The Philosophy, Procedures, and Cost of Developing a Classical Biological Control of Weeds Project[1]

John J. Drea, Jr.

Beneficial Insects Laboratory, PSI
Agricultural Research Service
U.S.Department of Agriculture
Building 476, BARC - East
Beltsville, Maryland 20705

ABSTRACT: This paper presents the philosophy behind classical biological control of weeds and discusses the steps to establishing a viable project at a weed's native and foreign locations. The concept of classical biological control — the introduction of exotic natural enemies to control plants of exotic origin — is examined through several examples of successful projects, in particular alligatorweed (*Alternanthera philoxeroides*) and Klamath weed (*Hypericum perforatum*). Implementation of a typical project involves twenty steps. These include the activities required prior to actual field research, the research itself at the plant's native and foreign locations, meeting the requirements for the introduction and release of natural enemies, and post-release studies for the final evaluation of the project. The authorization that must be obtained during a project is considered. A short discussion, with examples, of the approximate costs and benefits of successful projects is given.

THE PHILOSOPHY OF THE BIOLOGICAL CONTROL OF WEEDS

For every plant, there is a guild of phytophagous (plant-eating) organisms. Farmers, homeowners, foresters, and those directly interested in the welfare of certain plants wage continual battle to protect useful plants from insects, mites, nematodes, diseases, and other "pests." Classical biological control involves the manipulation of these phytophagous organisms, not to protect plants from attack but to encourage and provoke attack of those plants we consider weeds. For the purpose of this discussion, a weed is an unwanted plant of foreign origin; such weeds are often referred to as "pests."

Under normal conditions, phytophagous organisms and their plant hosts develop a mutual relationship. If the plant becomes numerous, the phytophages become numerous. Thus the phytophages, along with physical and other factors, help reduce the plant population to a level that cannot support large numbers of plant feeders. Consequently, the dependent organisms decline to low population levels but are not eliminated. The result is a series of oscillations of the plant population and its natural enemies, the phytophages. The ideal situation is one in which the oscillations of the plant population do not rise above a level of acceptable economic or environmental loss. Populations above this level may require the use of biological, chemical, or physical methods of control, or a combination thereof, to reduce the populations of the pest.

When a plant species invades a new area and its associated natural enemies are left behind, there is little to hinder the growth and spread of the plant. Often the insects, diseases, and other biotic organisms of the invaded area do not attack the introduced plant, or their attack is of little consequence and the invader becomes a weed. Most of the important weeds in North America are not native.

The goal of classical biological control of weeds is to reunite a weed in an invaded area with the most effective and safest of its natural enemies that did not come with it. The term classical differentiates biological control that uses exotic natural enemies from more recently developed techniques such as the use of hormones, pheromones, and genetic engineering.

Successful classical biological control is achieved when natural enemies that are host-specific are introduced, established, and distributed and the weed is reduced to economically or environmentally acceptable (nonpest) status. Because conditions in nature vary greatly, control may range from slight, through partial, to complete in a given area. Furthermore, control may vary within different geographic regions infested by the same weed.

Plants such as Klamath weed (a St. Johnswort, *Hypericum perforatum*), which

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came from Europe and covered western North American pastureland (Holloway 1964), and alligatorweed (*Alternanthera philoxeroides*), which came from South America and clogged southern waterways in the United States (Coulson 1977), have caused millions of dollars of damage in North America. Introduced insects have brought these weeds under control, at least in some areas.

In recent years, the use of less effective organisms on target weeds has received more attention. Although these agents do not directly control a plant, they may reduce the survival capacities of the pest by stressing it. This in turn may enhance the impact of chemical pesticides, plant competition, or other environmental pressures on the weed.

Exotic biotic agents have been used successfully to control introduced plants in many parts of the world (Goeden 1978). Often this technique is investigated only after all other control techniques have proven to be too costly, ineffective, or hazardous. This discussion focuses on the use of arthropods to control weeds, but the philosophy and the steps involved are generally applicable when other natural enemies such as pathogens and nematodes are used.

The concept of biological control is relatively simple. However, it is not a rapid method of control, nor is it without a substantial initial capital expenditure. When it is successful, the results obtained are permanent, requiring little, if any, additional funding but with a very favorable cost to benefit ratio.

PROCEDURES IN A BIOLOGICAL CONTROL OF WEEDS PROJECT

Preliminary Phase

Fiscal considerations of the project

Justification for the expenditure of funds is a major preliminary aspect of any project. The cost of planned research must be acceptable in relation to the financial loss or ecological damage caused by the weed if it is not controlled. Weed control projects often require ten or more years for completion. Consequently, funding must have a solid base and an efficient mechanism for distributing funds over the life of the project.

Authoritative identification of the target plant species or complex of species

It is essential to know the taxonomic identity of the plant before entering into an extended and expensive research program. Identification is the key to determining the origin of the plant, its close botanical relatives, what information already exists regarding its natural enemies, and its economic or environmental importance.

Information search

A thorough search of the literature, museum records, and collections is indispensable to obtain information on the biology, distribution, and fauna and flora associated with the plant and its close relatives.

Feasibility of biological control

There must be some reasonable indication that the project will be successful or worthwhile. Some factors to be considered are: the origin of the plant (exotic or native), its botanical relationship to other plants, efficacy of other weed control methods, actual and potential geographic range of the plant, and the complex of natural enemies associated with the target plant.

Consideration of conflicts of interest

Any conflict of interest that may arise from the successful control of the target weed should be identified and a strategy should be planned for its resolution. Conflicts may be based on the use of the plant as food, fuel, or fiber, or because of its aesthetic or environmental value. The fact that another weed may take over if the target weed is substantially reduced should not discourage attempts to control the plant. (We do not forego medical research on one disease because another disease may attack the cured individual!)

Selection of foreign areas for research

Presumably, the best area for obtaining effective natural enemies of an exotic weed pest is the native home of the species or genus of the plant. Usually a plant is not a pest where it originated, in part because of the action of natural enemies. In its native home a plant often develops a close and singular relationship with many of the organisms associated with it. The closer the relationship between a plant and a phytophage, the greater the likelihood that the natural enemy is host-specific. This, in turn, increases the potential for a successful project.

Selection of personnel and laboratory facilities

The success of a project is partially dependent upon the personnel and the facilities involved. The integrity of the research is totally dependent on the personnel and the available facilities. The personnel must be qualified and dependable; the research facilities must be conducive to high-quality research. Good quarantine facilities are mandatory; the escape of an unwanted organism through human error or because of poor facilities could be disastrous for the country involved, its neighboring states, and the science of biological control.

Selection of the species of plants to be tested

Before any phytophagous organism is released into a country, it must undergo a series of screening tests to ensure that the organism will not become a noxious pest. Consequently, a representative list of plant species that will be subjected to host specificity tests must be established. The list should include selected food crops, range and forage plants, plants of aesthetic value, endangered plant species, native relatives of the target species, and other plants of economic or environmental value. The list of plant species is prepared by a committee composed of entomologists, botanists, environmentalists, and others knowledgeable in the interaction of plants, insects, pathogens, and other aspects of a control program. The committee is under the auspices of the Technical Advisory Group (TAG), a permanent committee of the Animal and Plant Health Inspection Service

(APHIS), U.S. Department of Agriculture, that provides technical guidance, advice, and recommendations relating to biological control of weeds projects.

Survey of fauna associated with the plant in invaded areas

An essential part of the preliminary phase of a project is the collection of baseline data on natural enemies associated with the plant in the invaded areas. Life tables developed from this data will provide insight into the relative importance of the domestic phytophagous organisms and their potential relationship with the target weed. The first natural enemies selected for study are those that attack the plant at a vulnerable period in its cycle or feed on parts of the plant free from attack by native phytophages.

Obtain domestic authorization and approvals

During initial phases of the program, TAG helps resolve conflicts of interest that may arise relating to control of a particular plant species. TAG advises APHIS on the issuance of permits for entry and interstate movement of organisms, in addition to those required by specific states. As stated earlier, the input from TAG is essential to the development and approval of the list of plant species to be tested.

Foreign Activities Phase

Contact with and authorization from appropriate officials in foreign countries

Many countries have, in addition to the normal requirements for entry and travel within a country, specific restrictions relating to research within their borders. Therefore, all legal requirements related to the entry and exit of natural organisms and any extended residence of individuals involved must be determined, complied with, or planned for prior to any foreign activities of the project. Furthermore, it is a diplomatic courtesy and necessity to inform other appropriate officials of the host government (e.g., Ministry of Agriculture) of plans for travel and research within their jurisdiction. Also, American diplomatic missions to the countries involved should be informed of official activities of the project personnel.

Foreign exploration

Guided by accumulated information, surveys are made to locate populations of the target plant in its natural habitat and to collect all natural enemies associated with it. When possible, juvenile arthropods are reared to the adult stage for identification. The collected specimens are sent to appropriate specialists for authoritative determination. Many associated species can be eliminated from further consideration if they are identified as economic pests. Detailed field observations help investigators select promising species for study and possible introduction.

Contact with and support by research organizations within the host countries also help during this phase of a project. Problems with research, facilities, transportation, lodging, and language often can be solved by colleagues from the countries visited.

Host acceptance test

Because possible varietal or racial differences may occur in the target plant species, one of the first studies of a potential agent is a host acceptance test. The potential agent must attack the variety of the plant growing in the invaded area, otherwise, additional research with the phytophage is of little direct value.

Screening tests

The phytophage must be sufficiently restricted in its host range, and must not present an unacceptable threat to other plant species. To determine the degree of host specificity, research should include host range studies, studies of selective feeding and oviposition, and starvation tests. Screening can be done simultaneously on several candidate agents. These tests may require several years of foreign activity. Federal quarantine regulations require that, whenever possible, testing should be done at a foreign location.

Tests that cannot be completed at the foreign location because of inconclusive results, plant rearing difficulties, budget restrictions, quarantine requirements of the host country, etc., may be conducted at a domestic quarantine laboratory with appropriate authorization.

Continual foreign support

Provisions should be made to ensure continued support of the foreign phase of the operation, since additional specimens eventually may be needed to augment the domestic research. Foreign support may be obtained by establishing "permanent" overseas facilities, through cooperative agreements with foreign institutes, or by short-term trips by domestic personnel.

Domestic Activities Phase

Quarantine requirements and legal documentation

For security purposes, every biological control agent coming into the United States must enter through a quarantine facility. Permission for entry, in the form of a shipping permit, must be obtained from the Plant Pest Quarantine offices of APHIS. To obtain this permission, TAG must review the results of the research conducted with the natural enemy to determine if the organism should be allowed into quarantine in the United States for supplemental research. After this review, TAG may accept the results or recommend that entry be denied, or that additional research be completed before a permit is issued for importation.

Establishment of release sites

Several suitable release sites should be selected prior to the release of a natural enemy. These sites should be relatively permanent, free from chemical applications, near other infestations of the weed, and at the disposition of the research project. This is an important part of the entire project; unless the organisms are given a reasonable chance to survive, multiply, and disperse, all the research leading to that stage will be fruitless.

Clearance for field release in the United States

The research must show that the phytophage is not a risk to any aspect of the environment and that it is host-specific to the degree established as necessary at the onset of the project. There must be clearance from TAG and authorization granted by APHIS for release of the organism from quarantine. An Environmental Assessment, required by the National Environmental Policy Act, must be completed by APHIS prior to the initial release of a biological control of weeds agent. In addition, any state regulations relating to shipment, receipt, or release of the beneficial organism within state boundaries must be considered and followed.

Release of beneficial phytophages

All previous activities have been directed toward this moment in the project. The release of a beneficial phytophage must be done with considerable care. The transportation of the target weed's natural enemy to the field must be made with minimum stress. Freezing, overheating, dehydration, and delay must be avoided. Some insects must be kept separate or isolated during transit to avoid cannibalism. Weather conditions and time of day may be critical. In general, the natural enemy must be released under the best possible conditions. The healthier the phytophage the greater the chance for establishment.

Post release studies

Studies should continue after the phytophage has been released into the field to evaluate its status and its impact on the weed. If a colony is established, the impact of the phytophage should be monitored. A program of redistribution can be established if the organism is slow to disperse to new areas. Also, it is important to determine whether additional species of natural enemies are needed to complement the effect of the initially introduced species.

If there is a reduction in the population of the weed, studies should be made to determine what species of plant(s) is replacing the weed. If applicable, the natural enemies of these species and assessment of their impact should be incorporated into any integrated pest management program for the target weed.

The results of the project need to be published in a timely manner. Scientific and popular papers should be prepared during the project to make the information available to the scientific community, the public, and the administrators who require concrete results to authorize continued financial support for this project and for future projects.

A cost to benefit analysis should be made to justify the expenditure of funds and determine the impact of the control of the weed on the environment, agriculture, wildlife, and wherever else the plant was a pest.

THE FINANCIAL COST AND BENEFIT OF A BIOLOGICAL CONTROL OF WEEDS PROJECT

Despite the amount of effort expended in the research on the biological control of weeds, relatively little has been directed toward cost-benefit analysis of this control approach. Few, if any, entomologists are economists and relatively few projects have been subjected to the scrutiny of an economist's evaluation. With the growing competition for research funds, economic evaluation is becoming a major part of a biological control project.

According to Harris (1979), the development and implementation of a single weed project in Canada required from Can. $1.2 to Can. $1.5 million (as of 1979). Calculations by Andres (1977) for the alligatorweed project indicated about U.S. $1 million cost. The greatest expenditure is supporting the scientists involved in a project; researchers have reported a commitment of from 19 to 28 scientist-years for a single biological control of weeds project.

Figures for the financial benefits are as difficult to determine, if not more so. Consider that once a plant has been reduced to nonpest status it may be replaced by another species of weed. In Australia, the control of one form of skeletonweed, *Chondrilla juncea*, by the introduced rust fungus, *Puccinia chondrillina*, was followed by the increase of two other forms of the weed. Because the take-over is proceeding slowly, the financial cost of the control obtained is considered to be justified (Cullen 1985).

Replacement by another weed does not always occur. When Klamath weed was reduced by beetles introduced into the western United States, bunch grass returned and the pastures regained productivity (Holloway 1964).

Sometimes a weed is controlled before the potential extent of infestation by the plant has been attained. If Klamath weed had not been reduced to the status of a roadside plant, how much of North America would it have invaded? Similarly, how many miles of canals would have been blocked by alligatorweed if the beetle and the other biotic agents had not been effective?

If the beneficial organisms have become established and are effective, what has been gained? According to DeBach (1974), every dollar of research in classical biological control yields a $30 benefit. It is very difficult to determine the actual financial benefit for the biological contol of a weed. Often, prerelease studies to determine the monetary loss caused by a weed or its extent of infestation are not conducted. This is especially true for range and pasturelands that are marginal in their support of livestock, or for those areas that are considered more import for their role in preserving natural diversity.

The figures derived by the Australians for the control of *Chondrilla* are probably some of the best estimates available, although they, too, are contested. Cullen (1985) reports that "in 1979 values, the savings in reduced production losses for the 1978–79 season was Aus. $48.928 million."

After the natural enemies of a weed are released and control becomes apparent, the project leaders may be directed to other demanding projects. They will not have time for intensive or detailed benefit analyses. I doubt that we will ever arrive at a concrete measure of the benefit of the biological control of any weed. However, we can say that the plant used to be a pest and that we are not bothered by it anymore. The plaque erected by the ranchers in the west to commemorate the control of Klamath weed by imported leaf-feeding beetles is one of the best indications of a successful project. Other plaques are in order elsewhere.

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