

STATUS OF BIOLOGICAL CONTROL OF WEEDS IN HAWAI'I AND IMPLICATIONS FOR MANAGING NATIVE ECOSYSTEMS

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ABSTRACT

Biological control of weeds in Hawai'i dates back almost 90 years. Seventy-three species of insects and one disease organism have been introduced in an effort to control 21 species of weeds. Forty-three of these introduced species of insects and one species of fungus have become established on 19 weeds. In 11 cases, populations of the phytophagous organisms have been sufficiently high and persistent enough that they succeeded in partially or completely eliminating the host weeds as significant ecosystem components. The majority of biocontrol programs have been aimed at controlling agricultural weeds. The problem of weeds in native ecosystems was serious enough to require initiation of a biological control program on weeds in Hawaiian forests in 1983. Biological control of weeds has several drawbacks: 1) it can be expensive; 2) implementation may take 10 years or more; 3) chances of success are about 50%; 4) a potential ecological hazard exists when introducing a foreign organism into an ecosystem; 5) it may be difficult to justify, economically and ecologically; and 6) conflicts of interest can arise between individuals or groups with different views about whether a plant is a problem or not. When weed control is restricted to agricultural concerns, most of these problems can be overcome. However, if biological control of weeds is extended to natural ecosystems, several of these problems become critical and can prevent progress or greatly reduce their efficacy. Biological control of weeds in native ecosystems should be considered a management tool to be used in conjunction with all other management tools available to the resource manager, rather than an overall solution to weed problems.

INTRODUCTION

Hawai'i has one of the oldest and most extensive biological control programs in the world. Others have reviewed the more successful projects against several species of weeds in Hawai'i (e.g., Davis *et al.*, this volume). These projects, however, represent only a small number of the programs thus far initiated. In this paper, biological control of weeds in

Hawai'i is reviewed, the potential of biological control as a management tool for protecting native ecosystems is examined, and the problems that can be expected when initiating a new program are summarized. Emphasis will be on biological control of weeds with insects, although some work with pathogens will be mentioned.

STATUS OF BIOLOGICAL CONTROL OF WEEDS IN HAWAI'I

By 1982, on a worldwide basis, biological control had been attempted against 82 species of weeds through release of 189 potential biocontrol agents, including insects, plant pathogens, nematodes, and mites (Julien 1982). Of these, 73 insects and one plant pathogen had been introduced for control of 21 weeds in Hawai'i (Table 1). Approximately half of Hawai'i's target species were cosmopolitan weeds. In these cases, the insects were first tested, released, and proven effective against the host weeds in other countries.

In Hawai'i, biological control of weeds in agricultural situations is not a new, experimental, or untested management tool. It is a proven technique with a long history of development and a respectable rate of success, and some unforeseen ecological problems (Howarth 1983). Biological control is now a long-term goal of most management programs for agricultural weeds and natural areas in Hawai'i.

Biological control of weeds in Hawai'i until now has focused on those weeds on agricultural lands, primarily rangelands. However, several weeds such as firetree (*Myrica faya*), blackberry (*Rubus argutus*), clidemia (*Clidemia hirta*), and glorybush (*Tibouchina urvilleana*) have invaded Hawaiian forests, and programs against lantana (*Lantana camara*) and prickly pear cactus (*Opuntia ficus-indica*) have possibly reduced these weeds as major problems in some natural areas.

BIOLOGICAL CONTROL OF WEEDS IN NATIVE HAWAIIAN ECOSYSTEMS

Interest in the biological control of weeds that affect natural areas in Hawai'i has been renewed with increasing recognition of the value of the areas and the importance of impacts of weeds in them. A biological control research program begun in 1983 is jointly funded by the Hawaii Department of Land and Natural Resources, the U.S. Department of the Interior National Park Service, and the U.S. Department of Agriculture Forest Service. A new quarantine facility dedicated to studying biological control of introduced weeds with insects in Hawaiian forests has been constructed in Hawaii Volcanoes National Park.

The quarantine building was completed in the spring of 1984, certified by the Animal and Plant Health Inspection Service and the State of Hawai'i in October, and received its first shipment of foreign insects in December of that year. The facility is an escape-proof insect quarantine building,

Table 1. Introduction of insects and diseases for the biological control of weeds in Hawai'i.*

Target weed	Common name	Origin	Release dates	Total species released	Total species established	Success of program**
<i>Ageratina adenophora</i> (Sprengel) King and Robinson	Maui pāmakani	Central America	1944	1	1	Partially effective; excellent control in drier areas, ineffective in most moist areas
<i>Ageratina riparia</i> (Regal) King and Robinson	Hāmākua pāmakani	Mexico	1955 1973 1974	4***	3***	Very successful; plant has been eliminated as a weed over most of its range
<i>Clidemia hirta</i> (L.) D. Don	Clidemia, Koster's curse	Tropical America	1953 1969	2	2	Effective in open pasture, but not effective in shade areas where greatest problem exists
<i>Cyperus rotundus</i> L.	Purple nutsedge	Eurasia	1922 1925	2	2	No detectable effect
<i>Elephantopus mollis</i> Humboldt, Bonplaud Kunth	Elephant's foot	Central America	1961	1	1	No detectable effect (Davis & Krauss 1962)
<i>E. scaber</i>		Cosmopolitan		1	?****	No effect; not believed established

Target weed	Common name	Origin	Release dates	Total species released	Total species established	Success of program**
<i>Emex spinosa</i> (L.) Campdera and <i>E. australis</i> Steinhell	Emex	N. Africa Western Europe South Africa	1957 1962 1962	3	1	Very successful control of both plants by the same insect
<i>Hypericum perforatum</i> L.	Klamath weed	Eurasia N. Africa	1965- 1966	3	3	Very successful; plant almost impossible to find
<i>Lantana camara</i> L.	Lantana	Tropical America	1802- 1974	27	15	Very successful; few surrounding patches in very dry areas
<i>Myrica faya</i> Aiton	Firetree	Island of Atlantic Ocean	1955	1	1	No detectable effect
<i>Opuntia cordobensis</i> Spegazzini		Argentina	1949	1	0	Not established (Weber 1951)
<i>Opuntia ficus-indica</i> (L.) Miller (= <i>O. megacantha</i> (L.))	Prickly pear, pānini	Central America	1949 1950 1951	8	4	Very successful; few patches left at higher elevations
<i>Pluchea symphytifolia</i> (Mill.) Gillis	Sourbush	Tropical America	1955 1959	2	2	No detectable effect

Table 1, continued.

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Target weed	Common name	Origin	Release dates	Total species released	Total species established	Success of program**
<i>Rubus argutus</i> Link (= <i>R. penetrans</i> Bailey or <i>R. lucidus</i> Rydberg)	Blackberry	North America (?)	1962- 1968	5	3	Not considered effective
<i>Schinus terebinthifolius</i> Raddi	Christmas berry	South America	1932 1954 1961	3	2	No detectable effect
<i>Salsola kali</i> L. (= <i>S. australis</i> R. Brown)	Russian thistle	Eurasia	1980	2	0	No effect since insects not established
<i>Tibouchina urvilleana</i> L.	Glorybush	SE Asia 1964	1938	3	2	No detectable effect
<i>Tribulus terrestris</i> L. and <i>T. cistoides</i> L.	Puncture vine	Cosmopolitan Tropical	1962 1963	2	2	Very successful; complete control both formed by same two insects
<i>Ulex europaeus</i> L.	Gorse	W. Europe	1927 1958 1961	3	1	Destroys 50% of seeds, but no detectable decrease in spread of plant (Markin 1984)

Target weed	Common name	Origin	Release dates	Total species released	Total species established	Success of program**
Total 21				74	45	Very successful 8 Partially successful 3 No effect 10

*Release data from Lai and Funasaki (1983) unless noted. Some of the data differ slightly from summaries presented by Julien (1982) and Goeden (1978).

**Ranking of success based on interview of Hawaii Department of Agriculture entomologist and weed control personnel (1984-85).

***One agent was a disease.

****Fate unknown, no further reference in literature.

in which insects from foreign countries can be received, screened to remove diseased or parasitized individuals, studied, and host-tested against native and agricultural plants to determine if their feeding is specific enough to qualify as suitable biological control agents. Both the quarantine facility and the research program are operated under the supervision of the Hawaii Department of Agriculture, with additional support from the National Park Service, the Department of Entomology at the University of Hawaii, and the U.S. Department of Agriculture Animal and Plant Health Inspection Service. A Steering Committee, comprised of representatives of each of these agencies, sets priorities for the program.

For the first time, a program for biological control of weeds that threaten native ecosystems has been specifically set up and funded. Presently (1987), the facility is screening and host-testing potential biological control agents of banana poka (*Passiflora mollissima*), considered Hawai'i's major forest weed (Warshauer *et al.* 1983). As time, money, and availability of candidate insect biological control agents allow, expansion of the program should include other forest weeds such as firetree, yellow Himalayan raspberry (*Rubus ellipticus*), and glorybush, as well as participation with other agencies in programs dealing with *Clidemia*, gorse (*Ulex europaeus*), and other species.

PROBLEMS WITH BIOLOGICAL CONTROL OF WEEDS

An examination of past biological control programs in Hawai'i and elsewhere in the world indicates that biocontrol is not the simple solution to weed problems that many resource managers presume it to be. Considerations in setting up a program, particularly for weeds in native ecosystems, include: a predicted success rate of about 50%; high program costs; time required to test, establish, and evaluate agents; ecological hazards; economic justifications; and conflicts of interest. These will be discussed below.

50% Success Rate

In Hawai'i, 73 insects and one plant pathogen have been introduced for biocontrol of 21 plants (Table 1) (Lai and Funasaki 1983). The target weed was completely eliminated as a problem except in a few isolated patches in eight cases; weeds were eliminated in limited areas in three cases; and in the remaining 10 cases, the insects have failed to become established, or if established, have failed to exert any noticeable effect. The success rate for biocontrol in Hawai'i is thus approximately 50%.

DeBach (1974) estimated that complete or substantial biocontrol success was achieved for weeds about 55% of the time, worldwide. The most recent summary of the status of biological control of weeds (Julien 1982) reviewed and evaluated the effectiveness of programs against 82 species of terrestrial plants. Since each of his sources reported the results differently, it is difficult to summarize and compare accurately the different programs. However, the following interpretive conclusions can be drawn.

Worldwide, biological control programs on lantana have been implemented in at least 18 countries or island groups, using most of the same insects that were effective in a successful control program in Hawai'i (see Davis *et al.*, this volume). However, outside of Hawai'i, no country reported satisfactory control, and only five countries indicated partial control -- a success ratio of only 28%. This ratio seems unusually low, given that biocontrol of lantana is one of the oldest and most extensive programs in the world.

In contrast, 10 species of cactus have become established throughout arid regions of 11 countries or island groups. Efforts to control these plants have been very successful, with at least nine, or 83%, of the control programs reporting partial to complete success. The most successful control programs worldwide for any weed (Julien 1982) are against Klamath weed (*Hypericum perforatum*). Biological control has been initiated against this weed in seven countries or island groups, with partial to complete success reported by all.

Of the remaining 70 species of weeds discussed by Julien (1982), 97 control programs have been initiated worldwide. Of these, partial to complete success was reported for 33 (47%). (The success ratio may now be higher, since at least 25% of the programs were listed as ongoing or unevaluated at the time of Julien's report.)

Worldwide, the success rate for weed biocontrol programs resulting in at least partial to substantial or complete control of the target weed is thus about 50%, comparable to the success rate in Hawai'i. However, as noted by Harris (1980, 1981), we may be underestimating the success achieved. Normally, a program is considered successful if ranchers or land managers can report disappearance of the weed from an area. However, insects, once established, may not kill the plant outright but may induce stress sufficient to prevent further spread, reduce regeneration, or reduce competitiveness of the weed in a particular ecosystem. In this sense, biocontrol of weeds in Hawai'i may have been more successful than recognized in the past. Unfortunately, quantitative monitoring of regeneration and reduction or spread of weeds is usually not a strong component of biological control programs.

High Program Costs

A prerequisite to conducting a biological control program with insects is access to an escape-proof facility in which foreign insects can be quarantined while their biology and feeding preferences are studied. Besides the two quarantine facilities in Hawai'i, nine state or Federal facilities are located on the U.S. Mainland (Klingman and Coulson 1982). These are the only facilities certified to receive direct shipments of foreign insects. Any potential agent entering the U.S. must be cleared through one of these quarantine facilities before being sent to other university, Federal, or state laboratories. The cost of constructing and equipping a new quarantine facility is fairly high. The smallest, simplest design that meets both U.S. Department of Agriculture and state certification (such as the one recently constructed at Hawaii Volcanoes National Park) today costs over \$150,000. A larger facility has just been

completed by the U.S. Department of Agriculture at Albany, California, at a cost of about \$1 million. Of course, a biological control program aimed at a specific weed does not require its own quarantine facility if it can use an existing one. But most facilities are already dedicated to specific programs, so the waiting list for new programs may be quite long. In addition, a new program must assume its share of overhead and operating costs.

Quarantine facility costs are only a minor part of a biological control program. The insects attacking the target weed in its native range (probably a foreign country) must be inventoried by scientists in order to select promising agents. If possible, preliminary biological studies of the insects should be conducted in their natural ranges to determine their life histories and association with the weed; feeding tests in the field, to determine the variety of hosts of the promising agent, should also be done. If foreign scientists with suitable facilities can be located, much of this work can be contracted. Otherwise, U.S. scientists must be assigned to the foreign country on a part- or full-time basis. For the banana poka control project, approximately \$40,000 a year is budgeted for foreign exploration, including expenses of hiring local help and periodic visits by U.S. scientists. On the *Clidemia* project, a scientist has been stationed in Trinidad for two years, at a cost of about \$48,000 per year (Nakahara *et al.*, this volume).

The operation of the quarantine facility where most the work will be conducted, including the salaries of at least one scientist and support personnel, costs approximately \$100,000 a year. For the program in Hawai'i, presently aimed at banana poka, foreign exploration, quarantine work, and equipping and setting up the quarantine facility is estimated at about \$1 million over a five-year period. Additional effort beyond five years will likely be required for successful control.

Andres (1977) estimated that the total cost of a biocontrol program for a single weed species ranges between \$1 and \$2 million. Harris (1979) stated that in Canada, a complete biological control program for a single weed would require 18.8 to 23.7 scientist years, would cost between \$1.2 and \$1.5 million, and would require the establishment of 2.3 biocontrol agents. These costs are relatively small compared with the annual cost of applying herbicides to control many agricultural weeds. However, when biological control is applied to non-agricultural weeds, particularly in natural ecosystems, \$1 to \$2 million could be considered excessive by some in relation to the intangible values we are trying to protect.

Time Requirements

The time necessary to set up and conduct a successful biological control program for a weed is considerable. Construction and approval of a quarantine facility or obtaining permission to use an existing structure can be expected to take a minimum of two years. Once a facility is in operation, given that a guaranteed supply of foreign insects for testing has been arranged, it can take three to five years to evaluate 10 or more insects; five of these may be selected for release. The establishment of insects in the field usually requires a rearing facility to propagate the

insects, which are then released at different locations and times of year, the goal being to achieve the right combination of variables for establishment. This can take an additional two to three years. Thus, 7-10 years may be required for successful establishment of five insects.

Once insects have been released and established in the field, it may take quite some time before their populations have built up and spread sufficiently to cause appreciable impact on the target weed. In Hawai'i, impact on target weeds has been quite rapid; this is attributable to the moderate climate and use of insects that produce many generations per year. In 1973-74, for example, two insects and one plant pathogen were released to control Hāmākua pāmakani (*Ageratina* (= *Eupatorium*) *riparia*); by 1980, almost complete control had resulted (Nakao *et al.* 1981; Lai *et al.* 1982). In 1965-66, agents were introduced to control Klamath weed, and by 1972, the target weed was nearly eliminated (Davis 1971, 1972). In 1962 and 1964, agents were introduced to control two species of puncture vine (*Tribulus terrestris* and *T. cistoides*). Within four years, the weeds were completely eliminated in many areas (Davis and Krauss 1966). Even more spectacular were the results obtained in controlling emex (*Emex australis*); the weed was nearly eliminated in most areas within three years (Davis 1961; Davis and Krauss 1962).

The impacts of cactus insects in Hawai'i have been more gradual. Species were introduced from 1949 through 1951 and within five years had destroyed much of the cactus at low elevations. However, nine years later they were reported still spreading and only causing appreciable damage at altitudes above 3,000 ft (900 m) (C.J. Davis, pers. comm., 1986).

The small weevil *Apion ulicis* was successfully introduced to Hawai'i in 1958 to destroy the seeds of gorse. In 1966, the weevil was reported established (Goeden 1978). Yet by 1972, its populations still were very low, with only 1.5% of the gorse pods attacked. By 1984, the population had increased and 84% of the pods were infested (Markin 1984).

Hawai'i's most famous biocontrol program, for lantana, began in 1902. A fair degree of control was obtained by the early 1950s but release of new insects continued through that decade (Krauss 1962). It is generally accepted that lantana was not controlled until the early 1960s, a period of almost 60 years after introduction.

In general, insects introduced for weed control have become established in Hawai'i in 10 years or less, often with significant destruction of the plant in as short a time as three to four years. Even under optimum conditions, however, a program can take a minimum of 10-15 years from inception until significant control is obtained.

Ecological Hazards

In the biological control of weeds, starving adult insects have been known to move to nearby species, usually closely related to the weed, once the host weeds have been decimated. The best-known example is *Teleonemia scrupulosa* (Hemiptera: Tingidae), introduced into Africa in the early 1950s to control lantana (Davies and Greathead 1967; Greathead 1971). The

insect readily became established and rapidly built up high populations which, combined with drought, brought about complete defoliation of the lantana. Without a food source, the starving adults moved to adjacent fields of sesame (*Sesamum indicum*), on which they tried to feed. The adults were able to live on the alternate plant but were unable to reproduce, and in a short time the population of *T. scrupulosa* also died.

Additional cases have been reported when insects introduced for control of puncture vine and Klamath weed attacked related plants on which they were able not only to feed but to successfully reproduce (Andres 1980, 1985). Adults of insects introduced to Hawai'i to control Klamath weed have also been found feeding on the related plant *Hypericum degeneri* (Davis 1971). The small leaf rolling moth *Croesia zimmermanii*, introduced to control blackberry, was discovered feeding on 'ākala (*Rubus hawaiiensis*), one of two endemic *Rubus* species in Hawai'i (Gagné 1972). In none of these cases has the introduced insect caused appreciable damage to the new host, but these cases emphasize that there is an element of risk when introducing any new biological control agent.

Economic Justifications

To determine whether the expense and effort of a biological control program is justified, the economic and ecological impacts of any weed should be fully evaluated before any biological program is initiated. Biological weed control programs can be expensive and may not be justifiable if the weed is actually causing few or no problems. In some cases, alien plants have probably been designated as weeds and control programs initiated against them without fully understanding their economic impact to agriculture. The same difficulty can occur for weeds in native ecosystems, where the impact is not economic but ecological; however, determining ecological values may sometimes be difficult.

Another consideration is that nothing is gained by biological control if another disruptive weed invades the habitat from which the target species has been removed. In the United States, Klamath weed was successfully controlled by the introduction of its natural enemies but was replaced by the weed *Elymus caput-medusae* in many areas (Huffaker 1959). A similar situation may have occurred on the island of Hawai'i, where a successful biological control program eliminated lantana over large tracts of rangeland on the western side of the island; some of this rangeland is now unusable since it has been invaded by Brazilian peppertree or Christmas berry (*Schinus terebinthifolius*). If the biocontrol program for banana poka in Hawaiian forests is successful and this weed is eliminated, will native trees and shrubs regenerate, or will weeds such as alien *Rubus* spp., firetree, strawberry guava (*Psidium cattleianum*), or introduced grasses dominate?

One argument against biological control presumes that the weed will disappear if left alone long enough. This is possible since many weeds are primary invaders that take advantage of disturbed ecosystems resulting from grazing, fire, logging, or soil disturbance. If areas are managed properly so that no further disturbances occur, natural succession may take its

course, and eventually climax species will replace and eliminate the weed. This solution has been proposed for the control of gorse in New Zealand, where it has been suggested that this weed acts as a nurse crop for native forest trees and shrubs. If left alone, in 15 to 50 years gorse will mature, die, and be replaced by native climax forest (Hackwell 1980). On most oceanic islands, however, this scenario is far less likely to occur, especially where invading plants change successional patterns, soil nutrients, light and moisture regimes, and other processes in favor of alien species and to the disadvantage of natives (Vitousek, this volume).

Conflicts of Interest

Conflict of interest is always a potential threat to any biological control program. Many plants that need to be controlled on rangeland or in native ecosystems are important to other interest groups that claim the same areas for their own uses or objectives (for example, watersheds vs. hunting in Hawai'i). Conflicts of interest also occur where a weed is a serious problem in one area but is beneficial in adjacent areas. In Hawai'i, for example, the biological control program against the prickly pear cactus has been one of the most successful (Davis *et al.*, this volume). The program was first opposed by ranchers who occupied lands poorly supplied with water and feed and considered the cactus an asset during droughts (Fullaway 1954). In New Zealand, gorse is considered a prime weed problem, but some Angora and Cashmere goat farmers on marginal land can profitably use this shrub to establish and support their herds (Krause *et al.* 1984).

Conflict of interest seems almost continual between landowners who attempt to control noxious weeds and beekeepers who view the same weeds as a source of nectar and pollen. In Australia, beekeepers not only opposed efforts to control *Echium plantagineum* (Delfosse 1985), but initiated legal actions to stop the biocontrol program (Cullen and Delfosse 1985). A similar conflict presently exists in New Zealand, where beekeepers view gorse as a critical pollen source for overwintering hives. Their opposition has delayed the release of several very promising biological control agents (R. Hill, pers. comm. 1985).

As a final example, in Hawai'i, attempts to initiate a program to control banana poka may encounter opposition because hunters know that feral pigs (*Sus scrofa*) and the Kalij pheasant (*Lophura leucomelana*) use the fruit as a food source. Environmentalists might argue that because a native honeycreeper (Drepanidinae), the 'i'iwi (*Vestiaria coccinea*), is now using its floral nectary as a food source (Pung 1971), successful elimination of banana poka may impact 'i'iwi populations.

FUTURE OF BIOLOGICAL CONTROL IN HAWAII

None of the problems reviewed here are new. All have existed since the inception of biological control but have been unimportant as long as control was limited to a few major agricultural weeds. The benefits of a successful program were considered great enough to outweigh potential harm,

and landowners and agricultural interests were politically strong enough to support programs they believed were needed. This is no longer the case worldwide. The release of any new biological control agent must be approved by one or more review committees, which usually contain representatives of most interested groups. Also, if an opposing group felt ignored, it could initiate legal actions against the agency or scientist conducting the biocontrol program. This happened recently in Australia (Delfosse 1985), where the conflict over the control of weeds became sufficient to force the legislature to pass a series of laws to attempt to resolve it (Australian Commonwealth Government 1984; Field and Bruzzege 1984; Cullen and Delfosse 1985).

Biological control is still one of Hawai'i's more viable management tools to combat introduced plants. Questions, however, persist about the ecological hazards, effectiveness, and need for biocontrol programs, and more vigorous opposition can be expected when conflicts of interest occur. All individuals involved in biological control must strive to respond adequately to outside criticism. To this end, researchers must concentrate on more vigorous examination and documentation of results of past programs and the progress of ongoing ones. More rigorous selection and testing procedures are required before new agents are released, to ensure that they are the best available, have the highest chance of containing the host weed, but have minimal or at least acceptable adverse impacts on other plants. Host testing of native species (as well as agricultural species) will probably have to increase. Monitoring the success and failure of releases must receive more attention and support. As conflicts of interest will continue and probably increase, public education and involvement of user groups during planning should become an important part of any new program.

RECOMMENDATIONS FOR BIOLOGICAL CONTROL OF WEEDS AS A MANAGEMENT TOOL FOR NATIVE ECOSYSTEMS

In native Hawaiian forests, biological control can play an integral role and provide acceptable control of alien plants with minimal impact. For natural areas in Hawai'i as well as elsewhere in the world, biological control of weeds definitely should be considered as a management tool in planning any control or containment program. However, before embarking on such a program, all considerations of need, cost, impacts, etc. should be addressed. A successful program can completely and permanently eliminate the target weed as a significant ecological component, but many variables are likely to prevent this. Before undertaking a biological control program in a natural area, the following questions should be considered:

1. Are **funds** sufficient to set up the program and operate it to completion? Biological control is not cheap. A conservative estimate of a complete biological control program for one weed is at least \$1 million.

2. Is sufficient **time** available to set up and oversee a biological control program to its completion? An estimate based on experience in Hawai'i is that a new program takes 10 to 15 years to succeed.
3. Do researchers, managers, and administrators acknowledge that the **chance of success** for a biological control program is about 50%? Do they also acknowledge that even in the most successful programs, pockets of the target weed will persist where the ecological range of a weed is often greater than that of its natural enemies?
4. Is the **ecological risk** of introducing a foreign insect into a natural area acceptable? The chance that a properly studied introduced insect would move to a nontarget native or agricultural plant (after screening tests have been conducted) is very low, but nevertheless exists.
5. Are those advocating biocontrol willing to accept challenges, **conflicts of interest**, and opposition to the new program? As biological control expands to natural areas, public lands become increasingly involved. Other interest groups have valid uses for those lands or adjacent areas where the target weed may be considered an asset. Conflicts of interest can be expected.

If, after reviewing the above questions, the answers are all "yes", then biological control may provide one solution to a weed problem. However, it is not the only possible solution. In view of the chance that a biological control program may not succeed, the 50% success rate of past programs, and the possibility of a program being halted before it can be completed, biological control should be considered as one alternative in a weed management program. If a biocontrol program is successful, the weed problem may be permanently solved; but more likely, other methods of alien plant management (chemical, manual, mechanical, cultural, and ecological control) will be needed to supplement biocontrol, at least in some areas.

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Literature Cited

- Andres, L.A. 1977. The economics of biological control of weeds. *Aquatic Botany* 3:111-123.
- Andres, L.A. 1980. Conflicting interests and the biological control of weeds. *Proc. V, Internatl. Symp. Biol. Contr. Weeds*, 11-20. Brisbane, Australia.
- Andres, L.A. 1985. Interaction of St. Johnswort insects and North American *Hypericum* species. *Proc. VI, Internatl. Symp. Biol. Contr. Weeds*, 235-239. Vancouver, Canada.
- Australian Commonwealth Government. 1984. Biological control act 1984, No. 139 or 1984 an act to make provision for the biological control of pests in Australian Capitol territory and for related purposes. Australian Commonwealth Govt. Printer.
- Cullen, J.M. and E.S. Delfosse. 1985. *Echium plantagineum*: catalyst for conflict and change in Australia. *Proc. VI, Internatl. Symp. Biol. Contr. Weeds*, 249-292. Vancouver, Canada.
- Davies, J.C. and D.J. Greathead. 1967. Occurrence of *Teleonemia scrupulosa* on *Sesamum indicum* Linn. in Uganda. *Nature* 213:102-103.
- Davis, C.J. 1961. Recent introductions for biological control in Hawaii -- VI. *Proc. Haw. Entomol. Soc.* 17:389-93.
- Davis, C.J. 1971. Recent introductions for biological control in Hawaii -- XVI. *Proc. Haw. Entomol. Soc.* 21(1):59-62.
- Davis, C.J. 1972. Recent introductions for biological control in Hawaii -- XVIII. *Proc. Haw. Entomol. Soc.* 21:187-90.
- Davis, C.J. and N.L.H. Krauss. 1962. Recent developments in the biological control of weed pests in Hawaii. *Proc. Haw. Entomol. Soc.* 18(1):65-67.
- Davis, C.J. and N.L.H. Krauss. 1966. Recent introductions for biological control in Hawaii -- XI. *Proc. Haw. Entomol. Soc.* 19(2):201-204.
- Davis, C.J., E. Yoshioka, and D. Kageler. [this volume] Biological control of lantana, prickly pear, and Hāmākua pāmakani in Hawai'i: a review and update.
- DeBach, P. 1974. *Biological control by natural enemies*. London: Cambridge Univ. Pr.
- Delfosse, E.S. 1985. *Echium plantagineum*: a program halted by legal injunction in Australia. *Proc. VI, Internatl. Symp. Biol. Contr. Weeds*, 293-299. Vancouver, Canada.
- Field, R.P., and E. Bruzzese. 1984. Biological control of blackberry -- resolving a conflict of Australia. *Proc. VI, Internatl. Symp. Biol. Contr. Weeds*, 341-349. Vancouver, Canada.

- Fullaway, D.T. 1954. Biological control of cactus in Hawaii. *J. Econ. Entomol.* 47(4):696-700.
- Gagné, W.C. 1972. Notes and exhibitions: *Apotoforma* sp. *Proc. Hawn. Entomol. Soc.* 21:158-59.
- Goeden, R.D. 1978. Part II. Biological control of weeds. In *Introduced parasites and predators of arthropod pests and weeds: a world review*, ed. C.P. Clausen, 357-545. U.S. Dep. Agric. Handb. No. 480. Washington, D.C.: U.S. Govt. Print. Office.
- Greathead, D.J. 1971. Progress in the biological control of *Lantana camara* in East Africa and discussion of problems raised by the unexpected reaction of some of the more promising insects to *Sesame indicum*. *Proc. II, Internatl. Symp. Biol. Contr. Weeds*, 89-92. Rome, Italy.
- Hackwell, K. 1980. Gorse: a helpful nurse plant for regenerating native forests. *Forest and Birds* 13:25-28.
- Harris, P. 1979. Cost of biological control of weeds by insects in Canada. *Weed Sci.* 27:242-50.
- Harris, P. 1980. Evaluating biocontrol of weeds projects. *Proc. V, Internatl. Symp. Biol. Contr. Weeds*, 345-353. Brisbane, Australia.
- Harris, P. 1981. Stress as a strategy in the biological control of weeds. In *Biological control in crop production*, ed. G.C. Popowizas, 330-340. Symp. Agric. Res., May 18-21, 1980, Beltsville, Maryland. London: Allanheld, Osmun.
- Howarth, F.G. 1983. Classical biocontrol: panacea or Pandora's box. *Proc. Hawn. Entomol. Soc.* 24:239-244.
- Huffaker, C.B. 1959. Biological control of weeds with insects. *Ann. Review Entomol.* 4:251-276.
- Julien, M.H. 1982. *Biological control of weeds, a world catalogue of agents and their target weeds*. Commonwealth Inst. Biol. Contr. Farnham Royal, Slough, U.K.: Commonwealth Agric. Bur.
- Klingman, D.L. and J.K. Coulson. 1982. Guidelines for introducing foreign organisms into the United States for biological control of weeds. *Weed Sci.* 30:661-667.
- Krause, M.A., A.C. Beck, and J.B. Dent. 1984. *The economics of controlling gorse in hill country: goats versus chemicals*. Res. Rep. 149. New Zealand Agricultural Economics Research Unit.
- Krauss, N.L.H. 1962. Biological control investigation on Lantana. *Proc. Hawn. Entomol. Soc.* 18:134-136.
- Lai, P.-Y., and G.Y. Funasaki. 1983. List of beneficial organisms purposely introduced for biological control in Hawaii, 1890 to 1982. Plant Pest Control Branch, Hawaii Dep. Agric. Unpub. rep.

- Lai, P.-Y., G.Y. Funasaki, and S.J. Higa. 1982. Introductions for biological control in Hawaii: 1979 and 1980. *Proc. Hawn. Entomol. Soc.* 24(1):109-113.
- Markin, G.P. 1984. Biological control of the noxious weed gorse *Ulex europaeus* L.: a status report. [abstract] *Proc. Fifth Conf. Nat. Sci., Hawaii Volcanoes National Park*, 77. Honolulu: Univ. Hawaii Coop. Natl. Park Resour. Stud. Unit.
- Nakahara, L.M., R.M. Burkhart, and G.Y. Funasaki. [this volume] Review and status of biological control of clidemia in Hawai'i.
- Nakao, H.K., G.Y. Funasaki, S.Y. Higa, and P.Y. Lai. 1981. Introduction for biological control in Hawaii 1977 and 1978. *Proc. Hawn. Entomol. Soc.* 23:425-30.
- Pung, E. 1971. The diet of the i'iwi. *Hawaii Aloha Aina* 2:3-5.
- Rosenthal, S.S., D.M. Maddox, and K. Brunetti. 1985. *Principles of weed control in California*, 65-94. Fresno, Calif.: Thomson Pub.
- Vitousek, P.M. [this volume] Effects of alien plants on native ecosystems.
- Warshauer, F.R., J.D. Jacobi, A.M. LaRosa, J.M. Scott, and C.W. Smith. 1983. *The distribution, impact, and potential management of the introduced vine Passiflora mollissima (Passifloraceae) in Hawai'i*. Tech. Rep. 48, Univ. Hawaii Coop. Natl. Park Resour. Stud. Unit. Honolulu.
- Weber, P.W. 1951. Recent liberations of beneficial insects in Hawaii. *Proc. Entomol. Soc.* 14:327-330.