Conflicting Interests and Biological Control of Weeds

C.E. Turner
United States Department of Agriculture, Agricultural Research Service, Biological Control of Weeds Research Unit, Albany, CA 94706, U.S.A.

Abstract

Conflicting interests may arise when self-perpetuating and self-distributing natural enemies are introduced for the biological control of weedy plants. Conflicting interests are conflicts between the interests of different groups of society over the impact of biological control decisions. The inability to recall or limit the actions of introduced natural enemies may induce one or more of the following types of conflicts: (i) conflict over biocontrol of introduced target plants; (ii) conflict over biocontrol of native target plants; (iii) conflict over biocontrol risk to introduced nontarget plants; and (iv) conflict over biocontrol risk to native nontarget plants. These are reviewed. Two basic issues, uncertain impact and conflicting perspectives, are fundamental to these problems. There are two key decision points in the resolution of biocontrol conflicts, the choice of plants to target for biological control, and decisions regarding the use of specific organisms as biocontrol agents. It is important that these conflicts are addressed because they involve substantive issues, and because many potential biocontrol projects and agents are currently stalled due to unresolved conflicts. Different conflict resolution options, (i) authoritative decision, (ii) mediation, and (iii) litigation, are briefly reviewed.

Introduction


Although there are other modes of biological control (Batra 1982), this discussion will focus on introduction of relatively host-specific foreign phytophagous insects for
control of plants perceived as weeds. The ability of such introduced insects to subsequently reproduce and spread spatially and temporally is at once one of the advantages and limitations of this mode of biocontrol. The inability to recall and limit the actions of natural enemies once introduced may induce conflicts between different interests.

Conflicting interests here refer to conflicts between interests of different groups of society over impact of biocontrol decisions. These conflicts occur between interests that might benefit and interests that might be impaired due to biocontrol decisions. In the biological control literature such conflicts have been termed 'conflicting interests' or 'conflicts of interest' (Andres 1981; Andres et al. 1976; Delfosse and Cullen 1981; DeLoach 1978, 1981; Huffaker 1957, 1959, 1964). Because biological control is generally unknown to the public, most of the conflicts are not yet in the public arena. Most conflicts referred to in this paper are presently conflicts as perceived by the biocontrol of weeds community. It is important that we address the problem of conflicting interests because it involves substantive issues (cf. Rawlins 1984), and because many potential biocontrol projects and insects are presently in a state of limbo due to unresolved conflicts.

<table>
<thead>
<tr>
<th></th>
<th>Introduced Plants</th>
<th>Native Plants</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Target Plants</strong></td>
<td>Conflict over biocontrol of introduced target plants</td>
<td>Conflict over biocontrol of native target plants</td>
</tr>
<tr>
<td><strong>Nontarget Plants</strong></td>
<td>Conflict over biocontrol risk to introduced nontarget plants</td>
<td>Conflict over biocontrol risk to native nontarget plants</td>
</tr>
</tbody>
</table>

Fig. 1. Types of conflicting interests in biological control of weeds.

There are two issues fundamental to the problem of conflicting interests in biocontrol of weeds: uncertain impact and conflicting perspectives. The intent of a biocontrol introduction is to control the target plant without causing harm to nontarget plants. Researchers in biological control try to reduce the uncertainty of impact through, for example, host-specificity testing. But actual impact of a biocontrol organism on the target plant as well as on nontarget plants is, of course, imperfectly predictable. We live in a diverse society with a diversity of perspectives which often conflict. This is normal in a diverse and democratic society. Different individuals and groups have different perspectives on the value of different resources such as native plants and communities, honeybees, livestock, and cultivated plants. If we could perfectly predict the biological impact of a biocontrol project or agent these conflicts would nevertheless occur, because any given level of impact has different meaning to different interest groups. However, we are better able to assess the trade-offs involved with a better knowledge of the impact of biological control.

**Types of Conflicting Interests**

Conflicting interests in biocontrol of weeds may be readily grouped into four types according to conflict over target or nontarget plants, and indigenous or introduced origin of plants (Fig. 1): (i) conflict over biocontrol of introduced target plants; (ii) conflict
over biocontrol of native target plants; (iii) conflict over biocontrol risk to introduced nontarget plants; and (iv) conflict over biocontrol risk to native nontarget plants. Most biocontrol projects contain at least one type of conflict, and many projects contain more than one.

**Target and Nontarget Plants**

Conflict over biocontrol of target plants is more straightforward than conflict over risk to nontarget plants, since intended impact on specific target plants is more defined than risk of unintended impact on nontarget plants. Previous discussions of conflicting interests have tended to focus on conflicts over biocontrol of target plants. Risk to nontarget species from biological control in general has been noted by Clark *et al.* (1984), Howarth (1983), and Pimentel *et al.* (1984). There has been an evolution in the practice of biocontrol of weeds from a period of no host-specificity testing and reliance on the judgement of the few workers in this field during the earliest days, through a period of host-specificity testing out of concern for safety to nontarget cultivated plants, to the present period where nontarget native plants are included in host-specificity testing.

Host range information, including field host records and host-specificity test data, is a critical element in conflicts over risk to nontarget plants. Host-specificity is a complex question, and discussions of host-specificity in biocontrol of weeds may be found in Dunn (1978a), Harris (1984), Harris and Zwölfer (1968), Wapshere (1974, 1983), and Zwölfer and Harris (1971).

The host range of the stenophagous insects typically considered for introduction as biocontrol agents varies from specificity for one host plant species to specificity for several closely related host plant genera. For these stenophagous insects, plant systematics is an excellent predictor of relative risk to nontarget plants. There is some slight risk that biocontrol insects might unexpectedly utilize a nontarget plant that is distantly related to the target plant, but nontarget plants that are closely related to target plants are at greater risk.

Risk to nontarget plants may be reduced by limiting the choice of biocontrol projects to target plants with few or no close relatives in the same region, and by the use of biocontrol insects with a very narrow host range. Such risk reduction would come at the expense of fewer biocontrol projects and fewer potential biocontrol insects per project.

**Introduced and Indigenous Plants**

Introduced plants involved in biocontrol conflicts are usually of some readily identifiable value to some economic group such as beekeepers, the ornamental plant industry, or growers of crop plants. We generally lack specific information about the value of native plants, and their value generally is not so readily linked to specific economic groups as above. The kinds of value that have been attributed to native plants are: (i) aesthetic (Ehrlich and Ehrlich 1981; Myers 1979); (ii) ecological (Ehrlich and Ehrlich 1981; Raven 1976; Slobodchikoff and Doyen 1977); (iii) economic (Ehrlich and Ehrlich 1981; Frankel 1970; Frankel and Soule 1981; Ilis *et al.* 1979; Jain *et al.* 1977; Myers 1979, 1983; Nault and Findley 1981; Schmidt 1980); (iv) ethical (Attfield 1983; Ehrlich and Ehrlich 1981; Myers 1979); and (v) legal (Federal Register 1980, 1983; McMahon 1980; Myers 1979; Versteeg 1984). Another type of value that might be attributed to native plants is scientific value, the value as study plants and populations to scientists and to scientific knowledge. Introduced plants may also be evaluated according to the above types of value.
Conflict Over Biocontrol of Introduced Target Plants

Conflict over biocontrol of an introduced target plant itself occurs when a naturalized plant is differently perceived as detrimental and beneficial by different groups (Table 1). There are presently no active biocontrol projects against tamarisk (Tamarix spp.; Tamaricaceae) and scotch broom (Cytisus scoparius [L.] Link; Fabaceae) in the United States, largely because of lack of resolution of conflicts over the biological control of these plants (Table 1; also Table 3). In the case of scotch broom, a formerly active biocontrol project was suspended indefinitely due partly to this type of conflict (Andres 1979). Two conflicts of this type have resulted in public participation in their resolution, and may provide alternative models of conflict resolution in the future.

Echium plantagineum L. (Boraginaceae) is a naturalized herb in Australia where it is known as Paterson's curse by those who consider it detrimental, and salvation Jane by those who consider it beneficial. The livestock industry generally considers it detrimental because of its alleged toxicity to livestock and because it competes with more desirable livestock forage. The beekeeping industry considers it beneficial because its flowers are a good resource for honeybees. Conflict over biocontrol of E. plantagineum has resulted in a legal battle that has gone to the High Court of Australia (Delfosse and Cullen 1981).

Table 1. Conflict over biocontrol of introduced target plants — North American examples.

<table>
<thead>
<tr>
<th>Introduced Target Plants</th>
<th>Biocontrol Conflicts</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Centaura solstitialis</em> L. (Asteraceae), yellow starthistle (Maddox <em>et al.</em>, <em>in press</em>; Reed and Hughes 1970).</td>
<td><em>C. solstitialis</em> flowers considered important resource for honeybees (Pellett 1920; Vansell, 1931).</td>
</tr>
<tr>
<td><em>Cytisus scoparius</em> (L.) Link (Fabaceae), scotch broom (Andres 1979; Holloway 1964a; Mountjoy 1979; Robbins <em>et al.</em> 1970).</td>
<td>Weedy as well as less aggressive varieties of <em>C. scoparius</em> grown as ornamental shrubs (Bailey 1949; Clark 1979).</td>
</tr>
<tr>
<td><em>Tamarix</em> spp. (Tamaricaceae), tamarisk, salt cedar (Anderson and Ohmart 1976; Hefley 1937; Lindauer 1983; Robinson 1965; Turner 1974; Watts <em>et al.</em> 1977).</td>
<td>Weedy <em>Tamarix</em> spp. considered good nesting habitat for a native gamebird, the white-winged dove (<em>Zonaida asiatica</em> L.; Columbidae); tamarisk flowers considered an important resource for honeybees; tamarisks grown as woody ornamentals (Andres 1981; Bailey 1949; Clark 1979; Vansell 1931; Watts <em>et al.</em> 1977).</td>
</tr>
</tbody>
</table>

Yellow starthistle (*Centaura solstitialis* L.; Asteraceae) is a Eurasian herb with spiny heads that is naturalized at highest densities in western North America in rangelands, croplands, and wastelands (Maddox *et al.*, *in press*; Reed and Hughes 1970). Livestock ranchers particularly favor biocontrol of yellow starthistle, and in the 1950s they requested that the University of California's Division of Biological Control initiate a biocontrol project against it. Yellow starthistle flowers are a good resource for honeybees in California's lowlands during the dry summer season (Pellett 1920; Vansell 1931). Beekeepers and the then California Department of Agriculture, with questions about the direct impact on the beekeeping industry and the indirect impact on honeybee-pollinated seed and fruit crops, expressed concern about the biological control of this plant. As a public institution, the University of California was reluctant to carry out a biocontrol program against this plant until the conflict was resolved. In 1959 the California Chamber of Commerce convened its Subcommittee on Weeds to examine
this conflict. Participating in this meeting were representatives from the beekeeping industry, cattle industry, sheep industry, County Agricultural Commissioners' Association, California Department of Agriculture, and the Division of Biological Control and the Department of Agronomy from the Berkeley and Davis campuses of the University of California. The net result of this meeting was a consensus agreement that the beneficial aspect of yellow starthistle was outweighed by the losses due to this plant to other segments of the California economy. The members of this meeting unanimously agreed to recommend biological control of yellow starthistle and investigation of plants useful to both the livestock and beekeeping industries in order to replace controlled weeds (California State Chamber of Commerce, 15 Jan. 1959, unpublished minutes of yellow starthistle conference).

Conflict Over Biocontrol of Native Target Plants

Conflict over biocontrol of a native target plant itself occurs when a native plant is differently perceived as detrimental and weedy by one group, but beneficial (at least in some, perhaps more moderate densities) by a different group (Table 2). This conflict is most acute with regard to the possible use of foreign organisms as biocontrol agents. The use of foreign organisms to control native plants that are perceived as weeds, at least at present densities, has been proposed for native plants that are important human allergenic plants (Harris and Piper 1970; Maw 1984) and for native plants that are considered undesirable rangeland weeds because they are unpalatable or toxic to livestock, compete with more desirable livestock forage, or impede the movement of ranchers or livestock (DeLoach 1978, 1981).

The general use of foreign organisms to control native plants would mark a departure from previous biocontrol practices. Such projects would usually also contain conflicts over biocontrol risk to nontarget native plants since most native plants have native close relatives in the same region. Any foreign stenophagous insects introduced to control indigenous plants are less likely to be host-specific to the native target plant since they would occur naturally on different foreign host plants (DeLoach 1981). It might be argued that the intent of use of foreign organisms to control native rangeland weeds is to merely suppress native plants that have expanded their density or distribution because of the disturbance of livestock management practices (DeLoach 1981) back to pre-disturbance levels. But biocontrol of weeds with introduced self-perpetuating organisms is not that finely predictable. The use of foreign seed-feeding insects only (J. DeLoach, USDA, Temple, Texas, pers. comm.), however, might well have the effect of reducing further spread of these plants without greatly reducing their populations, although sufficient host-specificity may be problematical. DeLoach (1978, 1981) has previously reviewed this type of conflict, and Pemberton (1985b) also addresses this topic.

Augmentative biological control with indigenous natural enemies (Batra 1982; Frick and Chandler 1978; Templeton 1982) combined with altered rangeland management practices might be an alternative to use of foreign organisms to control native weeds. Use of indigenous pathogens to control indigenous plants perceived as weeds has been considered at least to the stage of apparently successful field experiments for: oaks (Quercus spp.; Fagaceae) (French and Schroeder 1969); winged water primrose (Ludwigia decurrens Walter; Onagraceae) (Boyette et al. 1979); silverleaf nightshade (Solanum elaeagnifolium Cav.; Solanaceae) (Orr 1981; Orr et al. 1975; Robinson et al. 1978); persimmon (Diospyros virginiana L.; Ebenaceae) (Wilson 1965, 1969); and jointvetch (Aeschynomene sp.; Fabaceae) (Boyette et al. 1979; Templeton et al. 1978). Augmentation of native insects for biocontrol of weeds is not usually given serious
consideration because of the usual presence of native entomophagous natural enemies, particularly parasitoids (but see Frick and Garcia 1975).

The only known intentional introduction of foreign organisms to control native plants occurred in the United States, and this involved the introduction of a foreign population of a native insect onto an island. The so-called Mexican strain of a native cochineal insect (Dactylopius opuntiae [Cockerell]; Homoptera: Dactylopiidae) was introduced via

Table 2. Conflict over biocontrol of native target plants — North American examples.

<table>
<thead>
<tr>
<th>Native Target Plants</th>
<th>Biocontrol Conflicts</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Baccharis glutinosa</em> Pers. (= <em>B. viminalis</em> DC.) and <em>B. halimifolia</em> L. (Asteraceae), baccharis (DeLoach 1978, 1981; Wilken 1972).</td>
<td><em>B. glutinosa</em> considered characteristic component of three U.S. plant communities (Kuchler 1964, 1977); <em>B. glutinosa</em> considered locally important floral resource for honeybees and native Hymenoptera (Linsley and Cazier 1972; Vansell 1931); <em>B. halimifolia</em> considered characteristic component of one U.S. plant community (Kuchler 1964).</td>
</tr>
<tr>
<td><em>Larrea tridentata</em> (Sesse &amp; Moc.) Coville (Zygophyllaceae), creosotebush (DeLoach 1978, 1981).</td>
<td><em>L. tridentata</em> considered dominant of six U.S. plant communities, and characteristic component of one U.S. plant community (Kuchler 1964); <em>L. tridentata</em> a past and potential future source of industrial chemicals (Campos-Lopez and Roman-Alemany 1980; Mabry et al. 1977; Timmermann 1977); <em>L. tridentata</em> a potential source of biomass energy (Foster and Karipiscak 1983); five spp. of lizards and one sp. of snake restricted to <em>L. tridentata</em> flats (Mares and Hulse 1977); many arthropods associated with <em>L. tridentata</em>, including 18 spp. of herbivorous insects monophagous on <em>L. tridentata</em> (Schultz et al. 1977); <em>L. tridentata</em> may be important floral resource for native bees (Simpson et al. 1977).</td>
</tr>
<tr>
<td><em>Prosopis glandulosa</em> Torr. and <em>P. velutina</em> Wooton (Fabaceae), mesquite (DeLoach 1978, 1981; Reed and Hughes 1970).</td>
<td><em>P. glandulosa</em> considered dominant of six U.S. plant communities, and characteristic component of four U.S. plant communities (Kuchler 1964); <em>P. velutina</em> considered dominant of one U.S. plant community, and characteristic component of two U.S. plant communities (Kuchler 1964); <em>Prosopis</em> spp. considered important nitrogen-fixing plant in generally nitrogen-poor desert soils (Belden et al. 1982; Shearer et al. 1983; Virginia et al. 1984; Virginia and Jarrell 1983); <em>Prosopis</em> spp. considered important resource for wildlife (Martin et al. 1951); <em>Prosopis</em> spp. considered important floral resource for honeybees (Pellett 1920; Vansell 1931); <em>P. glandulosa torreyana</em> considered important shade tree in the U.S. Southwest (Clark 1979); <em>Prosopis</em> spp. potential source of biomass energy (Felder et al. 1983; Foster and Karipiscak 1983); <em>Prosopis</em> spp. locally important source of fuel in Mexico (Campos-Lopez and Roman-Alemany 1980); pods of <em>Prosopis</em> spp. potential source of food (Felder and Bandurski 1979; Felder et al. 1984).</td>
</tr>
</tbody>
</table>

Hawaii via Australia from Mexico onto Santa Cruz Island off the coast of southern California, to control native prickly pear cacti and their hybrids (*Opuntia littoralis* [Engelm.] Cockl., *O. oricola* Phil.; Cactaceae). Previous attempts to introduce this cochineal insect from populations on the southern California mainland failed due to lack of establishment of the insect. The introduction of the Mexican strain of *D. opuntiae* has resulted in a reduction of *Opuntia* density by two-thirds to three-fourths of the density before this biocontrol introduction. An important part of this biocontrol success
was the restriction of cattle grazing and the attempted eradication of feral sheep. The arrival on the island of a mainland predator of *D. opuntiae*, the entomophagous moth *Laetilia coccidivora* (Comstock) (Lepidoptera: Pyralidae), has slowed the effect of *D. opuntiae* on *Opuntia* more recently (Goeden 1978a; Goeden et al. 1967; Goeden and Ricker 1981).

Native plants that are perceived as undesirable weeds, at least at present densities, on U.S. southwestern rangelands include (DeLoach 1978, 1981): acacia (*Acacia farnesiana* [L.] Willd., *A. rigidula* Benth.; Fabaceae); white-brush (*Aloysia gratissima* [Gillies & Hook.] Troncoso [= *A. lycioides* Cham.]; Verbenaceae); ragweed (*Ambrosia* spp.; Asteraceae); sagebrush (*Artemisia* spp.; Asteraceae); locoweed (*Astragalus* spp.; Fabaceae); baccharis (*Baccharis glutinosa* Pers. [= *B. viminea* DC. (Wilken 1972)], *B. halimifolia* L., *B. neglecta* Britton, *B. salicina* Torr. & Gray; Asteraceae); Texan persimmon (*Diospyros texana* Scheele; Ebenaceae); goldenweeds (*Ericameria* spp., *Isocoma* spp.; Asteraceae); tarbush (*Flourensia cernua* DC.; Asteraceae); broomweed (*Gutierrizia microcephala* Gray, *G. sarothrae* [Pursh] Britton & Rusby, *G. sphaerocephala* Gray, *G. texana* Torr. & Gray; Asteraceae); bitterweed (*Hymenoxys odorata* DC., *H. richardsonii* [Hook.] Cockl.; Asteraceae); yaupon (*Ilex vomitoria* Ait.; Aquifoliaceae); juniper (*Juniperus* spp.; Cupressaceae); creosotebush (*Larrea tridentata* [Sesse & Mocino] Coville; Zygophyllaceae); cactus (*Opuntia* spp.); retama (*Parkinsonia aculeata* L.; Fabaceae); mesquite (*Prosopis glandulosa* Torr., *P. velutina* Wooton; Fabaceae); oak (*Quercus havardii* Rydb., *Q. marilandica* Muench., *Q. stellata* Wangehn., *Q. virginiana* Mill.; Fagaceae); groundsel (*Senecio douglasii* DC. [= *S. longitubus* Benth.]; Asteraceae); and nightshade (*Solanum* spp.).

According to DeLoach (1981), the seven best candidates for biological control among weeds of southwestern United States rangelands are the following native taxa: (i) broomweed (*Gutierrizia*); (ii) whitebrush (*A. gratissima*); (iii) tarbush (*F. cernua*); (iv) bitterweed (*Hymenoxys*); (v) baccharis (*Baccharis*); (vi) creosotebush (*L. tridentata*); and (vii) mesquite (*Prosopis*). This ranking was tentative and based upon damage caused by the weeds, beneficial and ecological values of the weeds, and biological control success potential.

**Conflict Over Biocontrol Risk to Introduced Non-target Plants**

Conflict over biocontrol risk to introduced nontarget plants occurs when one group favors the biocontrol of a target plant, while a different group opposes it due to perceived risk to nontarget introduced plants which are valued by this group (Table 3). This usually occurs when an economic plant that is used for food, ornament, or some other human use is closely related to a target plant. In practice, when field host records or host-specificity test data indicate host utilization of a major economic plant, the potential biocontrol insect is dropped from further consideration for biological control. The situation is more equivocal, however, when host range information indicates host utilization of minor economic plants such as many ornamental plants.

A leaf beetle, *Galeruca rufa* Germar (Coleoptera: Chrysomelidae), is a potential biocontrol insect for field bindweed (*Convolvulus arvensis* L.; Convolvulaceae) in North America. Because this beetle fed and reproduced on several varieties of sweet potato (*Ipomoea batatas* [L.] Lam.; Convolvulaceae) in host-specificity tests, it was dropped from further consideration as a biocontrol agent (Rosenthal et al. 1983; Table 3). The leaf beetle *Psylliodes chalcomera* Illiger (Coleoptera: Chrysomelidae) is a potential biocontrol insect for musk thistle (*Carduus nutans* L. complex; Asteraceae) in North America. This insect has never been recorded as a pest of the edible crop globe artichoke.
(Cynara scolymus L.; Asteraceae) in Europe, where Carduus spp., globe artichoke, and
the leaf beetle are all native. But because P. chalcomera fed and oviposited on globe
artichoke in host-specificity testing, this insect has effectively been dropped from
consideration as a biocontrol insect (Dunn 1978a, b; Dunn and Rizza 1977).

The leaf beetle Chrysolina gysophila Kuster (Coleoptera: Chrysomelidae) is a
prospective biocontrol insect for Dalmation toadflax (Linaria dalmatica Mill.;
Scrophulariaceae) in North America. In host-specificity tests, this beetle fed and
reproduced on snapdragon (Antirrhinum majus L.; Scrophulariaceae), which is grown
as an ornamental herb. There are no field records of this insect on snapdragons in
Europe, where both are native (Rizza and Pecora 1984; Table 3). The biocontrol status
of C. gysophila is presently unresolved until this conflict is resolved. The moth
Calophasia lunula (Hufn.) (Lepidoptera: Noctuidae) was previously introduced into
North America for the control of naturalized common toadflax (Linaria vulgaris Mill.)
despite the fact that larvae fed and developed into adulthood on snapdragon in host-
specificity tests (Harris 1963; Harris and Carder 1971).

<table>
<thead>
<tr>
<th>Target Plants</th>
<th>Biocontrol Conflicts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Convolvulus arvensis L. (Convolvulaceae), field bindweed (Holm et al. 1977; Reed and Hughes 1970; Rosenthal 1983; Rosenthal and Buckingham 1982).</td>
<td>Risk to related nontarget cultivated plants: Convolvulus and Ipomoea in the tribe Convolvulaceae, sensu lato (Melchior 1964); sweet potato (Ipomoea batatas (L.) Lam.) grown as edible crop plant; Convolvulus and Ipomoea grown as ornamentals (Bailey 1949; Clark 1979; Rosenthal et al. 1983; Rosenthal and Buckingham 1982).</td>
</tr>
<tr>
<td>Linaria dalmatica (L.) Mill., Dalmatian toadflax and L. vulgaris Mill., common toadflax (Scrophulariaceae) (Alex 1962; Harris and Carder 1971; Reed and Hughes 1970; Robecker 1974).</td>
<td>Risk to related nontarget cultivated plants: Antirrhinum, Cymbalaria, and Linaria in the tribe Antirrhineae (Melchior 1964; Munz 1926); snapdragon (Antirrhinum majus L.; Scrophulariaceae), an ornamental herb, is the most important closely related cultivated plant (Bailey 1949; Clark 1979; USDC 1982; USDA, SRS 1982); other closely related ornamentals include Cymbalaria (Linaria) muralis P. Gaertn., B. Meyer &amp; Scherb., L. maroccana J.D. Hook., and L. purpurea (L.). Mill. (Bailey 1949; Clark 1979).</td>
</tr>
</tbody>
</table>

The leaf beetle Chrysolina quadrigemina (Suffrian) (Coleoptera: Chrysomelidae) was
introduced into North America for the biological control of naturalized St. John’s wort
or Klamath weed (Hypericum perforatum L.; Clusiaceae), and is the organism chiefly
responsible for its successful control in northern California. This beetle was introduced
with the knowledge that it fed and reproduced on an ornamental species of St. John’s
wort (H. calycinum L.) in host-specificity tests, although it was thought unlikely to do
so in the field (Holloway 1964b). Since its introduction, however, C. quadrigemina is
now found on some field plantings of this ornamental groundcover, and has caused
significant damage to it at some sites (Andres 1985).

The lace bug Teleonemia scrupulosa Stål (Hemiptera: Tingidae) was introduced at
the Serere Research Station in Uganda in 1963 for the control of lantana (Lantana
camara L.; Verbenaceae). Following a massive population buildup of *T. scurpulosa* and the consequent collapse of the lantana population, *T. scurpulosa* was found utilizing nearby experimental plantings of sesame (*Sesamum indicum* L.; Pedaliaceae) in 1965. Adult *T. scurpulosa* fed and oviposited on the sesame, and a small proportion of larvae were able to develop into adulthood on it, though they were not reproductive. This utilization of adjacent sesame plantings occurred again, at least in immediately subsequent seasons. There had been some host testing of *T. scurpulosa* before its release in Uganda, although sesame itself was not tested (Davies and Greathead 1967; Fyfe 1937; Greathead 1971, 1973). Under current host testing protocol, it is likely that sesame would be among the host test plants (Wapshere 1974).

Table 4. Conflict over biocontrol risk to native nontarget plants — North American examples.

<table>
<thead>
<tr>
<th>Target Plants</th>
<th>Biocontrol Conflicts</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Carduus</em> spp., <em>Cirsium arvense</em> (L.) Scop., <em>C. vulgare</em> (Savi) Ten., <em>Silybum marianum</em> (L.) Gaertn. (Asteraceae), various naturalized thistles (Dunn 1976; Frick 1978; Holm et al. 1977; Moore 1975; Moore and Frankton 1974; Reed and Hughes 1970; Schroeder 1980).</td>
<td>Risk to related nontarget native plants: these are closely related genera in the subtribe Carduiinae (Dittrich 1977); c. 130 <em>Cirsium</em> spp. native to North America (Moore and Frankton 1974; Ownbey et al. 1975), 13 <em>Cirsium</em> taxa under U.S. federal review as endangered species (Federal Register 1980, 1983).</td>
</tr>
<tr>
<td><em>Euphorbia esula</em> complex, leafy spurge and <em>E. cyprissiastis</em> L., cypress spurge (Euphorbiaceae) (Best et al. 1980; Dunn 1979, Reed and Hughes 1970).</td>
<td>Risk to related nontarget native plants: c. 112 <em>Euphorbia</em> (incl. <em>Chamaesyce</em>) spp. native to America north of Mexico, and 14 <em>Euphorbia</em> taxa under U.S. federal review as endangered species; <em>E. esula</em> complex and <em>E. cyprissiastis</em> are in the subgenus Esula, as are 21 of the native <em>Euphorbia</em> spp. including two spp. under U.S. federal review as endangered species (Federal Register 1980, 1983; USDA, SCS 1982; Pemberton 1985a).</td>
</tr>
</tbody>
</table>

Conflict Over Biocontrol Risk to Native Nontarget Plants

Conflict over biocontrol risk to native nontarget plants occurs when one group favors the biocontrol of a target plant, while a different group opposes it due to perceived risk to nontarget native plants which are valued by this group (Table 4). As previously discussed, this risk is expected to be greater for nontarget plants closely related to target plants. This type of conflict is common especially in North America perhaps because many of our introduced weeds originate from Europe, and North America and Europe are floristically similar. This type of conflict will also be common if biological control projects involving the use of foreign biocontrol organisms against native weeds takes
place, since native weeds usually have native closely related species present here. This type of conflict is especially difficult because of its prevalence, the indirect nature of the conflict, and because the importance of native plants is more controversial and less quantifiable than the importance of cultivated plants. An important consideration in the assessment of these conflicts is that naturalized weeds may have a negative impact on native plants through interspecific competition and preemption of habitat.

The Wisconsin State Department of Agriculture in 1982 consulted with the Wisconsin Department of Natural Resources (DNR) about further introductions of the weevil _Rhinocyllus conicus_ Froelich (Coleoptera: Curculionidae) into the State for release against musk thistle. The DNR questioned the risk to the rare native dune thistle (_Cirsium pitcheri_ [Torr.] Torr. & Gray; Asteraceae) in Wisconsin from _R. conicus_. These two state agencies reached an agreement not to further release _R. conicus_ in Wisconsin until more information could be obtained concerning the question of safety to _C. pitcheri_ (J. Doll, Univ. Wisconsin, pers. comm.).

A moth (_Tyta luctuosa_ Denis & Schiffermuller) (Lepidoptera: Noctuidae) and a mite (_Acacia_ sp.) (Acari: Eriophyidae) are potential biocontrol agents against naturalized field bindweed in North America. Host-specificity tests have revealed that these arthropods may also utilize native species of _Calystegia_ (Convolvulaceae), a genus closely related to _Convolvulus_ (Clement et al. 1983; Rosenthal et al. 1983). The status of these prospective biocontrol agents for field bindweed in North America is currently in limbo pending some resolution of this conflict. _Lema cyanella_ (L.) (Coleoptera: Chrysomelidae) is a leaf beetle that is a potential biocontrol insect for Canada thistle (_Cirsium arvense_ [L.] Scop.; Asteraceae) in North America. In host-specificity tests, this beetle fed and oviposited on native _Cirsium_ species (Peschken 1984; Peschken and Johnson 1979). This insect was nevertheless introduced into Canada in 1983 (P. Harris, unpubl., Status of introductions and main indigenous organisms attacking weeds targeted for biological control: Canada, 1984). A subsequent petition to introduce _L. cyanella_ into the United States has been denied by the Working Group on Biological Control of Weeds (WGBCW) (discussed later), at least until more is known about its performance following the Canadian introduction (R. Bovey, USDA, College Station, Texas, pers. comm.).

The likelihood of utilization of nontarget plants and the probable impact of utilization are critical components in the interpretation of host range information prior to an introduction decision.

**Utilization**

The likelihood of post-release actual field utilization of natural populations of nontarget native plants depends on many factors including: (i) vagility of the insect; (ii) number of nontarget potential host species, based on host range information and taxonomic similarity to the target plant; (iii) abundance of each nontarget plant species; (iv) distribution of the nontarget plants relative to that of the target plant; (v) morphological similarity of nontarget plants to the target plant; (vi) chemical similarity of nontarget plants to the target plant; (vii) phenological similarity of nontarget plants to the target plant; and (viii) habitat similarity, including climate and substrate, of nontarget plants and the target plant.

Allopatry between the target plant and nontarget potential host species of particular concern should markedly reduce the likelihood of utilization of the nontarget potential host species. Yet the presence of other nontarget potential host species that bridge the distributional gap between the target plant and the nontarget potential host species of
Table 5. North American records of adult introduced biocontrol insects reared from natural field populations of native nontarget plants.

<table>
<thead>
<tr>
<th>Target plant</th>
<th>Biocontrol insect</th>
<th>Native nontarget plant</th>
<th>Place</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Alternanthera philoxeroides</em></td>
<td><em>Vogia malloi</em> Pastrana</td>
<td><em>Philoxerus vermicularis</em> (L.) R.Br.</td>
<td>Louisiana</td>
<td>Vogt <em>et al.</em> (unpubl. data)</td>
</tr>
<tr>
<td>(Mart.) Griseb. (Amaranthaceae)</td>
<td>(Pyralidae)</td>
<td>(Amaranthaceae)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Carduus nutans</em> complex</td>
<td><em>Rhinocyclus conicus</em></td>
<td><em>Cirsium undulatum</em> (Nutt.) Spreng. (Asteraceae)</td>
<td>Montana</td>
<td>Rees (1977, 1978)</td>
</tr>
<tr>
<td><em>C. pycnocephalus</em> L.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Silybum marianum</em> (L.) Gaertn.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Asteraceae)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Hypericum perforatum</em> L. (Clusiaceae)</td>
<td><em>Agrilus hyperici</em> (Creutzer) (Buprestidae)</td>
<td><em>Hypericum concinnum</em> Benth.</td>
<td>California</td>
<td>Andres (1985)</td>
</tr>
<tr>
<td><em>H. perforatum</em></td>
<td><em>Chrysolina quadrigemina</em> (Suffrian) (Chrysomelidae)</td>
<td><em>H. concinnum</em></td>
<td>California</td>
<td>Andres (1985)</td>
</tr>
<tr>
<td></td>
<td><em>Zeuxidiplosis giardi</em> Kieffer (Cecidomyiidae)</td>
<td><em>H. concinnum</em></td>
<td>California</td>
<td>Andres (1985)</td>
</tr>
</tbody>
</table>
concern could subvert this otherwise allopatric protection (Fig. 2). If other factors are equal, the greater the number of native nontarget species closely related to the target plant, the greater will be the possibility of host bridging to nontarget potential host species themselves allopatric with the target species.

Table 5 shows the known North American cases where adult introduced biocontrol insects have developed on natural populations of nontarget native plants. This is 7 of the 33 (21%) of the foreign arthropods deliberately introduced and established for the biocontrol of weeds in America north of Mexico (Julien 1982). In each case the nontarget plants utilized are closely related to the target plants. The amount of utilization in these cases is quite variable, being quite low in the case of the moth *Vogtiella malloi* Pastrana (Lepidoptera: Pyralidae) on *Philoxerus vermicularis* [L.] R.Br.; Amaranthaceae) (Vogt et al., unpubl. data) and the weevil *Micolarinus lareynii* (Jacquelin du Val) (Curculionidae) on *Kallstroemia grandiflora* Torr. (Zygophyllaceae) (C.E. Turner, unpubl. data); and ranging from 1 to over 1000 adult *R. conicus* reared/100 heads sampled/population between different native *Cirsium* species in California (C.E. Turner, R.W. Pemberton, and S.S. Rosenthal, unpubl. data). Despite the reduced likelihood of encounter between a stenophagous herbivore and rare potential host plants, three of the native *Cirsium* species utilized by *R. conicus* in California are rare and under U.S. federal review as endangered species. So far the number of adult *R. conicus* reared from these rare native thistles is quite low (C.E. Turner, R.W. Pemberton, and S.S. Rosenthal, unpubl. data).

![Diagram](image)

**Fig. 2.** Host bridge: nontarget host species A may function as a host bridge to nontarget host species B.

It has been hypothesized that the presence of native phytophagous insects on native nontarget potential host plants might competitively exclude introduced biocontrol insects that could otherwise utilize the nontarget plants as hosts (Harris, in Julien 1982; Harris 1984; Peschken 1984). However, other possible outcomes of such interspecific competition between native and introduced insects include coexistence and competitive displacement of the native insects. Moreover, the importance of interspecific competition in phytophagous insects is controversial and has proven difficult to document (Lawton 1984; Strong et al. 1984, and additional references therein). There are many cases known where accidentally introduced stenophagous insects utilize indigenous plants as hosts (e.g. Furniss and Carolin 1977), though information about the presence of indigenous insects doing the same type of feeding on these plants is not readily available. The utilization of native plants by introduced biocontrol insects has occurred at least in some cases (Table 5) despite the presence of native insect consumers. The utilization of *K. grandiflora* by the stem-mining weevil *Micolarinus lypriformis* (Wollaston) (Coleoptera: Curculionidae) occurs despite the presence of a native stem-mining long-
horned beetle (Cerambycidae) (R.B. Hawkes, unpubl. data; C.E. Turner, unpubl. data.); and the utilization of heads of native Cirsium species in California by the weevil R. conicus occurs despite the presence of native thistlehead insects (C.E. Turner, R.W. Pemberton, and S.S. Rosenthal, unpubl. data.).

**Impact of Utilization**

As Andres (1981) has noted, utilization and impact of utilization are different matters. Utilization of nontarget native plants will not necessarily result in significant negative impact on utilized populations or species. The density of a utilized plant population may decline in response to herbivory through outright killing of individual plants or by sublethal feeding damage that reduces plant reproductive output (seeds or clonal units). Although an introduced biocontrol insect may be able to complete development on a nontarget plant species in the field, insect survival rate may be greatly reduced on it compared to survival rate on the target plant species. Rees (1977, 1978) has shown this to be the case with R. conicus on Cirsium undulatum (Nutt.) Spreng. in Montana, and Vogt et al. (unpubl. data) have shown this to be the case also with V. malloi on P. vermicularis in Louisiana. On the other hand, R. conicus on some nontarget native Cirsium species in California seem to emerge in about the same high numbers as on its target plants (C.E. Turner, R.W. Pemberton, and S.S. Rosenthal, unpubl. data).

An introduced stenophagous insect may affect a utilized native plant population no more than native herbivores would have in the absence of the introduced insect. In this case, the chief impact of the introduced insect may be on any displaced native insect herbivores and any other species dependent on them (such as insect parasitoids), or the introduced insect may only eliminate individuals from the nontarget plant population that would otherwise have succumbed to other mortality factors acting on the population, such as inter-plant competition. Plants, as primary producers of biotic communities, have had long evolutionary experience with herbivory and generally exhibit apparent defenses and compensatory responses to herbivory (see recent reviews in Crawley 1983; Denno and McClure 1983; Edwards and Wratten 1980; Futuyma 1983; Harper 1977; and Price et al. 1980). Different plant species are variable in this regard, and indigenous species will not have had any specific evolutionary experience with an introduced herbivore. Stenophagous herbivores may, of course, have a negative impact on plant populations; the very practice and success of biological control of weeds attests to this.

**Theory**

Fig. 3 shows some factors that may affect the interaction between populations of a host plant species and populations of a stenophagous phytophagous insect species. There are three theoretical grounds for thinking that introduced stenophagous insects could have a significant negative impact on populations of native nontarget plants that they utilize as hosts. Populations of a monophagous insect and its one host plant species may interact in a reciprocal density-dependent fashion (Andres 1981; Harris 1984; Huffaker and Messenger 1964) such that a monophagous insect would not be expected to drive its single host plant species to extinction (Harper 1977, 1981). No introduced biocontrol insect has extinguished its target weed host in its area of naturalization, although this may have been approached in some of the Hawaiian Islands by two Microlarinus spp. introduced to control two naturalized Tribulus spp. (Julien 1982). Note that this involved two host plant species for each insect species, and occurred in an insular setting. The presence of an additional host plant species in the same area
could change the nature of the host–herbivore interaction, effectively subverting potential reciprocal density-dependence between a stenophagous insect and any one host plant species. A nontarget native plant species that is utilized as a host by an introduced biocontrol insect is more likely to be significantly affected if the target host species or additional nontarget host species are also present in the same area. The potential for this type of situation is obviously heightened for target weeds with many native close relatives combined with biocontrol agents with relatively broad host ranges.

A second consideration is the combined stress of plant interspecific competition and herbivory on a host plant population. Native plants growing in native habitats are typically exposed to interspecific competitive stress from associated plants. The combined stresses of plant interspecific competition and herbivory have a greater impact on plant populations than that of herbivory alone (Bennett 1970; Chater 1931; Goeden et al. 1967; Groves and Williams 1975; Harris 1981, 1984; Simmonds 1933; Whittaker 1979). This synergistic relationship also suggests that altered management practices to increase the level of interspecific plant competition upon target weeds should be an integral part of biological control programs, though this is not generally the case currently. In addition to affecting the degree of success of a biocontrol program against a target weed, management practices may also have another effect. Without improved management practices the target weed, if successfully controlled by biological control, may merely be replaced by yet another undesirable weed.

The third consideration is the regulatory effect that entomophagous natural enemies have on herbivore populations. Natural enemies — predators, parasitoids, and diseases — have an important regulatory influence on populations of herbivores (Edmunds 1973; Goeden and Louda 1976; Huffaker and Messenger 1964; Huffaker et al. 1976; Lawton and McNeill 1979; McClure 1977; Myers and Harris 1980; Price et al. 1980; Ripper 1956; Simmonds 1933). Indeed, biological control of insect pests is based on this relationship. But it is the intent of workers in biological weed control to attempt to

Fig. 3. Plant–consumer interactions.
introduce foreign biocontrol insects without their entomophagous natural enemies to increase the probability of successfully controlling the target weed. In contrast to native insects on native plants, introduced biocontrol insects that utilize nontarget plants will usually lack their natural enemies by design. This increases the potential for significant negative impact should host utilization of nontarget plants occur.

**Empirical Studies**

Studies of the impact of introduced stenophagous herbivores on native plants are most applicable to an empirical assessment of the impact of introduced biocontrol insects on nontarget native plants. Such studies are generally lacking, although they would be significantly informative. There are two types of opportunities for these studies: intentionally introduced biocontrol insects that utilize nontarget native plants (e.g. Table 5), and accidentally introduced stenophagous insects that utilize native plants. The most useful information from such studies is impact of the introduced insect on populations of the native host plant, whether this impact exceeds that from native sources of mortality acting on the host plant, and impact on populations of other native species that interact with the host plant. Also useful would be information about known host range of such introduced insects, and information about factors that might affect likelihood of host utilization and impact of host utilization, as previously discussed. Impact studies are under way at the Albany USDA laboratory on the *Micolarinus — Kallstroemia, Hypericum* insects — native *Hypericum*, and *Rhinocyllus* — native *Cirsium* systems. The following is a summary of the most severe cases of negative impact of accidentally introduced relatively host-specialized phytophages on North American native plants.

Two introduced fungi have had well-known and devastating effects on two formerly prominent native trees. *Endothia parasitica* (Murr.) A. & A. (Sphaeriales) is the pathogen responsible for chestnut blight of American chestnut, *Castanea dentata* (Marshall) Borkh. (Fagaceae). *Ceratocystis ulmi* (Buism.) C. Moreau (Microascales) is the pathogen responsible for so-called Dutch elm disease of American elm, *Ulmus americana* L. (Ulmaceae). The smaller European elm bark beetle (*Scolytus multistriatus* [Marsham.]; Coleoptera: Scolytidae) is an introduced insect that has been an important vector in the transmission of Dutch elm disease between trees (Elton 1958; Pirone 1978).

Fraser fir (*Abies fraseri* [Pursh] Poir.; Pinaceae) is a native coniferous tree of limited distribution (Little 1971) on mountaintops in the southern Appalachian Mountains, which may be considered ecological or habitat ‘islands’ (MacArthur and Wilson 1967; Stebbins 1980). The balsam woolly aphid (*Adelges picea* [Ratz.]; Homoptera: Adelgidae), accidentally introduced from Europe, is regarded as a severe threat to Fraser fir (Amman and Speers 1965; Bratton 1982); and the death of stands of Fraser fir due to this insect may lead to community-wide changes (Bratton 1982). Balsam woolly aphid also attacks other native species of fir that are more widely distributed (Baker 1972; Furniss and Carolin 1977). The balsam woolly aphid has been the target of an unsuccessful biological control program in North America (Clausen 1978; Schooley et al. 1984).

The so-called Bermuda cedar scales (*Carulaspis minima* [Targioni-Tozzetti] and *Lepidosaphes newsteadi* [Sulc]; Homoptera: Diaspididae) are two armored scale insects accidentally introduced into Bermuda in the early 1940s. They have virtually extirpated a native tree there, the Bermuda cedar (*Juniperus bermudiana* L.; Cupressaceae). The Bermuda cedar scales have been the target of a biological control program because of the important scenic value the Bermuda cedar had for the tourist industry (Bennett and Hughes 1959; Groves 1955; Rosen and DeBach 1978).
These two known cases where North American native plant species have been threatened by accidentally introduced stenophagous insects involve plants occurring on an actual island and on habitat islands. Many rare plant species occur on unusual habitat islands (Stebbins 1980), such as serpentine substrates, shale barrens, and vernal pools.

Conflict Resolution

There are two key decision points with regard to conflicts in the course of any biocontrol project: the choice of target plants for biological control, and decisions regarding use of specific organisms as biocontrol agents.

In the United States, the WGBKWC was established under the joint weed committees of the U.S. Department of Agriculture (USDA) and the U.S. Department of Interior to advise on conflicts over target plants, and to advise on the selection of test plants for host-specificity testing. The WGBKWC later expanded its role to advise on decisions about the introduction of foreign biocontrol organisms for study in domestic quarantine facilities and for release into the environment. The WGBKWC serves as principal advisor to biocontrol of weeds researchers and to the Plant Protection and Quarantine programs of the USDA Animal and Plant Health Inspection Service (APHIS), which has final legal authority for issuance of federal permits for introduction of foreign phytophagous organisms (Klingman and Coulson 1982). In practice, APHIS has always followed the recommendations of the WGBKWC with regard to introduction of foreign insects for biocontrol of weeds.

The WGBKWC presently serves a valuable advisory role, but there is no evidence that it is able to resolve serious conflicts. Biological control is not alone in this regard, as society is struggling in general over satisfactory means of resolving technological and environmental conflicts (Abrams and Berry 1977; Cormick 1980; Fischhoff et al. 1981; Jasanooff and Nelkin 1981; McCarthy 1976; Okrent 1981; Ramo 1981; Ricci and Molton 1981; Starr and Whipple 1980; Stockholm 1980; Susskind and Weinstein 1981; White 1980).

Three major mechanisms for resolving conflicts in biological control of weeds are: (i) authoritative decision; (ii) mediation; and (iii) litigation.

Authoritative decisions are made by authorized bodies of experts or by administrative agencies with jurisdiction in a particular matter. The functioning of the WGBKWC is a weak example of this process, since they are authorized only to make recommendations. Critical to decisions reached by this process are authorization to make decisions, membership of the decision-making group, and membership of those allowed informational input into this group. It is possible that some variation on the WGBKWC could function more effectively in resolving biocontrol conflicts.

Mediation is a process by which an independent and neutral party (the mediator) helps to facilitate voluntary and essentially cooperative negotiations between conflicting parties (Amy 1983; Abrams and Berry 1977; Cormick 1980; Fanning 1979; McCarthy 1976; Mernitz 1980; Stockholm 1980; Susskind and Weinstein 1981). The resolution of the yellow starthistle conflict in California, discussed previously, appears to be an example of this process. Mediation has a successful recent record of resolving difficult environmental conflicts (Fanning 1979; McCarthy 1976; Stockholm 1980; Susskind and Weinstein 1981) and appears to hold much promise for resolving biocontrol conflicts. Cormic (1980), Stockholm (1980), and Susskind and Weinstein (1981) discuss the interaction of mediation with the legal system and with agency involvement.

Litigation is a process by which a decision is reached through a legal contest between conflicting parties within the judicial system. Litigation over the Echium conflict in
Australia (Delfosse and Cullen 1981) is an example of this process. The main criticisms of litigation as a general means of resolving technological and environmental conflicts are that: (i) it is often very costly in time and money; (ii) it is of an adversarial nature which introduces a gaming element into the process; and (iii) decisions often turn on technical points such as procedural issues rather than on the more substantive issues involved (Abrams and Berry 1977; Jaspanoff and Nelkin 1981; McCarthy 1976; Stockholm 1980; Susskind and Weinstein 1981). However litigation may be appropriate when conflicting parties are unwilling to negotiate a compromise or when one party wishes to establish a legal precedent (McCarrthy 1976; Stockholm 1980).

Any of these three means of resolving conflicts may be appropriate at times. I suggest a step-wise approach, where authoritative decision is the first step. This process could efficiently decide low conflict cases and at least provide a first screening of high conflict cases. If this process is unable to satisfactorily resolve a high conflict case, I suggest that mediation be tried next if the conflicting parties are willing to attempt negotiating a compromise solution.

Any conflict resolution process should consider advantages and disadvantages of biological control in each case, and alternatives to biological control, including the impact of no control. In conflicts over target plants, advantages and disadvantages of the target plant need to be considered. In conflicts over risk to nontarget plants, advantages of biological control of the target plant need to be weighed against disadvantages of risk to nontarget plants. The severity of conflicts varies between projects and particular prospective biocontrol organisms. For each possible biocontrol project or agent, the greater their disadvantages, the greater should be the advantages of successful biological control to justify the project or use of the biocontrol agent.

Acknowledgments


References


