The contribution of biological control to the management of thistles

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Summary

CSIRO Division of Entomology has two major projects on the biological control of carduine thistles, one against nodding thistle (*Carduus nutans*) and another for scotch and Illyrian thistles (*Onopordum acanthium* and *O. illyricum*). The strategies for biological control of these target thistles are similar, although the agents used are different. Since thistle populations depend solely on seedling establishment for recruitment, the priority area in both projects is to limit seeding, with the ultimate aim to reduce the soil seed banks found in Australia to the much lower levels found in Europe. Both projects include insects that attack the capitula and thus have a direct impact on seeding; both also have insects that attack vegetative parts of the plant and thus indirectly limit seed production. The role of biological control in an overall management strategy for these two groups of thistles is briefly discussed.

Introduction

CSIRO Division of Entomology is currently conducting two biological control projects on carduine thistles. The targets are nodding thistle, *Carduus nutans*, and Scotch and Illyrian thistles, *Onopordum acanthium* and *O. illyricum*. Other countries have mounted biocontrol projects against nodding thistle, with varying degrees of success (Julien 1992), but this is the first time that a project has been undertaken for *Onopordum* (Briese 1990). These two projects have progressed in a similar manner with both having European and Australian components. The European phase of each had two major objectives; the obvious one of identifying potential biocontrol agents and conducting studies on their biology and impact, and a second, perhaps not so obvious, but of prime importance, involving basic research into the population dynamics of the weed in its native range. Both projects have also collected base line plant population data on the weeds in Australia before the releases of any agents were undertaken. Results of these pre-release studies show that the soil seed banks in Australia are generally several orders of magnitude greater than those found in Europe (Pettit *et al.* 1996, Woodburn and Sheppard 1996). Since the thistles involved in both of these projects rely solely on seedling germination and establishment for recruitment to their populations, the underlying philosophy for control has been to limit seed production and thus over time to bring about a reduction in Australian soil seed bank levels to the levels that are found in the plants' native ranges.

The proposed biocontrol agents

A list of the insects identified during the European studies as having most potential as biological control agents is presented for *C. nutans* and *Onopordum* spp. (Table 1), along with a brief description of the damage caused to the plant and a timescale for their release.

The agents chosen limit seed production either directly by attacking the flowering capitula, (*Rhinocyllus conicus* and *Urophora solstitialis* for nodding thistle, and *Larinus latus* and *Tephritis postica* for *Onopordum* spp.) or they reduce plant vigour and thus have an indirect impact on seed production (the remaining agents listed in Table 1). If heavy attack is sustained by some of these remaining agents, the flowering plant population can be directly limited by plant death in the rosette stage, as in the case of *Trichosirocalus* spp. All of these potential agents have been chosen because they are considered to complement one another by attacking different parts of the weed, e.g. receptacle and rosette feeders utilize completely different plant resources. When the same part of the plant is targeted for attack, the chosen agents either attack at different times, for example *Trichosirocalus* sp. nov. attacks *Onopordum* spp. from autumn to early spring whilst

Table 1. Candidate agents for the biological control of two thistles groups in Australia.

Agent	Type	Damage inflicted on target weed	Actual or proposed year of field release
Nodding thistle (*Carduus nutans*)			
Rhinocyllus conicus	receptacle weevil	larvae consume both receptacle tissue and developing seed, limiting seed production	1988
Urophora solstitialis	seed fly	larvae induce the plant to produce a lignified gall, acts as a metabolic sink and destroys seeds, lowers seed production	1991
Trichosirocalus horridus	rosette crown weevil	larvae feed on rosette meristems, reducing vigour and hence lowering seed production, can cause death of plant	1993
Cheilosia corydon	stem / root fly	larvae mines the elongating stem, and eventually mines way down to the root stock, reduces vigour of plant	1997?
Scotch and Illyrian thistles (*Onopordum* spp)			
Larinus latus	seed weevil	larvae destroy seed in the thistle head and reduce seed production	1992
Lixus cardui	stem-boring weevil	larvae mine the stem and can reduce plant vigour and size	1993
Tephritis postica	seed fly	larvae destroy seed in the thistle head and reduce seed production	1995
Tettigometra sulphurea	sap-sucking bug	adults and nymphs suck sap from plant and can reduce vigour and kill rosettes	1996 or 1997
Trichosirocalus sp. nov.	rosette crown weevil	larvae feed on rosette meristems, reducing vigour and hence lowering seed production, can cause death of plant	1996 or 1997
Botanophila spinosa	crown fly	larvae feed on rosette meristem or branch axils and deform plant growth	1998

Table 2. Structure and current status of tasks leading to the introduction and establishment of biological control agents in Australia (as of June 1996).

Carduus nutans

Agent	*R. conicus* seed weevil	*U. solstitialis* seed fly	*Trichosirocalus horridus* crown weevil	*Cheilosia corydon* stem/root fly
Exploration and selection of potential agents	Selected	Selected	Selected	Selected
Biology and impact of agent studied in Europe	Completed	Completed	Completed	Completed
AQIS/ANCA permit to introduce into Australia	Permission given	Permission given	Permission given	Permission given
Host-specificity testing in quarantine in Australia	Completed	Completed	Completed	Completed
AQIS/ANCA permit to field release in Australia	Permission given	Permission given	Permission given	Application pending
Field releases made at selected study sites	Releases made in November 1988	Releases made in December 1991	Releases made in May 1993	
Agent established in field	First recovery November 1989	First recovery October 1992	First recovery November 1993	
Evaluation studies commenced	November 1990	October 1992	April 1994	
Distribution of agents throughout infested areas	No redistributions made	Redistributions made 1993/96	Redistributions made 1994/96	

***Onopordum* thistles**

Agent	*Larinus latus* seed weevil	*Lixus cardui* stem borer	*Tephritis postica* seed fly	*Tettigometra sulphurea* sapsucker	*Trichosirocalus* sp. nov. crown weevil	*Botanophila spinosa* crown fly
Exploration and selection of potential agents	Selected	Selected	Selected	Selected	Selected	Selected
Biology and impact of agent studied in Europe	Completed	Completed	Completed	Completed	In progress	In progress
AQIS/ANCA permit to introduce into Australia	Permission given	Permission given	Permission given	Permission given	Permission given	
Host-specificity testing in quarantine in Australia	Completed	Completed	Completed	Imported into quarantine	Imported into quarantine	
AQIS/ANCA permit to field release in Australia	Permission given	Permission given	Permission given	Application submitted	Application submitted	
Field releases made at selected study sites	Releases made in Nov. 1992	Releases made in Nov. 1993	Releases made in Nov. 1995			
Agent established in field	First recovery Nov. 1993	First recovery Nov. 1994	Not yet recovered			
Evaluation studies commenced	Nov. 1996	Nov. 1996				
Distribution of agents throughout infested areas	Redistribution made 1993/96	Redistribution made 1994/96				

Botanophila spinosa attacks the rosette/developing stem from spring to early summer, or there the available evidence suggests there is no interspecific competition between agents, such as in the case of *R. conicus* and *U. solstitialis* for *C. nutans* (Möller-Joop and Schroeder 1986).

Current status of projects

The progress of research to date for both projects has been substantial (Table 2). An exception is *Cheilosia corydon* which severely damages nodding thistle in Europe. However it has proved impossible to rear this insect under artificial conditions, and the question of whether to release this insect in Australia remains to be resolved.

A separate project involving the redistribution of the biocontrol agents by CSIRO and NSW Agriculture (as well as KTRI Victoria for *Onopordum* spp.) was funded (by IWS/MRC) to speed up availability of the agents to the farming community. All agents for the two projects are or will be redistributed, with the exception of *R. conicus* (see Evaluation below).

Redistribution of agents

In the IWS/MRC funded project, primary nursery sites are established in strategic areas of the weeds' infestations in New South Wales and Victoria by the co-operating partners, using starter colonies provided by CSIRO. From these initial colonies local redistribution networks are set up and co-ordinated by the partners but utilizing the officers of local community groups such as Landcare and District Noxious Weed Officers. A broad summary of the releases made to date is shown in Table 3 (for further details see Briese *et al.* 1996).

Initial agent impact

It is essential in any biocontrol program that the research effort continues after release and establishment of the agent has occurred (Briese 1993). Funding bodies need to recognise the importance of this phase of any project. The only way to quantify the impact of the agents is to undertake studies on the population dynamics the weed as influenced by the insects. To date the nodding thistle project has made greater progress in this regard and it will be used as the example in this section.

Table 3. Summary of redistributions made for biological control agents for *Carduus nutans* and *Onopordum* spp.

	C. nutans		*Onopordum* spp.	
Year	*U. solstitialis*	*T. horridus*	*L. latus*	*L. cardui*
1993	3		14	
1994	5	2	20	14
1995	22	4	5	69
1996		36		

Impact of R. conicus

This insect was successfully used to control populations of *C. nutans* and closely related thistles in North America (Harris 1984, Kok and Surles 1975), and similar results were initially expected in Australia, where it was released in 1988 (Woodburn and Cullen 1995). However, while *R. conicus* very successfully destroys the vast majority of seed in the primary capitula, its impact rapidly declines as the season progresses (Woodburn and Cullen 1993, 1996). Despite their larger size, the contribution of primary capitula to the total seed production is minimal, for most seeds set are formed in the large number of smaller capitula produced in the middle of the flowering season. The timing and extent of renewed attack by a small partial second generation of weevils is of minimal importance. Estimates of the reduction in total seed set due to the activity of *R. conicus* have varied between 7 and 20% (Woodburn and Cullen 1993, 1996). Seed destruction in New Zealand, where this weevil has been released for over 20 years (Jessep 1975), range between 3 and 49% without apparent long-term reduction in thistle population densities. However, in North America where thistle populations have been controlled by this weevil in ten years or less, the reported declines in seeding are about 50% (Kelly and McCallum 1995).

Impact of U. solstitialis

Urophora solstitialis was identified by Sheppard *et al.* (1994) as a potentially important seed predator because it undergoes a well defined partial second generation and should therefore attack capitula throughout the flowering season. The literature on competitiveness between this agent and *R. conicus* was equivocal; there being both evidence that the seed fly might out-compete the weevil (Zwölfer 1973) and that the two agents could coexist in the same capitula (Möller-Joop and Schroeder 1986, Sheppard and Vitou personal communication).

The seed fly was released in Australia in 1991 (Woodburn 1993) (and in New Zealand and Canada in 1990 (Julien 1992)). It established strongly, thereby enabling evaluation of its impact on thistle population dynamics to commence in the following year. As anticipated, there was a partial second generation under Australian conditions, leading to attack on capitula throughout the total flowering period, and a measured reduction in number of seed of 45% one year after release. However, at the beginning of the season emergence of the flies from diapause is not in phase with the capitulum development of the thistle and the majority of the insects do not succeed in finding oviposition sites. It is expected that this asynchrony in fly emergence should, by natural selection, become attuned with the phenology of thistle flowering in Australia, thus increasing the effectiveness of this biocontrol agent (Woodburn 1996a).

Combined impact of R. conicus and U. solstitialis

As indicated above, it was expected that there would either be minimal interspecific competition between these two capitula-feeding insects or that the seed fly would out-compete *R. conicus* in its introduced environment. Research to date indicates that, in fact, *R. conicus* is the superior competitor in Australia, at least at the beginning of the flowering period when the primary immature capitula (the site of oviposition for both species) are in short supply. These capitula are heavily attacked by *R. conicus* (more than 150 eggs per capitula—which is much greater than egg densities in Europe) and they either abort, or the receptacle tissue is completely mined. *U. solstitialis* requires this tissue to form a vascular connection and induce gall formation. When thistle densities are high competition is not as severe because there are more early immature capitula for the insects to utilize. At one such site, the insects together reduced seeding by 70%, but with the major contribution being made by the seed fly (Woodburn 1996b). Due to adverse competition between these insects, it has been decided not to assist the spread of *R. conicus* through the redistribution network.

Impact of T. horridus

Field evaluation of this insect is still at a preliminary stage, with no data having been collected at the thistle population level. Impact on individual plants was monitored in the field, using plants sprayed with insecticide at fortnightly intervals throughout the weevil's oviposition period as controls. Ten per cent of the attacked plants died as a result of attack by *T. horridus*. The final rosette diameter of plants that had survived attack was 50% less, and capitula production 70% less than that of the controls (Woodburn unpublished). Assessment of attack by this insect on a plant population basis commenced in the autumn of 1996.

Expectations of biocontrol and time scale needed

Biological control of weeds has a relatively long history, and during this time there have been some quite spectacular successes, as well as many that were not so spectacular (Crawley 1990). The community is generally well aware of the successes, e.g. prickly pear and more recently salvinia, where plant populations have been decimated by the control agents. For practitioners in this area this is a two-edged sword in that the farming community is convinced of the worth of this approach but also expects that they will see similar rapid and dramatic results with their particular weed. In the case of the thistle species under consideration here such spectacular success in the short term is remote. Even if seeding were halted immediately, thistles would remain at unacceptably high levels for many years to come, due to the soil seed bank which is both relatively long lived and, compared to Europe, is very large (Pettit *et al.* 1996, Woodburn and Sheppard 1996). The essential message that needs to be delivered to the rural community is that biocontrol is a long term approach to reducing weed densities, though in the shorter term the spread of weeds may be limited by a reduction in seed output. An indication of the size of the task comes from a long term ongoing experiment conducted on Illyrian thistle, where seed production is reduced by mechanically removing 100, 90, 50 and 0% of capitula produced on experimental field plots. The size of the soil seed bank is monitored each year. After four years a significant reduction in the seed bank is only detectable in the 100 and 90% removal plots, and at 90% seed destruction, the more realistic level, the half-life of the seed bank is estimated at four years.

Role of biological control in overall management strategies

Given that biological control of thistles is a long-term solution, it becomes essential to maintain other forms of control to minimize the impact of these weeds in the shorter term. Overall management strategies can be developed in two stages. A first approach would be to determine the appropriate control method for a particular situation, e.g. cultivation and cropping on arable land, broadacre herbicide use on high-value improved pastures, biological control on non-arable rangelands of lower value and in weed refuge areas etc. Such spatial stratification of different control treatments could then lead to a truly integrated approach where biocontrol occurs together with cultural and chemical control methods. Such integration, however, would require careful planning to ensure that the increase in population of biological control agents and their impact is not inhibited by methods such as herbicide use and grazing management. Evidence exists that the use of insects and herbicides are compatible, if attention is given to the timing of application of chemicals relative to the insects' life-cycle (Trumble and Kok 1982). Once biocontrol agents start to modify the dynamics of thistle populations, changes will pass through to other components of the pasture environment, such as availability of germination microsites and interspecific plant competition. There is thus the potential for synergism between biocontrol and other methods such as grazing management in reducing impact.

The future of biological control of thistles lies as one component, albeit a key one, in an overall management system. The challenge to the CRC for Weed Management Systems is to develop such strategies for the different major thistle groups as they infest different land-types and land-uses.

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