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A biological weed control programme using insects against purple loosestrife, *Lythrum salicaria*, in North America

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Abstract. Purple loosestrife is a wetland perennial that was introduced to North America from Europe in the early 19th century and now occurs in large monotypic stands throughout much of the temperate regions. Because conventional control techniques have been proven ineffective, the development of a biological weed control programme began with surveys and host-specificity screening tests in Europe in 1986. Five insect species demonstrated the host-specificity required for introduction to North America. Four of the five species are now successfully established. Unique to this programme has been the ability to conduct a wide variety of concurrent ecological investigations. These include studies to identify potential natural enemies of introduced control agents, to assess the importance of genetic inbreeding and founder colony size on insect establishment, to measure patterns and rates of insect dispersal, to identify the effects of single- and multiple-species herbivory on the host plant, to refine insect propagation techniques, and to monitor insect and plant demographics. Only through increased visibility and credibility as a predictive science with proven implementation procedures, based on rigorous experimental tests, can we hope to integrate biological weed control successfully into national and international pest-management strategies.

Introduction

In recent years, interest in a biological method to control problem plants in natural areas in the United States of America has grown (US Congress 1993). All federal agencies must comply with standards to reduce the use and dependence on chemical control of weeds. But biological methods are not readily available, nor have they been well endorsed or financially supported. Despite an excellent safety record (Crawley 1989) scepticism concerning the safety and effectiveness of exotic-insect introductions for weed control remains high among the general public, administrators and even among scientists.

The successful control of *Hypericum perforatum* (Huffaker and Kennett 1959) and others that followed, have demonstrated that long-lasting, cost-effective, environmentally sound and effective control programmes can be implemented. But despite an increase in the number of programmes initiated, the ability to select and to establish control agents has not progressed to a point where the rate of success has improved (Crawley 1989). Basic questions about the kind of herbivore species to introduce, the impact of single and multiple species herbivory, and the release strategies to employ remain unanswered. The control programme targeting purple loosestrife (*Lythrum salicaria* L.), a Eurasian wetland perennial responsible for the degradation of many prime wetlands throughout temperate regions of North America (Thompson *et al.* 1987; Malecki *et al.* 1993), is intended to emphasize the need for research investigations during pre- and post-release phases of the programme.

The control agents

Detailed investigations in Europe began in 1986 with surveys for potential control agents and investigations on their life-history, distribution, impact, and host-specificity (Blossey 1993; Blossey *et al.* 1994a, b; Blossey and Schroeder 1995; Blossey 1995b). The biological attributes of the herbivores (host-specificity, fecundity, impact etc.) have served as guidelines for selection of control agents (Harris 1973; Goeden 1983), however, such characteristics are often difficult to observe in the field and their usefulness in distinguishing successful agents from unsuccessful ones is questionable (Crawley 1989). An attempt was made to rank nine potential control agents against *L. salicaria* which compared various selection approaches (Harris 1973; Goeden 1983; Wapshere 1985; Crawley 1986, 1989) but it produced contradictory results (Blossey 1995a). Therefore, the species proposed for introduction were selected based on information about their: (i) impact on the target weed in the field; (ii) host-specificity; (iii) distribution; and (iv) their feeding niche on *L. salicaria*.

Six species were selected as the most promising control agents for further investigations. These were a root-mining weevil, *Hylobius transversovittatus*, attacking the main storage tissue of purple loosestrife; two leaf-beetles, *Galerucella calmariensis* and *G. pusilla* capable of completely defoliating individual plants and entire *L. salicaria* populations; a flower-feeding weevil *Nanophyes marmoratus*; a seed-feeding weevil *N. brevis*; and a gall midge, *Bayeriola salicariae*, attacking leaf and flower buds.

Demonstrated host-specificity is of overriding importance before any control organism can be released. For as long as host-specificity tests have been done, practitioners have tried to overcome one of the shortcomings of these procedures that show broader host-ranges of control agents under test conditions than in the field (Cullen 1990; Shepherd 1990). During the screening programme for purple loosestrife we conducted various tests and compared results of different methods (Blossey *et al.* 1994a, b; Blossey and Schroeder 1995). In general, tests using entire plants, offered outdoors in multiple-choice tests, produced the narrowest host-ranges. But difficulties in data interpretation remain because, often, the design of a test influences its results. Until we have follow-up studies on the host-range after field release, we will not improve the predictability of our screening procedures.

After the initial host-specificity screening results became available, a questionnaire concerning the potential impact of this programme was sent to the Departments of Agriculture and of Natural Resources in 32 states in the temperate USA (Blossey *et al.* 1994a). The questionnaire asked for the occurrence, special concerns (rare or endangered) and ecological importance of *Lythrum alatum* and *Decodon verticillatus*, two plant species where some feeding by potential control agents had occurred. The questionnaire asked whether respondents would favour a release of biological control agents over a potential negative impact on *D. vertillatus* and *L. alatum*. While the majority favoured releases, responses ranged from extreme opposition to enthusiastic support (Blossey *et al.* 1994a). Often a split occurred between two agencies in a single state, with the most common concern being lack of sufficient information to evaluate danger to native plants. This, and the second most commonly expressed concern, that the introduction of another exotic species might create a problem similar to that caused by purple loosestrife, illustrate the necessity to assess and publish the impact on target- and non-target host-plants after insects have been released. Without scientific evaluation, the safety of biological control will remain the subject of doubt and, if public concerns are not taken into account, will suffer further serious restrictions. Conflict resolution will always be a part of biological control, and only sound scientific analysis can offer guidance to the necessary decisions. For example, based on the available information, one of the agents under consideration, *B. salicariae*, because of a wider host-range, was not proposed for introduction (Blossey and Schroeder 1995).

Based on the available knowledge at the time of introduction of the first control agents in 1992 the following predictions emerged (Malecki *et al.* 1993): (i) all species will become established throughout the current range of *L. salicaria* in North America; (ii) the root-feeder *H. transversovittatus* and the two leaf-feeders, *G. calmariensis* and *G. pusilla*, will be most important in reducing large populations, the flower- and seed-feeders will stabilize smaller populations, further reducing seed output in such a way that not every disturbance will lead to a new outbreak of *L. salicaria*; (iii) combinations of agents will have greater control effects than any species alone; (iv) control of *L. salicaria* will be achieved more rapidly in mixed plant communities where there is competition for space and nutrients; and (v) purple loosestrife abundance will be reduced to 10% of its current level over 90% of its range.

Purple loosestrife biocontrol in North America, 1992 to the present

Despite a long history of using insects for weed control and a considerable improvement in procedures, only about 60% of released agents become established (Crawley 1989). Factors determining the fate of releases (e.g. agent taxonomy, climatic pre-adaptations, the number of individuals released, the numbers and timing of releases, predation, weather conditions) are generally not scientifically evaluated and reasons for failures are largely based on observations (Crawley 1989; Lawton 1990). In the control programme against *L. salicaria*, agents were collected from climatically different source-populations and releases occurred across North America. Experiments were started to determine the best release procedure. Agents became established across the entire continent regardless of the source of the populations, the number of agents released, time of release, stage released, or whether cage- or open-field-releases were conducted (Hight *et al.* 1995).

Evaluations were made of the potential of predators and parasites to affect, negatively, the establishment and impact of the potential control agents. Coccinellid beetles (mainly *Coleomagilla maculata*) were the only natural enemies that may have negative effects on the leaf beetles (Blossey and Ehlers 1991; M. Tauber and C. Tauber unpublished) but their affect appears limited (Blossey personal observation). Additional experiments, comparing the release of inbred and out-crossed individuals of *G. calmariensis* were conducted to evaluate the influence of mass rearing and the potential for release of inbred populations on establishment success. After three years, initial observations suggest that even severe inbreeding did not result in establishment failures (R. Roush personal communication). However, the success of a mass-rearing programme may be affected (see below). Grevstad (this Volume) has started a larger study on the effect of different founder sizes on establishment success and dispersal. These investigations will continue.

Harris (1981) proposed that biocontrol agents should be considered 'stress factors', the aim being to increase stress load until the balance is tipped to the disadvantage of the target weed population. Myers (1985) argued that good control has been achieved, frequently, by a single agent replacing another less successful one. Introducing several control agents could result in the suppression of a formerly successful species by a competitively superior species (Ehler and Hall 1982). Crawley (1989), however, could not find any evidence that multiple-species introductions have ever led to the replacement of effective agents by less successful ones. On the contrary, agent combinations were recently reported to be more destructive to plants than a single species alone (Fowler and Griffin 1995; Hallett *et al.* 1995). Masters *et al.* (1993) found that spatially-separated herbivores interact via their common host-plant. Root-feeders showed a reduced performance if their host plant was simultaneously attacked by an above-ground herbivore. Above-ground herbivores showed improved performance on plant individuals that were simultaneously attacked by a root-feeder. Whether these interactions have any influence on the success of weed biocontrol in systems where above- and below-ground herbivores were released, needs further study. We are currently conducting these experiments for the *L. salicaria-Galerucella-Hylobius* system. This is a good example of how an ongoing biological control programme can benefit from simultaneously-conducted basic research, and vice versa.

Mass rearing is often an integral part of a biological control programme, since control agents are generally in short supply. A major concern has been the possible negative side-effects of laboratory mass-rearing (e.g. adaptations to rearing conditions) and reduced quality of the insects (Hopper *et al.* 1993). We have experimented with various field and laboratory mass-rearing techniques (Blossey and Hunt unpublished) and found a reduced fecundity and increased mortality associated with increasing duration of artificial rearing conditions. We now prefer to mass produce all species outdoors for one generation and allow subsequent overwintering. During 1994 and 1995 about 90000 leaf-beetles were shipped to 23 different states and to Canada, to collaborators in a wide range of organizations (universities, State Departments of Agriculture and Natural Resources, Natural Wildlife Refuges, Bureau of Reclamation, Tennessee Valley Authority, and the Animal Plant Health Inspection Service); many have started their own mass-rearing programme. We believe that we need to be concerned about the quality of insects released, not the quantity and recommend outdoor mass-rearings. Releasing fewer, but fitter, individuals might be a more successful approach and quality control should accompany every mass-rearing programme.

Increased attention should be given to follow-up studies to monitor target plant and control agent populations. The lack of published evaluations might (hopefully) reflect the lag time between releases and documented successes, since the biocontrol community has long agreed on the necessity of these studies (Schroeder 1983; Sheppard 1992). The future of biological control is intimately linked to the demonstrated safety and efficacy of our programmes. For example, releases of control agents against *L. salicaria* in the state of Wisconsin were only allowed once the Department of Natural Resources agreed on a monitoring plan for insect and plant populations.

An important consideration is the many different ways that insect or plant populations may be monitored. Our goal has been to develop standardized monitoring guidelines, sophisticated enough to allow valuable scientific evaluation but at the same time simple enough to allow participation by wildlife managers or their staff, who may have little guidance. Preliminary versions of a monitoring guide were tested in 1994 and 1995 and a final version will be distributed by the end of 1996. This should allow the comparison of results across the entire distribution of *L. salicaria*.

The magic formula for success?

A number of factors have contributed to the rapid growth of a coordinated biocontrol effort against purple loosestrife in the USA. *Lythrum salicaria,* based on its rapid spread, projected range and severity of impact, was identified as being among the most harmful non-indigenous species in the USA (US Congress 1993). This designation created interest for improvements in management approaches, including biological control, across the entire continent. From its inception, the biological control programme against *L. salicaria* has been a multi-agency effort. The overseas exploration by the International Institute of Biological Control was conducted in association with the USDA Agricultural Research Service (ARS) and the US Fish and Wildlife Service. The initial success of the inter-agency effort lead to the formation of a scientific advisory group (Purple Loosestrife Working Group, PLWG) with representation from several federal and state agencies and universities in the USA and Canada. Since 1986, this working group has provided continual guidance on all aspects of our biological control programme.

One of the major accomplishments has been to keep federal and state agencies actively involved and informed, through internal annual reports and through participation in decision-making processes. This broad-based involvement has facilitated maintenance of funding since 1985. Particularly important was the ability to pool resources from a variety of sponsors. Thus, in the absence of major grants, the cooperation across political and agency boundaries has been extremely beneficial. Once the first insects became available in 1992, they were distributed to seven states within the USA and to Canada. Workshops, held in Colorado and Minnesota in spring 1993, informed interested agencies on the life-history of the control agents, mass-rearing techniques, follow-up studies and monitoring techniques. Brochures, summarizing the available information, were produced to encourage the participation of other agencies in the control programme. In addition to regular meetings of the PLWG, we now conduct annual meetings to plan the future of the control programme. Participants representing 20-30 states (including Canada) and many federal agencies have attended.

Purple loosestrife is not an agricultural weed, and the people involved in the control programme are often resource managers, essentially a new audience in the USA for biological weed control. Their willingness to participate in basic research has enabled us to implement a scientific approach to the entire programme, with the intention of improving biological control as a science. The leadership provided by Cornell University and the willingness to share research results has created a unique cooperative environment that allowed the programme to move forward at a fast pace. Last, but not least, early results indicate that the selected control agents are going to be effective.

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