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Biocontrol of Weeds: Bureaucrats, Botanists, Beekeepers and Other Bottlenecks

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Abstract

Seven problems facing biocontrol of weeds are discussed: (1) inoculative biocontrol is a matter of public interest, requiring investigation of both monetary and ecological costs and benefits; but enabling legislation is also necessary; (2) prediction of agent damage needed to achieve control may be determined empirically by clipping; (3) laboratory host tests only measure the ability of the agent to utilize the plant — the opportunity to utilize it in nature and the advantage of doing so, also need to be considered; (4) most fears about biocontrol concern the reduction of species or genetic diversity. In fact, consumer pressure is the reason for diversity and the survival of rare plant species; (5) the probability of serious damage to an endangered plant depends on its distribution pattern; (6) some problems in establishing agents are related to the use of agent host races from other plant taxa. The possibility of increasing the genetic base of the agent is discussed; and (7) the alternative is a more precise identification and collection from the target taxon.

Lutte Biologique Contre les Plantes Nuisibles: Bureaucrates, Botanistes, Apiculteurs et Autres Goulots d'Étranglement

Le rapport traite de sept problèmes liés à la lutte biologique contre les plantes nuisibles: (1) la lutte biologique par inoculation constitue un domaine d'intérêt public dont les avantages et les inconvénients sur les plans économique et écologique doivent faire l'objet de recherches, et exige l'adoption le lois; (2) Il est possible de déterminer empiriquement, par échantillonage le degré de degâts materiels que doivent causer les agents biologiques pour parvenir à enrayer les plantes nuisibles; (3) les essais en laboratoire ne permettent que de déterminer la capacité de l'agent biologique à utiliser la plante. Il faut aussi examiner les possibilités et les avantages d'utiliser les agents biologiques dans la nature; (4) la majorité des préoccupations en matière de lutte biologique concernent la réduction des espèces ou de la diversité génétique. En fait, les pressions exercées par les consommateurs ont permis d'assurer la diversité et la survie des espèces de plantes rares; (5) les risques de perturbations graves à une espèce menacée d'extinction dépendent de sa répartition; (6) en matière d'établissement des agents biologiques, certains problèmes sont suscités par l'utilisation de races d'agents provenant d'hôtes d'autres taxons de plantes. Le rapport traite des possibilités d'élargir la base génétique des agents biologiques; et (7) la solution de rechange consiste à adopter de meilleures méthodes d'identification et de prélèvement des agents des taxons cibles.

Introduction

The recent rapid growth in the interest and use of biocontrol of weeds throughout the world has increased the urgency of a number of persistent problems. Several speakers from other disciplines have been invited to discuss aspects of these problems during the VI International Symposium on Biological Control of Weeds (Delfosse 1985). The purpose of this talk is to set the stage in the hope of increasing the progress towards solution. The seven problems that I think will be the most serious bottlenecks in the near future are as follows: (1) how to determine the public interest regarding a candidate weed; (2) poor predictability of effects on target weeds; (3) difficulty of interpreting screening tests; (4) concerns about effect of agents on plant diversity; (5) how to assess the threat to endangered plant species; (6) use of poorly adapted agent host races; and (7) inadequate taxonomic identification of the target weed.

Public Interest

Inoculative biocontrol must be done as a matter of public interest since the effects cannot be restricted to individual properties. Determination of this interest involves assessing the prospective monetary and ecological costs and benefits of biocontrol before releases are made. Biocontrol is only worthwhile if there is a positive return and if it is better than can be achieved by other means of control. To my mind, it is irresponsible to embark on a program likely to cost $2 million and 20 scientist-years (Harris 1979) without such a study. I would like to interest economists in how this should be done but have been horrified by the cynical attitude of some: with a large enough contract, they will determine whatever I want about the weed. I would rather collect the data myself, since unless I am convinced about the justification of the project, I am not likely to be able to get support for it. The problems are often not as great as they first seem: if the costs are in the order of $2 million (Harris 1979) and the benefits in terms of several hundred million/yr, either figure can be out by several million without affecting the justification for biocontrol. It is necessary to determine the returns from other means of controlling the weed for comparison with biocontrol; for example, I think that the study of Cranston *et al.* (1983) for knapweed in British Columbia is a good model for determining the economics of chemical control.

The political aspects of an inoculative project are often much more difficult to solve than the economic ones. For example, a lady in British Columbia complained that *Chrysolina quadrigemina* (Suffr.) (Coleoptera: Chrysomelidae) beetles had destroyed a stand of *Hypericum perforatum* L. (Clusiaceae) she used for making herbal tea (Wilkinson, pers. comm.). I am not sure that she ever understood that the beetles had done her a favour as the plant is toxic. Public uses of weeds run from occasional and unexpected uses like these to important industries like beekeeping, for which a weed may be a major source of pollen and nectar. All of these people have a justified complaint if their interests are not considered or are dismissed arbitrarily.

The approach that I favour is the preparation of an overview report with a wide enough circulation to uncover any interests that were overlooked. It helps the discussion between opposing interest groups, such as may occur between ranchers and beekeepers, if the losses and benefits are quantified in monetary terms. The reports presently being prepared by us also discuss the proposed agents and screening tests. I would like to see them published as a means of increasing their availability, but they are not suitable for most journals.

Not only is life easier if there is general support for a biocontrol project, but unless there is enabling legislation, it may be necessary that support is unanimous because of the rule of law principle. The rule of law is fundamental to a legal system. The Magna Carta in Britain in 1215 was concerned with the rule of law, as it restricted the King from acting arbitrarily, so that subsequently he required enabling legislation. Australia recently found that if there was no enabling legislation it did not matter if a biocontrol program was in the public interest and had general public support (Cullen and Delfosse 1985). The result was an out-of-court settlement with two graziers and two beekeepers who objected to the biocontrol of *Echium plantagineum* L. (Boraginaceae) (Anon. 1983). I suggest that if you do not already have it, you get enabling legislation for biocontrol of weeds.

Predicting the Effect of Biocontrol Agents

I find that there is a credibility gap when I cannot predict how much damage each agent will do to the weed and how much damage needs to be done to control it. Inundative biocontrol avoids this problem as the rate of application, such as 250 kg/ha of the white amur fish (*Ctenopharyngodon idella* Valenciennes; Cyprinidae) for the control of aquatic weeds (van Zon *et al.* 1978) is determined before it is released for use. Inoculative biocontrol if started from scratch is a 20-year program that normally involves the establishment of several agents before control is achieved. It starts with great optimism but by about the 10th year when one or two agents have been established that feed on the weed without reducing its density, the ranchers or other clients have lost faith and the bureaucrats with the funds are restless. The general feeling is that biocontrol is 'pie in the sky by and by'.

The need is to be able to measure progress towards the target in numerical terms. Plant species vary greatly in the amount of damage that they will tolerate. The general rule is that resistance to harvesting or grazing increases with the ability of the plant to replace its leaves (Hyder 1972). This presumably also applies to flowers and roots if these parts are damaged. For example, Julander (1968) found that the perennial forb *Valeriana edulis* Nutt. (Valerianaceae), a deer fodder plant, tolerated removal of 50% of its herbage for 10 years but declined when 75% of the herbage was removed. *Geranium richardsonii* Fisch. & Trautv. (Geraniaceae), on the other hand, declined under a 50% clipping regime; while the shrub *Holodiscus discolor* Maxim. (Rosaceae) was found by Garrison (1953) to produce more when all the annual production was removed during the winter months than if it was not clipped at all.

If *Valeriana* had been the target for biocontrol, an agent consuming 30% of the herbage would not have controlled it; but I do not think that it should be considered a failure as it has achieved at least half the damage needed for control. Shrubs are often more resistent to damage than are herbaceous plants, so it is not surprising that *Lantana camara* L. (Verbenaceae) was able to survive complete summer defoliation by *Teleonemia scrupulosa* Stål (Hempitera: Tingidae) in Hawaii (Andres and Goeden 1971). Control was finally achieved on sites with less than 100 cm rain/yr by establishing agents that attacked the plant during the winter months. Since the ability of plants to regenerate increases with the availability of moisture, the resistance to biocontrol with high rainfall is understandable. These differences could be quantified through clipping tests.

There are problems extrapolating clipping data obtained from potted plants to the field situation. For example Winder and van Emden (1981) reported that insects grazing on *Lantana tiliaefolia* Cham. were generally more detrimental to the plant than an equivalent loss through clipping; but the two were closely correlated. Bigger problems are the effects of competition from other plants and moisture stress. For example, the effects of selective grazing or clipping on one plant species growing in competition with other species was more detrimental to it than clipping all the vegetation (Norman 1960; Bentley and Whittaker 1979). Thus, the threshold should be obtained by inflicting various degrees of damage to a natural population of the weed. A greater amount of damage will be required for control on sites with a higher than average annual production and less if the weed is already under high environmental stress (Harris 1980*a*).

For annual plants the damage threshold might be determined in terms of seed production; but as with perennials, the threshold will vary with the site. For example, Shirman (1981) determined that on bare soil over 99.9% of *Centaurea diffusa* Lam.

(Compositae) seed would have to be destroyed to achieve control. In knapweed growing with relatively light competition from other species, Roze (1981) determined that the threshold was 94% seed destruction. This is close to the reduction already achieved by the seed-head flies *Urophora affinis* Frauenfeld (Diptera: Tephritidae) and *U. quadrifasciata* (Meig.) on some sites (Harris 1980*b*). Thus either the establishment of another agent or an increase in grass competition might tip the balance in these places.

Some aspects of the damage likely to be done by an agent were discussed by Goeden (1983). Other suggestions are likely to arise from the analysis of past successes and failures that are presently underway. It is particularly important to know how much damage individual agent species have actually inflicted. I hope in this regard that Julian's (1982) catalogue will be kept up to date and that the remarks will quantify the damage (such as 30% to 50% defoliation) rather than give a subjective assessment (such as substantial defoliation).

Interpretation of Screening Tests

The IV and V International Symposia on Biological Control of Weeds had papers relating to the difficulty of interpreting screening tests (Dunn 1978; Andres 1981). As far as I am concerned the problem is getting worse as the result of increasing doubts by the authorities responsible for approving agent releases.

Both insects and pathogens frequently have broader host ranges in the laboratory than they do in the field. The knapweed rust, *Puccinia jaceae* Otth. (Uredinales) produces a resistant type reaction in safflower (*Carthamus tinctorius* L.; Compositae) in the laboratory although it does produce a few viable spores. Some pathologists regarded the resistant reaction together with the absence of any field record from safflower as an indication that the crop was safe. On the other hand, other authorities interpreted the ability to produce spores on safflower as a cause for concern.

The parameters that determine whether an insect species will damage a plant species are: (*a*) its ability; (*b*) the opportunity; and (*c*) the advantage of doing so (Harris 1981). The ability to utilize a plant in the laboratory screening tests does not mean it will attack that plant species in the field unless the other two parameters are also positive. The opportunity of using the plant depends on the host-finding ability of the agent as well as its temporal and spacial coincidence with the plant. The advantages of using a plant species relate to plant abundance, its relative suitability as a food source, its mortality on the plant, and the degree of competition from other phytophages. Lawton and Schroeder (1977) and Strong and Levin (1979) established that the number of insects and pathogen species increased with the log of the area occupied by the plant species. Strong *et al.* (1984) suggested that this relationship is a function of the encounter frequency of phytophages that can utilize it. I prefer the alternative explanation that the number of niches for phytophages is limited by interspecific competition although the absolute number increases with area as a result of habitat diversity and variation in the habitat size required by different species. Moran (1983) reported that South African crops derived from native plants were almost exclusively attacked by native oligophagous and polyphagous insects, while introduced crops were attacked by both native and introduced species. Thus the resistance of native crops to introduced pests may result from competitive displacement, while introduced crops offer niches to both native and introduced pests. In terms of biocontrol of weeds, I suggest that feeding by a candidate agent on a plant in the laboratory is more indicative that it will be utilized in nature if the plant is an introduced crop than if it is a scattered native.

Impact of Control Agents on Plant Diversity

There is apprehension expressed by many ecologists, particularly plant ecologists, about the effects of biocontrol agents on species or genetic diversity. It is obvious that plant consumers have a major bearing on the association formed. The principle that covers the general effect is that organisms increase the diversity at lower trophic levels. Elimination of plant consumers results in the domination of a habitat by one or a few species and a decline in diversity. Indeed, Stanley (1973) suggested that the extremely simple flora of the Precambrium Era was typical of an uncropped community and that the sudden diversity that occurred at the end of the Era resulted from the appearance of consumers.

Certainly weeds introduced without natural enemies tend to exclude the native vegetation from habitats to which they are suited. The establishment of biocontrol agents increases the diversity at the site, although the target weed remains. Canadian examples are *H. perforatum* and *Carduus nutans* L. (Compositae) but there are many others around the world. Fears expressed by Fedorenko and Fraser (1978) that the white amur fish would decrease diversity by eliminating its preferred food plants, mostly desirable natives, before controlling the weed have not materialized (Pierce 1983). Indeed diversity has sometimes increased slightly (van Zon *et al.* 1978). Unfortunately the fish remains banned from Canada.

Table 1. Plant rarity[1] and risks from biocontrol control agents.

Plant	1	2	3	4	5	6	7	8
Frequency	Abundant	Abundant	Abundant	Abundant	Sparse	Sparse	Sparse	Sparse
Range	Large	Large	Restricted	Restricted	Large	Large	Restricted	Restricted
Habitat	Several	Specific	Several	Specific	Several	Specific	Several	Specific

Consequence of damage to plant survival increases from 1–8.
Likelihood of specialized agent achieving damaging populations increases from 8–1.

[1]Adapted from Rabinowitz (1981).

A field study by Brown (1982) on the effects of excluding consumers from an early succession plant association showed that there was a slower accumulation of plant species when consumers were present. Thus, the fears of plant ecologists are not without some basis, but I think that the effects are temporary, resulting from a slower accumulation of plants on bare ground when consumers are present.

Endangered Plant Species

The endangered species act of the U.S.A. prohibits actions that are likely to compromise the survival of an endangered species. This has meant both the biocontrol Review Committees and researchers have tended to shy away from candidate agents that are able to develop on an endangered plant in the laboratory. Rabinowitz (1981) classified plants (Table 1) into eight categories of increasing rareness. These are not equally at risk from a biocontrol agent that will feed on them. The likelihood of damage increases with the abundance, although certainly the consequence of damage for plant survival increases with rareness. Rabinowitz (1981) cites the example of *Aristolochia serpentaria* L. (Aristolochiaceae) in which rareness provides a survival advantage as the plant escapes from its herbivore *Battus philenor* (L.) (Lepidoptera: Papilionidae).

The result is that reproduction is greater so the plant becomes common locally and loses its advantage. A similar relationship has been established for other plants (Ralph 1977) and can commonly be found in biocontrol of weeds. For example, in British Columbia the relative population density of the moth *Tyria jacobaeae* L. (Lepidoptera: Arctiidae) and hence the damage inflicted by it has declined more than its host plant *Senecio jacobaea* L. (Compositae) (Harris *et al.* 1978). Root and Kareiva (1984) reported that the butterfly *Pieris rapae* (L.) (Lepidoptera: Pieridae) is an exception to the normal resource concentration behaviour, because the female flies a distance between each oviposition with the result that in dense collard stands many hosts are overflown. However, I would be surprised if on a regional basis the attack level per plant was not higher where there were many hosts than where there were few. Thus, I have little concern for endangered plants with a sparse distribution unless they meet the following three conditions: (1) they occur in the same region as a common host; (2) they are readily accepted by the agent; and (3) they support good agent survival. Even in these circumstances I am not concerned about plants in category 8 such as *Betula uber* (Ashe) Fernald (Betulaceae). This tree was rediscovered at the original sites 61 years after it was described. It consisted of 12 trees, 1 sapling and 21 seedlings. In a similar situation the only known population of the tree *Hakea pulvinifera* L. Johnson (Proteaceae) in Australia was eradicated by construction of a parking lot (Bell 1983). I think the only hope for such species is the protection of botanical gardens. Rabinowitz (1981) was unable to find any North American plant to fit category 7 so such species may not exist. The plants that I feel are at greatest risk are those in category 4, but even in these species, agent survival must be adequate for it to build up a large population or there is a large migration from a sympatric weed host. Plants targeted for inoculative biocontrol of weeds are normally those in categories 1 and 2.

The danger of a biocontrol agent to a rare plant should not be considered in isolation from other pressures on them. According to Sukopp and Trautman (1981), 89 of the 581 endangered plant species in Germany are in this predicament as the result of herbicide application. Thus, if the biocontrol of a weed is likely to remove the need to treat large areas with herbicides, it may save more rare species than it places at risk. Competition from the target weed may also threaten native species. Bell (1983) suggests that two Australian plants have been exterminated by competition from introduced plants and 50 species are threatened. Again the possible threat of one agent to a rare plant must be balanced against the saving of others.

Individual States and Provinces in North America have tended to compile endangered species lists of their own; however, frequently the plants listed are merely at the edge of their distribution and the species as a whole is not endangered. The result is that there is a confusion of plants that individual botanists think are worthy of protection. Fortunately, the Federal Register (U.S. Dept. Interior 1980) provides a well-researched list of plants endangered in the U.S.A. and with few exceptions, plants not on the list are not endangered on the continent.

Agent Host Races

Many problems with getting an agent established are related to the use of strains from other species or strains of the weed. For example, the thistle head weevil, *Rhinocyllus conicus* Froelich (Coleoptera: Curculionidae) consists of a number of host races. Collections from the thistle *C. nutans* in Europe were readily established on this thistle in North America but could not be established on *Silybum marianum* (L.) Gaertner (Compositae) (Goeden 1978). However, strains of the weevil have been established in North America on this thistle as well as on *Onopordum acanthium* L. (Compositae) by release of weevils collected from the target thistle.

Similarly, the rust *Puccinia chondrillina* Bubak & Syd. introduced into Australia is only effective against one form of *Chondrilla juncea* L. (Compositae) (Burdon *et al.* 1981). The specificity of host races is not always revealed in laboratory tests. For example, the spurge hawk moth, *Hyles euphorbiae* L. (Lepidoptera: Sphingidae), develops as readily on leafy spurge (*Euphorbia esula* L.; Euphorbiaceae) as it does on cypress spurge (*E. cyparissias* L.) in feeding tests. However, a stock of the moth obtained from cypress spurge and released on leafy spurge in Ontario in 1973 has not been found on leafy spurge but a large population did appear on cypress spurge 9 km away (Harris 1984).

It is obvious that if possible, importation for release should be from the same plant species and strain on which the release is to be made. According to DeBach (1969), many taxons designated as host races have sufficient genetic stability and isolation to be full species. There is some advantage in raising them to full species to remove confusion. This will require much greater use of biochemical techniques to investigate genetic isolation. For example, electrophoresis can also be used to help identify pathogens licensed for inundative biocontrol (see Feichtenberger *et al.* 1984).

There are some strategies that might be tried if the correct host strain is not available. In mosquitoes positive heterosis has been obtained by crossing strains from different geographical areas (Legner 1972). Also, Seawright *et al.* (1975) and Lorimer *et al.* (1976) obtained beneficial results by crossing inbred laboratory colonies before release. This might be used as a method of overcoming the vigour loss associated with prolonged laboratory propagation. Releases from several sources are presently being made to increase numbers, but not as far as I know to obtain hybrid vigour.

Huettel and Bush (1972) crossed two sibling species of the fly *Procecidochares* (Diptera: Tephritidae) from different host plants. The F_1 generation were laid into the host of the female parent but the back cross of the hybrid flies produced many individuals that readily accepted both hosts. I suggest that this technique might be used for expanding the host range of insects used for the control of *L. camara*. The genetic turmoil in this man-made polyploid species (Spies and Stirton 1982) has resulted in many plants that escape partially or completely from the control agents. Clones of the sterile cactus *Opunita aurantiaca* Lindley (Cactaceae) may present a similar problem. The moth *Tucumania tapiacola* Dyar (Lepidoptera: Pyralidae) survives on the cactus in Australia but died out when released in South Africa (Hoffman 1982). The cactus is a hybrid of disputed parentage (Arnold 1977; Moran and Annecke 1979) but nobody disputes the considerable variation within the species. Regardless whether the failure in South Africa is related to differences in the host plant or to the climate, an increase in the genetic diversity of the moth by crossing stock from different hosts in different regions would be advantageous.

Leonard (1982) suggested that the host range of pathogens introduced for biocontrol should be expanded to cover the variation in the weed population by crossing pathogen isolates with the appropriate genes for virulence. Presumably the capabilities of a control agent can also be increased by genetic engineering but the extent to which society will approve the release of such organisms is still to be determined.

Identification of the Target Weed

There are problems for biocontrol when there are uncertainties about the taxonomy of the target weed and this applies to about half the weeds targeted for biocontrol in

Canada. North American taxonomists do not necessarily follow European usage when classifying plants introduced from Europe. For example, all the knapweeds in the section Maculosae in the *Flora Europeae* that have been introduced to North America are placed in the species *Centaurea maculosa* Lam. (Compositae) (J. McNeill, pers. comm.). In Europe *C. maculosa* is a biennual diploid whereas the problem weed called *C. maculosa* in British Columbia is a perennial tetraploid that seems to be referable to the European *C. bibersteinii* DC. There is also another spotted knapweed in Saskatchewan that is clearly not the same as *C. bibersteinii*, so it is presumably new to the Canadian flora. Similarly, considerable time and effort has been wasted collecting and screening insects from the spurge called *Euphorbia esula* in Europe only to find that they died on the plant called *E. esula* in Canada. According to Radcliffe-Smith (1984), there are five species and three hybrids of spurge in Saskatchewan and 20 in North America that presently go under the name *E. esula*. Other examples are discussed by McNeill (1982). I suggest that the problem is serious enough that before a search is started in Europe for control agents, the weed species should be submitted to European botanists, so regardless of the name, the right plant will be searched.

The problem is more difficult if the weed has changed genetically since its introduction. For example, the man-made polyploid *L. camara* in South Africa consists of diploid to hexaploid forms with chromosome configurations from univalent to heptavalent; the plant is evolving differently in India and South Africa (Spies and Stirton 1982). In this situation I think that the best that can be done is to attempt to broaden the genetic base of the agent.

Test plants used for determination of the host range of an agent are largely selected on the basis of their relationship to the host (Wapshere 1974). This is a problem in the genus *Senecio*. According to Jeffrey *et al.* (1977) the variation range in the genus overlaps and even exceeds that of several other genera. They suggested that the present genus should be divided into three subtribes containing 16 genera. Also, according to Douglas (1982), *Senecio* taxons that are treated as species would be treated as subspecies in other genera of the Asteraceae. No wonder *Senecio* is the largest genus of plants in the world.

I suggest that biocontrol workers may need the help of a sympathetic botanist; but if such a person cannot be found, be wary of authoritative-sounding plant classifications.

Conclusion

Many of the problems that I have touched on will be discussed in more detail by other speakers during the V International Symposium on Biological Control of Weeds. Very likely this will be done from a different perspective so I hope there is a good discussion both at and after the Symposium and assists in reaching solutions. I feel strongly that some of the problems are so serious that unless they can be resolved soon, they will restrict the growth of biocontrol of weeds.

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