Evaluating the effectiveness of weed biocontrol at the local scale

K. Dhileepan

Queensland Department of Natural Resources and Mines, Alan Fletcher Research Station,
PO Box 36, Sherwood, QLD 4075, Australia

Summary

Too many biocontrol programs have focused mainly on the establishment and prevalence of the biocontrol agents, with only limited studies on the impact of biocontrol at the individual plant level. Long-term effectiveness of biocontrol at the population level of the weed, and the resulting social and economic benefits are often not studied. The need for a comprehensive evaluation as an integral part of any biocontrol program, reasons for the limited emphasis on evaluation studies, and the potential role of community organizations in evaluation studies are discussed. Advantages and disadvantages of various evaluation methods such as before and after release assessments, simulation experiments, relating damage levels to plant performance, and exclusion methods are compared. Evaluation methods commonly used in weed biocontrol programs in Australia are highlighted, along with an assessment on the success rates achieved. Evaluation protocols for aquatic and terrestrial weeds are suggested.

Key words: biocontrol, evaluation, methods, local scale

Introduction

Weed biocontrol programs have focused mainly on the establishment and prevalence of the biocontrol agents, with only limited studies on the impact of biocontrol at the weed population level (Hoffmann & Moran, 1998; McClay, 1995; McEvoy *et al.*, 1991). In Australia, more than 40% of weed biocontrol programs have had no negative impact on target weeds (Briese, 2000a). But the long-term impact of biocontrol, and the resulting social and economic benefits, impact on non-target organisms, and end-user satisfaction are often not studied. This is because evaluation is expensive, and requires long-term funding commitments and community support. Evaluation is also often perceived as basic research with no additional benefits to the community and the funding agencies, and is not a politically sensitive issue (McFadyen, 2000). However, evaluation is essential to:

- Measure the success or failure of biocontrol
- Satisfy government and funding bodies
- Increase the profile of biocontrol
- Extrapolate results to a regional scale
- Attract funding for future research
- Provide a sense of satisfaction and achievement

In this review a more generic model for evaluation at the local scale is presented along with suggested protocols. For details on the evaluation process and methodology for individual weeds, readers are referred to the following reviews: Auld, 2000; Briese, 2000a; Forno & Julien, 2000; and Syrett *et al.*, 2000.

Evaluation at a local scale

The success or failure of a biocontrol program can be measured by quantifying the populations of the biocontrol agents and their target weeds, and the resulting economic and social benefits. However, for environmental weeds it is often difficult to quantify either economic or social values. Evaluation at a local scale involves the following measurements:

- Prevalence and abundance of biocontrol agents over space and time
- Impact of biocontrol at individual plant and weed population levels.
- Assessment of system responses such as increase in pasture production, reduction in health hazards, increases in native plant species diversity, etc.
- Long-term impact of biocontrol on the target weed and other non-target organisms.

Evaluation methods

The success of a biocontrol program depends on the establishment of the biocontrol agent, and hence evaluation should initially focus on the agent establishment on a spatial scale. This could be obtained either by direct survey or through feedback from end-users. Abundance of biocontrol agents does not necessarily result in weed control. Hence, it is essential to quantify the impact of the biocontrol agents on the target weeds. Before and after-release assessments,

simulation experiments either in the glasshouse or in the field, relating plant performance to damage levels by the biocontrol agents, biocontrol exclusion methods, and monitoring the long-term changes in target weed populations are the common evaluation methods.

Difficulties in evaluation

Evaluation is labour intensive and involves both extensive (spatial and time scale) and intensive (individual plant and weed population levels) studies. Different evaluation methods may be required for different weeds, but all methods have deficiencies. Evaluation both at a local and regional scale often requires community support, and is dependent on local weather conditions, often resulting in erratic (but realistic) results. Timing of the evaluation is also an important factor, and evaluations conducted too early before agents have had a chance to achieve their full potential could give misleading results (McFadyen, 1998).

Visual impressions

This is a relatively simple method to demonstrate the impact of biocontrol agents. Before-and-after release photographs demonstrating the success of biocontrol of *Opuntia stricta*, *Eichhornia crassipes* and *Salvinia molesta* in Queensland are the best examples. This method is more reliable for weeds where the biocontrol agents have become abundant and cause drastic reductions in the target weeds within a short period. However, such dramatic changes in target weed populations often do not occur. In some circumstances, the agent may take several years to become abundant. In weeds with multiple agent introductions, variable and prolonged establishment times for different agents make the "before-and-after" release comparisons less reliable without adequate quantitative data. In the case of *Parthenium hysterophorus* with 12 biocontrol agents introduced in the last two decades, the time taken for the agents to become abundant ranged from a couple of years (stem galling moth *Epiblema strenunana* Walker, stem boring weevil *Listronotus setosipennis* Hustache and summer rust *Puccinia melampodii* Diet & Holway) to more than a decade (leaf feeding beetle *Zygogramma bicolorata* Pallister and seed feeding weevil *Smicronyx lutulentus* Dietz). Comparisons of photographs of parthenium infestations before and after the outbreak of defoliation by *Z. bicolorata* reveal a general declining trend in weed density (Figure 1). Even though it is highly likely that biocontrol is responsible for the changes in weed density there are no adequate pre-release quantitative data to support this. In other cases, the changes in weed density may be due to reasons other than the biocontrol. Hence, it is essential to get quantitative data to support any "before-and-after" release photographs. For bellyache bush (*Jatropha gossypiifolia*) and sicklepod (*Senna obtusifolia*), Queensland Department of Natural Resources & Mines (QDNR&M) initiated collection of pre-release baseline ecological data well before work on biocontrol was initiated.

Figure 1. Visual impression of the impact of defoliation by the leaf-feeding beetle *Z. bicolorata* on parthenium at Mt Panorama in Central Queensland. November 1996: parthenium infestation before the outbreak of *Z. bicolorata*. January 1997: complete defoliation by *Z. bicolorata*. July 1998: reduced weed density and increased pasture production following the defoliation.

Simulation experiments

This is the simplest of all evaluation methods that can be completed within a short period under controlled conditions. Simulation experiments in the glasshouse and field cage provide valuable information on the

potential impact of the biocontrol agents, but often at individual plant level. Such simulation studies provide valuable benchmark information for future field evaluations. In the glasshouse, defoliation for a minimum of 74 days is required to prevent *P. hysterophorus* from producing any seeds (Dhileepan *et al.*, 2000a). Evaluations in the field later proved that biocontrol was effective only in the years when the leaf-feeding *Z. bicolorata* was active for more than three months (Dhileepan, unpublished data). However the results from simulation studies have limited value, as they do not always reflect the impact observed in the field. This is possibly due to the exclusion of other biotic (inter- and intra-specific competition in plants and biocontrol agents, as well as natural enemies of biocontrol agents) and abiotic factors. For example, in simulation experiments, more than four *L. setosipennis* larvae per plant are required to have any negative impact on *P. hysterophorus* (Dhileepan, 2003). But in the field in only 16% of the sites the population of *L. setosipennis* exceeded the threshold level (Dhileepan, 2003). Reznik (2000) also failed to predict the broader-scale performance of the ragweed leaf beetle *Zygogramma saturalis* F. on the basis of simulation and cage experiments. Hence, extrapolating data from simulation experiments to a regional scale should be done with caution.

Damage levels vs. plant performance

Relating damage levels of various biocontrol agents to plant performance has been used to measure the impact of biocontrol in *Asparagus asparagoides*, *Carduus nutans*, *Echium plantagineum*, *Mimosa pigra*, *Onopordum illyricum*, *O. acanthium* and *Sida acuta* (Briese, 2000a). The simple measures of damage alone may not be sufficient to indicate the success of an agent (Farrell & Lonsdale, 1997). The bud-feeding weevil *Trichapion lativentre* reduced seed production in the weed *Sesbania punicea* by 98%, but failed to cause a corresponding decline in the density of mature plants, because the seed loss only removed plants that would have died from competition anyway (Hoffmann & Moran, 1991). This method, though often used to evaluate the impact at the individual plant level, can be used to monitor population changes of the weed if permanent sites are established and monitored over time. However, in weeds where the abundance of biocontrol agents is dependent on plant vigour this method may not be suitable. In *P. hysterophorous*, level of damage by the stem-galling moth *E. strenuana* is dependent on plant size, as a result less vigorous plants escape from gall damage (Dhileepan & McFadyen, 2001). It would be difficult to relate damage levels to plant performance for agents that do not produce obviously visible symptoms, and those feeding in the root zone with inter-plant movement behaviour. In *P. hysterophorus*, damage symptoms of *L. setosipennis* larvae, that bore through the stem as well as feed externally on the root, are difficult to detect. As a result, destructive sampling of plants at the end of a field cage trial revealed no relationship between the number of *L. setosipennis* larval feeding sites and plant vigour and flower production. A sequential destructive sampling is more suitable to measure damage levels of root feeding insects in the field. The main disadvantage of correlating damage levels with plant performance is that the correlations may be due to other unrelated reasons. While relating damage levels with plant performance, we are not manipulating damage levels of randomly selected plants or sites that are otherwise considered equal. In other words, reasons for differences in plant performance are predicted on the basis of damage levels, but not proven. Experimental manipulation of independent variables is required to show that the damage is causing the effect. This method when combined with biocontrol agent and weed population monitoring programs over several seasons at one or more sites would provide an estimate of cause and effect of biocontrol agents (Swirepik & Smyth, these proceedings). This method of evaluation is also less intensive and more suitable for long-term evaluation in perennial and tree weeds where biocontrol exclusion is difficult.

Biocontrol exclusion

Detailed experimental biocontrol exclusion is the preferred method to evaluate the impact of biocontrol agents. The advantage of this method is that it allows rigorous statistical analysis and provides more reliable information than other methods (Farrell & Lonsdale, 1997). However, this method is more costly and time consuming than other methods. Selective sampling of sites with comparable ecological conditions in the presence or absence of biocontrol agents within a region is acceptable at the spatial scale, but may not suitable for long-term evaluation. In parthenium, the impact of defoliation by *Z. bicolorata* can be evaluated by selective sampling of sites with and without defoliation within a property. However, this method has limitations for long-term evaluation, as sites with severe defoliation in one year may not have any defoliation the following year and *vice versa*. To quantify the impact of biocontrol more realistically, excluding the biocontrol agents physically by using exclusion cages or by pesticides, is desirable. Such experimental manipulation removes spatial variation in soil factors, climate, rainfall, grazing pressure, etc.

Biocontrol exclusion using pesticides

This is the most efficient method of evaluation for terrestrial weeds and best suited to small-scale experiments. The advantage of this method is that both treatment and control plots can be at the same site thereby eliminating the spatial variation. This method also provides information on weed density and seed bank if there had been no biocontrol agents. However, this method is labour intensive and expensive, and may not be suitable in certain situations due to pesticide residue problems. This method relies on the periodic application of pesticides, and prolonged wet seasons could increase the need for more frequent pesticide applications, especially for excluding rust fungi using non-systemic fungicides. Hence, this method may not be suitable for areas that cannot be accessed during prolonged wet and flood conditions. Biocontrol exclusion using pesticides has been successfully used to evaluate the effectiveness of biocontrol in *Sida acuta* (Lonsdale *et al.*, 1995), *Mimosa pigra* (Lonsdale & Farrell, 1998) *P. hysterophorus* (Dhileepan, 2001), and *Echium plantagineum* (Sheppard *et al*., 2001).

Biocontrol exclusion experiment in *S. acuta*, using insecticide showed biocontrol had a 11-fold reduction in seed output resulting in 34% reduction in plant density in the following year (Lonsdale *et al.*, 1995). In *M. pigra* biocontrol reduced the seed output, but the insecticides used in the exclusion experiments also had a negative effect on seed production, possibly due to disruption in insect pollination (Lonsdale & Farrell, 1998). However, in similar exclusion experiments on *Chrysanthemoides monilifera* the insecticides had no negative effect on seed production (Adair & Holtkamp, 1999). Exclusion experiments using insecticides showed that biocontrol in parthenium resulted in up to 90% reduction in weed density (Dhileepan, 2001), but the effectiveness of biocontrol was dependent on the agents prevalent and seasonal conditions (K. Dhileepan, unpublished data). In *E. plantagineum* biocontrol exclusion experiment using insecticide revealed that the root-crown weevil *Mogulones larvatus* reduced the plant survival by 43%, and the size and seed weight of survivors by 58% and 74%, respectively (Sheppard *et al.*, 2001).

Biocontrol exclusion using field cages

This method is less efficient compared to exclusion using pesticides and is not suitable for evaluating the impact of pathogens like rust fungi. Field cages can also affect plant vigour, influence agent performance, and exclude the impact of natural enemies (parasites and predators) on the biocontrol agents themselves, resulting in unrealistic results. Evaluation of the impact of *E. strenuana* (Dhileepan & McFadyen, 2001) and *Z. bicolorata* (Dhileepan *et al*., 2000a) on *P. hysterophorus* in field cages produced results different to the results obtained in pesticide exclusion trials in the field. Hence, results from such studies should be used with caution for broader-scale predictions. It is also difficult to maintain cages in the field for long-term evaluation and the experiments are restricted to the spatial scale of the cages.

Australian experience

In Australia over 60 weeds have been targets of biological control (Briese, 2000a). Evaluations involving agent establishment and abundance have been carried out in majority of the biocontrol programs in Australia. But detailed evaluations have been carried out only in a limited number of biocontrol programs. Among the 164 refereed research publications on the biological control of Australian weeds sampled from Current Contents® (1985-2002), Proceedings of the Australian Weed Conference (Vol.8–13) and Proceedings of the International Symposium on Biological control of Weeds (Vol.5-10), less than 12% of the papers included aspects relating to agent prevalence and impact at the individual plant level. Only 4% of the papers sampled evaluated the impact of biocontrol at weed population level. Quantitative data on the impact of biocontrol is available for 23 weeds (38%) at individual plant level and for 12 weeds (20%) at plant population level (Table 1). However, the Information available on the economic benefits of biocontrol is restricted to *P. hysterophorus* at local scale (Adamson & Bray, 1999), and *Xanthium occidentale* (Chippendale, 1995) and *Echium* spp. (Nordblom *et al.*, 2002) at regional scale.

Future prospects

Evaluation should be an integral part of all ongoing and future biocontrol programs. It is advantageous if all biocontrol programs collect pre-release baseline data on the target weed including the seed bank data. In programs where the agents take several years to become abundant, the pre-release data could also be collected during the agent establishment phase. If possible, this should be supplemented with aerial or satellite photographs of the weed infestation. Where possible, evaluation at the local scale should be linked with the community agencies (i.e. Landcare groups) and a long-term funding commitment from government and other funding agencies. Often evaluations are initiated either as soon as the agents are released or immediately after their field establishment. To obtain realistic results, evaluation should be based on the agents that have already attained their full potential in the field (McFadyen, 1998). Local scale evaluation should focus more on "extensive" studies in varying geo-climatic conditions, than on "intensive" studies in a few areas. This would help in extrapolation of evaluation results from the local to regional scale

Table 1. Evaluation of the effectiveness of biocontrol agents at individual plant and plant population levels in Australia.

Weed	Agent	Impact at plant level	Impact at plant population level
Asparagus asparagoides	*Zygina* sp.	Batchelor & Woodburn, 2002	
	Puccinia myrsiphylli	Morin *et al.*, 2002	
Carduus nutans	*Trichosirocalus horridus*	Woodburn, 1997; 2000	
	Rhinocyllus conicus	Woodburn & Cullen, 1996	
	Urophora solstitialis	Woodburn & Cullen, 1996	
Carduus pycnocephalus & *C. tenuiflorus*	*Puccinia cardui-pycnocephali*		Burdon *et al.*, 2000
Chondrilla juncea	*Puccinia chondrillina*	Hanley & Groves, 2002	
Chrysanthemoides monilifera	*Comostolopsis germana*	Holtkamp, 2002	
Cryoptostegia grandiflora	*Maravalia cryptostegiae* & *Euclasta whalleyi*	Vitelli *et al.*, 1998	Vogler & Lindsay, 2002
Echium plantagineum	*Longitarsus echii*	Smyth & Sheppard, 2002	
	Mogulones larvatus	Sheppard *et al.*, 1999	
	Meligethes planiusculus	Swirepik *et al.*, 1996	
Eichhornia crassipes	*Neochetina burchi* & *N. eichhorniae*	Heard & Winterton, 2000	Wright, 1981
Eriocereus martinii			McFadyen & Tomley, 1981; Tomley & McFadyen, 1985
Hypericum androsaemum	*Melampsora hypericorum*	Casanato *et al.*, 1999	
Hypericum perforatum	*Aculus hyperici*	Jupp & Cullen, 1996	Mahr *et al*., 1999
	Chrysolina quadrigemina		Clark, 1953; Briese, 1997
	Chrysolina hyperici		Clark & Clark, 1952
	Agrilus hyperici	Briese, 1991	
	Aphis chloris	Briese & Jupp, 1995	
Lantana camara	*Ophiomyia lantanae*	Broughton, 1999	
Mimosa invisa	*Heteropsylla spinulosa*	Ablin, 1995	

Table 1. (cont'd) Evaluation of the effectiveness of biocontrol agents at individual plant and plant population levels in Australia.

Weed	Agent	Impact at plant level	Impact at plant population level
Mimosa pigra	*Neurostr ota gunniella*	Paynter & Hennecke, 2001	Lonsdale & Farrell, 1998; Wilson & Flanagan, 1991
	Phloeospora mimosae-pigrae	Paynter & Hennecke, 2001	
Onopordum spp.	*Larinus latus*	Pettit & Briese, 2000; Briese, 2000b	Swirepik & Smith, 2002
Parkinsonia aculeata	*Penthobruchus germaini*	Lockett *et al*., 1999; Lukitsch & Wilson, 1999	
Parthenium hysterophorus	*Epiblema strenuana*	Navie *et al.* 1998; Dhileepan & McFadyen 2001	Dhileepan, 2001
	Zygogramma bicolorata	Dhileepan *et al.*, 2000a	Dhileepan *et al.*, 200b; Dhileepan, 2001
	Listronotus setosipennis	Dhileepan 2003	
	Conotrachelus albocinereus	David, 1998	
Pistia stratiotes	*Neohydronomus affinis*		Harley *et al.*, 1984
Prosopis spp.	*Algarobius bottimeri & A. prosopis*	Donnelly, 2002	
Rubus spp.	*Phrgamidium violaceum*	Mahr & Bruzzese, 1998	
Salvinia molesta	*Cryptobagous salviniae*		Room *et al.*, 1981
Senecio jacobaea	*Cochytis atricapitana*	McLaren *et al.*, 2000	
	Longitarsus flavicornus		Ireson *et al.*, 1991
Sida acuta	*Calligrapha pantherina*	Lonsdale *et al.*, 1995	Lonsdale *et al.* 1995; Wilson & Lonsdale, 1995

Suggested protocols

The following generic protocols are suggested for evaluating the effectiveness of biocontrol at local scale:

Aquatic weeds

- Pre and post-release sequential photographs of the weed infestation at yearly intervals. To enable quantification of impact, the photographs should be standardised and calibrated by field measurements. Abundance and damage levels of agents recorded annually at a regional scale with assistance from Landcare and community groups.
- Extrapolate changes in weed infestation levels with biocontrol agent abundance and damage levels.

Terrestrial weeds

- Quantitative pre-release data on the target weed population dynamics (including the seed bank, if relevant).
- Pre and post-release sequential photographs at yearly intervals.
- Score/index the agent abundance annually at a regional scale with assistance from property owners and community groups.
- Monitor the target weed population (seed bank, if relevant) and other vegetation once in 3-5 years
- Relate biocontrol agent damage levels to target weed and other vegetation changes.

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