final report

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The Biological Control of Paterson's Curse and Scotch Thistles

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The Biological Control of Paterson's Curse and Scotch Thistles

A long-term investment by grazing industries, State and Federal Governments

Milestone 6 - Project ECO10-D

Scientific Partners
CSIRO Entomology
Department of Agriculture WA
Department Primary Industries Victoria
NSW Department of Primary Industries
South Australian Research & Development Institute

Funded by:
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[1]

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[1] Cover photo. Paterson's curse agent exclusion experiment highlighting how well the weed grows in the absence of biological control agents compared with those attacked by the agents. Photo courtesy DPI Vic

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1 Executive Summary

Paterson's curse and Onopordum thistles are significant weeds that seriously impact the profitability of the grazing industries of Australia through lost productivity, control costs, stock management and collateral damage such as stock poisoning and fleece contamination. Similarly horehound and blue heliotrope have a detrimental effect on pasture but on a smaller scale. This project has delivered a suite of biological control agents and evaluated its performance empirically and qualitatively. The grazing industries of Australia are already deriving significant benefits as a result of this project and will continue to do so at an increasing rate as the agents spread and establish naturally and continue to be distributed by farmers.

Senator Troeth, the Parliamentary Secretary for Agriculture, Fisheries and Forestry, in November 1999 described the project as ***"an excellent example of government and industry working together for the national good."***

The project to date has been a great success with over 4,000 releases of biological control agents against the target weeds across Australia. In addition, the thistle component of the project was cited in an audit of research conducted by CSIRO as an example of a difficult project that, although inherently protracted, had been successfully applied and was having measurable benefits to the grazing industries. Due to the direct involvement of landholders in the release of agents and the quality of extension materials and presentations, the project also has a high grass-roots profile and approval by wool and meat producers.

1.1 What the Farmers Say

A survey of graziers affected by Paterson's curse, conducted in 2005, found the weed is still considered a problem to sheep and cattle production and profitability, but graziers involved in the biological control network report that as a result of the destructive activities of the suite of agents they have benefited by:

- 24% decrease in the weed due to insect agents,
- 31% average reduction in the use of herbicides,
- 12% increase in stock production,
- 9% increase in stock numbers, and
- Highly visible impact on Paterson's curse.

1.2 What the Economists Say

Paterson's curse - Based on a consideration of only the impact of the crown weevil, the annual benefits in terms of increased productivity (not including reduced cost of conventional control) is conservatively projected to rise to $73m by 2015.

The discounted (5%) net present value (NPV) of the benefit-cost stream from 1972 to 2015 is projected to be $259m, for a benefit/cost (B/C) ratio of 14.1:1 and an internal rate of return exceeding 17% on a total research investment of $21m (04/05 dollar terms).

***Onopordum* thistles**

Based on an investment of $3.7m in research, the biological control program has a net present value (NPV) of $18.0m and a benefit/cost ratio (B/C) of 9.6 at a discount rate of 8%.

1.3 Catalogue of Achievements

By investing in this biological control project, Australian Wool Innovation and Meat and Livestock Australia have facilitated a more rapid resolution of the weed problem and supported the delivery or establishment of:

- 4000 releases of species-specific biological control agents for Paterson's curse, *Onopordum* thistles, horehound, and blue heliotrope.
- A network of >1700 graziers involved in the project and integrating biological control into their pasture management regimes.
- A hands-on and motivated support team of 330 Field Officers, Weeds Officers and Landcare Groups trained in biological and integrated weed control.
- 322 weed control training workshops, talks, interviews and field days.
- A landmark project in biological control of a geographically dispersed weed of pastures. The project has:
    - achieved significant benefits for the wool and meat industries
    - pioneered a cost-effective agent distribution strategy based on farmers contributing directly to a community based program facilitated by scientists and weed officers
    - delivered the 5th best financial return of 36 Australian biological control projects assessed in 2006.

1.4 Technical Achievements

The project has delivered:

- Continual improvements such that the total number of agents released has more than doubled over the past two years compared to the previous 7 years since success in regional field collection has obviated the need to mass-rear insects in the laboratory.
- Comprehensive information packs and news specifically tailored to the needs of the states and different regions. The main target groups included journalists, producers, weeds and extension officers. To date the project has delivered numerous press releases on the biological control program, 4 book chapters, 19 refereed journal articles, 42 conference papers, and 20 technical articles and brochures.
- An integrated weed management approach incorporating the concepts of biological control, herbicide control, grazing management and pasture renovation. Farmers have been highly receptive to the project information kits that have resulted in a heightened awareness of weeds and improved farm management practices in 82% of farmers surveyed.
- Close collaboration between state agencies and CSIRO which has meant that the project advanced with respect to technically issues, dissemination of information and maintenance of the farmer network despite impediments to the project

caused by drought and other logistical problems. In particular, the active "interstate trade" in agents and information enabled the project to maintain a high level of momentum.

- Development of methodologies to measure the performance of biological control insects on both a regional and paddock scale. Simple monitoring studies have demonstrated plant, local and regional significant impacts on the population dynamics of the target weeds, including:
  - Death of target plants
  - An increase in the proportion of grasses and clover in pasture where the crown weevil and flea beetle are active attacking Paterson's curse.
- Pioneering community-based networks to fast track the release and establishment of biological control agents. The network was largely based around regional nodes in each state at which laboratory reared agents were released and established. Once the population at each node had built to a point at which harvesting of insects was cost-effective, insects were collected by graziers from surrounding farms with a view to establishing new nodes on their own properties. Typically, local weeds officers supervised the harvesting of insects and the maintenance of populations at each node. In this way the network of farmers quickly grew to include over 1,700 meat and wool producers who distributed agents to over 4,000 weed infested sites.

1.5 Other Benefits

- Producers with a real sense of ownership of the processes and outcomes of a highly successful community-based distribution system and biological control program.
- The continued support and leverage of MLA and AWI investment in the project by the 5 agencies providing the essential research services:

  CSIRO Entomology
  Department of Agriculture WA
  Department Primary Industries Victoria
  NSW Department of Primary Industries
  South Australian Research & Development Institute

- Permanently employed state and municipal weed officers have committed to support the farmers in optimising this biological control campaign. The collaboration that characterised this project is unique and contributed significantly to the successful operation of the agent distribution and communication network. Landcare, particularly in Victoria, has played a major role in linking farmers with research agencies.
- The research and extension program has provided a major training opportunity for some 26 scientists and technicians around Australia in weed management, biological control and farming systems.
- Farmers whose land is afflicted by the Paterson's curse are becoming more vocal and excited about the prospects of effecting serious control of the weed using the insect agents even to the point of not using herbicides.
- The development of and access to an increased State science and extension services network specialising in and focussed on biological control of weeds.

1.6 Recommendations for Further Work

1. To effectively fill the gaps in the ideal range and geographic distribution of the more recently introduced agents, it is recommended that the agents be distributed to additional sites, thus:

Flea beetle	1058 more sites
Pollen beetle	1586 more sites
Root weevil	1467 more sites

   Regions that need particular attention with respect to delivery of root weevil, pollen beetle and flea beetle include:
   - the northern 2/3 of range of Paterson's curse in South Australia and Eyre Peninsula where established colonies of agents have been exterminated or decimated by the fires of early 2005;
   - Gippsland in Victoria which was deemed of lower urgency than other parts of the State is in need of comprehensive releases of pollen beetle and flea beetle – the releases need to be complemented by the establishment and training of a support network of weed officers and distribution of information packs to end users.
2. Development of a CD to complement information and needs of end users already involved in distribution network. The collated information on the CD is would be integral to any extension of the project work from 2006 and will serve as the key source of information in the absence of the support of scientific input in the future.

More general needs include:

3. Provision of operating funds to promote, collate, maintain and interpret field data from the state agencies.
4. Training new field and weed officers in new regions (as yet not involved in distribution of agents) to a point where they can effectively work unsupervised and contribute to maintaining and expanding the network locally and regionally.
5. Evaluation of the project outcomes to empirically demonstrate the benefits of the project and to quantify the return on the investment of MLA, AWI and the respective state agencies.
6. Detailed ecological studies (PhDs) on the interaction of the agent species to answer questions such as - is feeding of pollen beetle multiplicative to the damage of the rosette feeding insects?

2 Introduction

The biological control of Paterson's curse (*Echium plantagineum*) and thistles (*Onopordum spp*) has been a long-standing investment by AWI and MLA since the projects started in 1988[2]. It is now realising benefits for the grazing industry and Paterson's curse management stakeholders more broadly. The key to achieving this emerging success has been facilitated by the sustained funding the project has enjoyed, creating the framework within which national collaboration between government agencies has flourished allowing the effective transfer of technology for the successful delivery of biological control to the wool and meat producers affected by these weeds.

To achieve this, the Wool and Meat Industries funded a multi-agency project on introducing the biological control insects from 1988-1993, establishing them nationally from 1993-1997 and then focussing on the Australia-wide distribution of the agents from 1997-2005. This project has been highly successful, particularly in the establishment of redistribution networks within each state. The extent to which biological control techniques have been adopted and incorporated into weed management systems by wool and meat producers as well as other sections of the grazing industry is clear testament to the level of their support (over 1700 farmers have been directly involved in the program).

2.1 Paterson's Curse

2.1.1 Paterson's Curse Biological Control – Project History

The CSIRO commenced work on biological control of Paterson's curse in 1972 after approval from the Australian Agricultural Council. A list of potential agents identified in Europe was proposed and host-specificity testing led to approval by Plant Quarantine for the release of six of the insects. The leaf mining moth *Dialectica scalariella* was first released in 1980, but establishment was unsuccessful and a High Court injunction initiated by apiarists stopped the program. The subsequent legal activity led to an inquiry by the then Industries Assistance Commission that concluded that biological control of Paterson's curse would be a benefit to Australia. The Australian Weeds Committee, the Standing Committee on Agriculture and the Australian Agricultural Council all recommended that the program be re-started. CSIRO recommenced work on this project in 1987 with support from the Australian Wool Corporation and the Meat Research Corporation (as The Woolmark Company and Meat and Livestock Australia were known then, respectively).

By June 1992 the project had achieved the following:

- Collection, shipment, rearing and redistribution of the leaf mining moth *Dialectica scalariella*, including studies of developmental and release requirements. This agent had been spread to more than 1000 sites throughout the range of the weed but has provided only limited impact
- Collection, shipment and rearing of the crown weevil *Mogulones larvatus*. Colonies were also supplied to all other affected States

[2] For more details on the history of the project refer to Appendix 1

- Collection, shipment, rearing and first two releases of the root weevil *Mogulones geographicus*
- Collection, shipment, rearing and host specificity testing in quarantine of the moth *Ethmia bipunctella*. Subsequently this work was discontinued when the moth was found to oviposit and survive on native Australian Boraginaceae.
- Collection, shipment and one release of the flea beetle *Longitarsus aeneus.* The release and all to attempts to rear this insect have subsequently failed and so work on this species was discontinued
- Collection and shipment of the lace bugs *Dictyla* spp. into quarantine at KTRI
- Studies on the likely interactions between both *Mogulones larvatus* and *Mogulones geographicus* following release in Australia
- Measurements of occurrence and damage levels of seven short-listed potential agents were assessed in their native range together with the impact of the whole phytophagous community. This work led to the development of a priority list for introductions based on their ecological characteristics
- Studies of the population ecology of the weed in relation to grazing and pasture competition and composition to test the impact of natural enemies on weed population levels and seed production
- Studies of the seed-bank dynamics of the weed in both the native range and Australia including the development of a theoretical model and various field tests.

In 1995, the focus of the project shifted to the effective distribution and establishment of the agents across the geographic range of weeds, i.e. effective application and extension. This was done by developing effective redistribution networks for selected control agents, and by setting up monitoring strategies to begin to evaluate agent impact on the target weeds and demonstrate the benefits of biological control to the industry. As the redistribution component accelerated, the final agents pollen beetle and flea beetle were cleared through quarantine in 1999.

Since 1999, the project has been directed at distribution logistics (particularly of the pollen beetle, flea beetle and root weevil), communication, extension, and an ongoing program of detailed monitoring and measurement of impact of the agents.

2.1.2 Paterson's Curse Agents

In the case of Paterson's curse, agents are not only able to attack the plant at different periods of its life-cycle, but are also active across the relatively broad range of geographic and climatic conditions over the distribution of this weed across southern Australia.

1. The crown weevil (*Mogulones larvatus*) is active and most effective early in the season (autumn and early winter) feeding in the crown of the rosettes that have germinated from summer storms and early breaks. Feeding in the rosettes that are young and small and the meristem (the site where new leaves are produced) makes crown weevil the most damaging of the 4 insects, and it has started to control the weed locally in south-eastern Australia.
2. The adults and larvae (the most damaging life-stage) of the root weevil (*Mogulones geographicus*) feed in the taproot of the rosette and are active later in the season (March-May), tolerating dry summers more successfully than the crown weevil

3. A second root feeder, the flea beetle (*Longitarsus echii*) complements the damage of root weevil by feeding in the cortex (outer layer of root tissue) of the taproot and also in the finer (lateral) secondary roots of the weed. The activity of flea beetle adults is even later in the season June – August) and for the larvae (September – December). The delay in flea beetle adult activity until winter facilitates its high survival rates even in the driest years. Like the root weevil, larval feeding below ground enables flea beetle to tolerate heavy grazing more successfully than the crown-feeding crown weevil.
4. The final insect released was the flower and seed-feeding pollen beetle (*Meligethes planiusculus*). Feeding directly on the reproductive plant growth, *Pollen beetle* damage adds to the impact the rosette feeding insects have on the weed.

Together, these insects attack Paterson's curse throughout its vegetative and reproductive growth, from low to high rainfall districts and under low to heavy grazing regimes. Redistributing all four insects therefore maximises impact on the weed not only within a single paddock but also across the geographic range of the weed.

2.2 Onopordum Thistles

Stemless thistle is a third species of *Onopordum* that is widespread in more arid grazing lands of South Australia and Western Australia, infesting some 1.6 million hectares. While economically not as important as are the other two *Onopordum* thistles (Scotch and Illyrian thistle) in south-eastern Australia, this project provides the opportunity to establish biological control agents on these thistles, preventing their further spread and impact for no extra cost. This is particularly relevant to Western Australia, where stemless thistle has spread since its introduction in 1955 despite active eradication campaigns based on herbicide use. Apart from the stem-boring weevil, agents that attack Scotch and Illyrian thistle will attack stemless thistle.

In the case of *Onopordum* thistles, from more than 120 insect species found to feed on them in their native European range, six were selected to form a complementary herbivorous guild, which attack stemless, Scotch and Illyrian thistles at different stages of development of the plants.

2.2.1 Thistle Agents

Thistle life-stage	**Biological control agent**
small rosette ⇒ large rosette	Rosette weevil (*Trichosirocalus briesei*) Petiole moth *(Eublemma amoena)* Crown fly *(Botanophila spinosa*),
stem elongation ⇒ flowering	Stem-boring weevil (*Lixus cardui*)
seed production ⇒ soil seed reserves	Seed weevil (*Larinus latus* Seed fly *(Urophora terebrans*)

2.3 Horehound

Horehound (*Marrubium vulgare*) occurs throughout Southern Australia, infesting some 26 million hectares. It is generally unpalatable to grazing stock due the presence of bitter alkaloids, but will taint the meat of animals that eat it, while the burrs are an additional problem for the wool industry through fleece contamination. In the early 1990s the Wool industry funded research leading to introduction of biological control agents for horehound One of these agents, the plume moth, has been recorded causing extensive defoliation at early release sites. The positive impact achieved by this moth and another agent, the clearwing moth, resulted in a significant demand for these species from woolgrowers and meat producers in the horehound affected areas.

2.3.1 Horehound Agents

Plume moth	*Wheeleria spilodactylis*
Clearwing moth	*Chamaesphecia mysiniformis*

2.4 Blue Heliotrope

Blue heliotrope (*Heliotropium* amplexicaule) is a toxic weed that competes strongly with summer pastures over several hundred thousand hectares in south-east Queensland and northern New South Wales. Over the past ten years it has substantially expanded its range and this is continuing to spread. Pyrrolizidine alkaloids present in it regularly cause cattle deaths in Queensland, and it affects beef, sheepmeat and wool producing regions. The wool industry funded a preliminary study in the early 1990s that identified candidate agents. These agents were studied in more detail during the late 1990s under RIRDC funding, leading the release of the leaf-beetle in 2001. Existing Paterson's curse redistribution networks in northern New South Wales can be used for release of the beetle, while CSIRO can supply agents and advice to Queensland producer groups seeking PIRD funds for a beetle program.

2.4.1 Blue Heliotrope Agent

Leaf-feeding beetle	*Deuterocampta quadrijuga*

3 Paterson's Curse Project Results

3.1 Farmer Survey

The primary benefits of the Paterson's curse component of the research program relate to a reduction in the impact the weed has on profitable grazing systems. The actual effects can be measured with some certainty and consequently has been the target of an extensive monitoring programme at key sites across the range of the weed. Whether the project has delivered significant benefits for the grazing industries of Australia relates to the perceptions of meat and wool producers. Has the project that has consumed many levy dollars really made a difference? The following survey results suggest it has.

Surveying farmers is a direct way gaining information on the performance of biological control. In fact from an industry perspective this group of individuals are the key stakeholders in this program. It is through the investment of their levies that the leverage was created to engage National, State and local organisations and their in-kind contributions. Farmers' perceptions of the biological program are therefore key in confirming the project's impact and success.

To understand the problem faced by farmers with Paterson's curse a survey was first conducted in 1996 by the project team. The main focus of this first survey was to quantify the scale of the Paterson's curse problem in terms of the size of the infestation, the costs associated with the weed and methods used to manage the problem. The survey was conducted again in 2005 with a section on biological control added (see Appendix 1). These two related surveys conducted at different points in time allow data and perception trends to be plotted from the point of view of the stakeholders independently of the empirical research findings.

3.1.1 Main Survey Findings

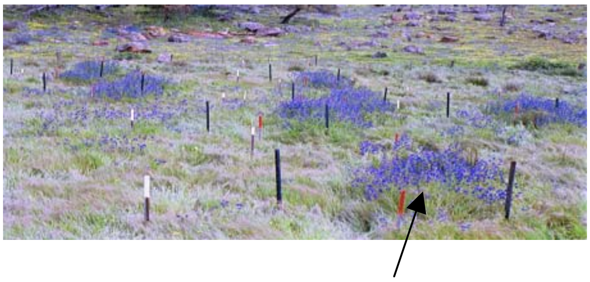


Figure 1 Protecting Paterson's curse with insecticides vividly demonstrates the potential impact of the insect biological control agents

Paterson's curse is still a major detriment to sheep and cattle production and profitability, but producers[3] involved in the biological control network report that as a result of the destructive activities of the suite of 4 agents they have benefited by:

- 24% decrease in the weed due to insect agents
- 31% average reduction in the use of herbicides

[3] Program Satisfaction and Results Survey. August 2005. See Appendix 1

- 12% increase in stock production,
- 9% increase in stock numbers, and
- Highly visible impact on Paterson's curse (depicted in Figure 1 - a photograph from Victoria).

When survey respondents were questioned on their impressions of the program:

- 96% stated that the biological control of Paterson's curse had been of benefit and a worthwhile investment for AWI and MLA
- 57% was the expected net reduction in the weed that will be achieved by the agents
- 82% had derived great assistance from the biological control information packs in understanding biological control and its place in integrated weed management, and
- 97% would like the Paterson's curse biological control program to be continued and expanded.

A most striking change is the shift from sheep to cattle production as the main income source for farmers (Table 1). In 2005, 61% of respondents list cattle as the main source of income, up from 45% in 1996. Correspondingly the number of sheep producers, both meat and wool, have declined by 10% each. This shift in farm enterprise is reflected in the mean number of sheep per property declining by 30% and cattle numbers increasing by 111%. Such a shift in grazing stock may benefit the biological control of Paterson's curse as it has been shown sheep grazing can severely limit the population of some insect species (see Section 6 on Integrated Weed Management).

Table 1: Property description

	1996 (n = 133)	**2005 (n = 46)**
Mean farm size in hectares	647	666
Mean number of sheep per property	2,240	1,565
Mean number of Cattle per property	202	428
Grazing enterprise ranked as primary source of income		
Cattle meat	45%	61%
Sheep meat	20%	10%
Sheep wool	31%	20%

For graziers, Paterson's curse is continuing to be a problem and most have had the weed on average for 25 years and even with that time to deal with it actively, the clear majority see the weed as a problem that is staying the same or increasing (Table 2) although the percentage of farmers has dropped from 82% to 64% between 1996 and 2005. This perception is confirmed by both the area and percentage of the property covered by the weed. Based on the survey results, this weed is clearly one that will not be controlled adequately with conventional management techniques.

Table 2: Paterson's curse infestation

	1996 (n = 133)	**2005 (n = 46)**
Mean time of Paterson's curse infestation (years)	20	25
Has Paterson's curse increased or remained the same? (Affirmative)[1]	82%	64%
Mean area of property in hectares with a light infestation[1]	100	100
Mean area of property in hectares with a medium infestation[2]	80	187
Mean area of property in hectares with a heavy infestation[3]	50	114
Mean total area of infestation per property	230	401
PC infestation as a % of property	35%	60%

1 This
Light infestation; regular cover of plants more than a metre apart.
2 Medium infestation; regular cover of plants less than a metre apart sometimes in clumps.
3 Heavy infestation; uniform cover, plants touching.

As a persistent weed, Paterson's curse is also a costly burden to the profitability to farmers. Loss of production from a heavily infested pasture can be as high as 45% and with a mean infestation of 114 hectares/property this is a substantial loss of income (Table 3). On top of this production loss, mean herbicide costs of $5,200/property and a loss of 13 working days only adds to the burden this weed has on farmers' livelihoods. In spite of this the majority of farmers believe it is very worthwhile to control Paterson's curse, due to the production gains they receive from their control efforts. Interestingly the benefits of control do not completely recover the losses due to the weed, and clearly better adoption of current techniques or new control measures are necessary to limit its impacts on farm profitability.

Table 3: Costs associated with Paterson's curse infestation

	1996 (n = 133)		**2005 (n = 46)**
Loss of production from a light infestation	3%		7.5%
Loss of production from a medium infestation	18%		22%
Loss of production from a heavy infestation	36%		45%
Mean area of Paterson's curse sprayed annually	178 Ha		226 Ha
Cost of herbicides	$18/Ha		$23/Ha
Mean herbicide cost/property (nominal)	$3,200		$5,200
Time used for control (days)	7		13.5
Change in production from Paterson's curse control efforts	+22%		+14%
Do you believe it pays to control Paterson's curse?	59%, yes		63%, yes

Set against this persistent and expensive weed problem biological control is starting to directly benefit farmers. Half the respondents believe biological control is already decreasing impact of the weed while improving the quality of their pasture through increased abundance of desirable perennial and annual grasses, clover and medics (Table 4). Significantly, the mean decrease in the weed's abundance due to biological control across all properties is 23% [4]. Based on results to date, farmers predict that biological control is capable of reducing Paterson's curse by 62% (Table 5). The controlling effect of the insects is also seen in the 38% reduction in herbicide use, a saving of around $2,000 and 5 working days based on the survey results.

[4] This reported decrease is not in conflict with the observations in Table 2 which indicate there is more Paterson's curse on the properties of the farmers surveyed in 2005 – the farms and farmers are different and for those that report a positive impact by the agents they are acknowledging that the weed problem would have been worse without biological control.

Importantly, the reductions in weed abundance are translating into production gains with small but significant increases in stock condition and numbers of 9% and 6% respectively. On average this translates to an extra 25 cattle and 90 sheep per property – a substantial increase in farm income.

Table 4: The impact of biological control insects on Paterson's curse

	1996 (n = 133)		**2005 (n = 46)**
Is biocontrol reducing the weediness of Paterson's curse? Affirmative	na		48%
Is biocontrol improving the quality of your pastures? Affirmative	na		50%
Mean decrease in Paterson's curse abundance due to insects' activity	na		23%
Mean decrease in herbicide use since release of insects	na		38%
Mean increase in stock condition since release of insects	na		9%
Mean increase in stock numbers since release of insects	na		6%

The positive sentiment of farmers with regard to the biological control program is effectively represented in Table 5.

Table 5: Farmer impressions of the biological control of Paterson's curse

	1996 (n = 133)		**2005 (n = 46)**
Was there any information provided at insect release? Affirmative	na		89%
Was the information easy to understand? Affirmative	na		89%
Has the information provided helped you integrate the biocontrol insects into your farm management? Affirmative	na		87%
Given enough time what do you believe the potential reduction in Paterson's curse will be?	na		62%
Has the biological control of Paterson's curse been a worthwhile investment? Affirmative	na		88%
Should the work on the biological control of Paterson's curse continue? Affirmative	na		93%

4 Communication and Extension

The profile and interest in the Paterson's curse biological control program has remained high throughout the life of the work. In fact over the last few years the media coverage and invitations to talk at workshops and field days has increased (Table 6).

Table 6: Number of talks, interviews and field days on Paterson's curse

Year	NSW	Vic	SA	WA	CSIRO	Total
1998	8			4	2	14
1999	10	5	4	2	5	26
2000	13			21	11	44
2001	12	17	3	7	13	52
2002	14	14	6	10	11	55
2003	15	23	7	4	21	70
2004	14	16	16	13	14	73
2005	13	3	11	8	12	47
Total	99	78	47	69	89	382

These public events have been underwritten by numerous press releases on the biological control program, 4 books, 19 refereed journal articles, 42 conference papers, and 20 technical articles. These publications are listed at Section 12.

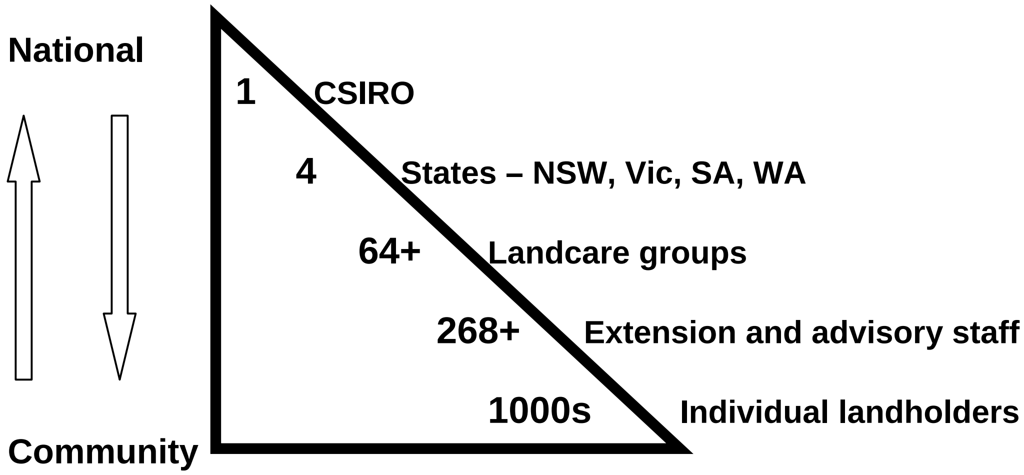
The direct involvement of farmers in the Paterson's curse program has been substantial with over 1700 participating in an insect release since the crown weevil was first released in 1992. Yet still the interest from farmers remains high as confirmed by the increasing number of releases made in the last years of the program (Tables 20 - 24) and the positive responses in the survey about the program as a whole (Table 5). The information brochures and published material, which were particularly well received (Table 5), are included on the disc appended to this document. All attendees at field days and recipients of agents received as a matter of course brochures and information packs relevant to the insects being handled on the day. This information was based on common principles and best practice methods developed by the interstate team of scientists, but modified to accommodate the idiosyncrasies of the individual states, and their weed officers and extension services. The results of the 2005 survey (Table 5) indicate 87% of farmers received information (usually disseminated with the agents) that they found to be helpful in integrating the biological control agents into their farm management systems.

The interest in the program extends beyond the direct contact with farmers and has attracted the considerable in kind support of weed professionals such as weed officers in WA and NSW, APCB officers in SA and CMA officers in Victoria. Without the support and involvement of these groups the large numbers of releases made in recent years from field days would not have been possible. The relationship between the collaborating agencies and the broader community is represented in Figure 2. As the arrows suggest the process is driven from the top down but the program has now reached a point where weed professionals are collecting and redistributing the crown weevil independently. In a few more years this independence will extend to the other insect species.

Table 7: The number of farmers, weed professionals and Landcare groups involved in the redistribution of insects

Group	NSW	Vic	SA	WA	CSIRO	Total
Farmers	732	338	260	169	210	1709
Weed Professionals	58	79	44	44	43	268
Landcare groups		59			5	64

Figure 2: Structure of the biological control redistribution networks.



5 Monitoring Insect Impact on Paterson's Curse

Monitoring the impact of the various insects was split into 3 components of decreasing order of complexity and was led by CSIRO. Level one monitoring involved detailed ecological experiments so the impact of various species could be recorded through time. From these detailed experiments more simple predictors of agent impacts, based on their abundance were developed so that multiple sites, across the distribution of Paterson's curse, could be sampled and biological control performance could be estimated across climates and different farm management regimes. The third level of monitoring was a simple presence of insects post release so rates of establishment could be determined one year after release.

The biology and impact of insects was initially confirmed by CSIRO in pot and in ground experiments so the potential of each insect could be assessed. Through this process the stem boring beetle, *Phytoecia coerulescens* was not included in the

Table 4. Level 3 Monitoring milestones for Paterson's curse (site inspection to confirm establishment)

Insect	Organization	Number of Sites			
		2003-04*	2000-05	2005-06	Total
crown weevil	SARDI	15	10	10	25
	DSE	5	10	10	25
	NSW Ag	5	10	10	25
	WA Ag	5	5	5	15
	CSIRO	5	10	10	25
Total		25	45	45	115
Root weevil[a]	SARDI	2	4		6
	DSE	0	3		3
	NSW Ag	5	8		13
	WA Ag	5	5		10
	CSIRO	5	10		15
Total		17	30		47
Flea beetle[1]	SARDI	15	8		23
	DSE	5	10	12	27
	NSW Ag	5	10	10	25
	WA Ag	5	14	19	38
	CSIRO	5	8	10	23
Total		25	48	59	132
Pollen beetle	SARDI	0 sites	0 sites		0
	DSE	2	7		9
	NSW Ag	2	2		4
	WA Ag	2	5		7
	CSIRO	2	2		4
Total		8	16	0	24
Grand Total		75	139	104	318

* Monitoring cannot take place until the year following release. Sites that have previously not been inspected for establishment should be checked this year. Data to be collected as set out in insect database.

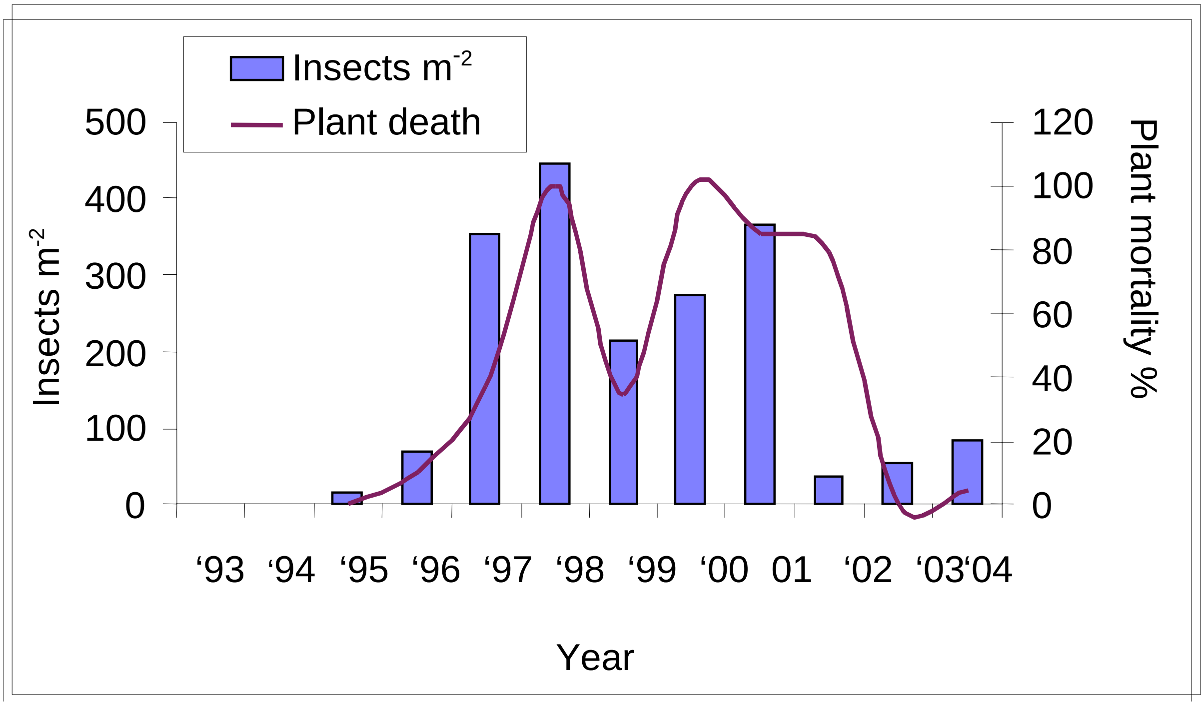
a Destructive monitoring of these species should not start until the 2nd year after release.

redistribution program because of a lack of impact on weed size and seed production. The value of this preliminary impact work was to allow resources to be concentrated on the most promising insects.

5.1 Crown Weevil

This was the first of the rosette/root feeding insects released into Australia. Priority was given to this species because of its ability to kill the weed before seeding in the native range of the weed. This ability was soon confirmed in Australia with a controlled experiment at Canberra in 1994/95 (Sheppard et al 2000). This experimental work was followed by observations of a field site at Yanco NSW where 5 years after release all the Paterson's curse on the site was killed before flowering. In subsequent years the population of crown weevil has oscillated in line with model predictions and has resulted in greater than 80% mortality over the last 8 years. At this site the farmer now neither considers Paterson's curse a problem weed nor actively controls it.

Figure 3: The population of crown weevil and plant mortality Paterson's curse at an orchard at Yanco NSW



Based on the impact of crown weevil on Paterson's curse at the Yanco site a good relationship between attack rate and weed mortality was found. Using this relationship, collaborating State agencies could estimate the impact of crown weevil by recording the number of individual weed plants attacked by the insect. Based on this the impact of crown weevil can be estimated across the country at a selection of sites. At an increasing number of sites, the impact of crown weevil has steadily grown, initially in Victoria and NSW (the Yanco site) and more recently in South Australia. In Western Australia no sites have reached a level where the insect is removing more than 50% of the weed. This difference between States reflects the climatic differences where seasonal late autumn breaks in Western Australia limit aestivation success reducing the population size of crown weevil. This consistent climatic effect of WA has been expressed in the Eastern States in recent years where drought has limited the population of crown weevil. Although the crown weevil is still spreading and reducing the weediness of Paterson's curse over a larger area, given the length of time it has been established in all States, it is likely the level of damage to the weed will remain at a similar level as today, where up to a third of properties will benefit from the activity of this insect. At remaining properties climatic and grazing pressure (see below) will limit the population of the crown weevil below the hundreds of insects per metre necessary to control Paterson's curse. In Table 8 the drop off in % sites is a function of the drought directly affecting the insect populations and indirectly through changes to stock management which results in higher grazing pressure and consequently more beetle trampling by the stock.

Figure 4: The relationship between crown weevil attack and mortality in Paterson's curse at Yanco, NSW.

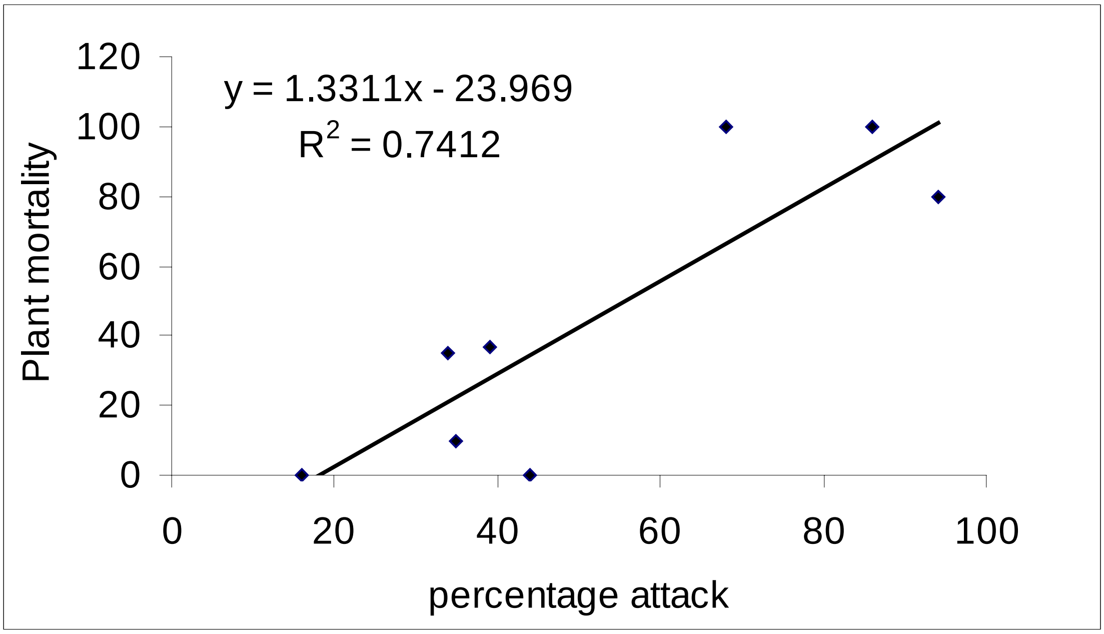


Table 8: The percentage of sites where crown weevil is reducing the abundance of Paterson's curse by more than 50%

	NSW	Vic	SA	WA	CSIRO
1996					0
1997	0	0	0	0	0
1998	1.7	0	0	0	100
1999	1.7	28.6	0	0	0
2000	2.5	50	0	0	100
2001	3.3	14.3	0	0	100
2002	4.2	28.6	0	0	100
2003	5.0	42.9	37.5	0	0
2004	6.7	50	53.9	0	0
2005	8.3	0	40	0	0

Based on the attack of crown weevil an estimate of weed mortality can be made. If the additional parameters of larval number and plant size are included a much more accurate estimate is obtained (Figure 5). This relationship also gives us a finer resolution and will estimate not just mortality but reductions in plant size and seed production (Sheppard *et al* 2001). Confirming the more detailed relationship was considered important, as it was believed a simple attack rate for the other insect species would not be sufficient to accurately estimate impact on the weed.

Figure 5: The relationship between the number of insects per plant size and plant mortality at Yanco, NSW

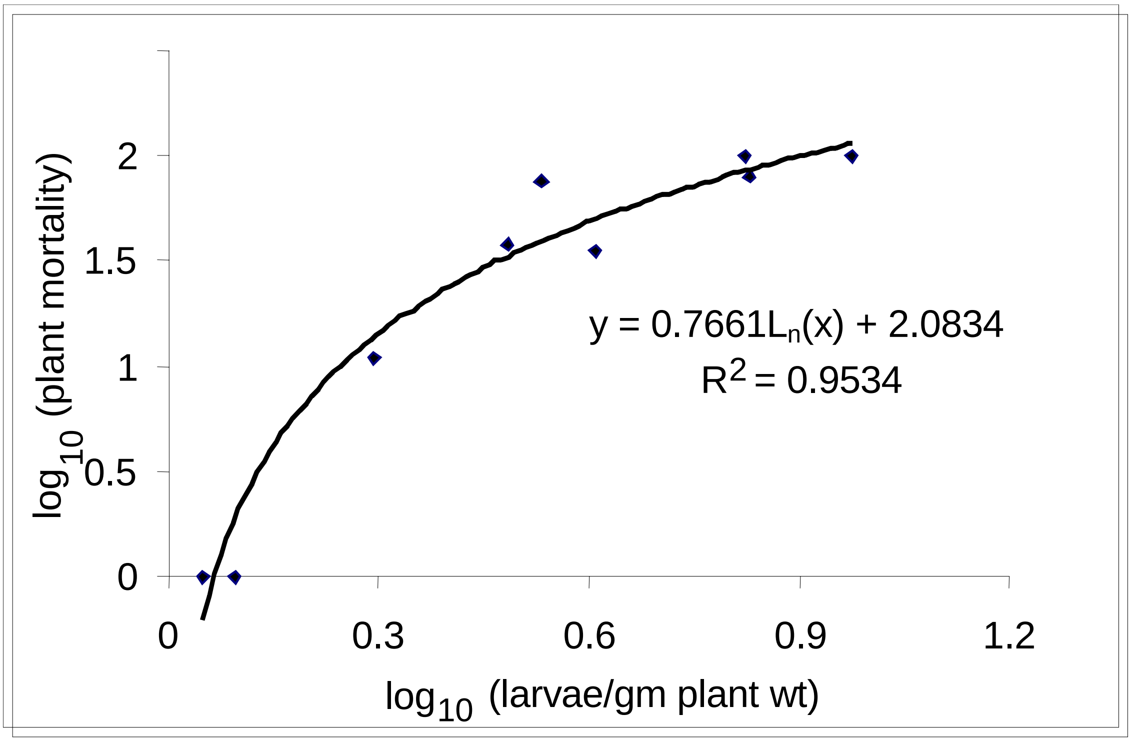


Figure 6: The relationship between the numbers of crown weevil and plant size

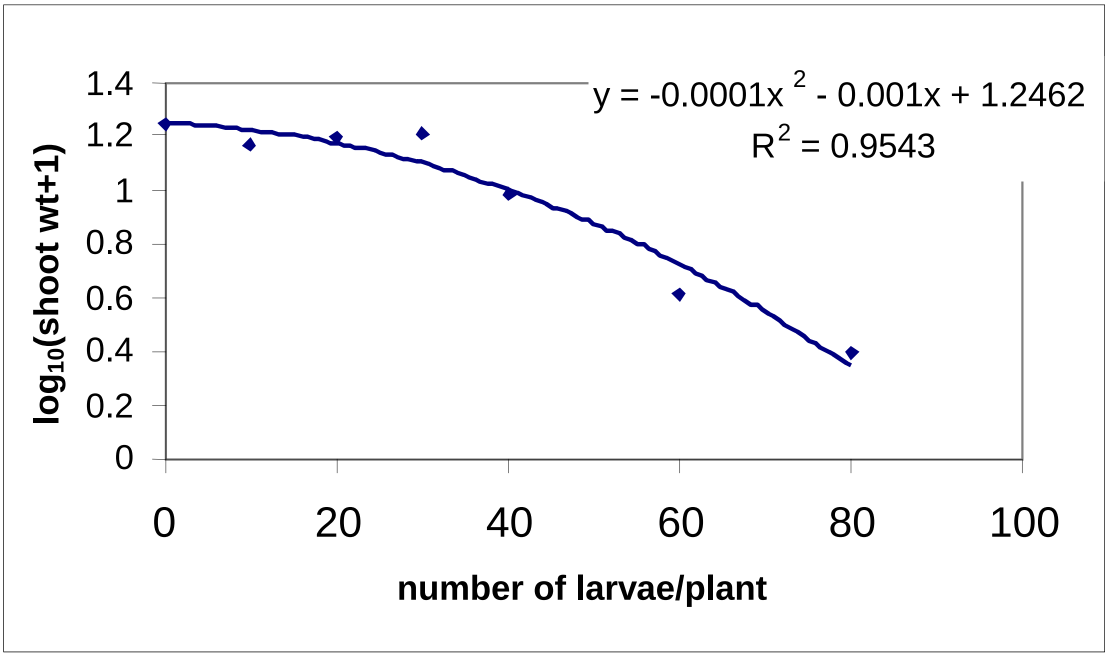


Figure 6 clearly shows the relationship between the size of the Paterson's curse plant (as measured by shoot weight) and the number of crown weevil – not unexpectedly as the number of insects increases the plant is consumed and becomes less vigorous. What is important in this graph is that the relationship can be described by a graph, which in turn can be used to fine tune the understanding of the interaction between the insects and the plants population dynamics.

The empirical measure of crown weevil damage to Paterson's curse has been both interpolated and extrapolated to calculate the productivity gains to the grazing industries. It is emphasised that the following breakout cell refers only to the crown weevil and does not include reference to the other agents or the spectacular performance of the flea beetle in particular. Since the funds applied to this project were directed at essentially 4 insects the B/C ratio is an underestimate by at least a factor of 4.

Benefits to grazing industries of Paterson's curse biological control project

Based on a consideration of only the impact of the crown weevil, the annual benefits in terms of increased productivity (not including reduced cost of conventional control) is conservatively projected to rise to $73m by 2015.

The discounted (5%) net present value (NPV) of the benefit-cost stream from 1972 to 2015 is projected at $259m, for a benefit/cost (B/C) ratio of 14.1:1 and an internal rate of return exceeding 17% on a total research investment of $21m (04/05 dollar terms).

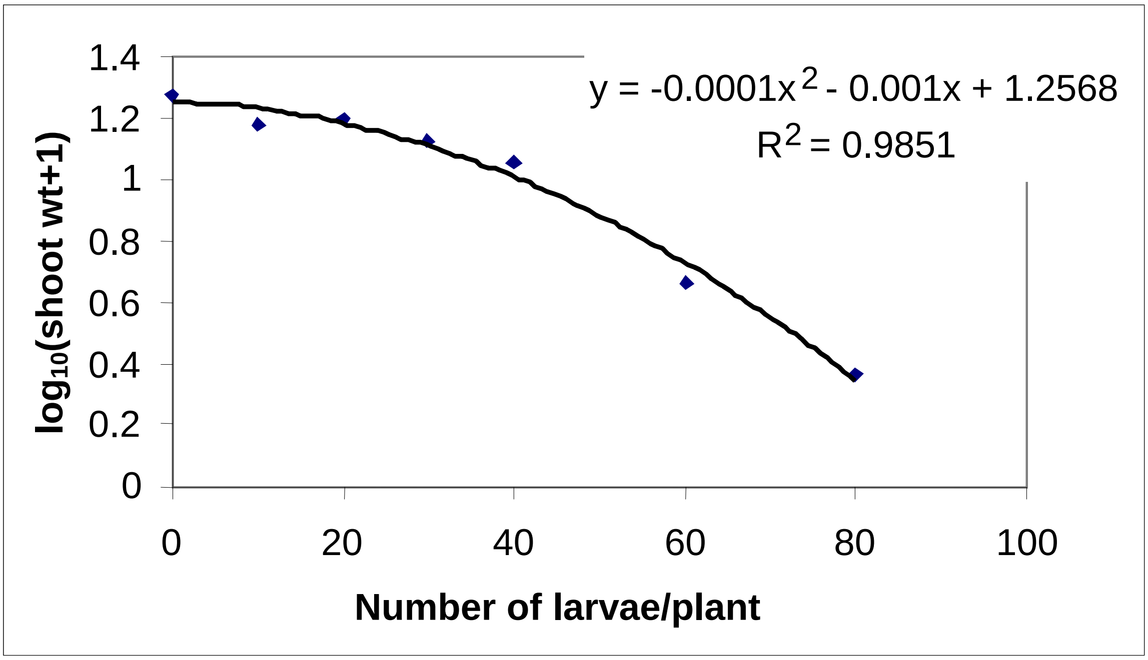
Impact assessed in 2000 by CRC for Weed Management Systems[5]
and
corroborated in 2006 by A.R. Page and K.L. Lacey of AEC Group[6]

5.2 Root Weevil

For the root weevil the relationship between number of larvae and plant size was confirmed by experimental work (Figure 7). As root weevil populations in the field reach levels where larval levels match those in Figure 6, substantial impact on the weed will be realised. Any future field monitoring of root weevil should be based on recording the number of larvae relative to plant size.

[5] Centre for International Economics (2000) Benefit-cost analysis for biological control of Paterson's curse. In An impact Assessment, The CRC for Weed Management Systems.
[6] A.R. Page and K.L. Lacey (2006) Economic impact of Australian weed biological control. CRC for Australian Weed Management. 165pp

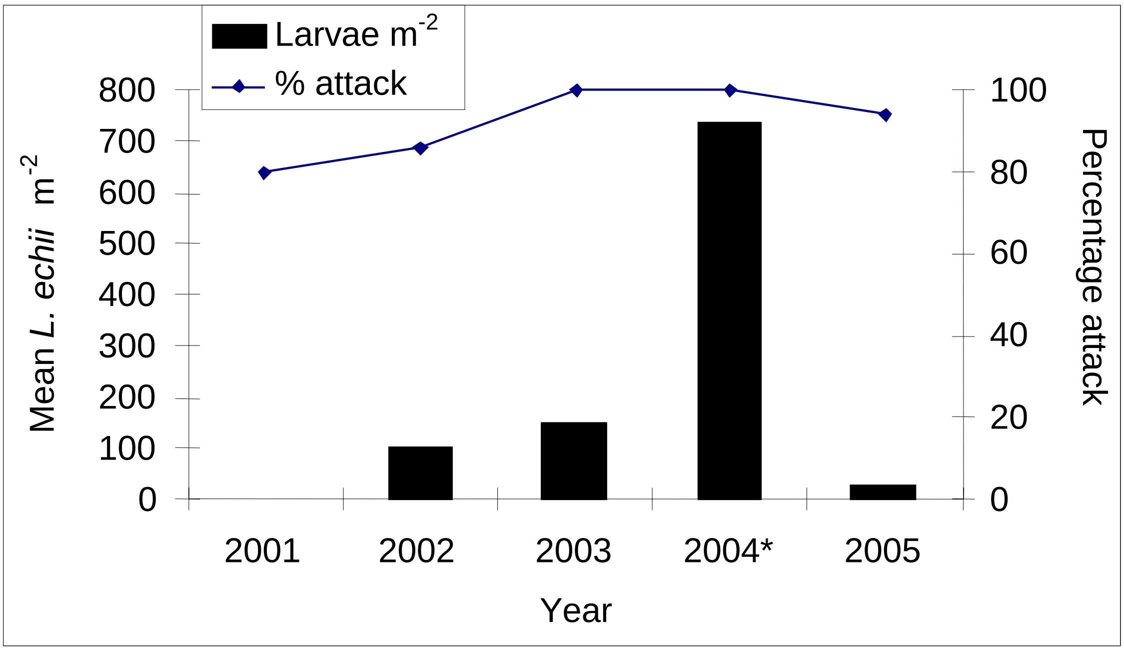
Figure 7: The relationship between the numbers of root weevil *per plant and plant size*



5.3 Flea Beetle

For the flea beetle the first site in Australia to record high population levels was at Tarcutta, NSW. At this site the insects were released in 1996 and by 2001 86% of plants sampled where attacked by the larvae of the flea beetle. Since 2001 the attack rate of flea beetle has remained high and population grown rapidly until 2005.

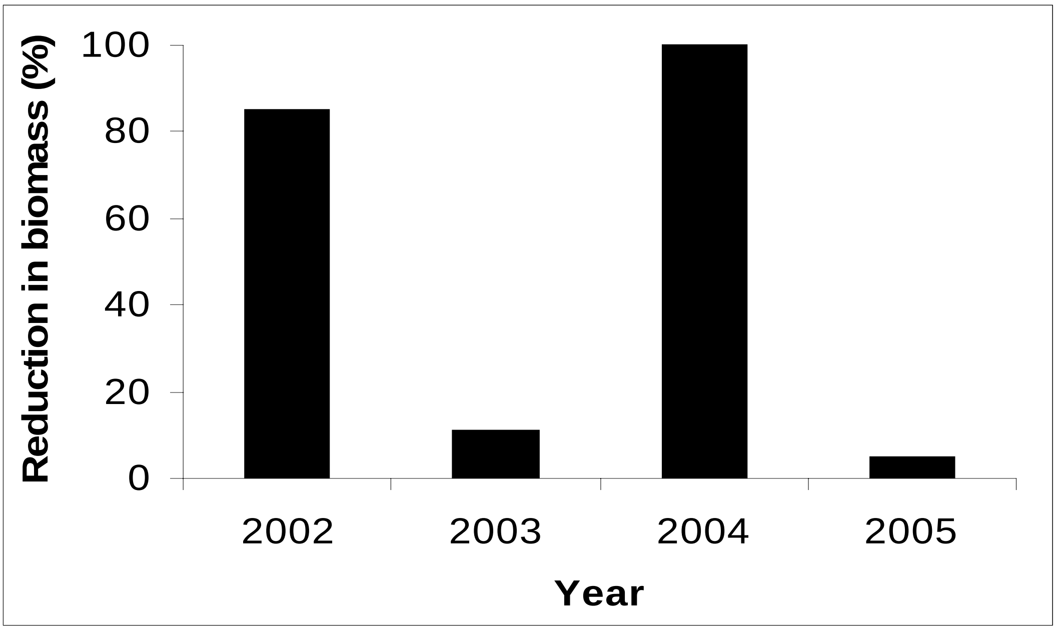
Figure 8: The population of flea beetle and attack rate of Paterson's curse at Tarcutta, NSW



* Site sampled 1,000 metres from original release and monitoring site. Original monitoring site no larvae survived due to 100% plant mortality.

The flea beetle's feeding on Paterson's curse resulted in 40% mortality in 2002 and using the larval-number to plant-size relationship, plant biomass and seeding was reduced by over 80% (Figure 8). Larval numbers in 2003 were restricted due to density dependant mortality in 2002 and with more weed in 2003 impact was limited to an 11% reduction of biomass. But in 2004 the flea beetle population had increased to such a magnitude, adult beetle feeding alone killed all Paterson's curse in the original 50 hectare release paddock and all plants on the 700 hectare property. With no available food the flea beetle population crashed (Figure 8) to zero. In 2005 larval numbers at the original release site recovered to 27 per metre - this is a remarkable achievement given that all insects had to migrate at least a kilometre - the distance to the nearest patch of live Paterson's curse. From this population the impact on the weed will increase greatly from the 5% reduction in 2005 (Figure 9). At the second site, where the beetle population had reached 700 per metre, no plants survived to flower in a 200m-wide band bordering the property where flea beetle was released. The fluctuating impact of flea beetle through time and space will continue and only further monitoring will confirm if this impact stabilises and becomes more consistent from year to year. Given the ability of flea beetle to successfully travel kilometres in a single season in large numbers, it is likely that sustained impact from year to year will be achieved.

Figure 9: The impact of flea beetle on the amount of Paterson's curse at Tarcutta, NSW



5.4 Pollen Beetle

At the time of writing (March 2006) there are no field sites where pollen beetle has reached a population density high enough to limit the seeding of Paterson's curse. When pollen beetle populations are large enough to reduce seed production recording the number of seed per length of cyme will provide an accurate (but time consuming) measure of its impact. This will be possible, as previous research carried out by CSIRO has shown the number of seed/length cyme in the weed to be consistent across sites and years (Smyth *et al* 1997).

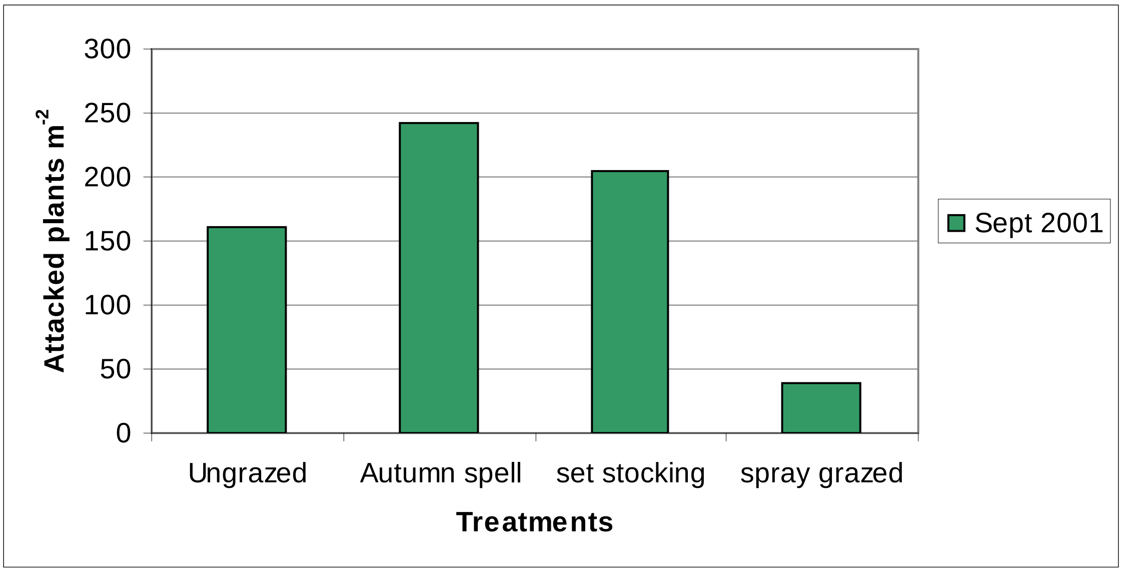
6 Integrated Weed Management

One of the objectives of the biological control program was to develop an understanding of the typical farm management on the performance of biological control insects as this would have two key outcomes;

1. Acquisition of knowledge or likely impacts of insects under real farming conditions so redistribution effort could be targeted to most successful insects
2. The knowledge gained from this work could be communicated to the farming community to maximise any benefits particular insects species have.

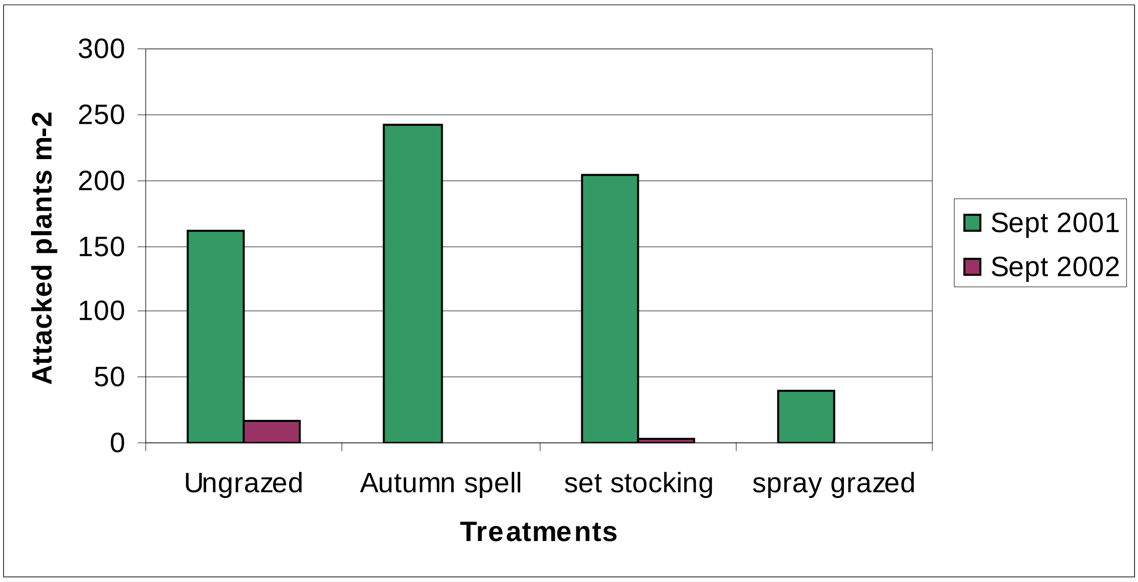
To address these aims a replicated field experiment was established at the Yanco Agricultural Institute to compare the differences between crown and root feeding insects (results of the work are summarised in Figures 10-12). In 2001, crown weevil had a well-established population of about 200 larvae m^{-2} in all grazing treatments except where herbicide had been applied. Killing Paterson's curse through the spray-graze treatment resulted in underdeveloped larvae starving and a reduction of larval numbers by 80%. By 2002 only small numbers of larvae could be detected in the un-grazed treatment and by 2003 could not be found, even though over 1,000 plants were sampled (data not shown). The dry conditions of 2002, particularly in the autumn, when crown weevil becomes active after aestivation, resulted in the majority of adults dying because of a lack of the weed. Larval progeny of the surviving crown weevil adults that feed in the rosette aboveground then suffered further high mortality due to heavy grazing because of a lack of feed. Under these conditions crown weevil cannot reach a population size that limits the dominance of the weed.

Figure 10: The effect of management treatments on crown weevil



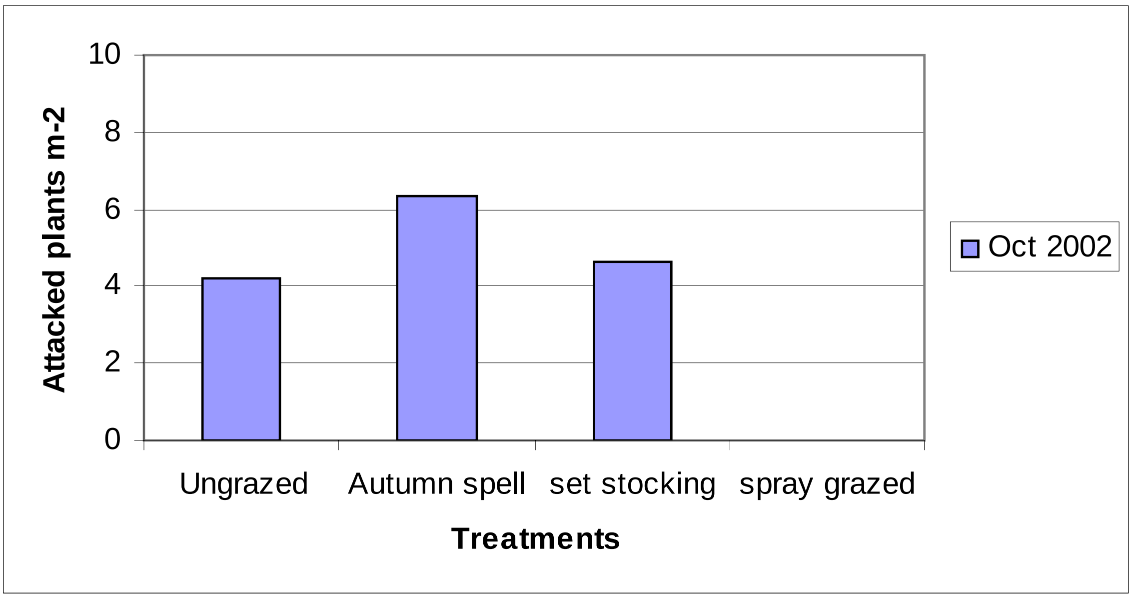
In contrast the ability of flea beetle to tolerate seasonal conditions and farm management practises has been confirmed in this study. Even under extreme drought conditions from late 2001-2002 the population of flea beetle was maintained at Yanco. Even continuous grazing by sheep at Yanco had no negative effect on the population of flea beetle (Figure 12). This is particularly noteworthy at this site where flea beetle was only released in 2000 and the population is still small, a time when it is most vulnerable to destructive events. The ability of flea beetle to spend the majority of its lifecycle below ground, away from hungry mouths and trampling hooves, and lie dormant well into winter give it the best chance of tolerating severe climatic and grazing conditions.

Figure 11: The effect of management treatments and season on crown weevil



The outcome of this research highlighted the potential of flea beetle and focused rearing and release efforts on this species in the last few years of the program.

Figure 12: The effect of Management treatments on flea beetle



7 Monitoring of Insect Establishment and Population Growth

After releasing insects the first measure of their success/progress is whether they can be found more than one-year post release. Whether an insect establishes is important information that can be used to adapt the release process to maximise establishment and subsequent insect population growth.

At a State level there are clear differences between the rates of establishment and the insect being released (Table 9). For the crown weevil rates of establishment are well above 50% except for WA. Here at sites with low rainfall and typically late seasonal breaks (May and later) crown weevil performs poorly because of its inability to aestivate in large numbers beyond April. In addition a second collection of crown weevil from a drier region in Portugal was introduced to the country to test whether it could aestivate for longer. Although the results from WA seem promising, this improved establishment rate is largely a result of improved release technique (see Tables 15 & 16). Releases of crown weevil in the later part of the program have been targeted to higher rainfall regions where the insect is more likely to do well. For pollen beetle and root weevil establishment rates are lower than crown weevil, except in WA where it establishes at almost twice the rate of the crown weevil. For root weevil the ability to successfully aestivate in large numbers until May is the main factor explaining this improved establishment. Flea beetle has proven to be the easiest insect to establish with an overall establishment success of 84%. Like root weevil the key to its establishment is its ability to aestivate until July, so even in the poorest of seasons, some rain is likely to have fallen to promote the germination Paterson's curse, for flea beetle to develop upon.

Table 9: Insect establishment rates

Insect	NSW	VIC	SA	WA	CSIRO	**Average**
crown weevil	58.9%	55.3%	79%	30.1%	87.3%	62.1%
crown weevil (Portuguese)	4	1	100%[2]	65.7%	3	65.7%
root weevil	62.1%	18%	54.5%	54.5%	88.9%	55.6%
flea beetle	60.7%	39.2%	84.7%	94.2%	88%	73.4%
pollen beetle	10.0%	40.9%	67%	55.6%	50%	44.7%

1. 3 releases made but establishment not checked
2. Only 3 releases made
3. Insects supplied to State Departments
4. Only 1 release made

Along with the species and State effects on insect establishment the other two key variables affecting this are the size and timing of the release (Tables 15 & 16). Releases of less than 100 adult insects resulted in poor insect establishment while increasing the number of insects has a strong positive influence. Protection from grazing, and plant health and vigour and life stage (rosettes for the root and crown feeders and new flowers for crown weevil) are also important factors in increasing the likelihood of establishment.

Table 10: Effect of number of insects per release on establishment of the crown and root weevils.

Number of insects	Crown weevil	Root weevil
<100	35.4%	25%
100-1000	70.9%	47.4%
>1000	86.8%	76.9%

For the crown and root weevils, insects can be released in autumn, when adults are sexually mature or in spring when newly emerged adults are active feeding in the flowers of Paterson's curse in preparation for aestivation. Autumn is clearly the best time to maximise establishment success when adults have mated reducing the risk of allele effects (lack of mating success) that occur in spring when adults do not mate. To minimise allele effects, caging the spring release keeps males and females together in spring to maximise mating success in autumn and resulting in establishment rates approaching those of autumn releases.

Table 11: Effect of release timing and caging on the establishment of the crown and root weevils.

Time of Release	Crown weevil	*Root weevil*
Autumn	53.6%	75%
Spring (uncaged)	18.6%	42.9%
Spring (caged)	50%	46.6%

Following on from release and establishment, the next measure of insect success is a positive population growth rate and resultant increasing level of damage to the weed. The potential impact that controlled experiments attempt to predict will only be realised if the insects disperse and multiply over many years. Of the three species for which we have population estimates (see tables 17,18 & 19), only crown weevil has enough data from all States and between years to show a consistently positive trend (the high values in CSIRO data, 1996-1999 are biased by the Yanco site). For root weevil and flea beetle trends are masked by the low number of sites sampled (though the numbers are steadily increasing). From the CSIRO data on flea beetles, the numbers are declining due to density dependant mortality as a consequence of weed mortality.

Table 12: Crown weevil attacked plants m^{-2}

Year	NSW	Vic	SA	WA	CSIRO	Mean
1996					24.7	24.7
1997	3.1	0.3	0.06	*	248	62.9
1998	16.7	14.5	5.25	2.04	216	50.9
1999	29.0	25	*	*	65	39.7
2000	18.1	17.9	*	2.5	16.1	13.7
2001	19.5	16.2	*	*	24.5	20.7
2002	16.9	5.0	*	*	17.5	13.1
2003	10.5	5.3	105.8	7.96	26.2	31.2
2004	5.5	2.03	73.8	7.84	15.3	20.9
2005	12.5	5.0	129.6	17.6	13.9	35.7

* Not sampled

Table 13: Root weevil attacked plants m^{-2}

Year	NSW	Vic	SA	WA	CSIRO		Mean
2002							
2003	3	47	39.5	1.56	33.8		25.0
2004	4.7	3	40	5	2.87		11.1
2005	5.1		29.5	8.1	3.1		11.5

Table 14: Flea beetle attacked plants m^{-2}

Year	NSW	Vic	SA	WA	CSIRO		Mean
2002							
2003	2				101.8		51.9
2004	4.6	32.5	41	2.3	108.3		37.7
2005	3	11	46	7.1	61.1		25.6

8 Redistribution of Biological Control Insects Since the Start of the Project

8.1 Principles of Distribution Network

There are several critical phases in ensuring the successful establishment of a biological control agent: agent selection, host-specificity testing, and release. In the case of insects that are highly mobile and have multiple generations per year, release and distribution are relatively easy. However in the case of the agents used for the weeds targeted in this project, limited mobility and extended generation times indicated the need for special approach. The method in the project was:

1. Mass produce agents in the laboratory
2. Release large numbers of the insects at several protected nursery sites at weed infested field sites. At these sites the insects were kept captive in large portable screens where they were relatively well protected and given time to multiply.
3. Repeated harvesting and subdivision of the progeny of the original field release population was performed and subsequent establishment of more nursery sites, specifically targeting the set-up of at least one site in each region affected by the weed.
4. Steps 2 and 3 were repeated in all states resulting in a rapid build up in the populations of agents across the geographic range of the weed. An integral part of the method was ensuring that Step 3 was organised by a local weed officer or Landcare coordinator, and was supervised by a trained weed officer who gave participants brochures and information on how to manage their insects and their release into the field. The participants were required to record the details of their releases so that a comprehensive database on the spreading network could be established and maintained.

This release and distribution strategy has proven very successful and has contributed to the comparatively low cost of the project in achieving its aims. This efficiency is reflected in the project recording the 5th highest benefit/cost ratio of 36 projects analysed by Page and Lacey in 2006[7].

Further this strategy has ensured the primary stakeholders in this project, the graziers, have a robust sense of ownership and depth of understanding of biological control principles[8]. In turn, the farmer network, as long as it is maintained, is an important resource in the monitoring of agent establishment and impact.

Though the hands-on approach the project has been very effective in building the capacity of participants at all levels (scientists, technicians, weeds officers/Land Care coordinators and farmers) to engage in a major project with extensive ramifications and benefits for the farming community.

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[7] A.R. Page and K.L. Lacey (2006) Economic impact of Australian weed biological control. CRC for Australian Weed Management. 165pp.

[8] D.T. Briese, W.J. Pettit and A.D. Walker (1996). Multiplying cages: a strategy for the rapid redistribution of agents with slow rates of increase. Proceedings of the IX International Symposium on Biological Control of Weeds. Pp. 243-247. V.C. Moran and J.H. Hoffman (eds). 19-26 January 1996, Stellenbosch, South Africa. University of Cape Town.

8.2 Paterson's Curse Agent Redistribution

The redistribution of Paterson's curse insects builds on the successful research phase of the project completed in June 1998 (MRC Final report CS.209). By 1998 initial releases of crown weevil had reach a point where a colony near Yanco NSW could be harvested. Due to the size of crown weevil populations, large numbers of insects could be harvested and the number of releases and insects increased rapidly (see Table 15). Importantly, although this was the only site suitable for field collection for the next four years the benefits were not limited to NSW. The network and collaboration between the agencies allowed harvested insects to be moved efficiently around the country, greatly speeding the redistribution across the range of Paterson's curse. A testament to the effort of all these agencies is the million insects collected and released at over 1,000 sites nationally. The efforts on crown weevil have now reached a point where less effort is required and this is reflected in the reduced number of releases in later years. The population growth of crown weevil is now at a point where there are sites suitable for collection in southern mainland States in Australia.

Table 15: Release numbers for crown weevil

Year	NSW	Victoria	SA	WA	CSIRO	Total
1992					2 (66)	2
1993	6 (816)	3 (300)[1]		4 (900)		13
1994	6 (720)	7 (700)			1 (300)	14
1995	59 (5066)	40 (4,000)	4 (400)	4 (200)	2 (340)	109
1996	139 (12338)	58 (5,800)	32 (2,456)	109 (10,525)	2 (100)	340
1997	187 (20330)	44 (8,020)	19 (1,400)	31 (3,670)	9 (4,500)	290
1998	112 (46288)	10 (7,560)	9 (9,300)	7 (4,105)	20 (13,700)	158
1999	138 (110601)	12 (8,900)	9 (8,200)	14 (11,870)	40 (39,500)	213
2000	33 (54106)	10 (5,860)	23 (11,500)	8 (7,085)	8 (7,500)	82
2001	53 (65070)	28 (27,146)	15 (7,100)	12 (22,019)	17 (14,850)	125
2002	31 (52320)	40 (40,000)	19 (14,000)	6 (6,870)	26 (15,840)	122
2003	45 (6120)	56 (52,500)	45 (30,998)	6 (4,040)	10 (9,550)	162
2004	20 (82000)	2 (1,600)	24 (18,200)	7 (5,124)	11 (11,000)	64
2005	54		11 (11,000)	1 (500)		1
Total releases	883	310	210	209	148	1760[2]
Total insects	455,775	162,386	114,554	76,908	117,246	926,869

[1] Numbers in parenthesis are total insects released in that year.
[2] Number of releases contracted under project milestones, 1994–2005 = 479

Root weevil was first released in Australia in 1994 and due to initial rearing difficulties has not been as successful as crown weevil in terms of the number of insects reared and released (

Table 16). Up until 2003 all insects released have been laboratory reared using a process that is time and resource limited. The efforts though in persisting with this species have now been realised with field sites in WA, SA and NSW where this species of insect can be field collected.

Table 16: Release numbers for root weevil

Year	NSW	Victoria	SA	WA	CSIRO	Total
1992						
1993						
1994					1 (40)	1
1995						
1996	4 (458)	2 (100)		3 (275)	1 (40)	10
1997	2 (182)	*	1 (600)	*	*	3
1998	7 (2,862)	2 (400)	2 (530)	*	4 (2,660)	15
1999	19 (9,185)	1 (200)	1 (400)	8 (5,515)	1 (500)	30
2000	8 (4,452)	5 (1,460)	1 (200)	8 (6,150)	*	22
2001	18 (11,050)	1 (400)	4 (1,620)	5 (3,715)	2 (2,300)	30
2002	9 (7,430)	1 (100)	1 (1,000)	4 (7,051)	5 (2,270)	20
2003	62 (6,120)	4 (900)	8 (7,500)	5 (5,319)	3 (3,120)	82
2004	19 (15,430)	3 (1,600)	8 (6,746)	7 (4,847)	7 (4,400)	44
2005	24 (18,000)	5 (1,440)	[2]	3 (1,650)	4 (3,112)	36
Total releases[1]	172	24	26	43	28	293
Total insects	75,169	6,600	18,596	34,522	18,442	153,329

* Rearing difficulties at the start of project
[1] Number of releases contracted under project milestones, 1994–2005 = 216
[2] Outside scope of project.

Flea beetle was the last of the rosette/root feeding insects to be released. Rearing of

Table 17: Release numbers for flea beetle

Year	NSW	Victoria	SA	WA	CSIRO	Total
1992						
1993						
1994						
1995						
1996		2 (90)			3 (570)	5
1997		9 (670)	1 (300)	*	2 (320)	12
1998		6 (2,600)	*	2 (250)	2 (840)	10
1999	5 (800)	1 (200)	3 (3050)	9 (4,000)	1 (500)	19
2000	7 (2,274)	7 (2,930)	5 (2000)	10 (3,800)	3 (1,900)	32
2001	2 (400)	6 (2,545)	3 (1,300)	31 (11,000)	6 (2,750)	48
2002	11 (2,410)	23 (11,050)	1 (1,000)	5 (2,020)	20 (9,800)	60
2003	11 (4,481)	30 (15,480)	15 (5,150)	14 (4,200)	14 (4,950)	84
2004	20 (24,650)	34 (13,200)	63 (21,700)	32 (9,900)	48 (29,400)	197
2005	26 (16,450)	31 (10,000)	93 (50,450)	15 (5,400)	80 (25,000)	245
Total releases[1]	82	149	184	118	179	712
Total insects	51,465	58,674	84,950	40,570	76,030	311,689

[1] Number of releases contracted under project milestones, 1994–2005 = 213

this species was more successful than root weevil and thus it was possible in the first 6 years to release 2.5 times as root weevil (712 versus 293, see Tables 21 & 22). This species also established well resulting in field collection sites in all Southern mainland States by 2003 allowing large numbers of insects to be collected and released.

Pollen beetle was the last insect released in Australia and has the least distribution of all the insects released on Paterson's curse. This species has only been field collected for the last 2 years at 3 sites.

Table 18: Release numbers for pollen beetle

Year	NSW	Victoria	SA	WA	CSIRO	Totals
1992						
1993						
1994						
1995						
1996						
1997	1 (450)				1 (500)	2
1998	*	2 (1,150)	*	*	1 (1000)	3
1999	2 (1,000)	9 (10,800)	1 (550)	3 (2,350)	2 (7,000)	17
2000	5 (5,000)	6 (4,780)	1 (5,000)	17 (61,000)	1 (3,000)	30
2001	*	4 (4,500)	*	*	2 (5,000)	6
2002	1 (1,000)	16 (18,500)	*	1 (1,000)	1 (1,000)	19
2003	2 (2,000)	22 (21,600)	1 (1,000)	5 (5,600)	1 (1,000)	31
2004	10 (16,500)	21 (21,000)	12 (12,000)	8 (8,000)	7 (7,000)	58
2005	8 (8,000)					8
Total releases[1]	29	80	15	34	16	174
Total insects	33,950	82,330	18,550	77,950	25,500	234,200

[1] Number of releases contracted under project milestones, 1994–2005 = 128

All the insects have easily exceeded the targeted milestones agreed to in the contracted program. The key to this success has been driven by three factors;

1. The dedication and drive of project staff to maximise rearing and release efforts beyond nominal targets.
2. The positive establishment and population growth of all insect species (to varying degrees) in all States allowing field collection.
3. The enthusiastic response from farmers and weed professionals to donate their time to help collect and redistribute insects.

In particular, for crown weevil and flea beetle, the large number of insects collected and releases made across the vast distribution of Paterson's curse could not have been made without their direct involvement. This process has truly been collaborative at all levels, from the community right through to a National research agency.

9 Onopordum, Horehound and Blue Heliotrope

9.1 Onopordum Releases and Monitoring

Table 19 CSIRO Onopordum – *agent releases per insect species.*

Year	*L. latus*	*L. cardui*	*E. amoena*	*T. briesei*	*U. terebans*	*B. spinosa*
1992	4 (1084)	1 (244)				
1993	3 (340)					
1994	8 (320)	6 (239)				
1995	18 (422)	14 (340)				
1996	5 (147)	51 (1580)		1 (40)		
1997	15 (837)	168 (5175)		1 (84)		
1998	42 (2418)	183 (9950)	20 (4,887)	2 (100)	1 (150)	
1999	100 (8799)	91 (stems)	7 (1,400)	2 (305)		2 (720)
2000	46 (7360)	38 (stems)	14 (5,825)		3 (334)	
2001	50 (5000)		5 (665)	2 (171)		
2002	2 (1000)		7 (1,205)	1 (200)		
2003	2 (1000)		3 (1,056)	2 (1,800)		
2004			19 (5,498)	5 (1,317)	1 (150)	
2005	4 (2,000)		16 (3,400)	21 (10,750)		
Total # of insects Milestone	236 (29,727) 228	549 (17,528) 280	91 (23,936) 55	37 (14,767) 40	5 (634) 7	2 (270) 2

Table 20 Onopordum – *number of agent releases per insect species.*

Insect	**Organisation**	**Number of Sites** (Milestone)			
		2003/04	**2004/05**	**2005/06**	**Total**
Seed weevil	CSIRO [a]				
	SARDI [b]		2 (2)	1 (2)	3 (4)
	WA [b]		2 (2)	2 (2)	4 (4)
	TOTAL	(0)	4 (4)	4 (4)	8 (8)
Petiole fly	CSIRO [a]	3 (10)	19 (15)	16 (10)	38 (35)
	SARDI [b]	0 (1)	2 (1)		2 (2)
	WA [b]	0 (1)	1 (1)		1 (2)
	TOTAL	3 (12)	22 (17)	16 (10)	41 (39)
Crown weevil	CSIRO [a]	2 (5)	5 (10)	21 (10)	28 (25)
	SARDI [b]	0 (1)	2 (1)	1	3 (2)
	WA [b]	1 (1)	1 (1)	1	3 (2)
	TOTAL	2 (7)	7 (12)	23 (10)	33 (29)
Seed fly	CSIRO [a]	0 (1)	1 (1)	0 (1)	1 (3)
	TOTAL	0 (1)	1 (1)	0 (1)	1 (3)
GRAND TOTAL		7 (20)	33 (34)	45 (25)	85 (79)

The lack of releases for Ea and T.b in 03/04 in SA & WA was driven by drought and a lack of plants at the right time of year.

a target weeds are Scotch and Illyrian thistle
b target weed is stemless thistle. In 2003/2004 no agents were available for release
All co-operators supplied with insect management leaflets

Table 21 Horehound and blue heliotrope number of agent releases.

Insect	**Organization**	**Number of Sites** (Milestone)			
		2003/04	**2004/05**	**2005/06**	**Totals**
Horehound					
Plume moth	WA [a]	0 (3)	10 (5)		10 (8)
	SA	10 (*)	12 (*)		22 (*)
	NSW	7 (*)	23 (*)	10 (0)	40 (*)
Blue heliotrope					
Leaf-feeding beetle	CSIRO	2 (1)	4 (3)		6 (4)
	NSW Ag	28 (2)	50 (6)		78 (8)
TOTALS		47 (39)	99 (37)	10 (0)	156 (60)

a Where insects are brought in from interstate new West Australian quarantine regulations may result in a delay in the execution of these releases.
* The number of releases made will be determined by insect populations at field sites and field day attendance.

In Western Australia drought continued to impact some of the horehound sites to the extent that there was no weed to be found, let alone any plume moth (*Wheeleria spilodactylus)* released. At 6 other sites in the state establishment was confirmed.

Although not part of the milestones, DPI Victoria assisted Victorian farmers in the redistribution of the horehound plume and clearwing moths. The plume moth was

Table 22. Level 3 Monitoring sites for Onopordum *(site inspection to confirm establishment)*

Insect	**Organisation**	**Number of Sites** (Milestone)			
		2003/04	2004/05	2005/06	Total
Petiole moth	CSIRO [a]	10 (10)	19 (10)		29 (20)
	SARDI [b]		2 (2)		2 (2)
	WA Ag[b]		2 (2)		2 (2)
	TOTAL	10 (10)	19 (14)	(0)	29 (24)
Crown weevil	CSIRO [a]	5 (5)	5 (5)	10 (10)	20 (20)
	SARDI [b]		1* (1)	1* (1)	2 (2)
	WA Ag[b]		2 (2)	0 (2)	2 (4)
	TOTAL	5 (5)	7 (8)	12 (13)	24 (26)
Seed fly	CSIRO [a]	0 (1)	0 (1)	0 (1)	0 (3)
	TOTAL	0 (1)	0 (1)	0 (1)	0 (3)
Seed weevil	SARDI [b]	1* (1)	1* (1)		2 (2)
	WA Ag[b]	1 (1)	1 (1)		2 (2)
	TOTAL	0 (2)	0 (2)		0 (4)
GRAND TOTAL		21 (18)	25 (25)	10 (14)	51 (57)

a target weeds are Scotch and Illyrian thistle
b target weed is stemless thistle
* Level 3 monitoring was undertaken at all sites however no sign of establishment was detected at any site mainly due to seasonal effects. In the case of T. briesei and E. amoena insufficient time had elapsed since the release of the agents.

released at 2 sites in 2003, 2 sites in 2004 and 8 sites in 2005. In November 2004, the clearwing moth was collected by DPI Frankston and larvae reared through to adults. In January 2005, eight releases were made. A total of 4624 eggs were sent to DPI NSW allowing them to do six releases, the remaining 1309 eggs were used to do two releases in Victoria (Euroa and Bacchus Marsh) on private properties. This is the first time that the clearwing moth has been able to be harvested and redistributed since being first released in Australia in 1999.

Table 23. Level 2 Monitoring sites for Onopordum *(Insect population change)*

Insect	**Organisation**	**Number of sites** (Milestone)			
		2003/04	2004/05	2005/06	Total
Stem borer	CSIRO [a]	(5)	(5)		(10)
	TOTAL	(5)	(5)	(0)	(10)
Seed weevil	CSIRO [a]	(5)	(5)		(10)
	SARDI [b]	0* (1)	0* (1)		0 (2)
	WA Ag[b]	1 (1)	1 (1)		2 (2)
	TOTAL	(7)	(7)	(0)	(14)
Petiole moth	CSIRO [a]	(5)	(5)		(10)
	SARDI [b]		0* (1)		0 (1)
	WA Ag[b]		1 (1)		1 (1)
	TOTAL	(5)	(7)	(0)	(12)
Crown weevil	CSIRO [a]	(5)	(5)	(5)	(15)
	SARDI [b]		0* (1)	(1)	0 (2)
	WA Ag[b]		1 (1)	1 (1)	2 (2)
	TOTAL	(5)	(7)	(7)	(19)
Seed fly	CSIRO [a]	(1)	(1)		(2)
	TOTAL	(1)	(1)	(0)	(2)
GRAND TOTAL		(23)	(27)	(7)	(57)

a target weeds are Scotch and Illyrian thistle
b target weed is stemless thistle
* no established sites to conduct level 2 monitoring

In WA only the rosette crown weevil and seed weevil have been recorded as present in the monitoring sites.

9.2 Benefit/cost Analysis of *Onopordum* Biological Control

The monitoring results have been analysed, initially by D. Briese in 2002 and subsequently by A.R. Page and K.L. Lacey in 2005[9]. Based on an investment of $3.7m in research, the *Onopordum* biological control program has returned a net present value (NPV) of $18.0m and a benefit/cost (B/C) ratio of 9.6 at a discount rate of 8%.

[9] A.R. Page and K.L. Lacey (2006) Economic impact of Australian weed biological control. CRC for Australian Weed Management. 165pp.

9.3 Horehound and Blue Heliotrope Monitoring

Table 24. Level 3 Monitoring sites for horehound and blue heliotrope

Insect	Organisation	Number of Sites (Milestone)			
		2003/04	2004/05	2005/06	Totals
horehound					
Plume moth	WA Ag	(0)	(3)	(0)	(3)
	SARDI	(0)	5* (5)	(0)	5 (5)
	DPI	(0)	(0)	(0)	(0)
	NSW Ag	(0)	5 (5)	(0)	5 (5)
Clearwing moth	DPI	1 (1)	1 (1)	(0)	2 (2)
Blue heliotrope					
Leaf-feeding beetle	CSIRO /	(1)	(1)	(0)	(2)
	NSW Ag	1 (1)	1 (1)	(0)	2 (2)
GRAND TOTAL		2 (3)	12 (16)	(0)	14 (19)

*Level 3 monitoring was conducted at 5 sites in the southeast of SA and confirmed as established. At 3 sites larvae were found up to 100m from the initial release point. This agent is now well established across horehound regions of most of SA.

Detailed monitoring of the clearwing moth was conducted by DPI Victoria in 2003/04 and 2004/05. Table 25 below shows an increasing level of attack from 2001 (29.1% of plants attacked) to 2004 (45.9% attacked), indicating that the clearwing moth populations are steadily increasing.

Table 25 Clearwing moth *at Wyperfeld (Victoria) 2001-2004*

Plant categories	*Nov. 2001*	*Nov. 2003*	*Nov. 2004*
Total number of plants without insect (%)	100 (70.9 %)	81 (49.7 %)	644 (54.1%)
Total number of plants with insect (%)	41 (29.1 %)	82 (50.3 %)	546 (45.9%)
Total number of plants (%)	141 (100%)	163 (100%)	1190 (100%)

In NSW the plume moth had established at the 5 sites examined and the blue heliotrope leaf-feeding beetle had established at 1 of the 2 monitored sites (the sites were still drought affected at the time of examination).

9.4 Benefit/cost Analysis of Horehound Biological Control

A.R. Page and K.L. Lacey conducted a benefit/cost analysis of the horehound biological control. The analysis is highly qualified since benefits are restricted to reduced vegetable fault in wool and take no account of increased pasture productivity through increased grazing area and reduced tainting of meat. With the limited information available to them they estimate the program has cost a total of $1.8m, resulting in a net present value of ($0.9) and a benefit cost ratio of 0.2 at a discount rate of 8%.

10 Recommendations

1. Apart from WA it is deemed that crown weevil has been effectively delivered to Paterson's curse affected pasture. The distribution of this agent to 1760 sites is considered ideal and therefore a model for the other more recently introduced species indicating the need for:

Flea beetle	1760 – 712 = 1058 more sites
Pollen beetle	1760 – 174 = 1586 more sites
Root weevil	1760 – 293 = 1467 more sites

   Where "ideal number of sites" less "sites achieved" = "number of sites needed". This deficiency does not indicate a failure but rather that if the full benefits of biological control are to be realised then there is a strong argument for further releases.

   Regions that need particular attention with respect to delivery of root weevil, pollen beetle and flea beetle include:
   - the northern 2/3 of range of Paterson's curse in South Australia and Eyre Peninsula where established colonies of agents have been exterminated or decimated by the fires of early 2005;
   - Gippsland in Victoria which was deemed of lower urgency than other parts of the State is in need of comprehensive releases of pollen beetle and flea beetle – the releases need to be complemented by the establishment and training of a support network of weed officers and distribution of information packs to end users.
2. Development of a CD to complement information and needs of end users already involved in distribution network. The collated information on the CD is integral to any extension of the project work from 2006 and will serve as the key source of information in the absence of the support of scientific input in the future. It is important to recognise the interdependence of CD and ongoing maintenance and promotion of the concept of biological control integrated into pasture management.

More general needs include:

3. Provision of operating funds to promote, collate, maintain and interpret field data from the state agencies. If the network of farmers is not serviced or the database not managed these valuable resources will be lost or at the least inoperable.
4. Training new field and weed officers in new regions (as yet not involved in distribution of agents) to a point where they can effectively work unsupervised and contribute to maintaining and expanding the network locally and regionally.
5. Evaluation of the project outcomes to empirically demonstrate the benefits of the project and to quantify the return on the investment of MLA, AWI and the respective state agencies.
6. Promotion of the interstate, interagency collaboration as a model for the effective leveraging of skills and resources.
7. Cognisance that State Agencies and research providers are unwilling to provide support for projects unsupported by industry

8. Detailed ecological studies (PhDs) on the interaction of the agent species to answer questions such as - is feeding of pollen beetle multiplicative to the damage of the rosette feeding insects?

11 Database CD

This document includes a copy of a database containing details of all releases made (under the auspices of the project partners) of Paterson's curse biological control agents up to 2005.

12 Publications

Information sheets, data recording sheets and brochures will be included in the resource CD currently under development by staff of Department of Primary Industries Victoria.

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Appendix 1 – Stakeholder Survey

Paterson's Curse Survey

This project is funded by,

and relies on the collaboration of,

Please return the completed survey to:-

Matthew Smyth
CSIRO Entomology
GPO Box 1700
Canberra ACT 2601

Thank you for participating in this survey. There are 50 questions to answer but this should not take long to complete as most questions may be answered by either ticking a box or scoring numbers in a box from 1-5. All information provided will only be used to produce overall summaries and individual answers will remain strictly anonymous.

The survey forms part of a National program aimed at controlling Paterson's curse while improving pasture productivity. Part of the information is needed to evaluate the effect of the biological control agents that you have released on your property. In addition the survey will provide important information on the seriousness of the problems caused by Paterson's curse to the grazing industries, and will therefore help ensure that funding for this work is maintained. The information on the success (or lack of success) of the different control methods, including biocontrol, can help improve current management techniques.

SECTION 1 - PROPERTY DESCRIPTION

Question 1 What is the name of your property? ______________________

Question 2 Where is the property located? ______________________

Question 3 What is the area of your property? _____ acres OR ________ hectares.

Question 4 Select the main enterprises conducted on your property. If necessary, you may select up to three enterprises (please rank them from 1 to 3, with 1 being the most important).

Cattle - meat
Cattle - stud
Sheep- wool
Sheep - meat
Sheep - stud
Winter crops
Summer crops
Horse stud

Other, please specify ________________________________

Question 5 What number of stock do you carry on your property?

Sheep [ ]

Cattle [ ]

Horses [ ]

SECTION 2 - PATERSON'S CURSE INFESTATION

(Prior to biological control)

Question 6 Where is Paterson's curse a major problem on your farm? Please number the appropriate boxes in order of priority (from 1 for the most affected to 5 for the least affected, but leave blank if there is not a problem).

Arable land
Non-arable improved pastures
Non-arable unimproved pastures
Cereal crop

Irrigated pasture

Question 7 How long has Paterson's curse been a problem on your property? Please tick a box.

less than 5 yea	5-10 years	10-15 years	15-20 years	20-30 years	over 30 years

Question 8 Over the past five years has your Paterson's curse problem? Please tick a box.

Increased ☐
Decreased ☐
Remained the same ☐

Question 9 What areas of your property have Paterson's curse infestations in the following categories? (in acres OR in hectares)

Light infestation (regular cover plants more than a metre apart) _______ ________

Medium infestation (plants less than a metre apart sometimes in clumps) _______ ______

Heavy infestation (Uniform cover, plants touching) __________ _________

Question10 Please estimate the reduction in production/carrying capacity as a result of Paterson's curse. Please tick a box for each category of infestation on your property.

Light (regular cover plants more than a metre apart)

0-10%	11-20%	21-30%	31-40%	41-50%	51-60%	61-70%	71-80%	81-90%	91-100%

Medium (plants less than a metre apart sometimes in clumps)

0-10%	11-20%	21-30%	31-40%	41-50%	51-60%	61-70%	71-80%	81-90%	91-100%

Heavy (Uniform cover, plants touching)

0-10%	11-20%	21-30%	31-40%	41-50%	51-60%	61-70%	71-80%	81-90%	91-100%

Question 11 What factors do you believe cause Paterson's curse to increase as a problem? Please rank 3 factors (from 1 for the most important to 3 for the least important)

Overgrazing by sheep

Overgrazing by cattle

Pasture improvement programs

Lack of competition from pastures

Lack of grass cover in the autumn/winter

Supering programs _____

Pasture opened up by drought _____

No known reason

Other, please specify ____

Coments

SECTION 3 - PATERSON'S CURSE CONTROL
(Excluding biological control)

Question 12 Have you attempted to control Paterson's curse on your property?

Yes ☐ No ☐

If your answer is **NO** please proceed to Question 25.

Question 13 What control measures have you used? Please indicate only the 5 most used methods (from 1 for the most used up to 5 for the least used).

How successful were the various control techniques you used at reducing your Paterson's curse problem? Please tick a box.

Control method	**Rank**		**Degree of success of control method (Please tick a box)**		
Control level	(1-5)	Name of herbicide if used	Not Successful 0-49% control	Reasonably successful 50-79% control	Very Successful 80-100% control
Chipping					
Slashing at early flowering					
Ploughing and sowing a crop					

Herbicide - spot spraying				
Herbicide - boom spray or aircraft				
Spray topping at flowering				
Spray / grazing				
Graze topping				
Supering pastures				
Sowing improved pasture				
Other, please specify				

Comments…………………………………………………………………………………………

Question 14 Are combinations of the above more effective than just implementing one control method? Yes ☐ No ☐ Uncertain ☐

Please comment on the best control program:

Question 15 If you use chemical herbicides, when do you spray Paterson's curse? Tick more than one if needed.

early autumn (rosettes)	late autumn-winter (rosettes)	early spring (before bolting)	late spring (bolting)	summer (flowering)	other (please specify)

Question 16 What is the approximate annual cost of the control method you use on Paterson's curse on your property? Please tick a box.

$0-10/hectare	$10-$20/hectare	$20-$30/hectare	$30-$40/hectare	$40-$50/hectare	over $50/hectare

Other, please specify

Question 17 On what percentage of the areas on your property infested with Paterson's curse do you use control measures? Please tick a box for each infestation level (see Question 10 for definition of levels).

	0%	up to 25%	up to 50%	up to 75%	over 75%	100%
Light infestation						
Medium infestation						
Heavy infestation						

Question 18 How frequently do you use control methods on these infestations of Paterson's curse? Please tick a box for each infestation level (see Question 10 for definition of levels).

	Regularly every year	Regularly every 2-3 years	Only when necessary	Never
Light infestation				
Medium infestation				
Heavy infestation				

Question 19 Over the past 5 years has your control program generally:- Please tick a box.

Increased ☐

Decreased ☐

Remained the same ☐

Varied from year to year ☐

Question 20 If you have used control measures for Paterson's curse on your pastures, do you believe the production from these areas has changed, and if so, by how much? Please tick a box.

Nil	**1-5%**	**6-10%**	**11-15%**	**16-20%**	**21-25%**	**Over 25%**

Comments…………………………………………………………………………………

Question 21 Approximately how much time would you spend on treating your Paterson's curse problem per year? Please tick a box.

Man Days / Year	**1-2**	**3-5**	**6-10**	**11-20**	**21-30**	**over 30**

Comments………………………………………………………………………/

Question 22 Using current control methods, how many years do you feel it will take to control your Paterson's curse problem? Please tick a box.

- 1-2 year ☐
- 3-5 years ☐
- 6-10 years ☐
- Ongoing ☐
- Uncertain, assess each year ☐

Question 23 Do you believe it pays to control Paterson's curse? Please tick a box.

- Very worthwhile investment ☐
- Only just pays for itself ☐
- Break-even ☐
- Does not pay ☐
- Hard to say / uncertain ☐

Question 24 From your experience, what are the major benefits of Paterson's curse control? Please select in order 1 to 5 (1 = most important).

Increased pasture growth
Increased carrying capacity throughout year
Increased livestock production (i.e. weight gain)
Improved farm income
Increased property value

Other, please specify……………………………………………….

Comments………………………………………………………………………

Question 25 What do you consider to be the main disadvantages or management difficulties associated with Paterson's curse control?
Please rank from 1 to 5 in order of importance (1 = most important).

Determining when to spray
Maintaining an ongoing program
Lack of time or equipment
The cost of controlling them
Knowing how many years it will take
Lack of effective herbicide
Other, please specify ___________________________________

SECTION 4 GRAZING MANAGEMENT

Question 26 Are you involved in a grazing system program such as Prograze or Pasture Plus? Yes / No. If 'yes' which one?_______________ How long have you been involved?________Do you believe you are benefiting from the changes to your grazing management?

Question 27 Which grazing methods do you use? Please supply the appropriate details, if you use more than one method please rank them from 1 for the most used to 5 for the least used)

Grazing System	Duration of Grazing	Stocking rate (DSE/Ha)	Duration of spell period	Paddock/Cell size	Rank
Continuous / Set Stocking rate					
Rotation					
Strip Grazing					
Time control/Cell					
Other, please specify					

Comments____

Question 28 Do you defer grazing at the autumn break? **Comments**………………………..

SECTION 5 BIOLOGICAL CONTROL

Question 29 Which insect species have been released on your property?

Insect species	Please tick	Year released
Crown weevil (*Mogulones larvatus*)		
Root weevil (*Mogulones geographicus*)		
Flea beetle (*Longitarsus echii*)		
Pollen beetle (*Meligethes planiusculus*)		

Question 30 Was the information supplied with the insect release easy to understand? Yes / No

Question 31 Did you feel confident that you could manage a release site after reading the information? Yes / No

Question 32 Has the information changed your expectations of biological control? Yes / No

Question 33 Has the information helped you integrate biological control into your farm management? Yes / No

Question 34 Since release, have the numbers of insect increased? Please tick the box(es) below.

Insect species	Yes	No
Crown weevil (*Mogulones larvatus*)		
Root weevil (*Mogulones geographicus*)		
Flea beetle (*Longitarsus echii*)		
Pollen beetle (*Meligethes planiusculus*)		

Question 35 Since release, have the insects spread from the release site into surrounding areas. Please tick the most appropriate boxes.

Insect species	Has not moved	Adjacent Paddocks	Your property	Neighbours property
Crown weevil (*Mogulones larvatus*)				
Root weevil (*Mogulones geographicus*)				
Flea beetle (*Longitarsus echii*)				
Pollen beetle (*Meligethes planiusculus*)				

Question 36 What damage is the insect doing to Paterson's curse on your property?

Insect species	Nil	Visible feeding	Stressing plants	Killing plants
Crown weevil (*Mogulones larvatus*)				
Root weevil (*Mogulones geographicus*)				
Flea beetle (*Longitarsus echii*)				
Pollen beetle (*Meligethes planiusculus*)				

Question 37 Is biological control reducing the weediness of Paterson's curse? Yes / No
If no, go to question 45.
Question 38 Has biological control decreased the amount of Paterson's curse on your property? Tick the most appropriate box.

Nil	1-20%	21-40%	41-60%	61-80%	Over 80%

Question 39 Is biological control increasing the productivity of your property? Yes / No
Question 40 Is biological control improving the sustainability of your property? Yes / No
Question 41 Has biological control decreased your herbicide use, if so by what percentage. Tick the most appropriate box.

Increased	Nil	1-20%	21-40%	41-60%	61-80%	Over 80%

Comments

Question 42 Has biological control improved the quality of your pasture? Yes / No
If yes, which pasture types have benefited the most, tick the most appropriate boxes.

Annual grasses	Perennial grasses	Clovers	Medics	Other

Comments

Question 43 Has biological control of Paterson's curse improved the condition of your stock by improved weight gain or increased wool clip. Tick the most appropriate box.

Nil	1-5%	6-10%	11-15%	16-20%	21-25%	Over 25%

Comments

Question 44 Has biological control of Paterson's curse increased the amount of stock your property can carry? Tick the most appropriate box.

Nil	1-5%	6-10%	11-15%	16-20%	21-25%	Over 25%

Comments

Question 45 Do you believe biological control has the potential to reduce the weediness of Paterson's curse on your property given enough time? Yes / No

Question 46 Have environmental factors limited the numbers of the biocontrol insects? Yes / No

Question 47 Has the biological control of Paterson's curse encouraged you to maintain your existing control efforts while the insects breed up into large numbers? Yes / No

Question 48 Do you believe biological control has been a worthwhile investment? Yes / No

Question 49 Should the work on the biological control of Paterson's curse continue? Yes / No

Question 50 Should there be work on biological control of other pasture weeds? Yes / No

If yes, what weeds are important in your region, please list below.

Ranking	Weed
1	
2	
3	
4	
5	

Do you have any other comments?