Agent performance: synthesis of session 5

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Introduction

The history of biological control of weeds is dominated by the success of relatively few projects (Crawley 1989). Historically, the overall rate of establishment of control agents is 64%, and the rate of 'effectiveness' is approximately 25% (Julien 1989). Dennill (1995) concluded that if this record is to be improved significantly, a better theoretical base is needed urgently. Others have expressed the same view (e.g. Julien 1989; Waage and Greathead 1988). The basis for developing this theory is the study of how agents interact with their target weeds, but what progress has there been in the last four years?

Despite relatively low success rates, biological control of weeds is viewed more and more by land managers as the control method of first choice, not a last resort, as in the past. Biological control is seen as a sustainable control strategy, providing long-term targeted non-polluting solutions to weed problems. However, if the faith of these supporters is to be maintained, we urgently need to demonstrate the effectiveness and economic value of biological control.

'Agent performance' was the title of session 5 of the IX International Symposium on Biological Control of Weeds. This session was particularly relevant to our discipline because the development of theory and the assessment of the value of biological control of weeds are both based on effective measurement of agent performance. The 21 oral- and poster-presentations in this session covered a wide range of subjects about agent/plant relationships, from physiological mechanisms for host-selection to population dynamics of weeds and agents. These subjects can be grouped into six distinct themes. (Unless specified by reference to a date, the papers referred to below are all in this Volume).

Research themes

Interactions between agents and targets
Sound development of a classical biological control or bioherbicide programme depends on reliable information about the ecological role of the potential control agents. Papers in this Volume addressing this topic describe the definition of the biological characteristics of agents (Bailey and Mortensen), the mode of action of agents (Traoré *et al.* two abstracts), agent population dynamics (Savov and Andow), the influence of parasitism (Hulley and Hayat), competition between agents (Jupp and Cullen; Woodburn), and their damage potential (Teshler *et al.*).

Teshler *et al.* reported that the feeding of the chrysomelid *Ophraella communa* augmented the effects of the normally-benign *Phoma* sp., leading to increased mortality of *Ambrosia artemisiifolia*. Exploiting synergy between insects and pathogens could increase the effectiveness of both classical control and bioherbicide programmes. Despite the common interest of plant pathologists and entomologists in biological control of weeds, the exploitation of such synergies continues to be a neglected field.

Better management of control agents
Several papers described improved techniques for managing agents after their introduction (Sheat *et al.*) or the status of existing programmes (Cofrancesco *et al.*; Markin *et al.*).

Explaining control processes
Most of the papers presented in the session examined the interactions between agents and the environment, seeking explanations for observed phenomena. Papers included the use of temperature-driven population models (Hayes *et al.*; McClay; Stewart *et al.*) and rainfall models (Morin *et al.*) to explain potential or actual distribution patterns, and population monitoring to explain the reasons for variation in control (Hulley and Hayat).

Developing biological control theory
The papers already cited add to the knowledge-base of biological control of weeds research. Few set

out to address theoretical issues directly, but there were notable exceptions. One important practical question that needs answering during any biological control programme is how large the founding population should be to achieve a high probability of establishment of the control agent. Grevstad (in session 4) modelled the effect of population size, environmental stochasticity, and Allee effects on establishment success and reported that these models are now being tested. In a closely parallel yet independent study, Memmott *et al.* (also in session 4) used a field-scale experimental approach to examine the influence of population size on the establishment of two insect species. Both studies suggest that releasing large numbers of insects is not likely to be a prerequisite for establishment success. This finding requires verification across a range of introductions, but if validated, these studies will be a major advance in improving the cost efficiency of biological control programmes. Harman and Syrett described the early stages of a study that will, in part, examine the population genetics of founding populations of the moth *Leucoptera spartifoliella*. All three studies have relevance beyond the field of biological control in elucidating the processes of alien invasions in general. Blossey *et al.* described the comprehensive control programme against purple loosestrife in North America, showing how sound research into most aspects of biological control theory, from agent selection methods to release strategies, can be integrated into a practical weed control project.

Syrett *et al.* summarized the characteristics that make chrysomelids attractive biological control agents. Although not predictive in itself, this synthesis provides a theoretical framework for comparing the effectiveness of agents developed in the future.

Predicting which agents are best

No papers addressed this issue directly, but two papers described retrospective studies that questioned the process by which control agents were initially chosen. Jupp and Cullen described how *Aculus hyperici* was selected as the preferred agent for control of *Hypericum perforatum* in Australia after studies in Europe revealed it to be a major natural control factor. Its performance in *H. perforatum* control in Australia is less clear-cut because of complex interactions between the mite and other agents, plant biology, and environmental conditions. In an important study,

Woodburn described how two insect species, *Rhinocyllus conicus* and *Urophora solstitialis*, compete in the seedheads of *Carduus nutans*, contrary to predictions (Zwölfer 1985). This could mean the joint presence of the two insects could achieve a lower annual reduction in seed crop than if *U. solstitialis* had been released alone. Although these comparative studies add greatly to our understanding of how control agents vary in their activity when released in a new environment, they show that we are far from developing a reliable methodology for ranking agents to identify those likely to be successful.

Measuring agent success

Despite the long history of research on biological control of weeds, relatively few projects have been rigorously assessed to evaluate their economic and environmental benefits. This has been pointed out many times. Notable exceptions include the economic evaluation of skeleton weed control (Marsden *et al.* 1980) and ragwort control (Coombs *et al.* session 7), and feasibility studies for control of New Zealand weeds (reviewed by Greer 1995). There are several reasons why such evaluations have been rare. Biological control is a gradual process, and it is difficult to measure incremental changes over many years, often against large background variation, confounded by annual variation in climatic factors. Often, evaluation is deferred until the latter stages of a programme when the effects of the control agents are peaking, but when funding is in decline, so evaluation is inadequate. The unsatisfactory term 'partial success' is often used and the real value of the projects is probably underestimated.

Increasingly, research resources are being allocated on a commercial basis (where continued support relies on producing results) or in fiercely competitive funding forums where demonstrating return on research investment is persuasive. Improved rigorous information about control success is therefore essential to maintain or improve the credibility and funding of projects on biological control of weeds.

McClay (1995) examined how evaluation studies could be made more rigorous, and described five principles for such research: assess the weed, not the agent; assess weed populations, not individuals; assess projects in the field and demonstrate that the agent is responsible. This advice is particularly important to retrospective evaluation of a project, once control agents have achieved maximum impact.

A new approach to measuring control success

Much of the literature on evaluation of biological control of weeds focuses on how agents limit weed populations, yet the most common plants in any environment are not weeds. It is often not the population density (or the vigour) of the plant that makes it a weed, but the nature of its interaction with its surroundings. This has been recognized recently in new legislation governing statutory management of weeds in New Zealand. The Biosecurity Act (1993) requires the development of five-year weed management strategies that outline what actions will be taken against each target weed in each region. At the end of the five-year period, the strategy must be audited to ascertain, not how much less weed there is (or how many control agents have been released), but how much the *effects* of the weed have diminished. I will now, therefore, discuss another approach that emphasizes the effects of weeds, which may allow assessment of the value of control before the agent is achieving maximum impact, reinforcing the continuing support of sponsors or clients.

Define and measure the effects of the weeds

Weeds interfere with the productivity of economic plants and animals, and with natural processes, by a range of mechanisms. To evaluate fully the effects of a weed, it is important to define what characteristics of the weed are responsible for any damage, and hence should be targeted by control measures. For example, *Carduus nutans* infests rangelands and pastures, excluding desirable fodder species and reducing pasture productivity. It is usually the area of ground covered by thistles rather than the number of thistles present that damages pasture, so that a small number of large rosettes may be as damaging as a large number of small rosettes. In New Zealand pastures, stocking rates, and hence the demand for forage, peak in late spring and grazing pressure at other times of the year is not high. Thus, it is the thistle cover in spring that limits animal production, not its presence at other times of the year. Similarly, in plantation forests in the North Island of New Zealand, seedlings of gorse and broom compete for light with newly-planted pine trees, so that it is the more rapid growth-rate of the weed seedlings than that of the pine trees that is critical.

The effects of a weed vary from habitat to habitat,

depending on the value of the land that is threatened. For example, gorse occupies land that could be used for pastoral production (where pasture cover is the critical factor), displaces rare and endangered plant species (cover and growth rate), competes for water and nutrients with pine trees in some forests (vigour), and poses a fire risk, particularly to dwellings in suburban areas (standing biomass) (Hill and Sandrey 1986). Gorse also has a positive effect as a nurse-crop for native-forest regeneration in high rainfall areas, although this effect would probably be enhanced if the growth-rate of gorse was reduced.

All environmental and economic effects of a weed should be recorded and, preferably, quantified. Although difficult to obtain, this information is essential as a sound basis for decision-making and future evaluation. In their presentation, Blossey *et al.* outlined attempts to define the diverse effects of purple loosestrife in North America. Where possible, such information should be obtained from sources independent of the control programme, preferably by the stakeholders in the weed problem.

Define the acceptable damage threshold

Hoffmann (1996) observed that expectations of biological control have been set at unrealistic levels, resulting in many projects being classed as failures. This is inevitable if the damage threshold of a weed is not identified early in a control programme. Weed scientists working in cropping systems have excellent models for weed/crop interactions and know the relationship between weed density (or cover) and crop yield (Auld *et al.* 1987). Measurements of the effects of weeds in pastures or rangelands are less common, and reliable measures in natural environments are rare (Greer 1995). When sound data on the effects of weeds are not available, it may still be possible to determine logically an acceptable level of damage. For example, where gorse and broom shade out young pine trees in New Zealand forests, acceptable control would be achieved if tree growth-rate exceeded weed growth-rate, reversing the existing competitive advantage. Some cover provided by non-competitive gorse or broom might even enhance tree growth by fixing nitrogen and protecting seedlings from frost (J. Zabkiewicz personal communication). Different measures of acceptable effects would be needed for each situation in which the weed is a problem.

Define the level of weed control needed to achieve the threshold

Once an acceptable level for the effects of the weed has been identified, the amount and form of weed suppression required to achieve that level needs to be determined. It is important that acceptable levels of control are developed in consultation with, and are agreed to by, stakeholders in the weed problem. Only then will these levels become an agreed target by which the future success or failure of a project can be measured as the project proceeds. One important outcome of this step may be a decision not to proceed any further.

Demonstrate that biological control can achieve this level

In the early days of a biological control project, it is not necessary to demonstrate that control has been achieved, only that it is feasible. For example, where suppression of size or growth-rate is important, artificial infestation experiments can show what population of the control agent is necessary to achieve the desired effect. If populations measured at release sites then approach this level, we can make more concrete statements about the likelihood of successful control.

Enhance control

Where populations of control agents at release sites do not approach the levels necessary to achieve acceptable control, other means must be sought for augmenting or enhancing that control, such as the introduction of further agents or the use of complementary control techniques.

Conclusions

We measure agent performance to refine and improve the way we go about biological control of weeds, and to record how well we have achieved our aims. Advances in the theoretical basis for the discipline would improve the effectiveness of biological control of weeds. Until recently, emphasis has been placed on reviewing the history of biological control, and then seeking generalities. A more concerted effort is needed to identify key issues that drive biological control practice, and to use an experimental approach to understand those issues.

The evaluation technique suggested here would provide a framework that would allow the development of targets and review points. The emphasis on an experimental rather than a population dynamics approach to measuring the impact of agents would allow progress towards targets to be measured from early in the programme. It may be possible to apply these criteria to historical projects by identifying the acceptable levels of effects that applied at the beginning of the control programme, to show whether some of the 'partial successes' do indeed provide valuable control.

Acknowledgements

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