30 Selection of Appropriate Future Target Weeds for Biological Control

Robert W. Pemberton

U.S. Department of Agriculture, Agricultural Research Service, Invasive Plant Research Laboratory, , Ft. Lauderdale, Florida, USA

The selection of appropriate target weeds is a serious consideration in classical biological control. It can take up to twenty scientist years (and actual years) for biological control of weeds projects to reach a successful conclusion (Harris, 1979; Peschken and McClay, 1995). Because not all programs are successful, the conclusion may be the completion of analyses associated with a project. During this time considerable investments, public or, private, will be devoted to a program. In addition, societal values may shift during this period, as has happened with the greater valuation of native species during the past 20 years. Currently, there is much debate about the safety of biological control (Louda *et al.*, 1997; Strong and Pemberton, 2000; Follet and Duan, 2000; Wajnberg *et al.,* 2001). Environmental considerations may restrict future biological control practice because of increased concerns about possible damage to non-target native plants, but these same environmental concerns also may expand the use of biological control through greater use against invasive weeds that threaten natural communities and their functioning. Developing appropriate selection procedures for future target plants, ones that can be controlled in an efficient and predictable manner, will be a key step in future biological control practice.

NATIVE WEEDS VS. INTRODUCED WEEDS

All of the chapters in this book deal with biological control of introduced weeds, except for common reed (*Phragmites australis* [Cav.] Trin. ex. Steud. = *P. communis* [L.] H. Karst.), which is a mixture of native and introduced genotypes within a single species (see chapter on this species, this volume). Native weeds have occasionally been targets of classical biological control, but it has proven difficult to release imported natural enemies against native plants because of the objections of conservationists and other biologists who feel that native species have unique ecological value. In addition, projects against exotic weeds have been favored because it has generally been believed that the chance of finding useful natural enemies is greater for exotic weeds. This is because introduced exotic weeds are usually attacked by generalist herbivores, whereas native weeds may have a saturated community of specialist insects occupying most of plants' niches. The absence of such suppressive specialized natural enemies is one of the primary reasons why populations of exotic weeds are thought to reach high pest densities.

Whether or not native weeds should be targeted for biological control has been the subject of disagreement and debate. Deloach (1980, 1985) argued for and conducted research programs on the use of biological control against native weeds of rangeland. Many of the most important weeds of rangelands in the southwestern United States are native species. Congeneric relatives of pest species of *Prosopis* and *Gutierrezia* in South America were found to be attacked by various herbivorous insects not found in the United States. These insects were considered as potential biological control agents of the U.S. plant species. The only insect released was an Argentine weevil (*Heilipodus ventralis* Kuschel), which was released against two native *Gutierrezia* spp. in New Mexico and Texas in 1988; establishment of the weevil was not confirmed (Julien, 1992). Pemberton (1985) argued against targeting native weeds for biological control because many of these plants are ecological dominants that have importance in natural communities. In addition, it is impossible to limit biological control agents only to situations where the target native weeds are problems. The introduced insects or pathogens would spread to parks and other natural areas, where plants are valued native species. Another concern is the wider host breadth needed for an agent introduced against a native weed. The agent's host specificity level would need to be broad enough for it to accept a novel host plant – the targeted native weed, which is usually a plant in the same genus as its original host(s). This increased host breadth could mean increased risks to closely related non-target plants. Native weeds are more likely to have closely related plants, particularly other members of the same genus, that could be harmed by biological control agents introduced against the targeted native weed. This is the situation with the introduction of *Cactoblastis cactorum* (Bergoth) to Nevis in the Caribbean in 1957 (Pemberton, 1995). The target *Opuntia* spp. were native weeds but other native *Opuntia* species that were adopted as hosts by the moth were not weeds (F. Bennett, pers. comm.). One of the targeted weeds (*Opuntia stricta* [Haw.] Haw. = *O. dillenii* [Ker Gawl.] L. D. Benson) is currently the principal non-target host of *C. cactorum* in Florida, where the moth either was accidentally introduced via commercial *Opuntia* importations (Pemberton, 1995) or spread on its own (Johnson and Stiling, 1996). Neither *O. stricta* nor the four other native *Opuntia* attacked by the moth in Florida are considered weedy, and one species is a federally-listed endangered species. If the moth spreads via *O. stricta* (which occurs along the Gulf of Mexico) to Texas and Mexico, many other *Opuntia* species, including rare species, will probably be harmed.

Although very few native weeds were ever targets of biological control, and the approach is now less acceptable than in the past, there remains some interest in the approach. A current list of candidate weeds for biological control in Texas contains some native weeds (J. DeLoach, pers. comm.). Projects against native weeds almost certainly would be a wasted effort. Alfred Cofrancesco, Chairman of the Technical Advisory Group (the multiagency federal committee that reviews release petitions for candidate biological control agents of weeds) has stated "It is highly unlikely that permission would be granted for the release of an exotic (imported) natural enemy for the control of a native weed in the United States" (A. Cofrancesco, pers. comm.).

SELECTING TARGETS TO MINIMIZE RISK TO NON-TARGET ORGANISMS

Avoidance of risks to economic plants that might be posed by introduced biological weed control agents has always been the most critical safety consideration of biological weed control. Biological control of weeds programs were, and still are, with few exceptions, the exclusive providence of federal and state departments of agriculture, and agricultural colleges in land grant universities. The regulation of biological control of weeds also has been the responsibility of federal and state agricultural institutions. Further, most of the target weeds have been agricultural problems. This agricultural orientation has worked exceptionally well to prevent non-target injury to economic plants but has worked less well to protect native plants. Native plants were not highly valued by society until about 30 years ago when the Endangered Species Act (1973) was passed. Adoption of native plants by introduced biological control agents then began to be reported in the scientific literature and the potential harm from such feeding debated, especially in the 1980s (Andres, 1985; Pemberton, 1985; Turner,1985; Turner *et al.*, 1987). Recent reports of damage by an introduced thistle weevil, *Rhinocyllus conicus* (Frölich), to native thistles (Louda *et al.*, 1997), and the threat of *C. cactorum* to native American and Mexican native *Opuntia* cacti (Johnson and Stiling, 1997; Strong and Pemberton, 2000) have increased concern about the safety of biological weed control practices.

An analysis of the non-target use of native plants by introduced biological control agents has been recently published (Pemberton, 2000). Known field host plant use (complete development) of native plants by the 112 insects, three fungi and one mite established on 55 weeds in the Caribbean, the continental United States, and Hawaii from 1902 to 1993 was evaluated. Almost all (40 of 41) of the native plants used by the biological control agents were found to be very closely related (same genera or equivalent) to the target weeds for which the agents were introduced. About half (16 of 31) of the projects on target weeds with closely related native plants in the United States lead to some non-target native plant use. This compares to less than 5% (1/24) of the projects on target weeds without close relatives (no native congeners – members of the same genera). In all but one of these cases (which involved the adoption of an unrelated native plant as a host), nontarget usage was predictable process based on taxonomic affinities. The analysis also strongly indicates that the host ranges of herbivores introduced for biological control are very stable. Because almost all the risks to native plants by biological control agents is borne by close relatives of the target weed, harm to native plants can be avoided by targeting weeds with few or no close relatives in the country or broad region that the weed infests.

Projects on weeds with close native relatives will require agents with greater host specificity, which may or may not exist. It is likely that fewer candidate agents in such projects will be safe enough to employ than in projects against weeds without close native relatives. Projects against weeds with close native plant relatives may be able to find and employ safe agents, but these projects will probably require more extensive host specificity testing, resulting in higher costs and longer research periods before safe agents are identified. The probability of success and the effort required will depend on the number of close relatives, how closely related they are to the target weed, and the host ranges of candidate agents.

The biological control program against leafy spurge (*Euphorbia esula* L.), for example, was able to minimize the risk to native species even though there are 112 native *Euphorbia* species in North America (Pemberton, 1985). Of these species, 25 are in the subgenus *Esula*, and thus closely related to the target weed. Furthermore, only one species in this subgenus, *Euphorbia robusta (Englem.)* (Small), is both perennial in its life history and sympatric in distribution with leafy spurge in the western United States. About two thirds of the tested agents, various *Aphthona* flea beetles, were found to be specialists on the subgenus *Esula* or section *Esula* (part of the subgenus *Esula*) and to require perennial host plants. This meant that only one native species, *E. robusta*, might be attacked. This complex of *Aphthona* beetles has begun to control leafy spurge in much of its U.S. range (Nowierski and Pemberton, this volume), and thus far, *E. robusta* is not known to have been harmed. Modest levels of adult *A. nigriscutis* Foudras feeding have been observed in one *E. robusta* population in Wyoming, where the plant is increasing in abundance because of the beetle's control of leafy spurge. (L. Baker, pers. comm.). It is worthwhile pointing out, however, that three fully evaluated candidate biological control agents were abandoned after years of study because of their ability to use *Euphorbia* species in other subgenera as developmental hosts.

The literature analysis of attack on non-target native plants and details of the leafy spurge biological control project both indicate that risk to native plants can be minimized. Host ranges of biological control agents are stable, and well designed host specificity research, based on taxonomic relationships between host plants and the flora where agents are to be released, can predict potential host range with confidence. Harm to non-target native plants has resulted from decisions about which weeds are targeted and which agents are released. Promising candidate biological control agents of exotic weeds are undergoing greater scrutiny and even ones posing only relatively modest risks to native plants may be rejected by the Technical Advisory Group (TAG) and the U.S. Fish and Wildlife Service.

Unlike conflicts with native plants, the resolution of conflicts between biological control agents and economic plants will depend largely on the dollar value of of the economic plants involved compared to the economic losses caused by the target weed. Potential harm to closely related crops may prevent projects from beginning, as has happened with potential projects against weedy grasses. Threats to horticultural plants may present less serious conflicts, depending on the value of the horticultural plants and the cultural attachments to the potentially affected species.

SELECTING TARGET WEEDS TO PROMOTE SUCCESS

McClay (1989) developed a system for ranking target weeds according to their suitability for classical biological control using the size of the infested area, environmental, and biological aspects as criteria. The method was revised by Peschken and McClay (1995). This interesting and thoughtful approach assigns specific numerical point values for each category within either economic or biological sections and then adds the points to obtain a suitability value. Up to 179 points are possible for weeds with no known biological control agents. In the section on economic losses, the target weed receives 30 points for "very severe," 20 points for "severe" and zero points for "light" damage. Additional points can be added for elements related to size of the infested area, expected spread, toxicity, available means of control, and economic justification in the economic losses section. A beneficial aspects category may subtract 0, 15, or 30 points. In the biological aspects section, most points are assigned for the geographic origin and habitat stability elements. In the geographic origins category, 30 points are given for non-native weeds, 10 points for native to North America and other regions, and zero points for cosmopolitan or unknown area of origin. In the habitat stability category, 30 points are given for high habitat stability (rangeland and permanent pastures), 20 points for moderate habitat stability (perennial crops and extensive roadside infestations), and zero points for annual cropland. Possible conflicts with valued plants, other than the possible benefits of the weed itself, include elements for the number of economic and ornamental species in the same genus and tribe, and the number of native North American native species in the same genus and tribe. These elements subtract no points but add a few points for the absence of economic, ornamental, or native plants that are closely related to the weed. For instance, in the element "number of native North American plants in the same genus," zero native species adds two points, 1-20 native species adds one point, and more than 20 native species adds zero points. The points assigned for particular elements directly reflects their relative importance to these authors. In the McClay-Peschken system, the seriousness of the weed is by far the most important consideration, while potential conflicts with valued plants, aside from beneficial aspects of the weed, literally count for little in the ranking. This is a significant weakness in their system because potential risks to economic and native plants can prevent the release of potentially useful agents, as well as prevent the selection of a weed as a target for biological control. This system, however, reflects much of the traditional thinking with regard to target weed selection. This system is nevertheless valuable to assist in the evaluation and comparison of potential targets, if not to precisely select them. The seriousness of the current problems caused by a weed and the probable impact of a weed if left uncontrolled are obviously extremely important considerations, but the relative benefit of controlling the weed needs to be considered in light of the potential risk.

Pemberton (1996) drew on some known ecological patterns of plants and insects herbivores that predict herbivore species richness to help compare and judge potential target weeds. Larger numbers of herbivores are known to be associated with plants with larger geographic ranges (Southwood, 1960; Strong *et al.,* 1984), increased commonness of a plant within its geographic range (Southwood, 1961; Strong, 1979), and the number of species of plants in a genus (Lawton and Schroeder, 1977). Plants with more complex architecture also are known to have more insect herbivores (Lawton and Schroeder, 1977). A greater abundance of insect species associated with particular plant characteristics can mean more potential biological control candidates, which in turn could relate to increased chance of control. Evaluating potential target weeds with and with out these plant characteristics may help identify weeds that will be more easily controlled.

PREDICTING SUCCESSFUL BIOLOGICAL CONTROL

Estimates of the rate of success for classical biological weed control vary widely, depending partly on whether success is defined in terms of control by specific agents or by whole programs (McFadyen, 1998), as well as differing methods of measuring or estimating success. It has been difficult to accurately predict the success in biological control of weeds, both with regard to the kinds of natural enemies that will be successful control agents and the types of weeds that can be controlled. Although it has not been possible to predict success, it is clear that biological control has been successfully used against a wide variety of weed types. Success has been achieved against weeds from a broad taxonomic spectrum, from primitive groups such as ferns (*Salvinia molesta* D. Mitch.) (Room *et al.,* 1981) to members of advanced angiosperm families such as the Asteraceae (e.g., *Senecio jacobaea* L.) (Pemberton and Turner, 1990). Likewise, weeds of diverse life forms, from annual herbs to trees, have been controlled by the approach (Table 1). Also, weeds growing in a variety of habitats, from agricultural crops to natural areas, have been controlled (Table 2). Most targeted weeds have been problems of rangeland, aquatic habitats, or, increasingly, of natural areas. Programs have rarely been

Table 1. Examples of Successful Biological Control Projects against Weeds of Different Life Forms

Life Form	Weed Species	Region	Reference
Fern	*Salvinia molesta* D. Mitch.	Australia	Room et al.,1981
Annual herb	*Ambrosia artemisifolia* L.	Russia	Kovalev et al., 1983
Biennial herb	*Carduus nutans* L.	United States	Kok and Surles, 1975
Perennial herb	*Hypericum perforatum* L.	W. United States	Huffaker and Kennett, 1959
Shrub	*Lantana camara* L.	Hawaii	Knauss, 1962
Vine	*Passiflora mollisima* L.H. Bailey	Hawaii	E. Tujillo, pers. comm.
Tree	*Acacia longifolia* (Andrews) Willdenow	South Africa	Dennill and Donnelly, 1991

Table 2. Examples of Successful Biological Control of Weeds in Diverse Environments

Environment	Weed Species	Region	Reference
Annual row crop	*Xanthium occidentale* Bertol.	Australia	Morin et al., 1996
Perennial row crop	*Solanum elaeagnifolium* Cav.	South Africa	Hoffman et al., 1998
Range lands	*Senecio jacobaea* L.	W. United States	Pemberton and Turner,1990
Aquatic habitats	*Alternanthera philoxeroides* (Mart.) Griseb.	SE United States	Buckingham, 1994
Natural vegetation	*Acacia* spp.	South Africa	Dennill and Donnelly, 1991

attempted against weeds of row crop agriculture, but there have been a few successes (Table 2). Weeds infesting lands in both temperate and tropical areas and on both islands and continents also have been successfully suppressed. The diversity of weeds that have been controlled biologically is a clear indication of the great utility of the method and of the variety of situations in which it can be employed, even if it is not possible to predict the outcome of particular projects.

HOW TARGETS ARE SELECTED

Weeds are selected for biological control research in a number of ways. Individual scientists or laboratories often begin to develop projects on new weeds because they perceive the need for such a program because of their direct experience and cooperator-client interest. Surveys of weed scientists, botanists, and land managers can be useful to determine and rank weeds for their importance. Because many biological control researchers are government scientists, administrators and program leaders may choose new targets for research in response to such perceived needs or political pressures. In some cases, legislative bodies mandate research on particular weeds. Regardless of the need for a project on a particular weed, little can be achieved or even attempted without specific funding for the project. Initial funding often is used for feasibility studies on prospective target weeds to clarify the problem, evaluate conflicts with valued plants, obtain preliminary information on the existence of potential control agents, and develop support for the program.

FUTURE TARGETS FOR BIOLOGICAL CONTROL OF WEEDS

Lists of weeds that are problems in agriculture and natural areas have been developed by various government agencies, private groups, and scientific organizations. I evaluated these lists to help identify and assess potential candidates for biological control. Increased interest in invasive, non-native weeds affecting natural areas has led to the creation of exotic pest plant councils in Florida, and more recently in

Georgia, Tennessee, Kentucky, and New England . Each of these councils develops lists of weeds in categories related to the degree of invasiveness. To develop a compilation of the 26 most serious invasive species in the eastern United States (Table 3), I examined the unpublished lists of the Georgia, Kentucky, and Tennessee Exotic Plant Pest Councils, the Maryland Department of Natural Resources, the Virginia Department of Conservation and Recreation, the Morris Arboretum of the University of Pennsylvania, the Torrey Herbarium of the University of Connecticut, the South East Regional Association of Medical and Biological Organizations, The Nature Conservancy (Meyers-Rice and Randall, pers. comm.), and Randall and Marinelli (1996). The Florida Exotic Pest Council's list (Austin *et al.,* 2001) and Langeland and Craddock Burks (1996) was used to create Table 4, which lists 26 highly invasive weeds found in Florida. Both tables exclude many of the most serious weeds because they are already targets of active biological control programs or preliminary biological control research, and are covered in other chapters of this book. Neither of these lists includes all of the serious invasive weeds. For instance, Florida's Category 1 list (the most invasive species) contains 71 weeds but I have selected 26 of the more severe of these. Three of the weeds, *Ligustrum sinensis* Lour., *Lonicera japonica* Thunb., and *Sapium sebiferum* (L.) Roxb., listed for the eastern United States (Table 3), are Catergory 1 weeds on the Florida Council's list. Likewise, *Nandina domestica* Thunb. and *Lygodium japonicum* (Thunb.) Sw., on the Florida list, are significant invasive weeds of the eastern United States. Table 5 lists important agronomic and nuisance weeds in the eastern United States and Florida. To help create this list, I drew upon an unpublished list of Texas weeds that are considered candidates for biological control (Tracy, unpub.).

Ideally, the relative benefits and risks associated with potential projects on particular weeds should be judged in order to choose the best targets. It is, however, beyond the scope of this analysis to obtain and compare data (should they even exist) on the damage and threats associated with all of the weeds under consideration. Also, because we are not able to predict success of biological control, it is difficult to meaningfully compare the benefits likely to be achieved. All of the listed invasive weeds are considered by many workers and organizations to be significant problems, so significant benefit from biological control can be assumed, if not easily compared. There is less certainty regarding the benefits to be achieved from controlling the listed agronomic weeds. The potential risk of introduced agents to valued plants based on the weed's taxonomic affinities to other plants is easier to judge and compare. For each weed, the tables list the number of native congeners in the United States, the eastern United States (and for Florida, for the relevant lists), as well as qualitative indications of the number of economic relatives and whether or not the weeds themselves are valued.

All of the weeds on these lists are introduced species and are therefore more appropriate targets for biological control than native weeds**.** Some important invasive weeds in both the eastern United States and Florida have many native relatives and others have none. Exotic honeysuckles (*Lonicera japonica* and the three other invasive *Lonicera* species) are among the most serious invaders in the eastern region, but unfortunately there are 18 *Lonicera* species in the U.S. flora, including 12 in the eastern United States. The invasive and native *Lonicera* species belong to many of same subgeneric groups (Krussmann, 1977), which may make it very difficult to avoid non-target damage to native *Lonicera* from introduced biological control agents. Exotic privets (*Ligustrum sinense* and *L. vulgare* L.) also are serious weeds in the region and there are no native *Ligustrum* species in the New World. *Ligustrum* spp. would therefore be much better targets than *Lonicera* with regard to environmental safety. From an economic perspective, both the honeysuckles and privets have economic value themselves as ornamentals and both genera have many other ornamental species. Privets are among the most common hedge plants used in the region. Japanese honeysuckle (*L. japonicum*) has significant cultural value because its fragrant flowers are much loved and the plant is a symbol of the American South. Horticultural usage and cultural values related to invasive plants may be reshaped by scientific evidence and education. Weeds of row crop agriculture have been infrequent targets of classical biological control. In many crop situations the weeds are a complex of species and so the reduction of one weed may not contribute to significantly lower the level of weed infestation in these crops. Biological control of a particular species probably would not reduce herbicidal application in most row crops. However, there are some situations in which a large

Table 3. Invasive Weeds of Natural Areas in the Eastern United States: Temperate Region(Excluding Species in Earlier Chapters).

Weed	Common Name	Family	Area of Origin	Native Congeners US; E US	Economic Relatives	Valued Plant
Acer platanoides L.	Norway maple	Sapindaceae (Aceraceae)	Eurasia	9; 7	yes	yes
Ailanthus altissima (Miller) Swingle	tree of heaven	Simaroubaceae	China	none	no	yes
Ampelopsis brevipedunculata (Maxim) Trautv.	porcelain berry	Vitaceae	NE Asia	2; 2	no	some
Berberis thunbergii DC.	Japanese barberry	Berberidaceae	Japan	20; 6	yes	some
Celastrus orbiculatus Thunb.	oriental bittersweet	Celastraceae	NE Asia	1; 1	no	some
***Coronilla varia* L.**	**crown vetch**	**Fabaceae**	**Eurasia, N. Africa**	**none**	**many**	**yes**
Dioscorea oppositifolia Thunb.	Chinese yam	Dioscoreaceae	NE Asia	3; 3	yes	some
Elaeganus umbellata Thunb.	autumn olive	Elaeagnaceae	temperate Asia	1; 1	no	some
Euonymus alatus (Thunb.) Siebold	burning bush	Celastraceae	NE Asia	4; 3	yes	yes
Euonymus fortunei (Turcz.) Hand.-Mazz.	winter creeper	Celastraceae	Asia	4; 3	yes	some
Ligustrum sinensis Lour.	privet	Oleaceae	Japan-Korea	none	yes	yes
***Ligustrum vulgare* L.**	**privet**	**Oleaceae**	**Europe**	**none**	**yes**	**yes**
Hedera helix L.	English ivy	Apiaceae (Araliaceae)	Eurasia	none	no	yes
Lonicera japonicum Thunb.	Japanese honeysuckle	Caprifoliaceae	E. Asia	18; 12	no	yes
L. maackii Maxim.	Amur bush honeysuckle	Caprifoliaceae	NE Asia	18; 12	no	some
L. morrowii Gray	Morrow's honeysuckle	Caprifoliaceae	Japan	18; 12	no	some
L. tartarica L.	tartarian honeysuckle	Caprifoliaceae	Turkey, C. Asia	18; 12	no	some
Meila azedarach L.	Chinaberry	Meliaceae	Asia	none	yes	some
Microstegium vimineum (Trin.) A. Camus	Japanese grass	Poaceae	Asia	none	many	no
Miscanthus sinenis Andersson	miscanthus	Poaceae	NE Asia	none	many	yes
***Rhamnus cartharticus* L.**	**European buckthorn**	**Rhamnaceae**	**Eurasia**	**11; 3-4**	**no**	**some**
R. (Frangula) *alnus* L.	smooth buckthorn	Rhamnaceae	Eurasia	11; 3-4	no	some
Sapium sebiferum (L.) Roxb.	Chinese tallow	Euphorbiaceae	NE Asia	1; 0	no	yes
Wisteria sinensis (Sims) Sweet	Chinese wisteria	Fabaceae	China	3; 3	yes	yes

Species numbers and geographical occurrence from USDA Soil Conservation Service (1982), National list of scientific plant names, Vol.1.

Table 4. Invasive Weeds of Natural Areas in the Eastern United States: Subtropical Region–Florida (excluding weeds covered in previous chapters).

Weed	Common Name	Family	Area of Origin	Native Congeners in US; E US; FL	Economic Relatives	ValuedPlants
Acacia auriculiformis A. Cunn. ex Benth.	earleaf acacia	Fabaceae	N. Australia	17; 8; 6	yes	yes
Ardisia crenata Sims	coral ardisia	Myrsinaceae	India to Japan	1; 1; 1	no	some
Ardisia elliptica Thumb.	shoebutton ardsia	Myrsinaceae	Indomalaysia	1; 1; 1	no	some
Bishofia javanica Blume	bishofia	Euhorbiaceae	Indomalaysia	none	none	some
Causurina equsetifolia L.	Australian pine	Causurinaceae	Australia-SE Asia	none	no	yes
Colubrina asiatica (L.) Brongn.	**latherleaf**	**Rhamnaceae**	**Old World tropics**	**6; 5; 3**	**no**	**no**
Cupaniopsis anacardioides(A. Rich.) Redkf.	carrot wood	Sapindaceae	Australia	none	no	some
Dioscorea bulbifera L.	air potato	Dioscoreaceae	Old World tropics	3; 3; 3	yes	no
Ficus altissima Blume.	lofty fig	Moraceae	SE Asia	2; 2; 2	yes	some
Ficus benghalensis L.	banyan fig	Moraceae	India-Pakistan	2; 2; 2	yes	yes
Ficus microcarpa L.F.	laurel fig	Moraceae	Indomalaysia	2; 2; 2	yes	some
Hygrophila polysperma (Roxb.) T. Anders.	**green hygro**	**Acanthaceae**	**Indomalaysia**	**1; 1; 1**	**no**	**no**
Hymenachne amplexicaulis (Rudge) Nees	West Indian marsh grass	Poaceae	tropical America	none	many	no
Lygodium japonicum (Thunb.) Sw.	Japanese climbing fern	Lygodiaceae	E Asia	1; 1; 0	no	no
Jasminum dichotomum Vahl	Gold Coast jasmine	Oleaceae	tropical W Africa	none	yes	some
Jasminum fluminense Vell.	Brazilian jasmine	Oleaceae	tropical W Africa	none	yes	some
Macfadyena unguis-cati (L.) A. Gentry	cat's claw vine	Bignoniaceae	tropical America	none	yes	some
Nandina domestica Thunb.	heavenly bamboo	Berberidaceae	India-NE Asia	none	no	some
Neyraudia reynaudiana (Kunth) Keng ex Hitchc.	silk reed	Poaceae	SE Asia	none	many	no
Panicum repens L.	torpedo grass	Poaceae	Old World	33; 23; 13	many	some
Pennisetum purpureum Schumach.	**Napier grass**	**Poaceae**	**Africa**	**none**	**many**	**yes**
Rodomyrtus tomentosa (Ait.) Hassk.	downy rose myrtle	Myrtaceae	tropical Asia	none	yes	some
Scaevola sericea Vahl	Beach naupaka	Goodeniaceae	Old World tropics	1; 1; 1	no	some
Schefflera actinophylla (Endl.) Harms	octopus tree	Apiaceae(Araliaceae)	Australia-Indonesia	none	no	some
Solanum tampicense Dunal	wetland nightshade	Solanaceae	W Indies, Mexico	32; 24; 8	yes	no
Thespesia populnea (L.) Sol. ex Correa	seaside mahoe	Malvaceae	Old World tropics	none	yes	no

Species numbers and geographical occurrence are from USDA Soil Conservation Service (1982), National list of scientific plant names, Vol. 1.

Table 5. Agronomic Weeds of the Eastern United States (Excluding Weeds Covered in Other Capters)

Weed	Common Name	Family	Area of Origin	Native Congeners US; E. US	Economic Relatives	Valued Plant
Abutilon theophrasti Medic.	velvetleaf	Malvaceae	India	16; 3	yes	no
Agrostemma githago L.	corn cockle	Caryophyllaceae	Europe	none	no	no
Capsella bursa-pastoris (L.) Medic.	shepherd's purse	Brassicaceae	Eurasia	none	yes	no
Chenopodium album L.	lambs quarter	Amaranthaceae (Chenopodiacea)	Eurasia	30; 17	no	some
Cyperus rotundus L.	purple nutsedge	Cyperaceae	Eurasia	82; 67	no	no
***Digitaria sanguinalis* (L.) Scop.**	**large crabgrass**	**Poaceae**	**Europe**	**20+; 15+**	**yes**	**no**
Lamium amplexicaule L.	henbit	Lamiaceae	Eurasia	none	yes	no
Lamium purpurea L.	purple deadnettle	Lamiaceae	Europe	none	yes	no
Malva neglecta Wallr.	common mallow	Malvaceae	Eurasia	none	yes	some
Plantago lanceolata L.	narrow leaf plantain	Plantaginaceae	Eurasia	23; 14	no	no
Plantago major L.	broad leaf plantain	Plantaginaceae	Eurasia	23; 14	no	no
***Portulaca oleraceae* L.**	**common purselane**	**Portulacaeae**	**Europe**	**8; 8**	**no**	**no**
Rumex crispus L.	curly dock	Polygonaceae	Eurasia	25; 13	yes	no
Saponaria officinalis L.	bouncing bet	Caryophyllaceae	Eurasia	none	no	no
Sesbania punicea (Cav.) Benth.	rattlebush	Fabaceae	South America	5; 5	yes	no
Sisymbrium altissimum L.	tansy mustard	Brassicaceae	Europe	1; 0	yes	no
Sisymbrium *irio* L.	London rocket	Brassicaceae	Mediterrean	1; 0	yes	no
Sonchus asper (L.) Hill	spiny sowthistle	Asterace	Europe	none	yes	no
Sonchus oleraceus L.	annual sowthistle	Asterace	Eurasia	none	yes	no
Sorghum halepense (L.) Pers.	Johnson grass	Poaceae	Mediterrean	none	yes	yes
***Stellaria media* (L.) Cyrillo**	**chickweed**	**Caryophyllaceae**	**Eurasia**	**28; 15**	**no**	**no**
Verbascum thapsus L.	mullein	Scrophulariaceae	Eurasia	none	no	no

Species numbers and geographical occurrence are from USDA Soil Conservation Service (1982), National list of scientific plant names, Vol. 1.

acreage crop is infested primarily by one weed, such as *Cirsium arvense* (L.) Scop. in wheat in western North America. In such cases, biological control of the key weed would be likely to significantly improve crop yield. Biological weed control has been most useful in controlling agricultural weeds that infest pastures and rangeland, and this may continue to be the best place for its use in agriculture.

The agricultural weeds listed in Table 5 are similar to invasive species infesting natural areas with respect to the numbers of these weeds that have closely related native species in the eastern United States. Of the listed weeds, only Johnson grass, *Sorghum halepense* (L) Pers., an important forage plant, has significant economic value. Johnson grass is the only listed weed that has a crop plant congener, *Sorghum bicolor* (L.) Moench. However, many of these agricultural weeds belong to families (Brassicaece, Lamiaceae, Malvaceae, Asteraceae, and Poaceae) that contain many crop plants. Targeting these weeds would likely entail host specificity testing against many crop plants and probably require longer and more expensive programs.

Grass weeds have rarely been targets of biological control, primarily because of the large number of crop grasses, but also because of the concern that grass insects may not have the same levels of specificity as insects feeding on other plant families. Lower levels of specificity in grasses may be incorrect (Pemberton, 1980), and recently, some projects on grass weeds have been initiated. Two grasses, *Phragmites australis* (Cav.) Trin. ex Steudel and cogongrass, *Imperata cylindrica* (L.) P. Beauv., are subjects of other chapters in this book. Another project involves a cordgrass, *Spartina alterniflora* Loisel, a native of eastern North America that has invaded salt marshes on the west coast of North America. A delphacid bug, *Prokelisia marginata* Van Duzee that is native to the eastern United States, was recently introduced into the state of Washington to try to control it (D. Strong, pers. comm.). Japanese stiltgrass, *Microstegium vimineum* (Trin.) A. Camus, one of the most aggressive weed invaders of forest understory, also appears to be good candidate for biological control. Japanese stiltgrass has no congeneric native or economic species in the United States.

In my opinion, the potential risk of biological weed control to native plants should be viewed as more important than any potential risks to nonnative ornamental plants. Native species are not replaceable, but alternatives exist for most ornamental species. Substitutes are available for both weeds that are valued as ornamentals and for the ornamental relatives of targeted weeds, given the array of commercially available horticultural plants. Plants having high cultural value, such as Japanese honeysuckle, might be difficult to replace. It is interesting to note that many of the invasive weeds in the eastern United States and Florida are woody species imported for horticultural use. Most of these weeds are still valued as ornamentals to some degree. Biological control of some weeds with ornamental value may be possible by adopting the more limited goal of slowing the spread of such plants, without killing existing plants in the horticultural landscape. The privets *L. vulgare* and *L. sinense* are valued primarily for their leafy stems that can be are planted and trimmed into hedges. Their small white flowers and fruits are of little horticultural importance, so introducing natural enemies attacking these reproductive structures, instead of the roots, stem, and leaves, may be a suitable approach and a reasonable social compromise. The lost seed of these kinds of plants would not limit the ability of nurseries to reproduce them because most are propagated vegetatively.

It is interesting to note that all the more serious invasive weeds of the temperate eastern United States (Table 3) are native to the north temperate zone, and most (18 out of 26) are native to northeast Asia. Invasive weeds in Florida (Table 4), with the exception of the warm temperate northern part of the state, are of diverse geographic origins from areas with warm climates. The agronomic weeds (Table 5), with the exception of *Sesbania punicea* (Cav.) Benth, are herbaceous plants from Europe or Eurasia, with some species extending to temperate Asia. The USDA, ARS currently has biological control laboratories in Argentina, Australia, and France. These laboratories focus on the discovery and development of biological control agents for both insect and weed pests that are problems in the United States. CABI (Commonwealth Agricultural Bureaux International) biological control laboratories in Switzerland and the United Kingdom also are important developers of biological control agents for North American pests. The Sino-American Biological Control Laboratory in Beijing is the result of a cooperative arrangement between USDA-ARS and the Chinese Academy of Agricultural Sciences, intended to facilitate biological control surveys by American biological control scientists in China. If invasive weeds in the temperate areas of the eastern United States are targeted more frequently, a greater presence of USDA-ARS or CABI biological control staff will be needed in temperate Asia to support these programs.

There are a great number of weeds in the eastern United States that could become targets of biological control. But limited resources make it possible to address only a portion of these weeds. Selecting targets with fewer conflicts with native and economic plant relatives should lead to shorter, less costly programs, and so may be the best use of these resources. Avoiding native weeds and choosing weeds with fewer native relatives also will evoke less criticism and conflict with conservationists and others concerned with protecting native plants. This will help preserve biological control, which is a critical tool for use against invasive species. It is certain that the pressure on the environment from invasive weeds will increase in the future. Many invasive weeds will become more damaging to the environment than they presently are. Some plants that have naturalized, but are not currently invasive, will invade in natural areas. Other plants presently used in horticulture will naturalize, and new weeds will be accidentally introduced. Large numbers of novel plants with invasive potential will continue to be purposely imported, unless the current laissez-faire policy toward plant importation is replaced by policies restricting importations of species likely to become invasive. Given the great momentum of economic globalization and the international horticultural trade, regulating and limiting horticultural imports may be difficult. The need for biological control of weeds will, therefore, without question, be more critical in the future.

REFERENCES

Andres, L. A. 1985. Interaction of *Chrysolina quadrigemina* and *Hypericum* spp. in California, pp. 235-239. *In* Delfosse, E. S. (ed.). *Proceedings of the V1 International Symposium on Biological Control of Weeds*. Canada Agriculture, Vancouver, British Columbia, Canada.

Austin, D. F., K. Bradley, K. Craddock Burks, N. Colile, J. Duquesnel, D. Hall, R. Hammer, K. Langeland, R. Pemberton, D. B. Ward, and R. F. Wunderlin. 2001. Florida Exotic Pest Plant Council's List of Invasive Species. http://www.fleppc.org (accessed June 1, 2001).

Buckingham, G. R. 1996. Biological control of aquatic weeds, pp. 413-480. *In* Rosen, D., F. D. Bennett, and J. L. Capinera (eds.). *Pest Management in the Subtropics, Biological control – a Florida perspective.* Intercept, Hanover, United Kingdom.

Dennill, G. B. and D. Donnelly. 1991. Biological control of *Acacia longifolia* and related weed species (Fabaceae) in South Africa. *Agriculture, Ecosystems and Environment* 37: 115-136.

DeLoach, C. J. 1980. Prognosis for biological control of weeds of southwestern U.S. rangelands, pp. 179-199. *In* Delfosse, E. S. (ed.) *Proceedings of the Vth International Symposium on Biological Control of Weeds*. CSIRO, Brisbane, Australia.

DeLoach, C. J. 1985. Conflicts of interest over beneficial and undesirable aspects of mesquite (*Prosopis* spp.) in the United States as related to biological control, pp. 301-340. *In* Delfosse, E. S. (ed.). *Proceedings VIth International Symposium of Biological Control of Weeds*. Canada Agriculture, Vancouver, British Columbia, Canada.

Follett, P. A. and J. J. Duan (eds.). 2000. *Nontarget Effects of Biological Control*. Kluwer, Dordrecht, The Netherlands.

Harris, P. 1979. The cost of biological control of weeds in Canada. *Weed Science* 27: 242-250.

Hoffmann, J. H., V. C. Moran, and F. A. C. Impson. 1998. Promising results from the first biological control programme against a solanaceous weed (*Solanum elaeagnifolium*). *Agriculture, Ecosystem and Environment* 70: 145-150.

Huffaker, C. B. and C. E. Kennett. 1959. A ten-year study of vegetation changes associated with the biological control of Klamath weed. *Journal of Range Management* 12: 387-400.

Johnson, D. M. and P. D. Stiling . 1996. Host specificity of *Cactoblastis cactorum* (Lepidoptera: Pyralidae), an exotic *Opuntia*-feeding moth in Florida. *Environmental Entomology* 25: 743-748.

Julien, M. 1992. *Biological Control of Weeds, a World Catalogue of Agents and their Target Weeds.* 3rd ed. Commonwealth Agricultural Bureaux International, Wallingford, United Kingdom.

Kok, L. T. and W. W. Surles. 1975. Successful biocontrol of musk thistle by an introduced weevil, *Rhinocyllus conicus*. *Environmental Entomology* 4: 1025-1027.

Kovalev, O. V. S. Y. Resnik, and V. N. Cherkashin. 1983. Specific features of methods of using *Zygogramma* Chevr. (Coleoptera, Chrysomelidae) in the biological control of ragweeds (*Ambrosia artemsiifolia* L., *Ambrosia psilostachya* DC.). *Entomologicheskoe Oborzreniye* 62: 402-408.

Knauss, N. L. 1962. Biological control investigations on lantana. *Proceeding of the Hawaiian Entomological Society* 18: 134-136.

Krussman, G. 1977. *Cultivated Broad Leaved Trees and Shrubs*. Vol. II. Verlag, Berlin (English language translation by M. Epp, 1985). Timber Press, Portland Oregon, USA

Langeland, K. A. and K. Craddock Burks. 1998. *Identification and Biological of Non-native Plants in Florida's Natural Areas.* University of Florida, Gainesville, Flordia, USA.

Lawton, J. H. and D. Schroeder. 1977. Effect of plant type, size of geographic range and taxonomic isolation on number of insect species associated with British plants. *Nature* 265: 137-140.

Louda, S. M, D. Kendall, J. Connor, and D. Simberloff. 1997. Ecological effects of an insect introduced for the biological control of weeds. *Science* 277: 1088-1090.

McClay, A. S. 1989. *Selection of suitable target weeds for classical biological control in Alberta.* AECV89-RI. Alberta Environmental Centre, Vegreville, Alberta, Canada.

McFadyen, R. E. C. 1998. Biological Control of Weeds. *Annual Review of Entomology* 43: 369-393.

Morin, L., B. A. Auld and H. E. Smith. 1996. Rust endemics, climate and control of *Xanthium occidentale,* pp. 385-391. *In* Hoffmann, J. H. and V. C. Moran (eds.). *Proceedings of the IX*th *Symposium on Biological Control of Weeds*. University of Cape Town, Cape Town, South Africa.

Pemberton, R. W. 1980. International activity in biological control of weeds: patterns limitations and needs, pp. 57-71. *In* Delfosse, E. S. (ed.). *Proceedings of the V*th *International Symposium on Biological Control of Weeds*. CSIRO (Commonwealth Scientific and Industrial Research Organization), Melbourne, Australia.

Pemberton, R. W. 1985. Native weeds as candidates for biological control research, pp. 869-877. *In* Delfosse, E.S. (ed.). *Proceedings of the VI*th *international Symposium on Biological Control of Weeds*. Canada Agriculture, Vancouver, British Columbia, Canada.

Pemberton, R. W. 1995. *Cactoblastis cactorum* (Lep.: Pyralidae) in the United States: an immigrant biological control agent or an introduction of the nursery industry? *American Entomologist* 41: 230-232.

Pemberton, R. W. 1996. The potential of biological control for suppression of invasive weeds in southern environments. *Castanea* 61: 313-319.

Pemberton, R. W. 2000. Predictable risk to native plants in weed biological control. *Oecologia* 125: 489-494.

Pemberton, R. W. and C. E. Turner. 1990. Biological control of *Senecio jacobaeae* in northern California, an enduring success. *Entomophaga* 35: 71-77.

Peschken, D. P and A. S. McClay. 1995. Picking the target – a revision of McClay's scoring system to determine the suitability of a weed for classical biological control, pp. 137-143. *In* Delfosse E. S. and R. R. Scott (eds.). *Proceedings of the VIII*th *International Symposium on Biological Control of Weeds,*1992 in Canterbury, New Zealand. CSIRO, Melborne, Australia.

Randall, J. M. and J. Marinelli (eds.). 1996. *Invasive Plants – Weeds of the Global Garden*. Brooklyn Botanic Garden Publications, Brooklyn, New York.

Room, P. K., K. L. S. Harley, W. I. Forno, and D. P. A. Sands. 1981. Successful biological control of the floating weed salvinia. *Nature* 294: 78-80.

Schroeder, D. and R. D. Goeden. 1986. The search for arthropod natural enemies of introduced weeds for biological control- theory and practice. *Biocontrol News and Information* 7: 147-155.

Southwood, T. R. E.1960. The abundance of Hawaiian trees and the number of their associated insect species. *Proceedings of the Hawaiian Entomological Society* 17: 299-303.

Southwood, T. R. E. 1961. The number of species of insects associated with various trees. *Journal of Animal Ecology* 30: 1-8.

Strong, D. R. 1979. Biogeographic dynamic of insect plant communities. *Annual Review of Entomology* 24: 89-119.

Strong, D. R., J. H. Lawton, and T. R. E Southwood. 1984. *Insects on Plants*. Harvard University Press, Cambridge, Massachusetts, USA.

Strong, D. R and R. W. Pemberton. 2000. Biological control of invading species: risk and reform. *Science* 288: 1969-1970.

Turner, C. E. 1985. Conflicting interests and biological control of weeds, pp. 203-225. *In* Delfosse E.S. (ed). *Proceedings of the VI*th *International Symposium on Biological Control of Weeds*. Canada Agriculture, Vancouver, British Columbia, Canada.

Turner, C. E, R. W. Pemberton, and S. S. Rosenthal 1987. Host utilization of native *Cirsium* thistles (Asteraceae) by the introduced weevil *Rhinocyllus conicus* (Coleoptera: Curculionidae) in California. *Environmental Entomology* 16: 111-115.

USDA Soil Conservation Service. 1982. *National list of scientific plant names*. Vol. 1. List of plant names. Soil Conservation Service Technical Publication 159. Washington, D.C.

Wajnberg, E., J. K. Scot, and P. C. Quimby. 2001. *Evaluating Indirect Effects of Biological Control.* CAB International, Wallingford, United Kingdom.