EVALUATING PROPOSED BIOLOGICAL CONTROL PROGRAMS FOR INTRODUCED PLANTS

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ABSTRACT

Introduced plants in native ecosystems can be managed with a variety of techniques, including biological control, the introduction and establishment of natural enemies of the weed. While generally accepted as a permanent and ecologically accepted method of management, biocontrol has drawbacks, including high initial costs, long delays before results are visible, and a variable success record. It is therefore recommended that before a new biological control program is initiated, a full evaluation be made of the weed and its role in native ecosystems, local agriculture, and other areas in an effort to identify potential problems. A 20-point checklist with a subjective scoring system is proposed for making this evaluation. The scoring system provides a numerical total, which should indicate the potential for success of the program. The system may be more valuable as a method of ranking similar programs (to indicate which may be the best investment of funds and time) than as a predictive tool. To demonstrate the scoring system, three weeds considered major threats to native ecosystems in Hawai'i are evaluated.

INTRODUCTION

Other authors have discussed methods for evaluating introduced plants in native ecosystems to identify those that affect the systems severely enough to justify control efforts. Others have also discussed various control or management techniques available to resource managers to achieve control. One management technique is biological control, the introduction and establishment of the natural enemies of the introduced plants. Biological control is particularly attractive because, if successful, it can bring about a permanent solution to the weed problem; environmentally, it may be the least damaging control technique available for use in native ecosystems.

The biological control of weeds in Hawai'i and elsewhere has historically been almost entirely restricted to agriculture, usually

focusing on weeds that are major problems over large areas of rangeland. These weeds have caused easily recognizable losses for which costs can readily be identified and quantified. Obtaining support for biocontrol programs in such cases and justifying costs have therefore been relatively easy.

Securing support for biological control as a management option in native ecosystems may be more difficult to justify on economic grounds. Many remaining native ecosystems consist of small scattered blocks of public or private lands, increasing the chances of conflicts of interest and the potential for adverse impacts on interspersed private lands. Other problems, including low success rates, long lapses in initiating new programs, and initial high costs of biological control, may become more critical on natural areas than for programs aimed at weeds on agricultural lands with better funding. We have already discussed several possible problems with biological control and potential impacts on new programs (Markin *et al.*, this volume). The need for more public education about biological control in natural areas is another problem to consider.

The potential difficulties are great enough to justify developing criteria for evaluating proposed biological control programs. Ideally, such evaluation would allow predictions of program success and would provide indications of the difficulties in, and expenses of, a new program. Such a process would also provide a checklist for planning and organizing a proposed program. This paper presents a checklist of 20 factors that could influence the success of a proposed program and a scoring system for evaluating each factor.

PROCEDURES IN CONDUCTING BIOLOGICAL CONTROL

The history of biological control of weeds dates to 1902 (Julien 1982). Since that date, this science has undergone many changes, particularly in our understanding of the underlying natural processes that we are trying to control (population dynamics) and the approach we are using for selecting and establishing new agents. Biological control today follows a fairly standard procedure for selecting, testing, and establishing control agents (Huffaker 1957, 1959; DeBach 1964, 1974; Frick 1976). In initiating a program to control a weed, we generally follow a fairly prescribed sequence. For planning purposes alone, almost 100 steps or decision-making points have been identified in flow diagrams attempting to systematize the entire process of conducting a biological control program (Grabau and Spencer 1976). We have summarized these in 10 sequential steps, each incorporating a separate part of the process (Table 1).

To identify where problems are most likely to occur in a biological control program, we have reviewed past programs in Hawai'i and elsewhere in the world, including those that were not successful. Based on this review and on personal experience in planning and implementing weed control programs in Hawai'i, we have identified 20 critical factors that have contributed to the successes, failures, or difficulties of earlier programs

Table 1. Major steps in conducting a program aimed at biological control of an introduced plant.

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1. Determine range, economic, and ecological impact of the target plant.

2. Conduct literature review to determine what is known of the target plant.

3. Identify the original natural range of the target plant and the probable genetic epicenter for the genus.

4. Explore natural range of the target plant and of related species to inventory associated natural enemies.

5. Select the most promising natural enemies for potential biological control agents.

6. Determine biology and ecological requirements of candidate agents.

7. Conduct host testing to determine plants other than the target weed that each candidate agent can survive on, or temporarily feed on.

8. Select the most promising agents and obtain approval for their release.

9. Begin releasing agents.

10. Conduct an evaluation of the program to determine degree of success or reason for failure.

(Table 2). These factors apply to programs that use either insects or plant pathogens as the controlling agent. However, we restrict our discussion to programs using plant-eating (phytophagous) insects, since Gardner (this volume) has already discussed plant pathogens.

EVALUATION OF CRITICAL FACTORS

To evaluate the importance of each factor in a proposed program, we have used a scoring system on a scale of 0 to 5. A factor that could hinder or deter a program's success is scored 0. A factor that should simplify a program or contribute significantly to its success is scored 5. One factor has been used to eliminate a biocontrol program entirely, based on its impact on past programs. A program should not be started if this factor is rated zero. Another factor is weighted much more heavily (25) than other factors to encourage biological control if this condition is met.

Scoring of each critical factor is the responsibility of the resource manager and/or researcher, based on knowledge of the weed's biology, history, and role in local agriculture and society. (The role of the weed

Table 2. Checklist of critical factors that can influence the success of a proposed biological control program against an introduced plant, with a scoring system for indicating the relative importance of each factor to the overall program.

Critical Factor	Score
1. Availability of Quarantine Facilities	
--Quarantine facilities do not exist.	0
--Quarantine facilities and support laboratories available.	5
2. Administrative Support	
--Program administrators unfamiliar with or negative towards biological control.	0
--Program administrators personally familiar with biological control and committed to its support.	5
3. Long-term Funding	
--Uncertain: appropriated yearly or dependent upon outside sources.	0
--Funding totalling over $1 million committed for 5 years.	5
4. Available Scientific Expertise	
--No local scientists available or familiar with biological control of weeds.	0
--Trained and experienced scientists and technicians available to be assigned to or assist the project.	5
5. Geographic Area Affected	
--Weed established on a large geographic area such as a continent.	0
--Weed established in a very isolated geographic area, e.g., an island system.	5
6. Ecological Range of Weed	
--Weed well established in a number of ecological zones.	0
--Weed limited to a very narrow ecological zone.	5
7. Life Cycle of Weed	
--Weed an herbaceous annual.	0
--Weed a perennial shrub.	5

Critical Factor	Score

8. Density and Local Distribution of Weed
--Weed occurs as widely scattered individuals. 0

--Weed forms dense stands covering large areas. 5

9. Associated Insects and Pathogens
--Many insects or pathogens, both native or introduced,
attack weed and support numerous parasites and
predators. 0

--Few insects or pathogens have become established
on the weed. 5

10. Economic Importance of Target Plant
--In parts of its range, weed is a major
agricultural plant. Don't begin

--The weed has no recognized agricultural uses. 5

11. Redeeming Values
--Weed is recognized for some socially accepted purpose,
e.g., esthetic values, cover for wildlife,
watershed protection, etc. 0

--Weed has no redeeming values, now or
predicted for the immediate future. 5

12. Related Agriculturally Important Plant Species
--A related species of the plant is a major
economic crop within same ecological range. 0

--A related species of plants is of minor economic
importance, with different ecological requirements. 5

13. Use by Beekeepers
--Weed is widely used by beekeepers as a major source
of nectar and pollen. 0

--Weed has not been recognized, or used, as a
source of honey and pollen. 5

Table 2, continued.

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Critical Factor	Score

14. Related Endangered Species of Plants
--A related species of plants (within the same genus)
is an endangered species and shares the same
ecological range as the weed. 0

--No closely related species are endangered or threatened,
at least in the same geographic area. 5

15. Status of Target Weed Worldwide
--Plant is recognized as a problem only in a
very limited area. 0

--Plant has been introduced to many other areas of the world
and is recognized in most as a major weed. 10

16. Previous Biological Control Programs
--No programs attempted in other parts of the world. 0

--Major efforts made at biological control in other parts
of the world, including release of one or more
successful agents. 25+

17. Accessibility of the Plant for Study in its Natural Range
--Natural range covers underdeveloped, unfriendly,
or politically unstable countries. 0

--Natural range includes at least one developed country
that is friendly towards the United States. 5

18. Availability of Research Facilities in its Natural Range
--Agricultural research facilities staffed by trained
entomologist lacking, or at least not available. 0

--Well-staffed agricultural research facilities
engaged in biological control available. 5

19. Availability of Wild Genotypes
--Wild forms of the plant in undisturbed native ecosystems
unknown or represented by limited isolated populations. 0

--Plant still growing wild over large areas
of the original geographic range. 5

Critical Factor	Score
20. Availability of Closely Related Species	
--No closely related species within the same genus.	0
--Weed has many closely related species within the same genus.	5

in native ecosystems is considered serious if a biocontrol program for it is being considered, and thus is not scored here.) Each critical factor is generally self explanatory, but a narrative for each extreme is provided for demonstration purposes (Table 2).

Availability of Quarantine Facilities

The introduction of any live insect into the United States requires special permits issued by the U.S. Department of Agriculture Animal Plant Health Inspection Service. Permitting is totally dependent upon the availability of an approved quarantine facility in which the insects can be received, screened to remove diseased or parasitized individuals, and studied. There are at present two insect quarantine facilities in Hawai'i and nine on the U.S. Mainland (Klingman and Coulson 1982). Information on facilities and workers in biological control of weeds in the United States has been compiled by Coulson and Hagan (1985).

It was formerly possible to make introductions at a certified facility where preliminary screening and testing could be done, then conduct less-critical study at an approved state or university laboratory or insectary. This approach was recently used for introducing a native plant pathogen into Hawai'i. The screening was accomplished at the Federal Plant Pathogen Quarantine Facility at Frederick, Maryland, then the pathogen was introduced to Hawai'i and studied at the Department of Plant Pathology at the Mānoa campus of the University of Hawai'i (Trujillo *et al.* 1986). New regulations now make this procedure impossible in Hawai'i.

If a quarantine facility does not exist or is unavailable for use, an alternative temporary facility can be constructed and equipped. This, however, can cost $150,000 to $250,000 and take one to two years before it is fully approved. For a permanent, certified facility, the expected expense could exceed $1 million.

Administrative Support

This criterion, although obvious, warrants serious consideration. Administrators define long-term goals and program directions and allocate space, funding, and manpower. Their attitudes and continual support, and the infrastructure of the agency, are critical in approving a new

biological control program and in obtaining the necessary support. A legislative mandate for control acts to encourage administrative support.

A new biological control program usually requires 7-10 years before the first agents are released. Several years of monitoring should follow release. Therefore, an organization with primarily short-term objectives and priorities that often change, or that are revised yearly, probably does not provide suitable continuity in which to initiate a biological control program.

Long-term Funding

Biological control of weeds is expensive. Even if a quarantine facility is available, the cost of a full-scale program (Table 1) aimed at a single weed has been estimated at $1-2 million (Andres 1977; Harris 1979). Will the supporting agency commit itself for this amount over a 7-10 year period? If sufficient long-term funding is guaranteed, a major factor has been overcome. If the program must compete for available funding or find outside support, it may be dropped before it is completed. Of course, the funding cycles of most Federal and state agencies create a certain amount of risk that must be accepted for progress to occur.

Available Scientific Expertise

Biological control is now a recognized science taught in entomological departments throughout the U.S. According to Coulson and Hagan (1985), 219 investigators at present directly or indirectly conduct research related to biological control in the U.S. Department of Agriculture. Most of these researchers are presently engaged in the control of insects, with only 35 listed as actively working on the control of weeds. We estimate that an additional 20 to 30 qualified persons are located in at least six state plant and insect laboratories. If an experienced investigator can be found to head or at least participate in a new program, initiation and operations are greatly simplified. If experienced personnel are not available, inexperienced people must be hired and trained or existing entomologists transferred and trained. This increases the time before the new program is fully operational by an additional year or two.

Geographic Area Affected

The immediate goal of any biological control program is the introduction and release of an insect (occasionally a nematode, mite, or pathogen) into the ecosystem in which the weed is present. Once established, agents do not usually remain at their point of release, but eventually spread over part or most of the range of the weed. The total range of the weed must be considered in evaluating the impact of a biological control program, not just the natural area that is to be protected. The chance of conflict of interest (Andres 1980) increases in proportion to the size of the area and the number of people familiar with the weed in that area. If the weed is newly established and localized in a natural area, opposition to biological control should be minimal. (Interest in biocontrol at this point might also be slight until a larger area is occupied.) In contrast, a weed that is found well beyond the boundaries of a natural area is more likely to be considered beneficial in another area with different land use priorities.

The geographic range of a weed is not limited by political boundaries, and the effect of a biological control program on neighboring countries must also be considered. On the U.S. Mainland, when a researcher applies for permission to release a new biological control agent, the release request is submitted to a review committee representing various U.S. government agencies and institutions. Applications for agent release are also routinely forwarded by this review committee to Canada and Mexico if the weed exists in these countries (Klingman and Coulson 1982).

Ecological Range of Weed

The range of ecological areas over which an introduced weed has become established can affect the degree of success of a biological control program. In many past programs, the climatic range of introduced agents was not as broad as that of their host weed, resulting in pockets of unaffected plants. In Hawai'i, a successful program against prickly pear cactus (*Opuntia* spp.) has left much of this species unaffected at elevations above 3,300 ft (1,000 m). Lantana (*Lantana camara*), despite 50 years of effort and the introduction of over 35 different insects, still remains a serious weed in parts of several of the Islands (Davis *et al.* this volume).

A similar problem with extensive range has occurred with Klamath weed (*Hypericum perforatum*) in North America. While three introduced agents were successful in controlling this weed in the United States and most of Canada, the northernmost extreme of the weed's range in British Columbia was beyond the climatic tolerance of released insects; there the weed remains unaffected (Williams 1984). Surviving pockets can be ignored, handled by conventional methods of management, or efforts can be made to find additional biological control agents adapted to additional areas.

Life Cycle of Weed

In the past, most successes in biological control of weeds have been against shrubs and other perennial plants. This suggests that annual weeds, with their short life cycles and long periods of dormancy while in the seed stage, are difficult for biological control agents to attack (Huffaker 1957). In Hawai'i and other tropical and subtropical areas where many annuals can grow throughout the year, this may not be as critical as elsewhere. Two very successful weed programs in Hawai'i have been against two annuals, the puncture vine (*Tribulus terrestris*) and the spiny emex (*Emex spinosa*) (Markin *et al.*, this volume).

Density and Local Distribution of Weed

Generally, biological control programs have been conducted against weeds that formed extensive and dense stands, replacing large areas of desirable vegetation (usually range plants). To protect undisturbed native ecosystems, biological control may be considered against plants that are scattered, particularly early in the process of invasion. Biological control may not be as effective against scattered target plants as in dense stands of the weed because of insect survival and dispersal difficulties. For example, biological control of the prickly pear cactus *Opuntia aurantiaca* in Australia with the use of *Dactylopius austrina* (a wingless sucking insect with immature stages dependent upon wind dispersal)

was very effective in dense stands of cactus, but was ineffective in controlling isolated cactus patches. The effective but expensive solution was to disperse the insect manually to isolated clusters of plants (Hosking and Deighton 1979).

Associated Insects and Pathogens

The success rate for establishing new biocontrol agents in an area to date is about 50% (Markin *et al.*, this volume). Unfortunately, many established insects fail to build sufficient populations to overwhelm or significantly damage their host due to biologic interference by local parasites and predators that attack the introduced agents (Goeden and Louda 1976). A survey of naturally occurring predators (particularly ants) and general parasites attacking local Lepidoptera (butterflies and moths) and Coleoptera (beetles) in native ecosystems may indicate whether or not such problems might occur. No guidelines can be given for interpreting the results of such a survey. Presumably, however, the more abundant and diverse the parasites and predators, the greater the chance of interference with biological control introductions.

A preliminary survey of the insects already associated with the target plant is also useful to identify existing phytophagous insects. The survey may indicate that some potential biological control agents are already present. In North America, the introduced weed Scotch broom (*Cytisus scoparius*) once was a target for biological control (Goeden 1978; Julien 1982). A preliminary survey, however, showed that 10 European species of phytophagous insects had been accidentally introduced and were already attacking the plant (Waloff 1966).

Economic Importance of Target Weed

Although it may be difficult for resource managers to visualize any redeeming value for a weed invading a native ecosystem, they should realize that many weeds were introduced as potential crops and may still be used in agriculture. Of 20 major introduced plants in national parks in Hawai'i (Gardner and Davis 1982), ginger (*Hedychium* spp.) and common guava (*Psidium guajava*) are grown commercially, and koa haole (*Leucaena leucocephala*) and at least four species of grasses are recognized as livestock forage plants. Proposing biological control programs for common guava, ginger, koa haole, or any of these grasses may not be well supported because of opposition from agricultural interests. The original biological control program against cactus in Hawai'i was opposed by some ranchers, since they had learned to use cactus as an emergency food and moisture source for cattle during drought (Fullaway 1954). However, the cactus control program eventually was started anyway (Davis *et al.*, this volume).

Related Agriculturally Important Plants

Initiation of a biological control program for a weed closely related to a plant of recognized agricultural value is difficult but has been successfully accomplished. Biological control was undertaken and insects released successfully against thistles and knapweeds (*Cirsium, Carduus* spp., and *Centaurea* spp.) (Frick 1976; Goeden 1978; Julien 1982) in the U.S. despite their close relationships (all are in the same

tribe, Cynareae) to the safflower *Carthamus tinctorius* and the artichoke *Cynara scolymus*, both important agricultural plants. The ultimate decision to release biological control agents against this group of weeds was made by a review committee, which probably paid considerable attention to the benefits to be derived from a successful program against these major agricultural weeds, as opposed to possible losses if the agents proved capable of attacking an agricultural crop. Such a crossover is not likely and would have been demonstrated by extensive studies of the host range of the insect in its native homeland and by quarantine studies in the United States. However, the extra time required for these studies no doubt increased the expense of screening agents for thistles and knapweeds.

Holm *et al.* (1977) identified the 18 worst weeds of agriculture on a worldwide basis, and 10 of these are grasses. Yet not a single biological control program has ever been attempted for the group (Pemberton 1980), due to their relationships to major crop plants. Some programs are now being given serious consideration (C.W. Smith, pers. comm.). In Hawai'i, the sugar cane industry has been an important influence on proposals to control grasses in the past. As a rule, biocontrol programs should generally not be sought where target plants are closely related to crops of major economic importance (Table 2, item 10).

In Hawai'i, we are presently facing the problem of commercial species closely related to the forest weed banana poka (*Passiflora mollissima*). This plant, which grows at elevations of 1,000-2,000 ft (300-600 m) (LaRosa 1984, this volume), is related to the edible passion fruit *P. edulis*, which was grown commercially on 40 acres (16 ha) in 1984 (Anonymous 1985), but always at an elevation of less than 900 ft (300 m). Although it will be difficult to find a control agent that will not attempt to feed on passion fruit when starving, we hope to find one that not only does not prefer it but cannot successfully complete its life cycle on passion fruit or cannot survive in the warmer, drier conditions below 900 ft (300 m) elevation. To date, we have identified several insects that fit these criteria, but it will entail considerable extra time and cost in screening potential agents.

Use by Beekeepers

Beekeepers regularly oppose biological control programs because even the most noxious weeds may be important sources of nectar and pollen. The subject has been discussed earlier (Markin *et al.*, this volume), so it is sufficient to note that if the target weed is regularly used by beekeepers over any part of its range, opposition can be expected.

Related Endangered Species

Besides economically important plants related to the target weed, threatened or endangered species must be considered when releasing a new biological control agent. If one or more endangered species is even distantly related to the weed to be controlled, much more extensive host testing will be necessary to demonstrate the safety of potential biological control agents. The problem of related endangered species has recently complicated efforts to control leafy spurge (*Euphorbia esula*) in North America (Pemberton 1985).

Redeeming Values of Target Weed

In Hawai'i, some of our weeds were accidentally introduced, but many were deliberately brought in as potential agricultural crops. Others were introduced for landscaping, medicinal purposes, or ornamentals. Many of these plants are still valued for these purposes, or new purposes that have been since discovered, and conflicts of interest can be expected with their user groups (Andres 1980). Learning the history of the weed and its present intrinsic value to the local population are important parts of planning a new biological control program; identifying potential conflicts of interest before they occur is critical.

Status of Target Weed Worldwide

There is considerable value in working on weeds that are recognized as problems in other parts of the world. Other countries may be willing to cooperate in a new biological control program by participating in the actual research, providing financial support, or exchanging information if they already have a program of their own under way.

Previous Biological Control Programs

Emphasizing weeds that have already been successfully controlled by biological control programs in other countries is one of the surest guarantees of success. This factor is given great weight in Table 2 (25 points). Usually, the control agents are readily available and need only a minor amount of additional host testing against related native plants before they can be released. In Hawai'i, at least three of our most successful programs followed this pattern -- prickly pear cactus, Klamath weed, and puncture vine. However, even selecting weeds which have been successfully controlled in other countries does not guarantee success in a new area. We have been successful in controlling lantana in many areas of Hawai'i, but introduction of the insects effective in Hawai'i into 18 other countries where lantana is also a problem gave only partial success in five of the cases (Julien 1982).

Accessibility of Plant in Its Natural Range

An essential early step in conducting a biological control program is sending an explorer to the weed's country of origin to study and select potential agents. Easy and continued accessibility to the natural range of the weed is essential. If a weed's natural range is in undeveloped countries, the lack of maps, transportation systems, and general accommodations can hamper exploration. There are also countries where, for political reasons, an American would not be welcomed or want to venture.

Availability of Research Facilities in Plant's Natural Range

An additional way to simplify a proposed study and increase its chance of success is to conduct as much of the biological work and screening as possible within the natural range of the target weed. This can often be done cheaply and easily by using foreign facilities where a visiting scientist can be stationed, or a local scientist hired. In Italy, France, Greece, Argentina, and Korea, the U.S. Department of Agriculture maintains facilities where this type of work can be done (Coulson and Hagan 1985). Other facilities are maintained by the Commonwealth Institute of Biological Control in countries such as Trinidad, where the Hawaii Department of

Agriculture is presently doing most of its work on clidemia (Nakahara *et al.*, this volume).

Availability of Wild Genotypes of Target Weed

Another problem in biological control is the possibility that in its natural range the target weed may have become extinct or its range greatly reduced due to deforestation or replacement by agriculture. This problem has been encountered in our effort to control banana poka. To date, no wild plants have been discovered in three different surveys of the Andes, and the few insects collected have come from domestic plants growing around homes or in commercial plantings. At this time we are beginning to suspect that the original natural range of this plant, the forested areas of the Andes, has been almost totally eliminated by agricultural development (G. Taniguchi and R. Pemberton, pers. comm.). The situation limits our selection of races and genotypes of the few insects we have been able to find. Good genetic variation is an important characteristic of a successfully introduced species (Wilson 1963; Mackauer 1976).

Availability of Closely Related Species

Successful introduction programs for biological control were reviewed by Hokkanen and Pimental (1984), who pointed out that almost half of all successful biological control agents were not collected on the target hosts (both plants or insects), but on species closely related to the target. The implication is that insects associated directly with the target weed may have evolved a balance with their host, which prevents them from overwhelming and destroying it and therefore destroying themselves. Insects not directly associated with target weeds may be more likely to reach population levels needed to eventually overwhelm targets. Work with a weed in a genus with few species could therefore be a disadvantage, while working with a weed with many closely related species may provide a much larger pool of candidate biological control agents.

USE OF SCORING SYSTEM

To use the scoring system for evaluating chances of success with biological control of a particular weed, a resource manager or researcher, based on familiarity with his or her agency or organization, the native ecosystem at risk, and the target weed, can assign a value from 0 to 5 (more than 5 in two cases) to 18 of the 20 critical factors outlined above. The more values other than 0 or 5 are used, the more subjective the system becomes. The same people should rate all possible programs. When totalled, the final score can be used as an indication of probable success. A score of 100 or more would indicate that a program for a particular weed has a very good chance of success. Realistically, the scores are not a true indication of success of a proposed program; rather, scores provide an indication of the difficulty or ease with which a program can be completed. Difficulties with any one of the 20 factors mentioned may make a successful program very difficult or even impossible. Generally, however, no factor alone will totally negate a successful program. Most difficulties can be overcome with sufficient commitment of manpower and resources.

RATINGS FOR THREE IMPORTANT WEEDS
IN NATIVE ECOSYSTEMS OF HAWAI'I

To demonstrate the proposed scoring system, three weeds that are major threats to native Hawaiian ecosystems were selected and scored. All three weeds have been discussed by others in this volume -- banana poka (LaRosa), firetree (*Myrica faya*) (Whiteaker and Gardner), and gorse (*Ulex europaeus*) (Tulang). Scores applied to each of the 20 critical factors and the totals are shown in Table 3. Scores for factors 1 through 5 are the same for all weeds, since it is presumed the work would be done by the same research organization.

Banana poka. A biological control program against this weed has begun, and we have already referred to some of the problems encountered. Several preliminary studies have also been completed on the plant's local biology (LaRosa 1984) and distribution (Warshauer *et al.* 1983). Its present status in Hawai'i has also been discussed (LaRosa, this volume). In summary, the weed is presently established on over 100,000 acres (40,000 ha) but is restricted to forests between 3,000 and 6,500 ft (1,000-2,000 m). It is a perennial vine and forms very dense, continuous stands, usually worse where the forest canopy has been opened.

Our surveys have indicated the presence of few general insect predators associated with this plant, and our study of insects on blackberry (*Rubus argutus*), another introduced weed with similar distribution, has led us to believe there may not be a large population of general larval parasites in the rain forest ecosystem where banana poka is found (Nagata and Markin 1986).

The major disadvantage of biological control for this species in Hawai'i is that banana poka is related to the edible passion fruit *P. edulis*, which is commercially raised on a very limited scale (Anonymous 1985). Fortunately, passion fruit is grown only at lower elevations (below 900 ft or 300 m), so we hope to find an agent with a sufficiently narrow climatic range to exclude it from lower elevations. Banana poka is not used by beekeepers, and there are no native species in the same genus, or family, in Hawai'i. There are several possible areas of conflict, including the fact that native birds now utilize its nectar and that the feral pig (*Sus scrofa*) and the kalij pheasant (*Lophura leucomelana*), both game species, eat its fruit.

Banana poka is established in Australia and New Zealand but is not considered a weed in either country. A survey in South America has been conducted to identify potential biological control agents (Pemberton 1982), so some information exists on its natural enemies. This plant's natural range is in the high Andes (9,000 ft or 3,000 m and above) of northern South America, and problems encountered in trying to work in some parts of this area include political instability, few research facilities, and few trained entomologists with whom to collaborate. Also, the plant apparently has been exterminated by agricultural development over much of its natural range, although a large number of domestic varieties and closely related species exist in South America.

Table 3. Evaluation of three proposed biological control programs of introduced plants of Hawaii.

	Assigned Score		
Critical Factor	Banana poka program	Firetree program	Gorse program
1. Availability of quarantine facilities	5	5	5
2. Administrative support	5	5	5
3. Long-term funding	3	3	3
4. Available scientific expertise	5	5	5
5. Geographic area affected	5	5	5
6. Ecological range of weed	5	3	5
7. Life cycle of weed	5	5	5
8. Density and local distribution of weed	3	5	5
9. Associated insects and pathogens	5	5	4
10. Economic importance of target plant	5	5	5
11. Redeeming values	3	5	5
12. Related agriculturally important plants	0	5	5
13. Use by beekeepers	5	5	5
14. Related endangered species of plants	5	5	1
15. Status of target weed worldwide	0	0	5
16. Previous biological control programs	0	0	5
17. Accessibility of the plant for study in its natural range	0	4	5
18. Availability of research facilities in its natural range	1	4	5
19. Availability of wild genotypes	0	3	5
20. Availability of closely related species	5	3	2
Total	65	80	90

Banana poka appears to be a difficult biological control subject to undertake, based on the final total score of 65. The major problems are conflict of interest due to its close relationship to the edible passion fruit, and the difficulty in working in its natural range, either to study it or to obtain a usable supply of insects for evaluation.

Firetree. One survey of the natural range of firetree for associated natural enemies has been conducted in the Azores, Madeira, and Canary Islands in the Atlantic (Hodges and Gardner 1985). In Hawai'i, the plant is distributed on all major islands except Moloka'i and infests an estimated 85,000 a (35,000 ha) ranging from 1,900 to 6,600 ft (500-2,000 m). It has invaded many different ecosystems, which suggests that we may have difficulty finding biological control agents that can cover the extremes of its range. It is a perennial small to large tree, and in many areas it forms very dense stands.

Firetree has never been considered an agricultural plant in Hawai'i or in its natural range, nor are any of its close relatives used in agriculture. However, wax myrtle (*M. cerifera*) is grown as an ornamental in Hawai'i (Neal 1965). While the weed has a small flower, it is presently not recognized by beekeepers as a source of nectar or pollen. Similarly, the weed has no relatives in the same family in Hawai'i, so it is not related to any rare plants. While *M. faya* at one time was used for reforestation and ground cover, since 1944 its noxious nature has been recognized, and several mechanical and herbicidal programs have been initiated for its control (Kim 1969; Gardner and Kageler 1982).

Firetree is recognized as a weed only in Hawai'i; therefore, no biological control programs have been attempted except in Hawai'i, where one insect, *Strepsicrates smithiana*, was established in 1955. The insect has only been found to attack the closely related wax myrtle (Krauss 1964; Julien 1982). The original natural range of the plant is restricted to islands in the Atlantic Ocean, and political stability is not a problem. Most of these islands contain limited agriculture research facilities which could be used by visiting scientists. Unfortunately, wild stands of this plant in undisturbed native ecosystems are apparently limited (Hodges and Gardner 1985). Finally, firetree belongs to a fairly small family with only 45 species in two genera (Neal 1965).

In conclusion, the extensive distribution and ecological range of firetree in Hawai'i may make it a difficult plant to control with a single biological control agent, although its native range is well suited for conducting foreign exploration. Unfortunately, the limited wild populations of this plant in its natural range, lack of closely related species, and few reported associated insects probably indicate that there will be some difficulty finding natural agents with which to work. The species does not show potential for agricultural conflicts, but being a problem only in Hawai'i, and belonging to a very small family of plants, means that little work has been undertaken to provide background information. However, when compared to banana poka (with a score of 65), firetree, with a score of 80, may be more amenable to biological control.

Gorse. Gorse is a perennial shrub with spines, which, once established, rapidly forms very thick, impenetrable stands. It is a potentially significant problem in native ecosystems in Hawai'i, although many resource managers are unfamiliar with it. It is presently restricted to two infestations, totalling about 35,000 a (14,000 ha), on Maui and Hawai'i; dense stands cover less than 7,500 a (3,000 ha) (Markin *et al.* 1988). In Hawai'i its range is generally limited to between 3,000 and 6,600 ft (1,000-2,000 m) in open pasture, although it has begun to invade forests dominated by both native and alien species. Insects associated with gorse in Hawai'i have been surveyed (Markin 1984), and no native insects were found attacking it, although several introduced Lepidoptera already feed on its flowers. One biological control agent, a small seed weevil (one of three insects introduced in the 1950s) is now well established.

Gorse was once used for food by sheep (*Ovis aries*) and to form hedgerows in Hawai'i. However, since the 1940s, it has been declared a noxious weed. It has no close relatives in Hawai'i that are presently used in agriculture. However, as a legume, it is distantly related to many agricultural and native species. Fortunately, gorse is in a different tribe (Genisteae) than all native and important introduced species. In other parts of the world, gorse is widely used by beekeepers as a major source of nectar and pollen, but not in Hawai'i.

To date, we have been unable to find any recognized uses for gorse, although in other parts of the world it is still used for livestock foraging, hedgerows, and firewood. Because of its status as a major weed in many different parts of the world, a considerable amount of literature on it exists, including several annotated bibliographies (Anonymous 1975, 1978; Gaynor and MacCarter 1981).

From its native range in western Europe, gorse has been introduced to many parts of the world, including India, South America, New Zealand, Australia, the west coast of the United States, as well as Hawai'i. In all of these areas it is considered a major weed problem.

The natural range of this plant is western Europe, and extensive surveys have been conducted on its natural enemies in England, France, Spain, and Portugal. In Europe, at least 20 closely related species of *Ulex* are known (although many are considered synonymous by some authorities), and over 100 insects have been found attacking them. The British Commonwealth Institute for Biological Control, headquartered in England, has, at the request of New Zealand, conducted extensive studies of this plant in Europe.

In general, we believe that the past efforts devoted to the study of this weed, both by the State of Hawai'i and foreign countries; the earlier efforts at biological control; the extensive facilities and availability of experienced scientists familiar with gorse in Europe; and the respectable list of natural enemies known to attack it and its close relatives indicate that there is a good chance that a biological control program against this weed in Hawai'i would be successful.

CONCLUSION

This checklist provides resource managers or researchers with a decision-making tool that can be used to predict the potential success of biological control of an introduced plant in native ecosystems. The scoring system is subjective, and we undoubtedly have omitted many critical factors that other investigators would include. Values we have assigned to each critical factor may not be considered by others to be realistic or representative of the importance of a factor under the local conditions and environment in which they have to work. However, if a resource manager concludes that biological control of a weed in a natural area is a viable management option, the scoring system may be useful as a method for comparing the chances of success for a number of weed species.

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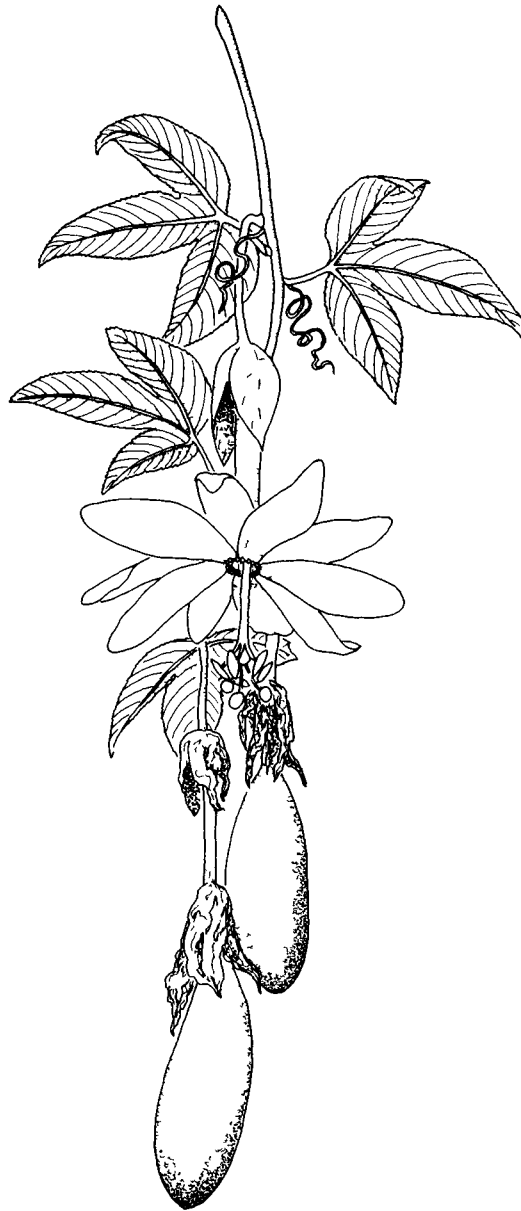
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