phylloxera vitifoliae* (Fitch) (Homoptera: Phylloxeridae), blueberries by the Japanese beetle, *Popillia japonica* Newman (Coleoptera: Scarabaeidae), corn by the European corn borer, *Ostrinia nubilalis* (Hubner) (Lepidoptera: Pyralidae), and cotton by the pink bollworm, *Pectinophora gossypiella* (Saunders) (Lepidoptera: Gelechiidae). All of these beneficial trees or crops were "controlled" by "new associates" that evolved in geographically isolated areas on plants different from but closely related to the plant controlled. We see no basic difference between these cases and purposefully introduced insects or fungi that might control snakeweeds, hemp sesbania or dogfennel.

Progress and Prospects for Biological Control of U.S. Native Weeds

An examination of the major weed species that damage North American rangelands, pastures, crops and natural areas reveals that many species are native plants that have increased greatly in density since European settlers arrived. Some of these are serious competitors with forage plants in rangelands or pastures, some have taken advantage of the recent abundance of disturbed areas such as cropland or roadsides, some are poisonous to livestock and some cause serious allergies or dermatitis to humans. A cursory analysis of the amount and type of damage caused, the various beneficial values, the taxonomic relationships with crops or other beneficial plants, the center of diversity of the weed genus and the probability of finding insects, mites or plant pathogens that might control the weed indicates that several of these native weeds could be viable candidates for biological control by the introduction of foreign control agents. These factors taken together make possible a rough prioritization of the weeds for biological control attempts.

Western Rangelands

Native plants in more than 25 genera seriously damage western U.S. rangelands (DeLoach *et al.* 1986). We have conducted explorations in southern South America for natural enemies of 10 rangeland weeds. We found promising candidate natural enemies for 6 of these and more extensive explorations probably would reveal candidates for others. Conflicts of interest have been resolved so that testing could begin on 4 species and we have tested candidate insects in Argentina for 2 weed species.

Snakeweeds (Gutierrezia; *Asteraceae*: *Astereae*). Snakeweeds appear to be most promising native weeds for biological control in western rangelands because of the great damage they cause (high toxicity to livestock, strong competition with beneficial forage plants, dense stands and large area infested), their very low beneficial economic and ecological values, and the several promising candidate control insects found in Argentina (DeLoach 1981). The genus is native in North America but 11 species also are native in Argentina and Chile. Personnel of the ARS biological control laboratory at Hurlingham, Argentina, have found 75 species of insects, a mite and a pathogen that attack the plant, 17 of which are candidate biological control agents. At Hurlingham, we have tested 2 root borers (a weevil, *Heilipodus ventralis* [Hustache] [Coleoptera: Curculionidae]), and a moth, *Carmenta haematica* [Ureta] [Lepidoptera: Sesiidae]), a leaf beetle (*Stolas ingrata* [Boh.] [Coleoptera: Chrysomelidae]), and 2 flower feeders (a moth, *Homoeosoma* n. sp. [Lepidoptera: Pyralidae], and a fly, *Trupanea patagonica* [Brethes] [Diptera: Tephritidae]). Two of these, *H. ventralis* and *C. haematica*, have been tested on North American plants in quarantine at Temple, Texas; *H. ventralis* has been approved for release, and *C. haematica* appears equally host-specific.

Over a four-year period, we have released several thousand *H. ventralis* at 11 locations in Texas and New Mexico, together with our cooperators J.V. Richerson (Sul Ross Univ., Alpine, Texas) and D.B. Richman (New Mexico State Univ., Las Cruces). From the first releases of adults, made both in field cages and in snakeweed surrounding the cages in June and July 1988, we could make no recoveries. During the next 3 yrs, we released eggs and adults at several locations from May through early December. We placed each egg in a small hole drilled in the snakeweed stem near the base and wrapped the stem with teflon tape to prevent the escape of the larvae and to prevent predation. In subsequent examinations, most of the eggs had hatched but the neonate larvae had died without feeding. In 1991, we placed neonate larvae rather than eggs in some plants, and we placed eggs and larvae in stems of the alternative host, *Grindelia* sp. (Asteraceae), at one location. To date, we have found living, tunneling larvae twice, in small late-fall subsamples. A few had tunneled 5-10 mm in *Gutierrezia microcephala* (DC.) Gray in west Texas in 1989 and 2 (a 1st and a 2nd instar) were found in *Grindelia* sp. near Temple in 1991.

Several possible problems have been apparent, for which we have made adjustments in the release procedures. First, snakeweed stands underwent severe natural diebacks during 1988 and 1989 which killed many of the plants in which we had placed eggs. We made releases throughout the growing season (except in early spring) on selected healthy plants but with limited success. The winter of 1989-90 was one of the coldest on record and the young larvae may have been killed by the cold before they had time to tunnel below the soil surface. During 1991, we released many eggs using a flour paste but these were eaten by ants (previous tests in Argentina had shown no predation). In small samples taken after release, neonate larvae fared better than released eggs. We suspect that the plant tissue deteriorates or reacts to prevent feeding during the several days before the eggs hatch. These studies illustrate the exceptional difficulties that may be encountered during the establishment phase of some biological control agents. We plan to continue releases of *H. ventralis* under varying conditions. Also, a petition will be submitted in the near future to release *C. haematica*. Research in Argentina is continuing on the 2 flower-feeding species. The leaf beetle *S. ingrata* may have too broad a host range for release.

Annual broomweeds (Gutierrezia *spp.* and Amphiachyris *spp.*; *Asteraceae: Astereae*). These are serious range and pasture weeds from Texas and Kansas westward. They compete with forage plants and cause eye damage, loss of weight, low conception rates, and low calf weights in heavily infested pastures but they are not toxic. They have very low beneficial values. The foliage- and flower-feeding insects from Argentina being tested for snakeweed control also feed on these broomweeds and could give some degree of control if released.

Mesquite (Prosopis *spp.*; *Leguminoseae*). Mesquite has the greatest number of promising candidate natural enemies of any target weed we have studied. This is probably because it is a diverse, moderately large genus whose center of diversity is southern South America. Nearly 400 species of insects attack the genus in Argentina and Paraguay, of which at least 38 species could be biological control candidates (Cordo and DeLoach 1987). Among the most promising are an *Apion* weevil and 8 species of Bruchidae that feed on seeds, and several species of leaf-tiers, twig-girdlers, and stem-borers. We have not yet begun testing because the substantial conflicts of interest between the harmful and beneficial values of mesquite have not been resolved (DeLoach 1981). A promising compromise could be to introduce only seed feeders that would reduce mesquite's invasiveness without harming its beneficial values. The technique of controlling a woody, aggressive weed with seed feeders has been successful in South Africa with *Sesbania punicea* (Cav.) Benth. (Leguminosae) and is being tested in Australia with *Parkinsonia aculeata* L. (Leguminosae) and in South Africa on mesquite.

Baccharis *spp.* (*Asteraceae*). This is a genus of South American origin with 400+ species (*ca.* 22 species in the U.S.). Willow baccharis (*B. neglecta* Britton) is a weed of only moderate importance in pastures and abandoned fields in central Texas and with very little beneficial value. Seepwillow (*B. salicifolia* [R&P] Pers.) is a phreatophyte along southwestern streams. It was once considered a weed in the era when all phreatophytes were considered undesirable. Today, it is found only occasionally (being displaced by saltcedar) and is not considered a weed; it has beneficial value for streambed stabilization, as a late-summer pollen and nectar source for honeybees and for limited wildlife cover. Two species of *Baccharis* are used as ornamentals and 1 is endangered (Turner 1985, DeLoach *et al.* 1986). At our laboratory, P. E. Boldt has tested the stem-boring beetle, *Megacyllene mellyi* (Chev.) (Coleoptera: Cerambycidae), and the leaf beetle, *Stolas fuscata* (Klug) (Coleoptera: Chrysomelidae); both are from Brazil and Argentina. Both were previously tested and released in Australia to control *B. halimifolia*. We did not release *M. mellyi* because it attacked many species of *Baccharis*. *S. fuscata* readily attacked *B. salicifolia*, the species from which it was collected in Argentina (it is one of the few species native in both areas), but could not develop on the target weed *B. neglecta*; therefore, we did not release it either. Several other promising insects have been found in Argentina (P.E. Boldt and H. A. Cordo, unpublished data). Although *Baccharis* appeared to be an easy target because of the previous work in Australia, the insects released there (where only one introduced species of *Baccharis* occurs) are not sufficiently host-specific for release in the U.S. (where 20 species are native). Further research has been postponed in favor of more damaging weeds.

Creosotebush (Larrea; *Zygophyllaceae*). Cordo and DeLoach (unpubl. data) reported 110 species of insects that attack 3 of the 4 species of Larrea native in Argentina. They concluded that the most promising control agents were 3 species of grasshoppers, 3 scale insects, 2 stem borers, and a flower-feeding katydid. Creosotebush causes great damage in southwestern ranges and it has few beneficial values. However, it is the dominant plant of much of the Chihuahuan, Sonoran and Mojave Deserts, it is host to several near-specific bees, and its control could cause increased soil erosion if ranchers and subsistence farmers continued overgrazing after control. These conflicts-of-interest have not yet been resolved.

Pricklypear cactus (Opuntia). Argentine insects, especially *C. cactorum*, for many years have provided excellent control of pricklypear cactus in several countries (Julien 1987); *C. cactorum* probably could also provide control in North America. Biological control of pricklypear has never been approved in the U.S. because pricklypear has considerable beneficial values (emergency drought grazing for livestock, wildlife food, and human food) and because many native species of *Opuntia* exist, most of which are not weedy and some of which are beneficial, rare, or endangered. Recently, *C. cactorum* has been discovered in Florida, probably having been blown in by storms from the Caribbean. If it is not soon eradicated, it can spread across the Gulf states to the southwest. Control of pricklypear may occur whether desired or not.

Sagebrush (Artemesia; *Asteraceae*), *juniper* (Juniperus) and *oaks* (Quercus). Sagebrushes, junipers and oaks have increased greatly in density, are severe competitors with more valuable plants (James *et al.* 1991), and sagebrush and oaks are toxic (Kingsbury 1964). However, sagebrush is important wildlife food (more than 50% of the diet of the sage grouse and antelope). Juniper is also important for wildlife (25-50% of the diet of the cedar waxwing and critical nesting habitat of the endangered golden-cheeked warbler). Chinese juniper (*Juniperus chinensis* L.) is one of the most used of all ornamental shrubs throughout the U.S. and other species are also valuable. Oaks are the most valuable of all terrestrial plants for wildlife (Martin *et al.* 1951) and probably are also the most valuable ornamental tree in North America (Bailey and Bailey 1976). All these weeds are of wide native distribution in the northern hemisphere and damaging natural enemies likely exist in Europe and Asia. Conflicts would have to be resolved before a control program could begin. The possibility of finding just the right control agent that would attack the weed species and not beneficial species, or that would spare beneficial species in certain habitats, would appear slim, though not impossible.

Other rangeland weeds. Preliminary investigations have been made for biological control of several other weeds (DeLoach *et al.* 1986). For retama (*Parkinsonia aculeata* L.; Leguminosae), a seed beetle, *Penthobruchus germanii* (Pic) (Coleoptera: Bruchidae), was tested in Argentina and has been released in Australia. In the Southwest, retama is weedy in rangelands but is also a valued ornamental; a seed feeder would not harm its ornamental usage. Success in Australia would suggest that it could be tried in the U.S. if it does not attack the very closely related genus *Cercidium* (Leguminosae), which is not weedy and is a valued ornamental and component of the native plant community. Orange sneezeweed (*Helenium hoopesii* Gray; Asteraceae) is very toxic to sheep in the central Rocky Mountain region. Natural enemies probably could be found on related species of *Helenium* in Argentina.

We have found a few damaging insects in Argentina on loco (*Astragalus* spp.; Leguminosae) (DeLoach and Cordo, unpubl. data). However, even though a few species of loco are very toxic and kill many cattle in the U.S., nearly 400 native species of *Astragalus* occur here, several of which are beneficial or endangered. The South American species are from a section of the genus different from the weedy North American species and their natural enemies likely are not sufficiently host-specific to introduce. Many species are also native in Eurasia and more suitable natural enemies might be found there. Whitebrush (*Aloysia* sp.; Verbenaceae), huisache (*Acacia farnesiana* (L.) Willd.; Leguminosae), bitterweed (*Hymenoxys odorata* DC.; Asteraceae) and tarbush (*Flourensia cernua* DC.; Asteraceae) also have relatives in Argentina. However, whitebrush and huisache have substantial beneficial values. Bitterweed and tarbush have little conflicts of interest and are good candidates for biological control, but more explorations are needed in Argentina to find natural enemies.

Southeastern and Eastern Pastures

The possibilities for biological control of native weeds of humid-climate pastures of the southeastern U.S. have been little considered.

However, an analysis of the characteristics of these weeds reveals several promising targets, particularly using natural enemies from closely related plants in Argentina, Paraguay and southern Brazil (Charudattan and DeLoach 1988, DeLoach 1990). Two species of *Eupatorium* (Asteraceae) could be prime targets. Dogfennel (*E. capillifolium* [Lam.] Small) is probably the worst pasture weed and white snakeroot (*E. rugosum* Houtt.) is one of the more poisonous weeds in this area. The latter causes death of cattle and the toxin can be transferred to humans in cow's milk. Outbreaks of this "milksickness" caused great loss of human life in the early 1800s (Kingsbury 1964). The genus has only minor value as ornamentals. Bitter sneezeweed (*Helenium amarum* [Raf.] H. Rock; Asteraceae) is the third most important pasture weed of the southeast; it competes with forage plants and gives a serious off-flavor to cow's milk. Several other species of *Helenium* are poisonous to livestock. They have very little beneficial value. Natural enemies of all 3 of these weeds probably could be found on related species in Argentina.

Horsenettle (*Solanum carolinense* L.; Solanaceae) is the second most important weed of southeastern pastures. It and 5 other native species plus some introduced species are toxic or highly toxic to livestock and maybe to wildlife. The weed species have little beneficial value but extreme care must be used during host range testing to insure that control agents do not harm the closely related potato (*S. tuberosum* L.) or eggplant (*S. melongena* L.). Several insects have been found on *Solanum* species in Argentina and Brazil that could be candidates for biological control. Unfortunately, most species tested to date for control of *S. elaeagnifolium* Cav. in South Africa also feed on eggplant; these 2 plants, plus *S. carolinense*, appear to be in a closely related species group. The related poisonous jimsonweed (*Datura stramonium* L.; Solanaceae) also possibly could be controlled with South American insects (DeLoach 1990).

Bracken fern (*Pteridium aquilinum* [L.] Kuhn; Polypodiaceae) could be an especially promising candidate. It causes substantial losses, has little beneficial value, and the genus contains only 1 species of cosmopolitan distribution; this means that related species are at little risk and that foreign natural enemies should attack the plant. In addition, host-specific natural enemies have been found in South Africa and New Guinea that have been proposed for introduction into Britain (Lawton 1985).

Several other pasture weeds have some possibilities for biological control but some have important beneficial values. The seeds of ragweeds (*Ambrosia* spp.; Asteraceae: Heliantheae), cedar (*Juniperus* spp.), and croton (*Croton* spp.; Euphorbiaceae) are important as bird food (Martin *et al.* 1951) and broomsedge (*Andropogon* spp.; Gramineae) is related to the important native rangeland bluestems. Nevertheless, a 50-75% reduction in density of these species would greatly improve range and pasture conditions and would still leave populations for wildlife.

Crop Weeds

Crop weeds cause an estimated $6 billion in lost production annually in the U.S. (Chandler *et al.* 1984), or *ca.* 6 times the losses from weeds in rangelands. An estimated 85% of the groundwater pollution in the U.S. is from herbicides applied to control crop weeds, mostly alachlor, metolachlor and atrazine used in corn and soybeans in Illinois, Indiana, Iowa, Missouri, and Ohio or in the sandy areas of the southeastern states (Soper and King 1989). Crop weeds generally have been viewed as more difficult biological control targets than range weeds for the following reasons: 1) the frequent disturbance of the soil interferes with the life cycle and reproduction of biological control agents; 2) pesticides used to control insect pests also kill insect biological control agents; 3) the control of one weed species will not eliminate treatments still needed to control the other weed species present; 4) quick control is needed since many weeds increase to damaging levels within 1-2 months after the crop is planted; and 5) many crop weeds are annuals and/or grasses, which have been considered more difficult to control biologically than the perennial weeds of rangelands.

Although all these points are at least partially valid, biological control of some crop weeds still should be possible. Many weeds invade from field borders or spread from weeds remaining in the fields after cultivation or harvest and a reduction of populations of these weeds would reduce the next year's infestation. Pesticide applications can be scheduled to minimize damage to control agents. Most crops have only a few major weed species and biological control of more than one, or of all, may be possible. Some insects and plant pathogens can act quickly, as evidenced by the damage they can cause to crop plants under these same adverse conditions. Several of the most troublesome weeds are perennials and the plants surviving conventional controls are present and available to sustain biological control agents throughout the year. Some grasses are known to have host-specific enemies, especially plant pathogens. Several of the most important weeds of crops are difficult and expensive to control by current herbicidal or mechanical methods. Economic benefit can be obtained with biological methods with less than complete control.

The examples of beneficial plants "controlled" in these same conditions indicate that introduced control agents can be effective. The arguments against attempting introductory biological control of crop weeds are theoretical. The method has been tried only once, to control ragweed (*Ambrosia* sp.) in the USSR with reported success (Kovalev 1986) and recently in Croatia. The enormous losses caused by weeds in crops justify the risk of research funds to attempt control those crop weeds that have a reasonable prospect for success. To this end, we have made some effort to evaluate damage, beneficial values and success potential and to rank the potential weed targets (Charudattan and DeLoach 1988, DeLoach 1990).

*Hemp sesbania (*Sesbania exaltata *[Raf.] Rydb.; Leguminosae).* This is perhaps the most promising of the native crops weeds for biological control. It ranks only 11th in importance as a weed in the southeastern U.S. but it is 4th in soybeans, the crop where the greatest total losses from weeds occur. It has low beneficial values and the seeds are poisonous. In Peru, Vogt and Cordo (1976) reported that the principal U.S. weed species, *S. exaltata*, had been introduced and was heavily attacked and killed by native insects. Successful biological control has been achieved in South Africa of a related species, *S. punicea* (Cav.) Benth. (rattlebush) that is a lesser pest in the southern U.S., using these same insects, but introduced from Argentina. We have nearly completed host range testing at the ARS Biological Control Laboratory in Argentina (Gandolfo, Logarzo and Cordo, unpubl. data); the insects still appear host-specific and heavily attack *S. exaltata*.

*Cocklebur (*Xanthium *spp.; Asteraceae: Heliantheae).* This is the 3rd most important weed in the south and ranks 4th nationally. It is a major crop weed, a major pest in wool producing areas, and young plants are poisonous to livestock. It has essentially no beneficial values and sunflower is the only related crop in the tribe Heliantheae. The native distribution of the major weed species, the cosmopolitan *X. strumarium* L., is thought to include North America, but *X. spinosum* L., the only other species, is introduced. One insect, the stem borer *Nupserha vexator* (Pascoe) (Coleoptera: Cerambycidae) was introduced into Australia from India; it did not attack sunflower but also caused little damage to cocklebur (Julien 1987). We tested another cerambycid, *Apagomerella versicolor* (Boh.), in Argentina that also appears host-specific and causes a 60% reduction in seed production (Logarzo, Gandolfo and Cordo, unpublished data).

*Prickly sida (*Sida spinosa *L.; Malvaceae).* Sida is a major pest of cotton and is a lesser pest of soybeans, peanuts, and vegetables. It has no important conflicts of interest. In Argentina and Uruguay, 26 species of insects attack *Sida* (Vogt and Cordo 1976). The most promising are 2 species of baridine stem-boring weevils, 5 species of leaf beetles, and a defoliating sawfly. Only 1 species, the leaf beetle *Calligrapha polyspila* (Germ.) (Coleoptera: Chrysomelidae), has been tested; it could complete its life cycle on other malvaceous species (*Malva, Althea, Sphaeralcea*, and *Anoda*) and so has not been introduced. The other species should be tested.

Nutsedge (*Cyperaceae*). Two species of nutsedges, purple (*Cyperus rotundus* L.) and yellow (*C. esculentus* L.), together are the 6th most important weed in the south and 11th nationally. Purple nutsedge is introduced (it is ranked the worst weed in the world) but yellow nutsedge is native. The tubers of yellow have minor beneficial value as wildlife food. A native pathogen, *Puccinia canaliculata* (Schw.) Lagerh. (Uredinales), has achieved control of yellow nutsedge in field plots when applied as a bioherbicide but it does not attack purple nutsedge. Extensive searches in Pakistan, India and the Philippines have revealed 30 species of stenophagous insects that feed on purple nutsedge and a weevil in Argentina damages the rhizomes and tubers; many of them would probably also attack yellow (Frick 1985). Explorations in different parts of the world and more testing are needed.

Morningglories (Ipomoea *spp.*; *Convolvulaceae*). These are the second most important weeds in the South, especially in soybeans. Some of the weedy species are native and some are introduced. The genus has only minor beneficial values as ornamentals and for wildlife. However, sweet potato (*Ipomoea batatas* [L.] Lam.; Convolvulaceae) is closely related, and great care must be taken that candidate natural enemies do not attack it. The site of origin of the genus is tropical America. Brazilian scientists in the Department of Zoology, UNICAMP, Campinas, SP, are investigating the use of native insects to control morningglories; a beetle, *Botanochara impressa* Panzer (Coleoptera: Chrysomelidae), appears promising, but additional testing and explorations are needed (DeLoach 1990).

Pigweeds (Amaranthus *spp.*; *Amaranthaceae*). These are the most important crop weeds in the U.S. and they occasionally poison livestock. However, pigweeds are the ninth most important wild plant for wildlife food; they are a major food for songbirds and, to a lesser extent, for doves. Also, grain amaranth (*A. cruentus* (L.), has potential for development as a cereal grain and a few species are widely used as ornamentals. Explorers in Pakistan found a weevil that attacked only *Amaranthus* spp. In South America, 4 species of flea beetles (three species of *Disonycha* and one of *Phenrica*; Coleoptera: Chrysomelidae) and corimelaenid bugs commonly killed the plants (Vogt and Cordo 1976). If conflicts-of-interest could be resolved, these insects should be tested.

Sicklepod (Cassia obtusifolia *L.*; *Leguminosae*). Sicklepod is the 4th worst weed in southeastern crops and is especially important in soybeans and corn. It has very low beneficial values and its seeds are poisonous. A native pathogen, *Alternaria cassiae* Jurair and Kahn (Hyphomycetes), is a promising augmentative biological control agent. The origin of the genus is warm-temperate and tropical South America and explorations are underway in Brazil to find biological control agents for introduction (D.H. Habeck, personal communication, 1992).

Grasses (Gramineae). Signalgrass (*Brachiaria* spp.) is an important weed in rice and sugarcane in the southeast. In the U.S., this is a small genus of low beneficial value whose native distribution includes several warm regions of the world. Since it is not closely related to beneficial grasses in North America, the introduction of natural enemies could be feasible. Native panic grasses (*Panicum* spp.) rank 5th in importance in the southeastern U.S., where they rank 1st in sugarcane and 2nd in corn and soybeans. However, biological control is made difficult because the genus is important for wildlife food and because some forage grasses and millet are in the same genus (DeLoach 1990).

Weeds of Natural Areas

Poison ivy and poison oak (Toxicodendron *spp.*; *Anacardiaceae*). These are some of the most directly harmful weeds to humans around houses and natural areas in the U.S. The dermatitis caused by contact with the plants causes millions of dollars in lost work/yr, great suffering in affected people including children and much lost recreational opportunity from avoidance of outdoor areas. However, they rank 20th nationally among wild plants in wildlife value (mostly songbirds that eat the seeds) though they make up as much as 10-25% of the diet for only 3 species (Martin *et al.* 1951). Poison ivy is primarily an edge-loving plant and probably was not abundant in the nearly unbroken pre-settlement forests of the eastern U.S. However, every field, every house and