Biological control of broad-leafed pasture weeds (Paterson's curse, *Onopordum* and nodding thistles) What have we achieved and where to from here?

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Summary Since 1996 the Australian Wool Innovation (AWI) and Meat and Livestock Australia (MLA) have funded a national biocontrol agent redistribution project. Through this process, 17 insects have been released on three weeds and six are impacting on the fitness of their host. As a result, *Carduus nutans* has been controlled at study sites in the Southern Tablelands of NSW, *Onopordum* spp. seed production is being reduced by greater than 80% at several sites and plant mortality of *Echium plantagineum* is recorded at several sites. A recent economic analysis (Nordblom *et al.* 2000) has shown that redistribution needs to continue to maximise the potential of these insects across the entire range of the weeds.

Keywords Biological control, *Onopordum*, *Carduus*, *Echium*, redistribution, monitoring, impact.

INTRODUCTION

CSIRO Entomology initiated biological control projects against the broad-leafed pasture weeds *Echium plantagineum* (Paterson's curse), *Onopordum illyricum* / *O. acanthium* (Scotch and Illyrian thistle) and *Carduus nutans* (nodding thistle) in the late 1980s. Up until 1996/1997, Australian Wool Innovation (AWI) and Meat and Livestock Australia (MLA) funded the three projects independently, with the work focusing mostly on the importation, host-specificity testing and initial establishment of agents at a small number of nursery sites. From 1997/1998, the three projects were placed under one funding umbrella with a fourth project on the biocontrol of *Cirsium* thistles (run by DNRE, Victoria). The project focuses on the establishment, redistribution and monitoring of agents across temperate Australia, with the main objective being the fast tracking of the delivery of biocontrol to the end user. The process involves officers from CSIRO Entomology, State departments of Agriculture, local government and Landcare, who work to engage members of the community in the release and redistribution process, with the aim of handing over the final responsibility for local redistribution to them.

Monitoring of agent performance is carried out parallel to the release process. Monitoring has been developed around a three tiered structure, where level three monitoring provides data on broad scale establishment and initial spread, level two provides data on plant density and attack rate, and level one provides detailed data on the impact of agents on seed production and seed bank dynamics (see Briese *et al* 1998). Data collected provide information that supports management decisions for the future priorities of the project, as well as providing feed back to everyone from landholders to funding partners on the progress of the project.

Achievements to date During the life of the broad leaf pasture weed biological control projects, 17 species of agent have been released against the three target weeds (Briese *et al* 2002, Sheppard *et al.* 1999, Woodburn 1997, Woodburn and Cullen 1995, Woodburn 1993). Of these 17 species, three agents were established prior to the inception of the redistribution project and were not included in it. They are the Paterson's curse leaf-mining moth (*Dialectica scalariella*) and the stem boring weevil (*Phytoecia coerulescens*) and the nodding thistle seed weevil (*Rhinocyllus conicus*). The leaf miner was the first agent released on Paterson's curse in Australia, this agent quickly became established across the range of its host, and was therefore not considered for redistribution. In the case of the stem borer, a post-release impact study was carried out which indicated that it would have little impact of Paterson's curse (Smyth and Sheppard 2000). A decision was therefore made not to redistribute it away from initial sites.

Releases of the nodding thistle seed weevil (*R. conicus*) were completed prior to the advent of the current project (Woodburn and Cullen 1995). The seed weevil has dispersed naturally across the range of nodding thistle from a limited number of initial release sites in the three main regions of infestation, the Monaro, Central/Southern and the New England tablelands.

Table 1 lists the 12 agents that the project has focused on since 1997/1998. Of these, ten are established in the field, while it is too early to confirm the establishment of the *Onopordum* rosette fly (*Botanophila spinosa*) and seed fly (*Urophora terebrans*). The number of species established is high compared to the average establishment rate of 60–70% for biocontrol programs globally (Syrett *et al*. 2000). This reflects the value of funding the development of effective release and redistribution strategies.

Two species have failed to establish; the first species of seed fly (*Tephritis postica*) released on *Onopordum* thistles, and a second species of flea beetle (*Longitarsus aeneus*) released on Paterson's curse. Failure of the seed fly to establish has been attributed to the inability of the species to overcome the effects of small initial release numbers or Allee effect (Hopper and Roush 1993) associated with releasing a new species. Failure of the flea beetle to establish has been attributed to our inability to resynchronise the species to southern hemisphere seasons.

A GLIMPSE OF SOME MONITORING DATA

Nodding thistle The release and redistribution phase of the nodding thistle project has come to a conclusion during the past three years. However, the monitoring of the performance of the agents and their host plant has continued. Figure 1 illustrates that the mean *Carduus* seed bank at Yaouk and Kybeyan have declined from a high of 9500 seeds m^{-2} in 1989 to 397 seeds m^{-2} in 2001 ($P<0.0001$), a density that is comparable with European seed banks (Sheppard *et al.* 1988). Figure 1 also shows how plant densities varied over 1989–1995 compared to the last four years 1998–2001; these differences are significant ($P<0.001$). Figure 2 further supports the hypothesis that seed banks are being depleted at monitoring sites.

Plant densities have significantly declined since 1998 ($P<0.05$), while *T. horridus* attack by June has steadily increased to 60% of plants. At this attack rate, for the similar crown weevil for Paterson's curse, plant mortally has reached 100% (Sheppard *et al*. 1999).

***Onopordum* thistles** Level two monitoring of the performance of the *Onopordum* seed weevil (*Larinus latus*) indicates that local population densities at older release sites have now reached levels that are significantly suppressing seed production (Figure 3) and that this suppression is increasing with time. If these trends continue a reduction in the soil seed bank will result. Another positive indication of the performance of the seed weevil is that populations are routinely being found at isolated sites tens of kilometres from the nearest release.

Table 1. Agents released against the three broad-leafed pasture weeds in Australia.

Weed	Agent Species	No. of releases
Onopordum	*Larinus latus*	227
	Lixus cardui	549
	*Eublemma amoena***	40
	*Trichosirocalus briesii**	3
	*Botanophila spinosa**	2
	*Urophora terebrans**	1
C. nutans	*Urophora solstitialis*	101
	Trichosirocalus horridus	102
E. plantagineum	*Mogulones larvatus***	1124
	*Mogulones geographicus**	95
	*Longitarsus echii**	103
	*Meligethes planiusculus**	53

*Agents requiring further regional and local redistribution effort after April 2002.

** Agents requiring only further local redistribution effort after April 2002.

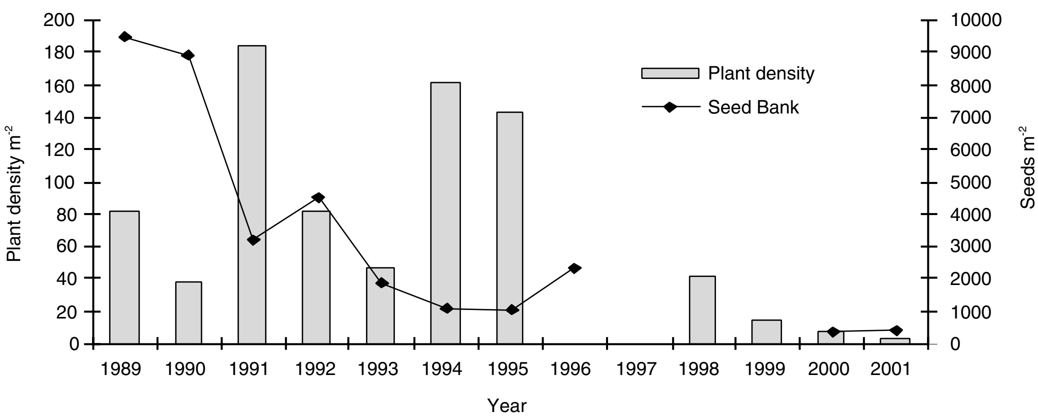

Figure 1. The *Carduus* soil seed bank and plant density at Yaouk and Kybeyan 1988–2000.

Paterson's curse Figure 4 shows the mean plant densities and crown weevil (*Mogulones larvatus*) attack rates (AR) from 30 level two sites sampled across Australia from 1997–2001. Highest AR (% of attacked plants) has been included to illustrate the full range of results being achieved at level 2 sites. The overall trend is that crown weevil attack rates across Australia are on the increase, although there are still a number of sites where little or no attack is being detected by the monitoring protocol. The weevils have established at these sites with low attack rates and it is anticipated that attack rate in high rainfall regions will increase with time, to the point where impact is detectable by the monitoring protocol. In contrast, the attack rate of *M. larvatus* in late break Mediterranean regions (particularly WA) has remained below 10%. The late break to the season (May–June) in these regions and the ability of the weevil to only aestivate successfully until April explains the difference in weevil attack rates. In contrast the flea beetle, *Longitarsus echii* has established at 84% of sites so far and is well suited to the climate in WA (Smyth and Sheppard 2002).

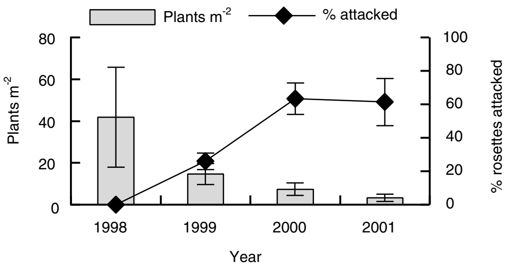

Figure 2. *C. nutans* plants m^{-2} and *T. horridus* attack rate (%) at eight monitoring sites.

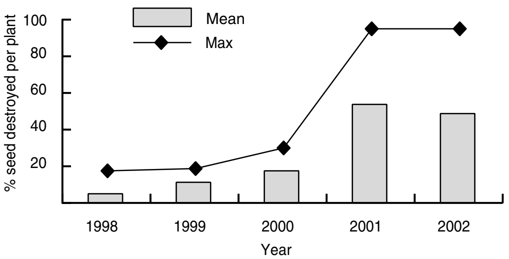

Figure 3. *Onopordum* seed destroyed by the seed weevil *Larinus latus* at eight level 2 sites during 1998–2002.

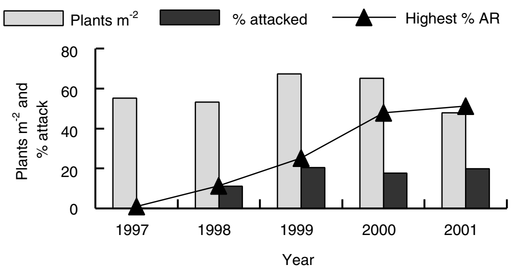

Figure 4. Paterson's curse and *M. larvatus* attack m^{-2} at 30 level 2 sites during 1997–2001.

DISCUSSION

Where to from here? There will be a need for ongoing redistribution effort of agents for both *Onopordum* (four agents, see Table 1) and Paterson's curse (four agents, see Table 1) so that the maximum benefit of the full biocontrol suite may be realised across the distribution of the target weeds.

How do we know when we've made enough releases? The *Onopordum* stem-boring weevil (*Lixus cardui*) is one of two agents for which the regional and local redistribution process may be considered complete. This decision was reached once requests for releases within the local network groups began to decline. The successful transfer of insect release technology to the community, which has produced ongoing local redistribution, also supports this decision. In contrast a simple numerical comparison of this release effort versus the release status of the Paterson's curse crown weevil illustrates the amount of work required to achieve complete local redistribution. *Onopordum* thistles infest one million hectares across NSW (Briese *et al.* 1990), and 549 releases of the stem borer have been made throughout this area. Paterson's curse infests 33 million hectares in Australia (IAC Report 1985), and to date there have been 400 releases of the crown weevil established (Nordblom *et al*. 2001). In simple terms the stem borer has 16 times as many releases per unit area as the crown weevil. The technology transfer process for the crown weevil lags behind because there is only a small number of nursery sites from which collection for redistribution is possible. Continued effort on the redistribution of the crown weevil should focus on the speeding up of the technology transfer process to local community groups supported by local government officers and Landcare.

The remaining seven agents (Table 1) that require ongoing redistribution are not yet at release and establishment levels that will allow redistribution by local collaborators. In the case of the three Paterson's curse agents, the technology and rearing facilities are in place to provide a complete regional release network over the next three to five years. The four *Onopordum* agents requiring ongoing release are not in such an advanced state as the Paterson's curse agents and release protocols will need to be perfected in coming seasons before regional redistribution can begin.

CONCLUSIONS

This project has provided a benchmark for the delivery of weed biocontrol in Australia. We are on the verge of success in the control of nodding thistle, have achieved significant impact on the seed production of *Onopordum* thistles and are witnessing population increases in Paterson's curse agents across a broad scale. Despite this, at the time of writing, future funding for the project is in doubt, even though a recent economic analysis (Nordblom *et al*. 2001) has demonstrated that investment in the speeding up of biocontrol delivery has a high benefit-cost ratio and substantially increases the economic returns of biocontrol.

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