CRC for Australian Weed Management #10
Technical Series

Economic impact assessment of Australian weed biological control

By: A.R Page and K.L Lacey, AEC*group*

CRC Weed management

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Report to the CRC for Australian Weed Management

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January 2006

Prepared by the AEC*group* for the CRC for Australian Weed Management

AECgroup

CRC Weed management

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Front cover: *Zygogramma bicolorata* on parthenium weed. Photo: Qld Dept Natural Resources & Mines

Table of contents

Section I – Overview of methodology and findings

Section II – Detailed cost benefit analysis (CBA) of biocontrol projects

CRC for Australian Weed Management #10
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Section I – Overview of methodology and findings

Executive summary

This report examines the return on investment of the Australian weed biological control (biocontrol) effort. The study has been funded by the Cooperative Research Centre for Australian Weed Management (Weeds CRC). The findings of this study are reported in two sections:

- Section I – Overview of methodology and findings; and
- Section II – Detailed cost benefit analysis (CBA) of biocontrol projects.

Methodology

The analysis was conducted in two stages; firstly the identification, collation and review of all past economic analyses on biocontrol in Australia, and secondly the evaluation and cost benefit analysis (CBA), where possible, of all remaining biocontrol programs undertaken in Australia. All programs where economic data was available were then aggregated to give an overall benefit cost ratio (BCR). For the analysis, all values were converted into 2004–05 dollars and, unless otherwise specified, all values in this document are expressed in 2004–05 dollar terms.

Return on investment

The aggregate results of the individual CBA programs indicate an overall benefit cost ratio (BCR) of 23.1. This implies that for every dollar invested in the weed biocontrol effort a benefit of $23.10 is generated. Based on this ratio and where an annual investment in weed biocontrol of approximately $4.3 million[1] is continued into the future, it is expected that weed biocontrol projects may provide, on average, an annual net benefit of $95.3 million of which $71.8 million is expected to flow to the agriculture sector. Initial costs of biocontrol programs have increased and are likely to continue to increase, due to expanded regulatory requirements over time. However, the overall benefits are so large that even were program costs to double the overall BCR would still be 11.6, that is a return of $11.60 for each $1 invested.

[1] This is the average annual expenditure on biocontrol for the period between 1980 and 2000.

Findings

The analysis of weed biocontrol programs found that:

- The overall weed biocontrol effort provided a strongly positive return on investment, with the benefits provided by the programs far outweighing the total costs incurred in weed biocontrol since the 1900s.
- Biocontrol programs contribute not only to the performance and wellbeing of the agriculture sector, Government and community, but also to the wider Australian economy. An annual production/economic benefit of $95.3 million is provided by the weed biocontrol effort, which is an estimate of the annual average benefit based on the historical performance of the overall biocontrol effort.
- The majority of programs were found to be desirable forms of investment. A number of programs provided additional benefits (environmental, social and production), which had to be excluded from, or were considered to be significantly under represented in, the analysis due to a lack of data required for quantification.
- Some programs considered to have been successful could not be evaluated due to a lack of available data. This does not imply that the project failed, rather that it was impossible to evaluate these projects as insufficient performance indicators were captured. This highlights the need to adequately monitor and capture relevant program and project performance data for ongoing management and evaluation purposes.
- All programs addressed a perceived industry or environmental need. However, there was only limited evidence available to demonstrate how the weed biocontrol effort responded to identified industry needs. That is, quantitative impact data was usually lacking and there was no clearly identified prioritisation process prior to commencing a biocontrol program.
- Quantified program returns identified a highly desirable overall return on investment in the form of an overall BCR of 23.1, which implies that for every dollar invested in biocontrol there are $23.10 provided as benefits. This BCR comprised BCRs of:
  - 17.4 for agriculture (control cost savings and increased production);
  - 3.8 to society (health benefits); and
  - 1.9 for Government (control cost savings).
- Whilst the biocontrol effort provided a significant number of environmental and social benefits, few of these were quantifiable, due to data limitations in either valuing the impact or in terms of deriving a value of an impact where its magnitude was not known.
- Success of biocontrol programs depends on successful establishment of the biocontrol agents. Where there has been poor establishment it was often not clear if this was a result of the failure of the research and development component or of the on-ground establishment activities.

Recommendations

The following recommendations are made:

- All prospective biocontrol programs undertake and publish an assessment of the target weed's impact prior to release of any agents, including the identification of:
  - Current distribution and density;
  - Rate of spread (historical and projected);
  - Magnitude and extent of impact of the weed (production, environmental and social).
- Research costs are recorded for the purposes of benchmarking and future analysis.
- Programs are monitored and evaluated throughout their active life, on completion and at intervals following the release and establishment of agents. This evaluation should include collection of data on the target weed's economic impact after the establishment of biocontrol.
- Similar data to that collected for production impacts is collected to better assess the social and environmental impacts of biocontrol programs. This could include data on the target weed's impacts on native biodiversity or specific threatened species, as well as data on control costs in particular situations, and on the cost of excluding the weed from sites of high environmental value.

1. Introduction

The Cooperative Research Centre for Australian Weed Management (Weeds CRC) commissioned the AEC*group* to examine the economic impact of, and benefits provided by, the Australian biocontrol effort against weeds.

Key stakeholders, namely the Government and industry, make a significant investment in weed biocontrol programs and, as such, require that the benefits flowing from these investments be identified. This is particularly important given the significant economic, environmental and social impact of weeds and the need to ensure that investments made are effective and give an adequate return.

1.1 Background

There has been significant investment in weed management initiatives since the first biocontrol program commenced over 100 years ago. However, there is little existing published data highlighting the success or otherwise of the outcomes of research into biocontrol for weeds and the agents that have been released. In some cases there is only limited information regarding the original impact (production, social or environmental) of the weeds, which significantly constrains future evaluations.

Biocontrol is defined as pest control making use of living natural enemies, antagonists or competitors and other biotic entities (Walton, 2005). Biocontrol is particularly effective where large areas of land have been invaded by weeds and chemical or mechanical control is uneconomical or impractical.

The impact or success of biocontrol can affect a range of stakeholders, from individual landholders through improved productivity or a decrease in control costs, to the community through social issues such as health impacts and amenity values, and the environment through reductions in threats to native ecosystems and biodiversity.

Discussions with those involved in biocontrol research indicate that the success of programs can often be difficult to measure due to the long time involved in achieving change and the changes in stakeholders and stakeholder perceptions and understanding of impacts over this time.

1.2 Scope and objectives

The purpose of the evaluation is to identify the role that weed biocontrol has played in Australia and to estimate the return on investment it has provided and the economic impact it has had on the wider economy.

Specifically the objectives of the study are to:

- Identify and review previously conducted economic studies of weed biocontrol programs;
- Collate the total cost of all biocontrol programs in Australia where data could be obtained;
- Estimate the net benefit from the individual weed programs and the overall biocontrol effort; and
- Estimate the net economic impact that the biocontrol effort has had on the Australian economy.

1.3 Report structure

This analysis has been conducted to identify and present the impact and benefits of the Australian weed biocontrol effort to key stakeholders. As such the analysis is presented in two sections:

- Section I – Overview of methodology and findings; and
- Section II – Detailed impact analysis and evaluation of individual weed biocontrol programs.

Section I is comprised of seven sections with an introduction and an overview of the approach and methodology, followed by a summary of the return on investment provided by the weed biocontrol effort, an estimation of the annual benefit derived from the existing programs and the wider economic benefits flowing to the Australian economy. This is followed by examples of the most notable highlights of the assessment, the project findings and an outline of suggestions to assist in the future appraisal and management of weed biocontrol programs.

Section II contains the cost benefit analysis (CBA) and review for each of the individual programs examined in the evaluation.

2. Approach and methodology

2.1 Literature review and data collation

The analysis encompassed the review of all weed biocontrol programs undertaken in Australia and is based on a wide and varied range of data and sources, with some data estimated on the basis of historical estimates and other data consisting of the opinion of industry experts. Very recent programs, where there has been insufficient time for actual field impacts, were excluded from the analysis.

Mr Colin Wilson undertook a detailed review of the literature (published and unpublished) and searched files and interviewed staff for all relevant weed biocontrol programs. The analysis outlined in this report is based on the data and information provided by Mr Wilson as well as additional consultation undertaken with researchers and industry participants, as referenced in the text. Basic information on the weed species (biology, distribution, impact), except where otherwise referenced, is taken from the following sources:

- Parsons and Cuthbertson (2001);
- Groves *et al*. (1995);
- Panetta *et al*. (1998); and
- ARMCANZ (2001).

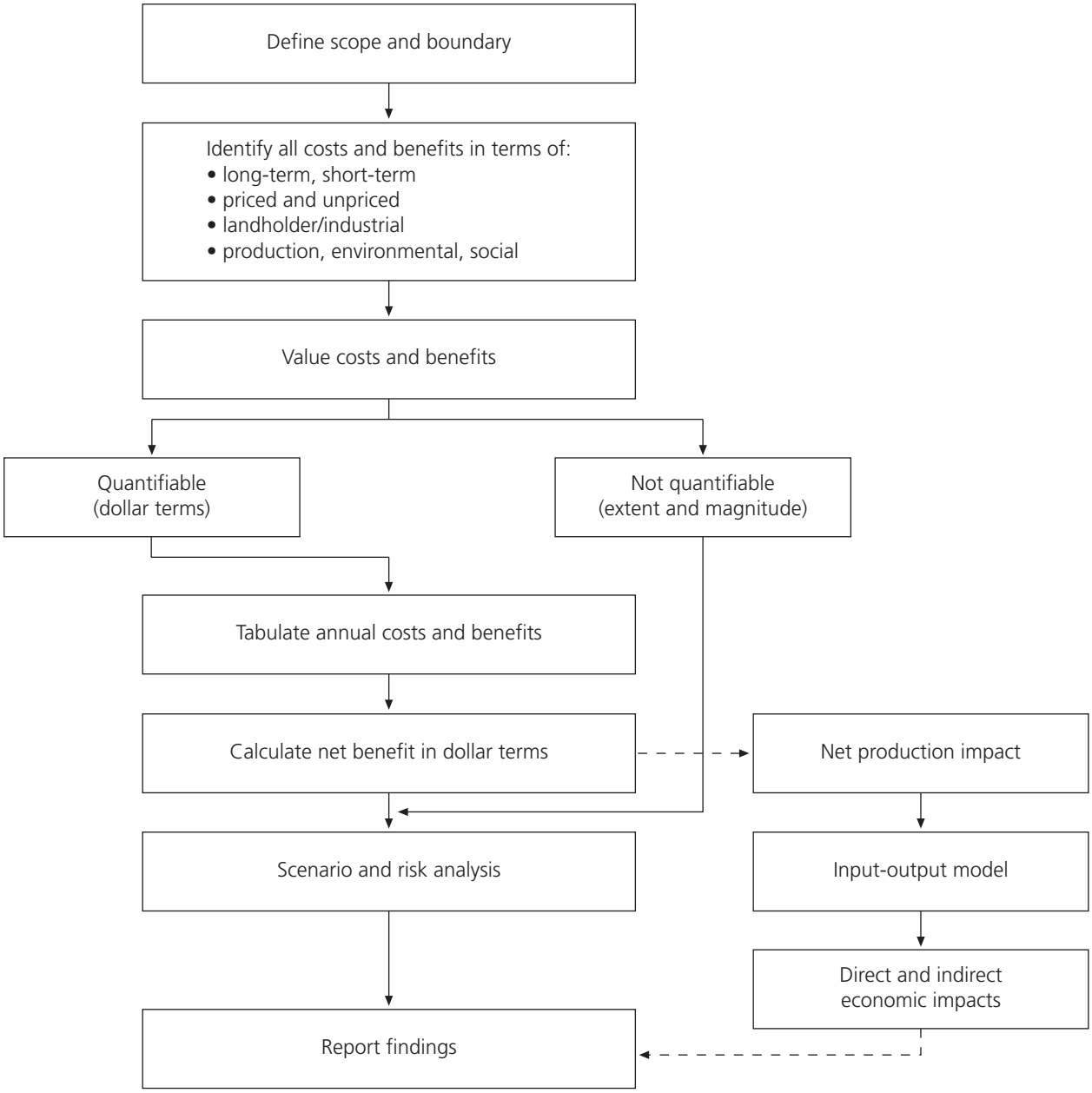
Information on the economic costs of individual weeds prior to the biocontrol programs is taken from published papers where available, or from unpublished reports to the various state governments (as referenced in the text). All such costs are converted to and quoted in 2004/05 dollar terms unless otherwise specified. Costs of the biocontrol programs are similarly sourced, usually from unpublished information in files of the department responsible. Where this information is not available or not complete, an average cost is used based on the number of scientists involved, duration of the program and proportion of their time in Full Time Equivalents (FTEs). The cost of one senior research scientist FTE for a year is set at salary of $100,000 times three, the multiplier used by the Federal Government for Cooperative Research Centres, which covers all operating costs including technical staff, facilities, administration, etc. In 2004/05 dollar terms, this means a typical small program employing one scientist overseas for 3 years, plus 50% of the time of a scientist in Australia for 5 years, would cost a total of $1,650,000, and larger programs would cost at least twice as much.

2.2 Evaluation framework

The principal evaluation framework utilised in the analysis was a cost benefit analysis (CBA) framework. A CBA was conducted, where data was available, on all relevant weed biocontrol programs conducted in Australia. These impacts were then grouped to examine the overall performance of the Australian weed biocontrol effort in light of successes and failures of individual programs. The CBA methodology is outlined in detail in **Appendix A**.

The production impacts of the biocontrol effort were identified and applied to an Input–output (IO) model to examine an indicative economic impact of weed biocontrol on the wider Australian economy. An outline of the two models, and how they interact, is given in **Figure 2.1**, with the IO model component identified by the three boxes connected to the rest of the model by dotted lines. The IO methodology is outlined in detail in **Appendix B**.

Figure 2.1. Evaluation framework



Source: AECgroup

The detailed CBA evaluations are included in Section II, and an overview of the findings and example highlights from the programs evaluated is outlined in the following sections. Of the 76 biocontrol programs identified, some were at an early stage where no evaluation is yet possible, and for others, information on costs of the program was not available so no evaluation was possible.

The key elements of this evaluation include:

- 76 biocontrol programs identified and reviewed for suitability;
- 36 biocontrol programs evaluated; and
- 29 CBAs included in the return on investment assessment for the overall weed biocontrol effort.

3. Return on investment

3.1 Introduction

This section examines the relative return on investment that weed biocontrol programs have generated (economic, social and environmental). This analysis examines two types of impacts, economic and non-economic impacts. Economic impacts are considered to be impacts that have a definitive dollar value such as an increase in yield, an increase in productivity or a reduction in costs expended to control/manage the target species. Non-economic impacts are those qualitative impacts such as decreased toxicity to the environment, preservation of native biodiversity and scenic amenity, decreased stress to farmers or families, etc.

Typically quantified economic impacts comprise cost savings, productivity increases and some health impacts. Environmental and social impacts have been discussed qualitatively as the requisite quantified data was rarely available.

3.2 Return on investment

The return on investment from weed biocontrol programs identified following the analysis are highlighted in **Table 3.1**. The cost of individual programs varied a great deal.

"Cheap" programs (eg annual ragweed) were usually undertaken by a scientist who was responsible for several other programs, and only dedicating 25% to 50% of their time to the particular program. Potential agents may have been sourced from overseas collaborators either free or at minimal cost, or from a scientist based overseas on another program and spending only a small proportion of their time on this program. Host-specificity testing was sometimes completed in less than 6 months, where the agent was easy to rear and the results were clear-cut.

"Expensive" programs (eg *Mimosa pigra*, lantana) involved prolonged overseas exploration in several countries, with other scientists undertaking host-testing in Australia. Where the host weed is closely related to native plants, or where some results were ambiguous or indicated non-target damage was possible, host-testing may have been much more extensive.

In the same way, the economic cost of the different weeds varies greatly. *Mimosa invisa* was a serious weed for a single industry in one region of the country, with control costs of up to $3.3 million per year. Blackberry is estimated to affect 8.8 million hectares of grazing land and to cost approximately $100 million per year in control and lost production. Economic costs for weeds with a purely environmental impact are still not quantifiable. Therefore, for example, the costs quoted for bridal creeper represent the impact on one small industry and in no way reflect the actual impact of this weed, one of the 20 Weeds of National Significance.

These differing costs and relative impact or success of the biocontrol effort mean that the economic return even on successful programs varies greatly. For example, biocontrol efforts for a complete success such as *Mimosa invisa* resulted in a BCR of 18. However, because of the enormous cost of the weed, even the very limited success with blackberry also resulted in a positive BCR of 2.5. Complete success with a widespread weed having major economic impacts on agriculture, such as prickly pear in the 1920s, skeleton weed in the 1980s or rubber vine in the 1990s, results in BCRs above 100, that is, a return of greater than $100 for every $1 invested. Complete failure, for example fireweed or sicklepod, results in the loss of the investment, but the amounts invested are so small relative to the benefits received from the major successes (less than $1 million in total) that overall these losses are swamped by the returns from the major successes.

The results indicate that, based on the programs evaluated, weed biocontrol projects have provided an average BCR of 23.1. This implies that for every dollar invested in weed biocontrol programs a benefit of $23.10 is generated. This was comprised of a BCR of:

- 17.4 for agriculture (control cost savings and increased production);
- 3.8 to society (health benefits); and
- 1.9 for Government (control cost savings).

Based on this ratio and assuming that the annual average investment of approximately $4.3 million[2] is continued into the future, it is expected that Australian weed biocontrol programs may provide, on average, an annual net benefit of $95.3 million of which $71.8 million is expected to flow to the agriculture sector. Initial costs of biocontrol programs have increased and are likely to continue to increase, due to expanded regulatory requirements over time. However, the overall benefits are so large that even were program costs to double the overall BCR would still be 11.6, that is a return of $11.60 for each $1 invested.

The following table summarises the results of the analysis and highlights in grey the case studies that were included in the assessment of the overall return on investment from the biocontrol effort.

[2] Average expenditure on weed biocontrol from 1980 to 2000 (in 2004/05 dollar terms).

Table 3.1. Impacts of biocontrol research programs examined

Weed	Research program				Economic impacts				Social impacts	Environmental impacts
	Year commenced	*Year completed*	*Total research years*	*Total expenditure (2004/05 $M)*	*Present value benefits ($M)*	*Present value costs ($M)*	*Net present value ($M)*	*Benefit/cost ratio*		
Acacia nilotica (prickly acacia)	1980	O	26	$5.3	$0.0	$2.3	-$2.3	0.0	N/a	N/a
Ageratina adenophora (crofton weed)	U	U	U	U	P	I	P	P	N/a	N/a
Ageratina riparia (mistflower)	1986	2001	4	$0.2	$0.0	$0.2	-$0.2	0.0	N/a	N/a
Alternanthera philoxeroides (alligator weed)	1976	2004	12	$1.4	$0.3 [(a)]	$0.8	-$0.5 [(a)]	0.4 [(a)]	Reduced chemical usage resulting in reduced toxicity to humans in recreational areas, improved recreational usage and access of water bodies and reduced areas to harbour disease vectors.	Improved environmental health of waterways, water flows, light penetration, drainage and oxygen levels and reduced water loss, sedimentation and flooding.
Ambrosia artemisiifolia (annual ragweed)	1985	1991	7	$0.6	$52.5 [(b)]	$0.5	$52.0 [(b)]	103.7 [(b)]	Reduced respiratory ailments worth $8.4M in 2005 in reduced medical expenses.	N/a
Asparagus asparagoides (bridal creeper)	1990	2004	15	$7.3	$8.2	$4.0	$4.2	2.0	Improved aesthetic, cultural value of land.	Improved biodiversity and sustainability of native ecosystems and improved environmental health.
Baccharis halimifolia (groundsel bush)	1961	1998	33	$9.6	$2.1 [(a)]	$3.1	-$0.9 [(a)]	0.7 [(a)]	Fewer groundsel bush related allergies.	N/a

Weed	Research program				Economic impacts				Social impacts	Environmental impacts
	Year commenced	*Year completed*	*Total research years*	*Total expenditure (2004/05 $M)*	*Present value benefits ($M)*	*Present value costs ($M)*	*Net present value ($M)*	*Benefit/cost ratio*		
Carduus nutans (nodding thistle)	1986	2000	15	U	$81.3 (c)	$11.9 (c)	$69.4 (c)	6.9 (c)	N/a	Increased biodiversity and environmental sustainability and improved environmental health.
Carduus pycnocephalus and *Carduus tenuiflorus* (slender thistles)	1987	1997	11	$2.1	$22.5	$1.6	$20.9	14.1	N/a	N/a
Chondrilla juncea (skeleton weed)	U	U	U	U	$1,425.5 (d)	$12.7 (d)	$1,412.8 (d)	112.1 (d)	N/a	N/a
Chrysanthemoides monilifera subspecies (boneseed/bitou bush)	1990	O	16	$7.1	$2.7 (b, c, e)	$5.1 (c)	$-2.5 (b, c, e)	0.5 (b, c, e)	Enhanced access and aesthetic value of coastal areas totalling $0.2M.	Improved biodiversity totalling $2.1M.
Cryptostegia grandiflora (rubber vine)	1984	2004	21	$3.6	$234.6	$2.2	$232.5	108.8	Reduced potential harm and health risks to humans.	Reduced damage to native plants, erosion, smothering of trees and pastures and shelter for feral animals and improved environmental health.
Echium plantagineum (salvation Jane/ Paterson's curse)	1972	U	U	U	$1,201.3 (c, f)	$23.1 (c, f)	$1,178.2 (c, f)	52.0 (c, f)	Reduction in hay-fever and skin irritation.	N/a
Emex australis and *Emex spinosa* (spiny emex/ double gee)	1974	1978	5	$2.0	$0.0	$1.7	-$1.7	0.0	N/a	N/a

Weed	Research program				Economic impacts				Social impacts	Environmental impacts
	Year commenced	*Year completed*	*Total research years*	*Total expenditure (2004/05 $M)*	*Present value benefits ($M)*	*Present value costs ($M)*	*Net present value ($M)*	*Benefit/cost ratio*		
Harrisia spp. (harrisia cactus)	1959	1976	5	$1.0	$19.4	$0.8	$18.6	23.5	N/a	Improved biodiversity and environmental health.
Heliotropium europaeum (common heliotrope)	1973	1991	19	$4.4	$0.0	$1.9	-$1.9	0.0	N/a	N/a
Hypericum perforatum (St John's wort)	1928	O	57	U	P	I	P	P	Decreased incidence of contact rash in humans.	Reduced fire risk and intensity of burn.
Lantana montevidensis (creeping lantana)	1996	2000	5	$0.2	$0.0	$0.2	-$0.2	0.0	N/a	N/a
Lantana camara (lantana)	1914	2004	64	$13.6	$3.0	$0.5	$2.5	5.6	N/a	Reduced threat to native habitats and improved environmental health and biodiversity.
Marrubium vulgare (horehound)	1989	2001	13	$1.8	$0.3 [(a)]	$1.2	-$0.9 [(a)]	0.2 [(a)]	N/a	Reduced threat to natural ecosystems.
Mimosa diplotricha (giant sensitive plant)	1982	1992	11	$1.7	$21.4	$1.2	$20.2	18.0	N/a	N/a
Mimosa pigra (mimosa)	1981	2004	24	$21.6	$6.1	$7.6	-$1.5	0.8	Improved access to and recreational use of waterways and increased cultural sustainability.	Improved biodiversity and environmental health.
Onopordum spp. (scotch, stemless and Illyrian thistles)	1988	O	18	$3.7	$20.1	$2.1	$18.0	9.6	N/a	N/a

Weed	Research program				Economic impacts				Social impacts	Environmental impacts
	Year commenced	*Year completed*	*Total research years*	*Total expenditure (2004/05 $M)*	*Present value benefits ($M)*	*Present value costs ($M)*	*Net present value ($M)*	*Benefit/cost ratio*		
Opuntia spp. (prickly pears)	1903	1987	35	$21.1	$3,110.3 [a]	$10.0	$3,100.4 [a]	312.3 [a]	Fewer injuries caused by prickly pear spines and decreased stress over lost production.	Improved biodiversity and environmental health.
Parkinsonia aculeata (parkinsonia)	1983	1990	8	$1.6	$0.0	$1.3	-$1.3	0.0	N/a	N/a
Parthenium hysterophorus (parthenium)	1977	O	29	$11.0	$38.6 [b]	$5.3	$33.3 [b]	7.2 [b]	Reduced allergies from parthenium worth $8.0M/year in reduced medical expenses.	Improved biodiversity.
Prosopis spp. (mesquite)	1992	O	14	$2.3	$0.8 [a, b]	$1.6	-$0.8 [a, b]	0.5 [a, b]	Reduced cost on medical treatment of approximately $5,000/year.	Reduced erosion, loss of biodiversity, damage to watercourses and shelter for feral animals.
Rubus fruticosus agg. (blackberry)	1977	O	29	$4.9	$6.1	$2.4	$3.7	2.5	Increased recreational value of public land.	Improved biodiversity but reduced food and shelter for native birds.
Rumex spp. (docks)	1982	1998	17	$1.3 [a]	P	$1.0 [a]	P	P	N/a	Improved biodiversity.
Salvinia molesta (salvinia), *Eichhornia crassipes* (water hyacinth) and *Pistia stratiotes* (water lettuce)	1974	1993	20	$5.1	$79.4	$2.9	$76.5	27.5	Increased recreational enjoyment of waterways.	Improved sustainability and health of native aquatic ecosystems.
Senecio jacobaea (ragwort)	1977	2005	29	$7.9	$97.2	$3.0	$94.2	32.4	Reduction in allergies caused by ragwort.	Improved biodiversity.
Senecio madagascariensis (fireweed)	1990	1994	5	$0.4	$0.0	$0.3	-$0.3	0.0	N/a	N/a

Weed	Research program				Economic impacts				Social impacts	Environmental impacts
	Year commenced	*Year completed*	*Total research years*	*Total expenditure (2004/05 $M)*	*Present value benefits ($M)*	*Present value costs ($M)*	*Net present value ($M)*	*Benefit/cost ratio*		
Senna obtusifolia (sicklepod)	1992	2000	9	$0.7	$0.0	$0.5	-$0.5	0.0	N/a	N/a
Sida acuta and *Sida rhombifolia* (spinyhead sida, Paddy's lucerne)	1984	1999	16	$4.2	$1.1 [a]	$2.5	-$1.3 [a]	0.5 [a]	N/a	Improved environmental health.
Silybum marianum (variegated thistle) and *Cirsium vulgare* (spear thistle)	1988	2002	15	$3.0	$0.0	$2.1	-$2.1	0.0	N/a	N/a
Xanthium occidentale (Noogoora burr)	1930 [g]	1975 [g]	45 [g]	$10.1	$23.4 [c, h]	U	U	N/a	Reduced dermatitis and hay-fever.	N/a
Total [i]					**$3,724.1**	**$64.9**	**$3,659.2**	**23.1 [j]**		

Note: N/a – Not applicable. O – Ongoing. U – Unknown. P – Unknown but believed to be positive. N – Unknown but believed to be negative. I – Unknown but believed to be outweighed by the benefits. [a] Data limitations have prevented the accurate quantification of significant economic impacts. As such this value is considered an underestimate. [b] This economic impact assessment includes social/environmental benefits/costs. [c] 5% discount rate used– program not included in Total. [d] 10% discount rate used – program not included in Total. [e] 40 year analysis. [f] 78 year analysis. [g] Approximate timeframes. [h] Figure is for PV starting from 1983, not the beginning of the biocontrol program. [i] Only includes analysis results for CBAs conducted at an 8% discount rate (shaded). [j] This is an average of the BCRs of all CBAs conducted at an 8% discount rate. An average has been used instead of a ratio of the total benefits and costs of the Australian weed biocontrol effort to temper the bias that results from the magnitude of benefits and costs of the prickly pear biocontrol program.

3.3 Impact of the prickly pear biocontrol program

The prickly pear biocontrol program provided a magnitude of benefit far greater than any other program because the impact of the weed had become so enormous prior to the successful biocontrol. If the prickly pear program is excluded from the analysis, the total weed biocontrol effort still has an aggregate BCR of approximately 12.3, that is, has returned $12.30 for each $1 invested.

3.4 Summary

Weed biocontrol programs have been demonstrated to provide a significant return on investment, far better than most alternative investments of public or industry money. A summary of the key economic, environmental and social impacts identified to flow from weed biocontrol programs are contained in **Table 3.2**.

Table 3.2. Summary of impacts of the weed biocontrol program

Economic	Environmental	Social
• Increased production (yield) • Cost reductions • Improved product quality • Increased market access • Reduced price penalties • Reduced risk • Assistance in pest animal control • Maintenance of tourism value	• Reduced toxicity from chemicals • Biodiversity (flora & fauna) • Reduced fire hazard • Maintenance of natural habitat/ecosystems	• Decreased health impacts • Improved market access • Improved food quality • Improved consumer satisfaction • Decreased exposure to chemicals • Reduced risk of variable income • Maintenance to cultural values • Improved recreational access to land and water • Improved scenic amenity

Source: AECgroup

4. Economic impact

4.1 Introduction

This section of the report details the expected economic impact to Australia flowing from the weed biocontrol effort. The analysis utilises an Input–output (IO) methodology to model the expected impacts of these investments.

4.2 Data inputs

Weed biocontrol programs generate an increase in output in the form of increased production and efficiency as well as social and environmental benefits[3]. It has been assumed that the increase in agricultural output is reinvested in the agriculture sector[4] as wages and other salaries and the purchase of additional production inputs, which go on to generate additional flow-on effects.

Benefits to Local and State Governments were not included as an economic impact as these were most likely to comprise transfers within the economy rather than the generation of additional economic activity. The economic impact of changed expenditure patterns from reduced health impacts were not included, as these were not considered to have a material impact on the health sector.

Based on an average BCR for all individual programs examined, a production BCR for the agricultural sector of 17.4 was identified. This implies that every dollar invested in biocontrol programs has, on average, provided $17.40 in economic (production) benefits to the agriculture sector. This BCR is used to represent the annual economic benefit expected to flow from future weed biocontrol programs if the historical performance of weed biocontrol is continued into the future.

The ratio identified may be applied to the expected annual expenditure on weed biocontrol to determine an indicative annual economic (output) shock within the Australian economy. This economic impact was then applied to an input–output model to identify the economic impact of weed biocontrol programs to the Australian economy.

4.3 Economic impact

The indicative annual economic impact of continuing the average expenditure on biocontrol ($4.3 million) on the Australian economy is outlined in **Table 4.1**.

Expenditure on weed biocontrol programs generates an economic impact on the Australian economy. If funding for weed biocontrol initiatives were to remain consistent into the future, the indicative economic impact of this expenditure may include:

- $128.0 million in gross output, with direct and indirect impacts totalling $71.8 million and $56.2 million, respectively;
- $65.4 million in value added or GDP, with direct and indirect impacts totalling $38.5 million and $26.9 million, respectively;
- $18.9 million in wages and salaries paid, with direct and indirect impacts totalling $5.9 million and $13.0 million, respectively; and
- 1,219 FTE employment positions, with direct and indirect impacts of 871 and 348 FTEs, respectively.

The above impacts are an indicative estimate of the level of annual economic impact maintained by the weed biocontrol effort into the future. The input–output model is an optimalisation model that utilises fixed production functions. As such, it seeks the most efficient distribution of spending for each round of economic activity, which in reality is unlikely to occur 100% of the time. Nevertheless, this provides a good indication of the annual flow-on impacts from weed biocontrol investment initiatives. A full list of the limitations associated with IO analysis is contained in **Appendix B**.

Table 4.1. Economic impact of the overall weed biocontrol effort (2004/05)

Impact	Gross output ($M)	Value added ($M)	Income ($M)	Employment[(a)]
Direct	$71.8	$38.5	$5.9	871
Indirect	$56.2	$26.9	$13.0	348
Total	**$128.0**	**$65.4**	**$18.9**	**1,219**

[(a)] Persons, full time equivalent

Source: AECgroup

[3] Economic impact can only be generated by a change in the level of production or transactions between industry sectors within an economy. Environmental and social impacts are not able to be included as they are not drivers to industry transactions.

[4] Predominantly in the sheep and beef cattle sectors.

5. Highlights of the evaluation

Detailed analysis of individual weed biocontrol programs is contained in Section II. This section presents some of the key findings identified by the analysis and highlights examples of how weed biocontrol programs have provided a significant return to industry, the environment and the wider community.

The benefits flowing from weed biocontrol programs include increases in industry productivity and viability, reductions in detrimental environmental impacts and increases in the social wellbeing of the Australian rural and regional community. Failures have also occurred, and one of these is highlighted. Failures mean that resources were utilised for the biocontrol program and were therefore not available for other possible investments. No benefits were obtained because the impacts of the target weed continued unchecked. The following highlights are presented in alphabetical order.

Basic information on the weed species (biology, distribution, impact), except where otherwise referenced, is taken from the following sources:

- Parsons and Cuthbertson (2001);
- Groves *et al*. (1995);
- Panetta *et al*. (1998); and
- ARMCANZ (2001).

Information on the economic costs of individual weeds prior to the biocontrol programs is taken from published papers where available, or from unpublished reports to the various state governments (as referenced in Section II). All such costs are converted to and quoted as 2004/05 dollar terms. Costs of the biocontrol programs are similarly sourced, usually from unpublished information in files of the department responsible.

Ambrosia artemisiifolia (annual ragweed)

Ambrosia artemisiifolia (annual ragweed) is an erect annual herb that grows to 1–2 metres in height. It was first recorded in NSW in 1908 and in Queensland in 1915. It has spread rapidly since the 1940s and is mainly found in northeast NSW and southeast Queensland.

Annual ragweed causes serious asthma, hay-fever and other allergies. An estimated 16% of the population living in infested areas develop hay-fever symptoms due to annual ragweed. In this analysis it is estimated that without biocontrol annual ragweed would have cost approximately $8.4 million in medical treatment in 2005.

The annual ragweed biocontrol program commenced in 1985 and ran until 1991 and resulted in the release of four biological control agents, with three becoming established. The program is estimated to have cost a total of $625,000 (in 2004/05 dollar terms), resulting in a NPV of $52.0 million and a BCR of 103.7.

Key benefits of the biological control program include:

- Approximately $8.4 million in reduced medical expenses (in 2004/05 dollar terms);
- Increased production through increased carrying capacity of pasture, although due to data limitations this benefit has not been quantified.

Asparagus asparagoides (bridal creeper)

Asparagus asparagoides (bridal creeper) is a climbing vine to three meters high on supportive vegetation with numerous branching stems from a perennial root system consisting of rhizomes with water-bearing tubers. First recorded in Victoria in 1886, bridal creeper is now found throughout Victoria and much of eastern and southern NSW as well as along the Murray River, the Yorke and Eyre Peninsulas and Kangaroo Island in South Australia and in southwest Western Australia.

Bridal creeper competes strongly with native vegetation, forming dense mats of tubers and rhizomes beneath the soil surface and forming a canopy over plants. Whilst predominantly an environmental weed, bridal creeper also has a production impact in orchards and pine plantations where it smothers and weakens trees and interferes with harvesting machinery. It poses a significant threat to the Murray Valley citrus industry where in the absence of effective biocontrol it would be expected to spread to the entire region.

The bridal creeper biological control program has resulted in the release of three biocontrol agents, all of which have established at at least some sites. The program ran from 1990 to 2004 and is estimated to have cost a total of $7.3 million (in 2004/05 dollar terms), resulting in a NPV of $4.2 million and a BCR of 2.0.

Due to data limitations this analysis only includes benefits to the Murray Valley citrus industry. The annual production benefit to the Murray Valley citrus industry in terms of reduced control costs is approximately $10.7 million. Biocontrol also provides significant environmental and social benefits such as:

- Improved biodiversity;
- Improved sustainability of native ecosystems;
- Improved scenic amenity; and
- Improved cultural value of land.

Carduus pycnocephalus and *Carduus tenuiflorus* (slender thistles)

Carduus pycnocephalus and *Carduus tenuiflorus* (slender thistles) are upright prickly plants, unbranched or heavily branched and can grow to 1–2 metres high. Slender thistles occur over approximately 8.25 million hectares in Victoria and are widely distributed in NSW and Tasmania. They are widespread but do not have a big impact in Western Australia or Queensland.

Slender thistles are mainly weeds of pastures but in higher rainfall areas also impact cropping industries. They are not grazed by stock due to prickles and discourage grazing of palatable plants in their vicinity, decreasing pasture productivity. They may also be toxic to stock although rarely eaten.

The slender thistle biocontrol program ran from 1987 to 1997 and has resulted in the release of one agent, which has established. The program is estimated to have cost a total of $2.1 million (in 2004/05 dollar terms), resulting in a NPV of $20.9 million and a BCR of 14.1.

The annual benefit to the wool industry as a result of biocontrol is estimated to be approximately $4.4 million. Biocontrol also provides benefits to other grazing enterprises outside of the wool industry, however, due to data limitations these benefits have not been quantified.

Chondrilla juncea (skeleton weed)

Chondrilla juncea (skeleton weed) is a relatively long-lived perennial rosette-forming plant. Skeleton weed is found through virtually the entire cereal growing area of NSW and Victoria and is still spreading through South Australia and Western Australia.

Skeleton weed is rarely a problem in native vegetation, however it is highly competitive in cereal crops, reducing yields by up to 50% in wet years and up to 80% in dry years. The tall wiry stems also provide an additional harvesting cost as they choke harvesting machinery. Prior to the biocontrol program, skeleton weed was one of the worst weeds of crops in temperate Australia.

The skeleton weed biocontrol program resulted in the release of four agents, three of which have become established. Marsden *et al*. (1980) estimate the cost of the program, when converted to 2004/05 dollar terms, to be $12.7 million (10% discount rate), resulting in a NPV of $1,412.8 million and a BCR of 112.1.

It is estimated that in 2004/05 dollar terms the benefits from increased wheat yield from biocontrol is worth approximately $70 million per annum, while the reduction in control costs are worth approximately $10.5 million per annum, providing a benefit to the agricultural sector of $80.5 million per annum (Marsden *et al*., 1980).

Chrysanthemoides monilifera subspecies (boneseed/bitou bush)

Chrysanthemoides monilifera subspecies (boneseed/bitou bush) are erect or sprawling perennial woody shrubs 1–3 metres in height. Subspecies *rotundata* (bitou bush) mainly occurs in coastal areas. By 1982 it infested 660 kilometres (60%) of the NSW coast including many National Parks and Reserves, and was the dominant species along a 220km stretch. Subspecies *monilifera* (boneseed) is widespread and has a severe impact on native vegetation in parts of Victoria. Boneseed is also found in the Mount Lofty Ranges in South Australia and the north and east coast of Tasmania.

Boneseed/bitou bush does not affect grazing as it is readily eaten by stock. However, it establishes readily in native vegetation communities, out-competing and eliminating native species, and is considered a threat to several rare native plants, threatened ecological communities and other significant areas, including World Heritage areas.

The boneseed/bitou bush biocontrol program has been running since 1990 and has resulted in the release of seven agents, with three becoming established. In an *ex ante* analysis CIE (2001) estimated that the cost of the program, once converted to 2004/05 dollar terms, was $7.1 million, with the potential to result in a NPV of $47.9 million and a BCR of 10.3. Anecdotal evidence indicates that the benefits of the program have been approximately one-twentieth of those predicted by CIE, resulting in a NPV of -$2.5 million and a BCR of 0.5 at a 5% discount rate (CIE, 2001).

The benefits of biocontrol, over the period between 1990 and 2030 and in 2004/05 dollar terms, are estimated to total $2.7 million (5% discount rate) (CIE, 2001), comprised of:

- $0.4 million in control costs savings;
- $2.1 million in increased biodiversity; and
- $0.2 million in enhanced access and aesthetic value of coastal areas.

Cryptostegia grandiflora (rubber vine)

Cryptostegia grandiflora (rubber vine) is a scrambling sub-shrub. Rubber vine was introduced to Queensland in the 1860s and by 1944 had infested 1,200 hectares. It now occurs along much of the Queensland coast extending into the Gulf and is a common component of riparian vegetation and floodplains.

Dense infestations of rubber vine can reduce carrying capacity by almost 100%. The cost to the cattle industry in 1991 was estimated to be greater than $8 million and in 2001 the cost was estimated to be approximately $18.3 million. Rubber vine also seriously damages native plant communities, especially gallery forests and dry rain forests.

The rubber vine biocontrol program ran from 1984 to 2004 and resulted in the release of two agents, both of which established. The program is estimated to have cost a total of $3.6 million (in 2004/05 dollar terms), resulting in a NPV of $232.5 million and a BCR of 108.8.

The benefits of biocontrol in 2005 are estimated to total $31.2 million, comprised of:

- $8.9 million in control cost savings;
- $14.3 million in increased carrying capacity;
- $4.2 million in reduced mustering costs; and
- $3.8 million in reduced loss of cattle.

The biocontrol program also provides the unquantified environmental and social benefits of reduced:

- Damage to native plant communities (especially gallery forests and dry rain forests);
- Smothering of tall trees and pastures;
- Number and extent of impenetrable thickets forming along streams;
- Erosion from decreased ground cover;
- Area available to harbour feral animals such as pigs;
- Chemical toxicity, improving environmental health and reducing impacts to non-targeted plants and animals; and
- Potential for harm and health risks to humans.

Echium plantagineum (Paterson's curse)

Echium plantagineum (Paterson's curse) is a winter annual growing as a rosette that later supports one to many erect flowering branches. In the early 1980s Paterson's curse was estimated to have infested approximately 918,000 hectares in Victoria, 4.0 million hectares in South Australia and 296,000 hectares in Western Australia, with these areas expected to have increased since then. It is also widespread in NSW.

Paterson's curse out-competes other plants, especially under light grazing. It is grazed by sheep but displaces other more desirable species as well as other weeds. It is not generally grazed by cattle or horses but is poisonous to pigs and horses. In 1985 Paterson's curse was estimated to cause an annual net loss of between $9 and $27 million in NSW, $2.3 million in Victoria, and $2.3 million in Southern Australia.

The Paterson's curse biocontrol program resulted in the release of seven agents, with five becoming established. When converted to 2004/05 dollar terms the program, including ongoing rearing and distribution of the agents, was estimated to cost approximately $23.1 million (5% discount rate), resulting in a NPV of $1.2 billion and a BCR of 52.0 between 1972 and 2050 (CIE, 2001).

Benefits of biocontrol include:

- Increased carrying capacity of pasture;
- Reduced displacement of other, more desirable species of pasture plants;
- Reduced poisoning of stock;
- Reduced expenditure on chemical control;
- Reduction in hay-fever; and
- Reduced skin irritation.

Harrisia martinii (harrisia cactus)

Harrisia martinii (harrisia cactus) can form dense impenetrable thickets 1–2 metres high and with 80–90% ground cover, which seriously reduces pasture productivity. Harrisia cactus was first introduced to Queensland between 1885–1890. It infests several widely scattered areas in Queensland and northern NSW, and has been recorded in Western Australia.

By 1978/79 the Queensland Government was spending $700,000 per annum on control, which resulted in a total expenditure between 1965 and 1980 of approximately $7 million. The total cost incurred from harrisia cactus between 1950 and 1982 was estimated in 1982 to be approximately $18.4 million, which in 2004/05 dollar terms represents a cost of $49.5 million.

The harrisia cactus biocontrol program ran for three years between 1973 and 1976, as well as two years of exploration in 1959 and 1972, and resulted in the release of four agents, two of which established. The program is estimated to have cost a total of approximately $1.0 million, resulting in a NPV of $18.6 million and a BCR of 23.5.

Annual control cost savings to industry and Government are estimated to be approximately $2.3 million per annum. Unquantified benefits of biocontrol include:

- Increased productivity due to increased carrying capacity of land;
- Improved biodiversity due to reduced competitiveness of harrisia cactus; and
- Reduced off-target chemical damage through reduced use of herbicides.

Lantana camara (lantana)

Lantana camara (lantana) is a brittle, much-branched, thicket-forming shrub, normally 2–4 metres tall but capable of scrambling over other vegetation to 15 metres high. Lantana was first recorded in Australia at Adelaide in 1841. It spread rapidly along the east coast of Australia and is now a prominent coastal and sub-coastal weed from Cairns to Bega, and is also found on both Lord Howe and Norfolk Islands.

The main economic damage is to the productivity of pastures but lantana is also considered a serious weed of the plantation and native timber and orchard industries. Annual losses in pastures are estimated at approximately $7.7 million (made up of approximately 1,500 stock deaths, reduced performance, loss of pasture and control costs). Total control costs by primary industries in Queensland are estimated as greater than $10 million/year. The costs of lost production in Australia due to lantana has been conservatively estimated as greater than $22 million.

The lantana biocontrol program began in 1914 and is ongoing, although prior to 1953 research was sporadic with only 12 years of research being conducted between 1914 and 1952. Over this period 30 agents have been released, with 17 becoming established and 4 of these effectively reducing the vigour of the weed. The program is estimated to have cost a total of $13.6 million, resulting in a NPV of $2.5 million and a BCR of 5.6.

Biocontrol is estimated to have increased productivity by approximately $1.2 million/annum, or $290,000/annum per biocontrol agent released. Other, unquantified benefits of biocontrol include:

- Reduced threat to natural habitat; and
- Improved environmental health and biodiversity.

Mimosa diplotricha (giant sensitive plant)

Mimosa diplotricha (previously *Mimosa invisa*) (giant sensitive plant) is a shrubby or sprawling prickly annual, which in some circumstances behaves as a perennial vine. Giant sensitive plant is a serious weed of tropical crops (especially sugarcane), orchards, plantations and pastures. It is known to have been present in Australia since approximately 1929, and is restricted to the coast of north Queensland.

The prickly stems of giant sensitive plant smother crops and impede harvesters. The plant is unpalatable to stock and forms dense, tangled thickets that can cause injury and death to trapped animals. Estimates of control costs, expressed in 2004/05 dollar terms, ranged from approximately $270,000/year (incurred in 1982) to $3.3 million/year (in 1992).

The biocontrol program ran from 1982 to 1992 and resulted in the release of two agents, one of which established. The program is estimated to have cost a total of $1.7 million, resulting in a NPV of $19.7 million and a BCR of 17.6.

Annual control cost savings are estimated to be approximately $3.2 million. Benefits, not quantified due to data limitations, include:

- Reduction in density of thickets that can trap animals, causing injury and death;
- Increased carrying capacity of land; and
- Improved stock and harvester movement.

Mimosa pigra (mimosa)

Mimosa pigra (mimosa) is a leguminous thorny shrub that grows up to six metres high. Mimosa was first recorded at Darwin in 1891. It spread rapidly from 1975 and covered approximately 80,000 hectares by 1983.

Mimosa has a number of economic, social and environmental impacts as it:

- Interferes with stock mustering, stock watering, irrigation and recreational use of waterways (including fishing);
- Smothers pastures, reducing productivity;
- Displaces native waterbirds (including magpie goose) and other fauna;
- Suppresses all other vegetation;
- Threatens traditional food gathering by Aborigines; and
- Threatens tourism (especially in Kakadu).

The mimosa biocontrol program was conducted between 1981 and 2004 and resulted in the release of thirteen agents, nine of which established. The program is estimated to have cost a total of $21.6 million, resulting in a NPV of -$1.5 million and a BCR of 0.8.

The annual benefit of biocontrol is estimated to be approximately $1.5 million in control cost savings. The benefits of reduced chemical usage due to biological control are $100/ha for national parks and reserves and $20/ha for grazing areas.

Other unquantified benefits of the program include:

- Potential productivity gains;
- Potential gains to the recreation and tourism industry;
- Environmental benefits; and
- Cultural benefits.

Onopordum spp. (scotch, stemless and Illyrian thistles)

Onopordum spp. (scotch, stemless and Illyrian thistles) grow in temperate or warm-temperate winter rainfall areas. They were first recorded as a weed in Victoria in the 1850's and are now established on grazing lands in a number of areas in southern Australia.

Scotch and Illyrian thistles infest approximately 1.1 million hectares, with scotch thistle in approximately 80,000 hectares in Victoria, and large parts of NSW, while stemless thistles infest approximately 1.6 million hectares in total.

These thistles are competitive weeds of pasture, are not eaten by stock, reduce the carrying capacity of pastures and cause vegetable fault in wool.

The scotch, stemless and Illyrian thistle biocontrol program started in 1988 and resulted in the release of seven agents, four of which established. The program is estimated to have cost a total of $3.7 million, resulting in a NPV of $18.0 million and a BCR of 9.6.

The annual productivity benefits are estimated to be approximately $7.4 million from increased carrying capacity and reduced vegetable fault in wool.

Opuntia spp. (prickly pears)

Opuntia spp. (prickly pears) grow in semi-arid warm temperate, sub-tropical and tropical regions. Prickly pear was first recorded in Australia in the 1800s and infested vast tracts of land in NSW and Queensland in the early 1900s.

Prickly pear is drought resistant and not usually grazed due to spines. It formed dense thickets creating an impenetrable barrier and seriously reduced the carrying capacity of land. In 1920 prickly pear was forcing approximately 400,000 hectares of land out of production each year and by 1926 had covered 24 million hectares, with at least half of this area totally abandoned for agriculture.

The prickly pear biocontrol program ran from 1903 to 1939, with additional research conducted between 1978 and 1987. Twenty biocontrol agents were released, with fourteen established, some of which have since disappeared. The program is estimated to have cost a total of $21.1 million in 2004/05 dollar terms, resulting in a NPV of $3.1 billion and a BCR of 312.3.

The annual production benefit of biocontrol in the Darling Downs is currently estimated to be approximately $294.6 million (half the $589.2 million production benefit received prior to mechanisation in the 1960s). Other regions aside from the Darling Downs also received a benefit from biocontrol in terms of increased productivity, however, due to data limitations these benefits have not been quantified. Benefits from the biocontrol program that have not been included due to data limitations include:

- Improved biodiversity due to reduced competitiveness of prickly pear;
- Improved environmental health and reduced impacts to non-target plants and animals due to the reduction in arsenic pentoxide and other herbicide use; and
- Fewer injuries caused by prickly pear spines.

Parthenium hysterophorus (parthenium)

Parthenium hysterophorus (parthenium) is an erect multi-branched ephemeral herb known for its vigorous growth to 1.5 metres tall (occasionally 2 metres). Parthenium was introduced to north Queensland in 1958 and recognised as a serious pest in Queensland in 1974 after a series of wet years. During the 1970s it spread at an exceptional rate and has become a dominant weed over thousands of hectares of grazing land in sub-coastal districts of Queensland.

By 1991 parthenium was present over 170,000 square kilometres of Queensland (10% of State) causing annual losses to beef producers of approximately $16.5 million through reduced stocking rates, reduction in daily weight gain and additional production and control costs. It was estimated in 1996 that if it continued to spread throughout its potential distribution range in Australia it could cost the beef industry from $109 to $129 million per year.

The parthenium biocontrol program started in 1977 and resulted in the release of eleven agents, eight of which established. The program is estimated to have cost a total of $11.0 million. Benefits already experienced resulted in a NPV of $33.3 million and a BCR of 7.2 at a discount rate of 8.0%. This is likely to increase significantly as the agents spread further and the weed seed bank continues to decline.

Key outcomes already achieved from the parthenium biocontrol program are:

- $380,000 annual productivity benefit in sown pasture;
- $986,000 annual productivity benefit in native pasture; and
- $8.0 million annual benefit in reduced medical expenses.

Unquantified benefits of the biocontrol program include:

- Improved market access and price outcomes for producers in previously infested areas;
- Slower spread into uninfested areas and reduced cost of control in new areas
- Reduced expenses on infrastructure; and
- Improved biodiversity.

Rubus fruticosus agg. (blackberry)

Rubus fruticosus aggregate (blackberry) consists of perennial, scrambling, prickly shrubs that often form large clumps 1–3, rarely to 7, metres high. The earliest record of blackberry in Australia was in 1842 in Adelaide. Blackberry was promoted by acclimatisation societies in the 1860s and recognised as an important weed in the 1880s. Blackberry occurs in all States except the Northern Territory and is of particular importance in NSW, Victoria and Tasmania.

Blackberry is a major weed of pastures, native forests and along streams and gullies. In 1984 the annual production loss and cost of control to NSW, Victoria and Tasmania was estimated to total $42.1 million (without taking into account social or biodiversity costs). In contrast, the benefits provided by blackberry were estimated to be just $660,000/annum. By 1990 losses and costs had increased to at least $70 million/year.

The blackberry biocontrol program has resulted in the release of one agent which established. The program is estimated to have cost a total of $4.9 million in 2004/05 dollar terms, which is conservatively estimated to have resulted in a NPV of $3.7 million and a BCR of 2.5.

Biocontrol is conservatively estimated to result in reduced losses to productivity of approximately $2.4 million annually, through a combination of:

- Increased carrying capacity of land;
- Reduced stock losses;
- Improved access to land and water; and
- Reduced access, competition and harvesting problems in forestry operations.

Unquantified benefits of biocontrol include:

- Increased light penetration allowing other plants to survive and increasing biodiversity; and
- Increased recreational value of public land.

Water weeds – *Salvinia molesta* (salvinia), *Eichhornia crassipes* (water hyacinth) and *Pistia stratiotes* (water lettuce)

Salvinia molesta (salvinia) is a free floating, entirely sterile, perennial aquatic fern. Salvinia was probably introduced to Australia soon after WWII and was first recorded as naturalised in 1952. It is widely established in dams, lagoons, ponds and rivers mainly along the east coast and has significant potential for further spread.

Eichhornia crassipes (water hyacinth) is an erect, floating perennial herb, reproducing from seed and also spreading via stolons. Water hyacinth was introduced to Australia in the 1890's and is now common in coastal rivers of Queensland and northern NSW.

Pistia stratiotes (water lettuce) is a free-floating aquatic herb, which rapidly forms dense mats. Water lettuce is probably native to northern areas of the Northern Territory. It also exists in scattered colonies along the east coast north of Sydney and inland waterways in Queensland.

Salvinia, water hyacinth and water lettuce (water weed) infestations:

- Restrict river navigation, fishing and recreation;
- Interfere with the operation of engineering structures;
- Obstruct or prevent irrigation and prolong flooding;
- Impede access of stock to water;
- Seriously degrade native aquatic ecosystems by preventing light penetration and reducing oxygen and pH levels in water;
- Cause massive loss of water through transpiration;
- Degrade the quality of drinking water; and
- Harbour disease vectors such as mosquitoes.

The biocontrol program for the three water weeds salvinia, water hyacinth and water lettuce ran from 1974 to 1993 and resulted in the release of seven biocontrol agents, six of which established. The program is estimated to have cost a total of $5.1 million, resulting in a NPV of $76.5 million and a BCR of 27.5.

The annual benefit of biocontrol in terms of control cost savings is estimated to be approximately $10.1 million. Biocontrol also reduces the negative impacts of water weed infestations described above, although these benefits are believed to have been previously adequately provided using chemical control where it was undertaken. However, use of chemicals in waterways is now restricted in most states.

Senecio jacobaea (ragwort)

Senecio jacobaea (ragwort) is a biennial or short-lived perennial herb to 0.8, rarely 1.8, m high. Ragwort was present in the Melbourne Botanical Gardens in 1852 and there are now approximately 820,000 hectares of grazing land infested in Victoria. It is widely distributed in Tasmania, particularly in the north, with approximately 16,000 hectares of cattle grazed pasture infested in Tasmania in the mid-1980s.

Ragwort is poisonous to grazing animals, taints honey and the pollen causes allergies in people. Ragwort causes a 5–20% reduction in pasture production and is an occasional weed of cropping areas. In Tasmania ragwort was estimated to cause production losses, when converted to 2004/05 dollar terms, of approximately $20.2 million in 1985 (Ireson, 2005). In Victoria costs were at least $3 to 5 million annually.

The ragwort biocontrol program ran from 1977 to 2005 and resulted in the release of seven biocontrol agents, five of which established. The program is estimated to have cost a total of $7.9 million, resulting in a NPV of $97.2 million and a BCR of 32.4.

The benefits of biocontrol are:

- $19.2 million annual productivity benefit in Tasmania;
- $400,000 annual saving to the Victorian community;
- Improved biodiversity by removing weed populations that out-compete many other plants;
- Reduced allergies and risk of poisoning from ragwort.

Senecio madagascariensis (fireweed)

Senecio madagascariensis (fireweed) is an erect, much-branched bush or herb that grows to approximately 60 centimetres tall. Fireweed was first collected in the Hunter Valley in 1918 and has since spread along the coast, northern tablelands, and western slopes of NSW and southeast Queensland.

Fireweed invades disturbed areas and reduces pasture productivity. It is generally unpalatable to stock but if eaten causes death or poor growth and condition of stock (cattle and horses) through poisoning. A survey by Sindel and Michael (1988) estimated that the costs to the dairy industry alone in NSW from fireweed were 100,000 man hours plus $250,000 per annum in 1985. Based on the results of this survey, fireweed was estimated to cost NSW farmers approximately $3.4 million annually in 1989.

The fireweed biocontrol program ran for five years between 1989 and 1994, but failed to identify any suitable agents for controlling the weed in Australia. Natural enemies found in Madagascar could attack other native plants in Australia and were rejected for use in Australia on these grounds. The fireweed program is estimated to have cost a total of $377,000, resulting in a NPV of -$0.3 million and a BCR of 0.0.

However, CBA shows that had any biocontrol agents specific to the control of fireweed been released, the distribution of biocontrol would have only needed to be 2.1% to breakeven. This highlights the low level of benefits generally required by biocontrol programs in order to provide a positive return on investment, due to the low costs of these programs relative to the costs of the weed.

5.1 Limitations

Data limitations constrained the evaluation of the full benefit (economic, environmental and social) provided by the biocontrol effort and in some instances limited cost data prevented the conduct of a CBA. These data limitations pertained most commonly to the:

- Impact of the weeds (economic, environmental and social);
- Rate of spread and distribution of the weed;
- Research and development costs (particularly with early projects); and
- Efficacy of biocontrol agents.

6. Findings

The overall weed biocontrol effort was found to provide a positive return on investment, with the benefits provided by those biocontrol programs that could be evaluated outweighing the total cost of all programs incurred since the 1900s.

The majority of programs were found to be desirable forms of investment. A number of programs provided benefits (environmental, social and production), which were excluded from or considered to be significantly under-represented in the analysis, due to a lack of data enabling their quantification.

Some programs considered to have delivered successful outcomes could not be evaluated due to a lack of available data. This does not imply that the programs failed, rather that it was impossible to evaluate them as insufficient performance indicators were captured. This highlights the need to adequately monitor and capture relevant project performance data for ongoing management and evaluation purposes.

The evaluation process was severely limited by data availability (pre and post biocontrol release) in the following areas:

- Impact of the weeds (economic, environmental and social);
- Rate of spread and distribution of the weed;
- Research and development costs (particularly with early projects); and
- Efficacy of biocontrol agents.

All programs addressed a perceived industry or environmental need. However, there was only limited evidence available to demonstrate how the weed biocontrol effort responded to identified industry needs. That is, quantitative impact data was usually lacking and there was no clearly identified prioritisation process prior to commencing a biocontrol program.

Success of biocontrol programs depends on successful establishment of the biocontrol agents. Where there has been poor establishment it was often not clear if this was a result of the failure of the research and development component or of the on-ground establishment activities.

Quantified program returns identified a highly desirable overall return on investment in the form of a BCR of 23.1, which implies that for every dollar invested in biocontrol there are $23.10 provided as benefits. This BCR comprised BCRs of:

- 17.4 for agriculture (control cost savings and increased production);
- 3.8 to society (health benefits); and
- 1.9 for Government (control cost savings).

Whilst the biocontrol effort provided a significant number of environmental and social benefits, few of these were quantifiable due to data limitations in either valuing the impact or in terms of driving a value of the impact as its magnitude is not known.

Biocontrol programs contribute not only to the performance and wellbeing of the agriculture sector, Government and the wider community, but also to the Australian economy. An annual production/economic benefit of $71.8 million to the agriculture sector, which is an estimate of the annual average benefit based on the historical performance of the Australian weed biocontrol program, would maintain within the Australian economy approximately:

- $128.0 million in output;
- $65.4 million in value added (Gross Domestic Product);
- $18.9 million in income; and
- 1,219 full time employment positions.

7. Recommendations

Following the conduct of the analysis, the AEC*group* provide the following recommendations for the future allocation of research funds and program evaluation to improve investment in weed biocontrol initiatives:

- All prospective biocontrol programs undertake an assessment of the target weed's impacts, including the identification of:
  - Current distribution and density;
  - Rate of spread (historical and expected); and
  - Magnitude and extent of impacts (production, environmental and social) and including quantification of economic impacts such as lost production and costs of control.
- Research costs are recorded for the purposes of benchmarking and future analysis.
- Programs are monitored and evaluated throughout their active life, on completion and at intervals following the release and establishment of agents to better gauge the performance of the program.
- Similar data to that collected for production impacts is collected to better assess the social and environmental impacts of biocontrol programs.

Appendix A: Cost benefit analysis

A cost benefit analysis (CBA) model is applied to the quantifiable components of the projects to identify their return on investment.

The CBA model used for each of the programs examined is also used to assess an indicative overall benefit flowing from the overall weed biocontrol effort. The process of steps to conduct a CBA is summarised in **Figure 2.1**, and the key steps of the process, adapted from Sinden and Thampapillai (1995), are discussed below.

Step 1. Define scope and boundary

To enable a robust determination of the net benefits of undertaking a given project, it is necessary to specify base case and alternative case scenarios. The base case scenario represents the 'without project' scenario and the alternative 'with project' scenario examines the impact with the program in place.

The base case (without) scenario is represented by line NB_1 (bc)[5] over time T_1 to T_2 (**Figure A.1**). The investment in biocontrol initiatives at time T_1 is likely to generate a benefit, which is represented by line NB_2 (abd). Therefore the net benefit flowing from investment in the biocontrol initiatives is identified by calculating the area (bcd) between NB_1 and NB_2.

Step 2. Identify costs and benefits

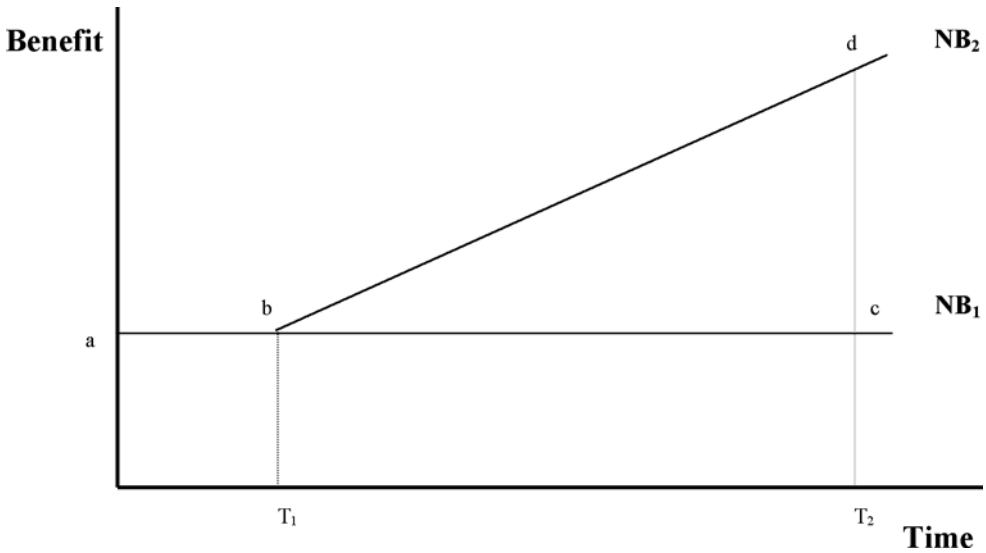
A comprehensive quantitative specification of the benefits and costs included in the evaluation and their various timings is required and includes a clear outline of all major underlying assumptions. These impacts both positive and negative are then tabulated and where possible valued in dollar terms.

Some impacts, such as environmental and social impacts, may not be quantifiable. Where this occurs the impacts and their respective magnitudes will be examined qualitatively for consideration in the overall analysis.

Step 3. Value costs and benefits

Each impact identified should be valued for inclusion in the CBA. Where the impact does not have a readily identifiable dollar value, proxies and other measures should be developed as these issues represent real costs and benefits. Where the application of market or non-market valuation techniques is not possible, the issue should be described qualitatively with respect to the magnitude and extent, and if it is expected to occur in the short-term or long-term.

Figure A.1. With and without scenarios



[5] The assumption of constant utility without the program is arbitrary and is used to explain the conceptual 'with' and 'without' scenario.

Step 4. Quantify the impact

Each of the identified impacts should be quantified and where this is not possible due to data availability then the impact should be discussed qualitatively to describe the nature and extent of its impact.

Step 5. Tabulate annual costs and benefits

The quantifiable benefits are tabulated to identify where and how often they occur. Tabulation provides an easy method for checking that all the issues and outcomes identified have been addressed and provides a picture of the flow of costs, benefits and their sources.

Step 6. Calculate the net benefit

This step adjusts for the time preference of money to enable the comparison of investment options by a common measure and requires the choice of a suitable discount rate.

The selection of appropriate discount rates is of particular importance because they apply to much of the decision criteria and consequently the interpretation of results. The higher the discount rate, the less weight or importance is placed on future cash flows.

The choice of discount rates should reflect the weighted average cost of capital. For this analysis a base discount rate of 8.0% was examined with a range from 4.0% to 10.0% examined.

Step 7. Scenario and risk analysis

Scenario and risk analysis allows for the testing of the key assumptions and the identification of the critical variables within the analysis to gain greater insight into the drivers to the case being examined. Variables such as the adoption rate or percentage of uptake may have a significant impact on the outcome of the analysis.

Decision criteria and interpretation

The decision criteria that are investigated in the CBA include:

- Net present value (NPV), which represents the present value of all benefits minus the present value of all costs;
- Benefit cost ratio (BCR), which is the present value of benefits divided by the present value of the costs; and
- Breakeven point, which indicates value of a critical variable required for the project to 'breakeven' or return a NPV of zero.

These decision criteria will allow the determination of the most economically desirable investment alternative, as well as the level of benefits that can be expected to flow from the biocontrol investment program. These results may be applied to future expenditure to identify the level of return that may be expected.

Due to the diverse nature of biocontrol projects, not all investment programs will be suited to analysis within an economic framework.

Appendix B: Input-output analysis

Input–output analysis measures the stimulus from additional economic activity through an economy in different ways, which are commonly measured and discussed as the first and second round effects[6]. These effects may be represented as multipliers. There are commonly four different types of multipliers:

- Output;
- Value added;
- Income; and
- Employment.

To estimate the economic impact to an existing economic activity/industry, a shock (eg change in the current output of an industry) is applied. In this case the shock is the additional output generated (increased production and cost saving) following the development of weed biocontrol measures[7].

Explanation of terms

Output

The output impact measures the increase in gross sales throughout the whole economy by summing all the individual transactions resulting, directly and indirectly, from the economic stimulus. The output impact is also useful in providing an indication of the degree of structural dependence between sectors of the economy. The output impacts are, however, regarded as overstating the impact on the economy as they count all goods and services used in one stage of production as an input to later stages of production, hence counting their contribution more than once.

Value added

The value added or gross domestic product[8] (GDP) impact measures only the net activity at each stage of production. GDP is broadly defined as the additional consumption, investment and government expenditure, plus exports of goods and services, minus imports of goods and services. The GDP impacts are the preferred measure for the assessment and contribution of a stimulus to the economy.

Income

The income impact measures the additional amount of wages and salaries paid to employees of the industry under consideration and to other industries benefiting from the stimulus to the economy.

Employment

The employment impact measures the number of jobs created by the stimulus, both directly and indirectly. It should be noted that short-term response to increased demand may be for employers to ask existing staff to work overtime and will therefore result in less employment than the numbers of jobs indicated by the economic impact of the stimulus. This short-term scenario is particularly true where the demand stimulus is seen as temporary. This is unlikely to occur with biocontrol programs as their impacts are felt over the long-term.

Limitations of input-output analysis

When using an input-output model, the two key limitations that should be kept in mind when interpreting the results are the constancy assumption of unchanged purchasing patterns between industries and the linearity assumption of constant returns to scale. A full list of the assumptions associated with input-output analysis is outlined below;

- The inputs purchased by each industry are a function of the level of output of that industry. The input function is generally assumed linear and homogenous of degree one (which implies constant returns to scale and no substitution between inputs);
- The total effect of carrying on several types of production is the sum of the separate effects. This rules out external economies and diseconomies and is known simply as the additivity assumption. This generally does not reflect real world operations;
- The system is in equilibrium at given prices. This is not the case in an economic system subject to external influences; and
- In the static input-output model, there are no capacity constraints so that the supply of each good is perfectly elastic. Each industry can supply whatever quantity is demanded of it and there are no capital restrictions. This assumption would come into play depending upon the magnitude of the changes in quantities demanded.

[6] First round or direct effects are those from the expenditure by the industry purchasing additional goods from other industries, whereas second round effects are those from the supplying industries increasing their purchases to meet the additional demand. The second and subsequent rounds of purchasing are termed the indirect effects.

[7] It is assumed that all of the cost savings are utilised by the enterprise through additional wages and salaries or purchases of inputs rather than in off farm investment.

[8] In a region, the term used is Gross Regional Product (GRP), at the State level the term used is Gross State Product (GSP), and at the national level, the term used is Gross Domestic Product (GDP).

CRC for Australian Weed Management #10
Technical Series

Section II – Detailed cost benefit analysis (CBA) of biocontrol projects

Before reading this section

This section outlines some general notes on the information provided in this document.

- Unless otherwise specified, all data referenced in this document have been adapted from research notes collated by Mr C. Wilson (2005), who undertook an extensive literature review and consultation process to gather background data, program costs and impacts.
- Unless otherwise specified, all values in the sub-sections entitled 'Background and biology' and 'Establishment and impact' have been expressed in original dollar terms for each biocontrol program.
- Unless otherwise specified, all values in the sub-sections entitled 'Biological control program', 'Cost benefit analysis' and 'Summary' have been expressed in 2004/05 dollar terms for each biocontrol program.
- With regards to the CBAs described in this document the term 'distribution' refers to the level of control achieved by biocontrol agents. It is a factor of both the spread of the biocontrol agents and their effectiveness at controlling the weed, providing an overall level of control across the entire infested area. For example, if biocontrol agents for a particular weed are established in 80% of the total area infested by the weed and provide a 50% reduction in the impact of the weed where they have become established, then the distribution used in the analysis would be 40% (the product of 80% and 50%). This is consistent across all CBAs unless otherwise specified.

1. *Acacia nilotica* (prickly acacia)

1.1 References

W.A. Palmer, Queensland Department of Natural Resources and Mines, *pers. comm.*, 2005

Kritikos, D., Brown, J., Radford, I. and Nicholas, M. (1999)

Mackey, A.P. (1997)

Radford, I., Nicholas, D.M. and Brown, J.R. (2001)

1.2 Background and biology

Acacia nilotica (prickly acacia) is a small thorny shrub or spreading single-stemmed tree growing to 4–5 metres high, and occasionally to 10 metres high. It prefers:

- Arid to semi-arid tropical and subtropical regions;
- 250–1,500 millimetres of rainfall; and
- Heavy clay soils but will grow on lighter soils and sands.

Generally the trees set seed at 2–3 years of age and can become prolific along artesian bore drains. Individual trees growing in bore drains have recorded seed counts of greater than 175,000/year.

Seeds can remain viable for approximately 7 years, with the tree itself able to survive in favourable conditions for between 30–60 years. Tree densities of up to 932/hectare have been recorded and, once established, seedlings and the mature plants are protected by thorns. Prickly acacia is also tolerant of fire and drought.

Cattle pass approximately 80% of ingested seeds and approximately 40% of these remain viable following the 6-day digestive cycle. Sheep pass few viable seeds. Water also disperses pods downstream and generally spread follows a step-wise exponential pattern with most expansions occurring in very wet years.

1.3 Establishment and impact

1.3.1 History in Australia

Prickly acacia was first recorded in 1803 and was introduced to Queensland in the 1890s. By the 1920s it was widely grown as a shade and ornamental tree. In 1926 the Department of Agriculture and Stock recommended it as a shade tree for sheep in western Queensland and seeds were distributed from horseback. By the 1930s it had become well established across Mitchell grasslands and in several coastal areas.

'Explosions' of prickly acacia occurred during the mid 1950s due to high rainfall, and during the 1970s from a switch to cattle from sheep. In 1985 there were approximately 6.7 million hectares infested across nine Queensland Local Government Areas (28% of the LGAs, or approximately 4% of Queensland), and 1,200 kilometres of infested bore drains. It is estimated that greater than 7 million hectares were infested by 1995.

Spread can be rapid, for example, one 20,000 hectare Queensland property which had four plants in 1960, by 1984 was 90% infested with 6,000 hectares of dense thickets. Prickly acacia has the potential to substantially increase its range in Australia to approximately 50 million hectares of grasslands in Western Australia, the Northern Territory and Queensland (or approximately 6.6% of Australia).

1.3.2 Production impact

Dense infestations in production areas:

- Reduce pasture production;
- Increase soil erosion;
- Increase mustering costs;
- Impede stock movement;
- Restrict access to water;
- Increase cost of maintaining bore drains;
- Increase the loss of water from bore drains;
- Damage vehicle tyres;
- Increase cost of fencing; and
- Injure animals.

Most production costs relate to reduction in pasture production and increased management costs, including:

- Mustering cost increases – the cost of mustering in grasslands not infested by prickly acacia is approximately $1.50/head. However in dense infestations costs can be as high as $17/head; and
- 25–30% canopy cover reduces pasture production by approximately 50%, and 50% canopy cover prevents any pasture growth. Maximum canopy cover in northwest Queensland is approximately 35%.

Prickly acacia can cost landholders up to $9 million per year in reduced beef and wool production, control costs, increased mustering costs and repairs to tyres.

The cost of treating the infestation conventionally was conservatively estimated at approximately $55 million. Current expenditure on control is estimated at

approximately $3–4 million annually. Reduced land value is potentially a major cost as reclamation costs of heavily infested lands often exceed the value of uninfested lands.

Prickly acacia can also have a beneficial impact from its:

- Use of leaves and pods as fodder in dry periods;
- Provision of shade; and
- Value as timber and fuel wood.

1.3.3 Environmental impact

Environmental impacts of prickly acacia include:

- Loss of grass cover;
- Increased bare ground;
- Higher soil surface temperature; and
- Change from grassland reptiles and birds to shrubland fauna, which provides a threat to several unique grassland species.

The Mitchell grass downs is one of the world's major grassland ecosystems and is home to approximately 25 rare and threatened animal species and 2 endangered plant communities. The Mitchell grass downs, due to prickly acacia, is being progressively converted into thorny scrublands. This provides a major impact on the environmental structure and dramatic effect on native fauna and flora.

1.4 Biological control program

Biological control for prickly acacia in Australia has operated since 1980. It has resulted in the introduction of 6 insects, with the seed beetle *Bruchidius sahlbergi* becoming established and widespread. The beetle provides seed destruction of between 0–80% but appears to be having minimal impact on the spread of prickly acacia. Seed predation prior to pod drop and removal by cattle is insufficient to cause major impacts on prickly acacia populations. The defoliating moth *Chiasmia assimilis* has established in coastal sites and is causing severe damage in some areas (W.A. Palmer *pers. comm.* 2005).

1.4.1 Development cost

The research program for prickly acacia biocontrol has run from 1980 to 2005 and has cost an estimated $5.3 million in total.

1.5 Cost benefit analysis

No CBA has been conducted as the biocontrol program is not believed to have provided any benefits to date.

1.6 Summary

The prickly acacia biocontrol project has resulted in the release of six agents, all insects. The seed beetle *Bruchidius sahlbergi* has become established and widespread, resulting in seed destruction of between 0% and 80%, but appears to have had minimal to no impact on the spread of prickly acacia. The defoliating moth *Chiasmia assimilis* has established and is causing severe damage in limited areas only. As a result the prickly acacia biocontrol project is considered to have provided no benefit to date.

2. *Ageratina adenophora* (crofton weed)

2.1 References

Dodd, A.P. (1961)

Haseler, W.H. (1963)

2.2 Background and biology

Ageratina adenophora (crofton weed) is a perennial shrub with a woody rootstock and numerous erect stems to 1–2 metres high. It grows in humid subtropical areas, steep slopes with rainfall greater than 1,500 millimetres and is frequently found in shaded wet areas fringing forests and rainforests and along streams.

2.3 Establishment and impact

Introduced to Australia in approximately 1875, it was first collected as a weed in Sydney 1904. Crofton weed increased and spread aggressively between 1940 and 1950 and is now found along the coastal strip from Sydney to the Mary River in Queensland.

Crofton weed is an aggressive weed in pastures in southeast Queensland where it:

- Reduces crop yield;
- Reduces carrying capacity of grazing land;
- Restricts movement of stock and machinery;
- Is unpalatable to cattle: and
- Is poisonous to horses.

2.4 Biological control program

Biological control has reduced plant vigour. A stem gall fly, *Procecidochares utilis*, was introduced in 1952. A leaf spot fungus, *Cercospora eupatorii*, believed to be accidentally introduced on the bodies of gall flies or in the boxes containing them, also impacts on the growth and spread of crofton weed.

Within 2 years of release, populations of *Procecidochares utilis* were heavily parasitised, but had still dispersed to the extent that its galls are on virtually every crofton weed plant. *Cercospora eupatorii* leaf spot fungus was found in Queensland in 1954 in an area where the gall fly had been released. Its lesions cause leaf fall and at times major defoliation. Adult gall flies carry the fungal spores and are capable of transmitting the disease.

Cercospora eupatorii is found on nearly all plants in all areas of Queensland. The efficiency of this disease is greatly increased by damage done to the plants by the gall fly. Up to 100% of small seedlings are attacked by the fungus and in most cases are killed. The fungus is a major factor in the control of crofton weed, particularly in the seedling stage.

Many areas within its potential dispersal range remain free of the weed. In view of the rapid spread of the plant prior to 1952, it is reasonable to assume that the dispersal and establishment of crofton weed would have continued in Queensland until all suitable areas were colonised, but for the introduction of the gall fly and fungus. The slowing down of the encroachment of the plant cannot be otherwise satisfactorily explained.

A continued very high population of galls is necessary to kill the plants, and a significant reduction in vitality of the plant can only be achieved by relatively large populations. Populations of developing galls can reach the level of 50% of stems in Queensland, but populations are generally much lower than this, due to high parasitism rates. It is considered that in isolation the effects of the gall fly population are restricted, but the small effect is magnified when combined with the leaf spot fungus.

2.4.1 Development cost

No research costs are available for crofton weed.

2.5 Cost benefit analysis

Due to the limited data available on costs of the crofton weed biocontrol program no CBA has been conducted for this program.

2.6 Summary

The crofton weed biocontrol project has resulted in the release of two agents:

- A stem gall fly, *Procecidochares utilis*, in 1952; and
- A leaf spot fungus, *Cercospora eupatorii*, first found in 1954 and was probably accidentally introduced to Australia with the stem gall fly.

Since 1952 the spread of crofton weed has not increased. Heavy infestations have been reduced in vigour and density, scattered plants have become less frequent and seedling growth less prolific. This appears to be primarily due to the gall fly (despite its low population density) and the fungus, as attack by the gall fly predisposes the plant to injury by the fungus.

While no CBA has been conducted it is believed that the crofton weed biocontrol program has provided a significant benefit through the prevention of the continued spread of the weed.

3. *Ageratina riparia* (mistflower)

3.1 References

W.A. Palmer, Queensland Department of Natural Resources and Mines, *pers. comm.*, 2005

3.2 Background and biology

Ageratina riparia (mistflower) is a low growing, sprawling perennial herb 40–60 centimetres high. It has numerous branching stems, which produce roots at the joints where they touch the ground.

Mistflower grows in humid subtropical rainforests, shaded riverbanks, sheltered moist slopes, steep south-facing slopes and prefers rainfall greater than 1,700 millimetres per annum.

3.3 Establishment and impact

First introduced to Australia in approximately 1875, mistflower was introduced to the NSW north coast in the 1920s and rapidly spread northwards. Mistflower is now found in all coastal districts of NSW and southeast Queensland. It is a major weed of northeast NSW and southeast Queensland and sometimes covers whole hillsides.

Mistflower is an aggressive invader of pastures and bushland and quickly invades disturbed areas. Impacts of mistflower include:

- Domination of riverine groundcover habitats;
- Reduction of carrying capacity of pastures;
- Restriction of stock and machinery movement;
- Displacement of native vegetation and animals; and
- Possibly toxic to stock (but no quantifiable evidence).

3.4 Biological control program

A stem gall fly, *Procecidochares alani*, was introduced and released in 1987.

3.4.1 Development cost

Host testing, mass rearing and release of the stem gall fly occurred between 1986 and 1988 at an estimated cost of $197,000, while negotiations and submissions for research into a fungus occurred in 2001 at an estimated cost of $39,600.

3.5 Cost benefit analysis

No CBA has been conducted as the biocontrol program is not believed to have provided any benefits.

3.6 Summary

The stem gall fly released in 1987 has had little impact due to attack from native parasites that have kept fly numbers below damaging levels. As such the program has not delivered any benefits and is considered unsuccessful.

4. *Alternanthera philoxeroides* (alligator weed)

4.1 References

Julien, M.H. (1980)

Julien, M.H. and Bourne, A.S. (1988)

Julien, M.H. and Chan, R.R. (1992)

Julien, M.H., Schooler, S. and Coventry, R. (eds.) (2004)

M. Julien, CSIRO Division of Entomology, *pers. comm.*, 2005

Reserve Bank of Australia (2005)

4.2 Background and biology

Alternanthera philoxeroides (alligator weed) is a perennial stoloniferous herb that grows best in aquatic areas. It can be found growing on banks of waterways, swamps, floodplain pastures, or in water, either rooted in soil near the water's edge, in substrate beneath shallow water, or as floating mats of interwoven stems.

Alligator weed is tolerant of saline conditions and is best suited to warm-temperate to tropical regions that have water or swampy mud flats, rivers, lakes and wet pastures.

Reproduction is entirely vegetative in Australia and plant material will readily develop roots when inserted into wet sand. Hollow stems and high growth rates allow extensive mats to develop over water from the banks. Free floating mats of alligator weed can remain self-sufficient once dislodged.

4.3 Establishment and impact

First recorded in Australia at Newcastle, NSW in 1946, alligator weed became established in the Sydney region. Alligator weed has been recorded at a number of sites in NSW and has a far greater potential distribution, with much of Australia being susceptible to invasion. There is estimated to be approximately 4,000 hectares of alligator weed in Australia and it is still spreading.

Alligator weed is a strong competitor in rice fields and pastures prone to waterlogging. In aquatic habitats it forms a tangled mat approximately 30 centimetres thick that floats mostly beneath the surface. On land it forms a mat approximately 10 centimetres thick and can become the dominant species in wetter sections of pastures. The tendency to form dense mats allows it to competitively displace other plants. Impacts of alligator weed include:

- Competing with and displacing other plant species;
- Restriction of water flow;
- Restriction of light penetration;
- Obstruction of navigation and drainage
- Reduced oxygen levels;
- Increased water loss through evapotranspiration;
- Increased sedimentation;
- Increased flooding impacts;
- Restricted stock and human access to water – dangerous for swimmers;
- Harbours disease vectors; and
- Linked to photosensitivity in lambs and calves.

Alligator weed invades both land and water and is very difficult to control. Mechanical harvesting or ploughing increases the rate of spread by dispersing plant fragments.

Well over $3 million has been spent to attempt to eradicate one small infestation to prevent losses of approximately $250 million. There is little data on the actual or potential economic or ecological impact of alligator weed.

4.4 Biological control program

Three species of biological control agent have been released in Australia, two of which have established and provide some control of the weed.

Agasicles hygrophila flea beetle was first released in 1976 and has been quite successful in controlling alligator weed growing in water, but is only effective in warm temperate areas. Within two years of release Liverpool City Council was able to cease their chemical control program costing approximately $26,000/annum.

Vogtia malloi leaf-feeding moth was first released in 1977. It became established and attacks alligator weed in water but is of limited effectiveness on land.

Biological control significantly reduced colony size and growth rate of floating plants, but not terrestrial.

4.4.1 Development cost

The research program for alligator weed biocontrol was conducted in two stages, with the majority of the research conducted between 1976 and 1982 (leading to the release of three agents). Additional expenditure between 1998 and 2004 are development costs only

as new agents have not been released. The biocontrol project is estimated to have cost approximately $1.4 million in total.

4.5 Cost benefit analysis

4.5.1 Data inputs

Annual saving to Liverpool City Council

The annual saving to Liverpool City Council from the alligator weed biocontrol project has been estimated to be approximately $26,000.

Distribution[1] of biocontrol

Biocontrol is estimated to have taken two years from first release to build up to 100% efficacy.

4.5.2 Model

A CBA model was used in this analysis as described in Section I. The analysis examined the benefits and costs that accrue due to replacement of pre-research control of alligator weed with biocontrol in Liverpool City Council. The net impact was identified by comparing the benefits and costs of the previous control with the benefits and costs since biocontrol. The net benefit of the program is estimated by the equation below:

$$NB = CS - RC$$

Where:

NB = The net benefit from the biocontrol of alligator weed program ($)

CS = The cost saving to Liverpool City Council from implementing biocontrol measures ($)

RC = The cost of research ($)

The cost saving to Liverpool City Council due to biocontrol is estimated using the equation below:

$$CS = \sum_{n=50}^{1} AS \times D_n$$

Where:

AS = The annual saving to Liverpool City Council from biocontrol ($)

D = The distribution of biocontrol in year *n* (%)

n = Year

The cost of undertaking the research is calculated using the equation below:

$$RC = \sum_{n=50}^{1} CR_n \times CI_n$$

Where:

CR = The research costs incurred in year *n* ($)

CI = An index for inflation to convert research costs to 2004/05 dollars

4.5.3 Results

The analysis examined the benefits to Liverpool City Council in terms of control cost savings following the release of biocontrol agents in the George's River. The results of the analysis are presented in **Table 4.1**. The biocontrol program provides a negative return on investment at all discount rates, with a NPV of -$0.5 million and a BCR of 0.4 at a discount rate of 8.0%.

Table 4.1. Results of analysis

Real discount rate	NPV ($ million)	BCR
4.0%	-$0.4	0.6
6.0%	-$0.4	0.5
8.0%	-$0.5	0.4
10.0%	-$0.5	0.4

4.5.4 Sensitivity

Cost savings

The breakeven value with respect to cost savings ranges from $45,900 (4% discount rate) to $74,100 (10% discount rate) per annum, *ceteris paribus*[2]. This is between 1.75 and 2.85 times higher than the base case saving of $26,000 per annum to Liverpool City Council. While it is considered that the saving to Liverpool City Council has not changed between 1976 and the present, this saving is considered a vast underestimate of the total saving from biocontrol based on the potential spread of the weed.

[1] In this document the term 'distribution' refers to the level of control achieved by biocontrol agents. It is a factor of both the spread of the biocontrol agents and their effectiveness at controlling the weed, providing an overall level of control across the entire infested area. This is consistent across all CBAs.

[2] All other factors remaining equal. Note that all sensitivity analyses conducted use this principle unless otherwise specified.

Table 4.2. Sensitivity analysis

Variable	Units	Base case	Breakeven point at 4% discount rate [(a)]	Breakeven point at 10% discount rate [(a)]
Cost savings	$/annum	$26,000	$45,900	$74,100

Note: [(a)] The breakeven value is the value of the input where the NPV for the specified discount rate equals 0.

The potential range of alligator weed, based on climate, includes waterways throughout most of southern Australia, extending south from Bundaberg in Queensland, through NSW, Victoria, Tasmania and South Australia, and north to Kalbarri in Western Australia. Biological control assists in preventing the spread of alligator weed and thus provides a potential cost saving.

Table 4.3 shows that at an 8% discount rate there would need to be only one additional outbreak of alligator weed similar to that on the George's River being controlled each year for the biocontrol program to be beneficial.

Table 4.3. NPV and BCR of alligator weed at 8% discount rate, outbreaks/annum

Outbreaks/ annum	NPV ($ million)	BCR
1	-$0.5	0.4
2	$0.4	1.6
3	$1.9	3.5
4	$3.9	6.1
5	$6.5	9.5
6	$9.7	13.7
7	$13.4	18.6
8	$17.7	24.3
9	$22.6	30.7
10	$28.1	37.9

4.5.5 Limitations of the analysis

This analysis has only included the benefits received by one Local Government Authority (LGA), Liverpool City Council, in terms of cost savings. These benefits are considered to be an underestimate of the actual benefits received, as:

- It is likely that other bodies and/or individuals have reduced their expenditure on controlling alligator weed, in line with the control cost savings experienced by Liverpool City Council;
- The reduction in chemical control has an additional benefit of reducing the level of toxicity of waterways infested with the weed. This provides a benefit in terms of improved environmental health and reduced non-targeted negative impacts to humans, animals and plants;
- It is expected that the release of biocontrol agents has helped in suppressing the spread of alligator weed, providing benefits in terms of avoided negative impacts associated with alligator weed (see below); and
- Biocontrol has been quite successful in controlling alligator weed growing in waterways, which provides the benefits of;
  - Improved water flows;
  - Greater light penetration;
  - Improved drainage;
  - Increased oxygen levels;
  - Reduced water loss through evapotranspiration;
  - Reduced sedimentation;
  - Reduced flooding; and
  - Reduction in the number of disease vectors through the removal of alligator weed which harbours these disease vectors.

Due to the unquantifiable nature of many of the benefits of the biocontrol program, the benefits represented in this analysis are expected to be underestimated.

4.6 Summary

The alligator weed biocontrol program has resulted in the release of three agents, two of which have become established. The program cost an estimated $1.4 million and has resulted in a NPV of -$0.5 million and a BCR of 0.4 at a discount rate of 8.0%.

This analysis is considered to underestimate the benefits of the program. The program was initiated at least in part to reduce further spread of this major weed, and has assisted this objective. If all benefits were quantified it would be expected to result in an increase in the NPV and BCR, and may result in a positive return on investment for the alligator weed biocontrol program.

Table 4.4. Summary of program benefits / costs

Type of benefit	Benefit / Cost	Detail
Economic	Reduced chemical control costs	Savings to LGAs in warm temperate areas of up to approximately $26,000 per annum.
Environmental	Improved control in alligator weed infested water bodies [(a)]	• Improved water flows; • Greater light penetration; • Improved drainage; • Increased oxygen levels; • Reduced water loss through evapotranspiration; • Reduced sedimentation; and • Reduced flooding.
	Reduced chemical toxicity	Improved environmental health of waterways and reduced non-targeted impacts to plants and animals.
Social	Reduced chemical toxicity	Reduced toxicity to humans in recreational areas.
	Improved recreational usage and access [(a)]	• Improved access to water; • Improved swimming conditions; and • Improved navigation.
	Reduction in disease vectors [(a)]	Reduction in environment suitable to harbour disease vectors in waterways.

Note: [(a)] These benefits/costs were already provided to some degree by control methods used prior to the biocontrol program, thus these benefits/costs can not be solely attributed to biocontrol. Due to data limitations the impact of biocontrol in relation to these benefits/costs has not been separated from the impact of prior control methods.

5. *Ambrosia artemisiifolia* (annual ragweed)

5.1 References

AEC*group* (2002)

ASCIA (2002)

Australian Bureau of Statistics (2005a)

Australian Bureau of Statistics (2004)

Australian Bureau of Statistics (1997)

I. Turnbull, Bellingen Shire Council, *pers. comm.*, 2005

McFadyen, R.E. (1984)

Reserve Bank of Australia (2005)

5.2 Background and biology

Ambrosia artemisiifolia (annual ragweed) is an erect shrub that grows to approximately 1–2 metres in height. It prefers disturbed open areas in temperate to subtropical regions.

5.3 Establishment and impact

Annual ragweed was first recorded in NSW in 1908 and in Queensland in 1915. It has spread rapidly since the 1940s and is mainly found in northeast NSW and southeast Queensland.

Annual ragweed causes serious asthma, hay-fever and other allergies. In the USA and Canada, annual ragweed pollen is a chief cause of hay-fever and a contributing factor in allergic asthma. Hay-fever affects less than 0.5% of the population in Britain and Europe where annual ragweed does not occur, but up to 20% in the USA where it is widespread. Up to 40% of hay-fever sufferers will subsequently develop asthma. In 1984, 40% of hay-fever sufferers in Casino, NSW, were identified as being allergic to annual ragweed.

Annual ragweed is unpalatable to horses and rapidly invades and suppresses poorly managed pastures. Seeds can remain dormant but viable for 40 years.

Annual ragweed can potentially provide a useful oil from seeds and it can be eaten by cattle when young.

5.4 Biological control program

Four biological control agents were released between 1985 and 1991, with two, the leaf-feeding beetle *Zygogramma bicolorata* and the stem-galling moth *Epiblema strenuana*, becoming established. Biocontrol has reduced populations and seed production in warmer areas, however quantification of the area and extent of this has not been recorded. Since 1998 annual ragweed has become only a minor problem in Queensland and northern NSW, and the biocontrol program is considered a complete success.

5.4.1 Development cost

The annual ragweed biocontrol program cost an estimated $625,000 over a seven year period between 1985 and 1991.

5.5 Cost benefit analysis

5.5.1 Data inputs

Resident population in area infested

The population living in the infested area has been estimated based on the 1982 figure of 1.31 million persons and population growth rates estimated using historic and projected population data[3].

Sufferers of hay-fever

Hay-fever is estimated to affect 2 in 5 people in Australia and New Zealand. A survey of hay-fever sufferers in Casino showed that approximately 40% of these people were allergic to annual ragweed. As such, a figure of 16% of the total population in the infested area has been applied in this analysis.

Health benefit

A health benefit of approximately $23.85 per sufferer of hay-fever induced by annual ragweed has been applied in this analysis. This is the estimated expenditure per person on medicine to treat hay-fever[4].

[3] Growth rate estimates have been calculated using population data for the Local Government Areas (LGAs) of Brisbane City, Logan City, Gold Coast City, Ipswich City (Part in Brisbane Statistical Division), Beaudesert Shire and Redland Shire.

[4] This figure is factored from the cost of medical treatment for parthenium induced respiratory ailments.

5.5.2 Model

A CBA model was used in this analysis as described in Section I. The analysis examined the health benefits (in terms of reduction in medical expenses) and costs that accrue due to control of annual ragweed with biocontrol. The net benefit of the program is estimated by the equation below:

$$NB = HB - RC$$

Where:

NB = The net benefit from the biocontrol of annual ragweed program ($)

HB = The health benefits from using biocontrol measures ($)

RC = The cost of research ($)

The health benefits from using biocontrol is calculated using the equation below:

$$HB = \sum_{n=50}^{1} SH_n \times EM \times D_n$$

Where:

SH = The number of persons suffering from hay-fever induced by annual ragweed

EM = Expenses on medicine for hay-fever per person ($)

D = The distribution of biocontrol in year *n*

n = Year

The number of persons suffering from hay-fever induced by annual ragweed is estimated as per the equation below:

$$SH = \sum_{n=50}^{1} PA_n \times PH \times HR$$

Where:

PA = The resident population in year *n* in the area infested with annual ragweed

PH = The proportion of the Australian population that suffers from hay-fever (%)

HR = The proportion of hay-fever sufferers that are allergic to annual ragweed

The cost of undertaking the research is calculated using the equation below:

$$RC = \sum_{n=50}^{1} CR_n \times CI_n$$

Where:

CR = The research costs incurred in year *n* ($)

CI = An index for inflation to convert research costs to 2004/05 dollars

5.5.3 Results

The analysis examined the health benefits achieved following the release of biocontrol agents for annual ragweed. The results of the analysis are presented in **Table 5.1**. The biocontrol program provides a positive return on investment at all discount rates, with a NPV of $52.0 million and a BCR of 103.7 at a discount rate of 8.0%.

Table 5.1. Results of analysis

Real discount rate	NPV ($ million)	BCR
4.0%	$126.9	227.6
6.0%	$79.2	149.9
8.0%	$52.0	103.7
10.0%	$35.6	74.7

5.5.4 Sensitivity

Hay-fever sufferers

The breakeven value with respect to the proportion of persons living in the infested area suffering from hay-fever induced by annual ragweed ranges from 0.1% (4% discount rate) to 0.2% (10% discount rate), *ceteris paribus*. This is well below the proportion of annual ragweed-induced hay-fever in which the benefit was estimated to apply. The proportion of persons living in the infested area suffering from annual ragweed-induced hay-fever does not significantly alter the findings of the analysis.

Expenditure by sufferers

The breakeven value with respect to the average expenditure by persons suffering from hay-fever on medical treatment ranges from $0.10 (4% discount rate) to $0.31 (10% discount rate), *ceteris paribus*. It is estimated that the average expenditure by hay-fever sufferers on treatment is $23.85 annually, significantly above the breakeven value. As such, this variable does not significantly alter the findings of the analysis.

Table 5.2. Sensitivity analysis

Variable	Units	Base case	Breakeven point at 4% discount rate [(a)]	Breakeven point at 10% discount rate [(a)]
Hay-fever sufferers	%	16%	0.1%	0.2%
Expenditure by sufferers	$/annum	$23.85	$0.10	$0.31

Note: [(a)] The breakeven value is the value of the input where the NPV for the specified discount rate equals 0.

5.5.5 Limitations of the analysis

Accurate data on the actual area infested and/or the number of people living in the infested area is not available. As such, the number of people living in the infested area has been estimated based on a 1982 figure reported by McFadyen (1984) for the population residing in the area infested by annual ragweed and growth rates calculated using population data for the LGAs of Brisbane City, Logan City, Gold Coast City, Ipswich City (Part in Brisbane Statistical Division), Beaudesert Shire and Redland Shire. While annual ragweed infestations occurred in all these LGAs, they do not represent the entire area actually infested by annual ragweed and, as such, may underestimate the impact. Further, these estimates do not consider any potential increase to the area infested by annual ragweed that may have occurred if biocontrol had not successfully reduced plant populations and seed production.

Due to data limitations, productivity benefits in terms of increased availability of pasture land were not included. Although this impact is believed to be minimal, its exclusion will underestimate the benefits of the biocontrol program.

5.6 Summary

The annual ragweed biocontrol program has resulted in the release of four biological control agents, with two becoming established. The program is estimated to have cost a total of $625,000, resulting in a NPV of $52.0 million and a BCR of 103.7 at a discount rate of 8.0%. This is considered to be an underestimate of the benefits, as the analysis does not include productivity increases from removal of annual ragweed in pastures.

Table 5.3. Summary of program benefits / costs

Type of benefit	Benefit / Cost	Detail
Production	Increased productivity	Small but unquantified increase in productivity due to increased availability of pasture land.
Social	Reduction in respiratory ailments	Reduced respiratory ailments costing approximately $23.85 per sufferer induced by the weed per annum. With a reduction of approximately 350,000 people suffering from hay-fever as a result of biocontrol in 2005, this equates to an estimated health benefit of approximately $8.4M in 2004/05 dollar terms.

6. *Asparagus asparagoides* (bridal creeper)

6.1 References

K. Batchelor, CSIRO Division of Entomology, *pers. comm.*, 2005

Kularatne, D., Holland-Clift, H., Kwong, R. and Morfe, T.A. (2005)

L. Morin, CSIRO Division of Entomology, *pers. comm.*, 2005

R. Kwong, Victorian Department of Primary Industries, *pers. comm.*, 2005

Reserve Bank of Australia (2005)

6.2 Background and biology

Asparagus asparagoides (bridal creeper) is a climbing vine that can grow to three metres high with numerous annual branching stems from perennial rhizomes that have many water-bearing tubers attached.

Bridal creeper grows in open woodlands and in coastal vegetation in warm-temperate regions. It prefers fertile, well-drained alkaline soils of light texture, and tolerates heavy shade, frosts and drought. Bridal creeper is also able to invade previously undisturbed areas.

6.3 Establishment and impact

First recorded as naturalised in Victoria in 1886, bridal creeper is now found throughout the State. Bridal creeper is also found along the River Murray, in the Yorke and Eyre Peninsulas and Kangaroo Island in SA, in coastal and irrigated areas of NSW, in the Toowoomba region in Qld and in southwest WA where it is most common in coastal regions.

Bridal creeper is continuing to spread and to increase its density in areas where it is already established. Bridal creeper can produce greater than 1,000 berries/square metre with these seeds dispersed by birds, rabbits and foxes.

Bridal creeper competes strongly with native vegetation, forming dense mats of tubers and rhizomes beneath the soil surface and developing into a canopy over plants to about three metres high. When actively growing at least 87% of the live plant weight is below ground. It is a major threat to native plant communities and biodiversity, including some endangered plant species.

Whilst predominantly an environmental weed, bridal creeper also has a production impact in orchards and pine plantations where it smothers and weakens trees and interferes with harvesting. It poses a significant threat to the Murray Valley citrus industry where, without any form of control, it would be expected to spread to the entire region.

Bridal creeper is susceptible to grazing by stock and does not persist in pastures or in cropping situations.

6.4 Biological control program

The biological control resulted in the release of three natural enemies for bridal creeper:

- *Zygina* sp.: a leafhopper released in 1999 is established and can cause defoliation in severe cases and reduces plant vigour;
- *Puccinia myrsiphylli*: a rust fungus was released in 2000 and attacks leaves and stems. Between the leafhopper and the rust fungus there is reduced photosynthesis, defoliation and reduced tuber formation. They are making a significant contribution towards reducing spread to new areas and density of existing populations; and
- *Criocerus* sp.: a leaf beetle was released in 2002 and strips new shoots and existing leaves. Establishment is confirmed at a few sites in Western Australia but it is too soon to fully evaluate the impact of the leaf beetle.

The control of bridal creeper is considered to be one of the more successful biological control programs in Australia, providing significant environmental benefits.

6.4.1 Development cost

The bridal creeper biocontrol program cost an estimated $7.3 million over a 15 year period between 1990 and 2004.

6.5 Cost benefit analysis

This analysis is considered to under-represent the total benefits of the biocontrol program as it focuses on production benefits, while bridal creeper is predominantly an environmental weed (see **Section 6.5.5**).

6.5.1 Data inputs

Spread of biocontrol agents

It is estimated that biocontrol agents will take 27 years to spread to the entire Murray Valley citrus region.

Spread of bridal creeper

Bridal creeper was estimated to cover 289 hectares of the Murray Valley citrus region in 2002. This analysis has utilised the most conservative rate of spread of bridal creeper identified by Kularatne *et al.* (2005) of 10% per annum without biocontrol.

Cost savings

The cost saving related to reduced chemical control is estimated to be approximately $1,600 per hectare, based on data provided in the report by Kularatne *et al.* (2005).

Release and maintenance costs of biocontrol

The release and maintenance costs of biocontrol are estimated to be:

- $70,600 in 2002;
- $83,100 in 2003;
- $54,600 in 2004;
- $123,800 in 2005 to 2008; and
- $33,200 thereafter.

These costs are based on 80 release sites as per cost data from Kularatne *et al.* (2005).

6.5.2 Model

A CBA model was used in this analysis as described in Section I. The analysis examined the benefits and costs that accrue due to replacement of pre-research control of bridal creeper with biocontrol in the Murray Valley citrus region. The net impact was identified by comparing the benefits and costs of the previous control with the benefits and costs since biocontrol. The net benefit of the program is estimated by the equation below:

$$NB = CS - CB - RC$$

Where:

NB = The net benefit from the biocontrol of bridal creeper program ($)

CS = The cost savings to the Murray Valley citrus industry following adoption of biocontrol measures ($)

CB = The cost of implementing biocontrol ($)

RC = The cost of research ($)

The cost savings to the Murray Valley Citrus industry following adoption of biocontrol is calculated using the equation below:

$$CS = \sum_{n=50}^{1} BS_n \times CC$$

Where:

BS = The spread of biocontrol agents in the orchard area of the Murray Valley citrus industry (ha)

CC = The cost of control prior to research ($/ha)

n = Year

The cost of implementing biocontrol is estimated as per the equation below:

$$CB = \sum_{n=50}^{1} BRM_n$$

Where:

BRM = The cost of release and maintenance of biocontrol agents in the Murray Valley region in year *n* ($)

The cost of undertaking the research is calculated using the equation below:

$$RC = \sum_{n=50}^{1} CR_n \times CI_n$$

Where:

CR = The research costs incurred in year *n* ($)

CI = An index for inflation to convert research costs to 2004/05 dollars

6.5.3 Results

The analysis examined the benefits to the Murray Valley citrus industry in terms of control cost savings following the release of biocontrol agents. The results of the analysis are presented in **Table 6.1**. The biocontrol program provides a positive return on investment at all discount rates, with a NPV of $4.2 million and a BCR of 2.0 at a discount rate of 8.0%.

Table 6.1. Results of analysis

Real discount rate	NPV ($ million)	BCR
4.0%	$26.8	5.6
6.0%	$11.2	3.3
8.0%	$4.2	2.0
10.0%	$0.9	1.3

6.5.4 Sensitivity

Spread of bridal creeper

The breakeven value with respect to the spread of bridal creeper ranges from 1.5% per annum (4% discount rate) to 8.4% per annum (10% discount rate), *ceteris paribus*. The analysis used the conservative 10% (low) rate of spread identified in Kularatne *et al.* (2005), which is greater than the rate of spread required to breakeven at a 10% discount rate.

Cost savings

The breakeven value with respect to the cost savings from biocontrol ranges from $280/ha (4% discount rate) to $1,230/ha (10% discount rate), *ceteris paribus*. The estimated cost of control prior to biocontrol is approximately $1,600/ha, which is greater than the $1,230/ha breakeven value at a 10% discount rate. Whilst this variable can significantly alter the value of the biocontrol program it does not impact on the finding that the bridal creeper biocontrol program was desirable.

6.5.5 Limitations of the analysis

Bridal creeper is predominantly an environmental weed and mainly affects roadsides, wooded remnant vegetation and National Parks. There is no quantified information available regarding the ecological impact of the weed or of the costs of mechanical and chemical control of the weed in these areas. As such the benefits of the biocontrol program are expected to be significantly underestimated, with biocontrol also expected to have provided benefits such as:

- Improved environmental outcomes such as greater biodiversity and survival of native plants and fauna dependent on these;
- A reduction in chemical spraying in environmental areas, while believed to be small, would result in a reduction in toxicity, improved environmental health and reduced non-targeted impacts to plants and animals; and
- The reduced coverage of bridal creeper in infested areas and prevention of further spread provides a social benefit in terms of improved aesthetic value of land.

Quantification of these benefits would increase the NPV and BCR of the bridal creeper biocontrol program.

6.6 Summary

The bridal creeper biological control program has resulted in the release of three biocontrol agents, all of which have established in at least some sites. The program is estimated to have cost a total of $7.3 million, resulting in a NPV of $4.2 million and a BCR of 2.0 at a discount rate of 8.0%. This is considered to be a significant underestimate of the benefits, as the analysis does not include any environmental benefits or reduced cost of control in areas other than the Murray Valley citrus industry.

Table 6.2. Sensitivity analysis

Variable	Units	Base case	Breakeven point at 4% discount rate [(a)]	Breakeven point at 10% discount rate [(a)]
Spread of bridal creeper	%	10%	1.5%	8.4%
Cost savings	$/ha	$1,600	$280	$1,230

Note: [(a)] The breakeven value is the value of the input where the NPV for the specified discount rate equals 0.

Table 6.3. Summary of program benefits / costs

Type of benefit	Benefit / Cost	Detail
Economic	Cost savings from reduced chemical control	The Murray Valley citrus industry is estimated to save approximately $1,600/ha in control costs. It is expected that bridal creeper would have infested the entire Murray Valley citrus growing area (6,729 ha) by 2036 without biocontrol, resulting in an annual cost saving of $10.7M per annum from 2036 onwards.
	Biocontrol release and maintenance costs	The release of biocontrol agents to sites in the Murray Valley citrus region will incur a cost of approximately $580,000 over the period between 2002 and 2007. Maintenance of biocontrol agents is expected to have an ongoing cost of approximately $33,200 per annum.
Environmental	Reduced spread and coverage of bridal creeper	Non-productive land such as wooded remnant vegetation, National Parks and roadsides receive the environmental benefits of: • Reduced risk of native plants being out-competed; and • Improved biodiversity.
	Reduced chemical toxicity	Reduced toxicity improves environmental health and reduces impacts to non-targeted plants and animals.
Social	Improved aesthetic, cultural value of land	Additional non-quantifiable social benefits providing use and non-use values for the wider community.

7. *Baccharis halimifolia* (groundsel bush)

7.1 References

W.A. Palmer, Queensland Department of Natural Resources and Mines, *pers. comm.*, 2005

McFadyen, P.J. (1978)

R. McFadyen, Weeds CRC, *pers. comm.*, 2005

Reserve Bank of Australia (2005)

Tutt, H.S. and Douglas, N.J. (1964)

7.2 Background and biology

Baccharis halimifolia (groundsel bush) is a densely-branched shrub to three metres high. Male and female flowers are borne on separate plants. Groundsel bush grows in disturbed open areas in humid warm-temperate to subtropical regions and thrives in saline semi-tidal areas and low coastal swamps.

7.3 Establishment and impact

Groundsel bush was introduced to Queensland in the latter half of the 1800s, and by 1937 was spreading rapidly in Queensland. It was first identified in NSW in 1941. It continues to spread in northeast NSW and southeast Queensland. The most serious infestation was recorded 50–150 kilometres north of Brisbane covering 13,000 hectares of Maroochy Shire. In 1978 groundsel bush was estimated to occur over a total area of approximately three million hectares.

Individual plants can produce up to approximately 1.5 million seeds and seeds can remain dormant in soil for several years. Groundsel bush can also produce some viable seeds in very dense shade.

Groundsel bush rapidly invades disturbed areas, especially overgrazed pastures. It forms dense impenetrable thickets 2–3 metres high and has the following production impacts:

- Restriction of stock and machinery movement;
- Reduced productivity by crowding out pastures; and
- Suspected of poisoning cattle and being toxic to sheep and chickens.

As an environmental weed groundsel bush forms a dense understorey in native *Melaleuca* wetlands, in coastal woodlands, along watercourses and in forest areas.

Groundsel bush is a nuisance in urban areas where wind-dispersed seeds stick in insect screens. It can also cause allergies.

The cost of control in Queensland was estimated at $500,000 in 1971, and greater than $1 million in 1977. In 1990 there was a preliminary economic assessment of groundsel bush in Caboolture Shire only, concluding a social net loss of greater than $800,000.

7.4 Biological control program

Biocontrol is achieving some control. The biological control program began in 1967 and although more than 35 insect species were tested only six insects and one pathogen were established in the field.

7.4.1 Development cost

The groundsel bush biocontrol program began in 1961 with a 12 week survey, and intensive research was conducted from 1967 to 1998. In total the groundsel bush biocontrol program is estimated to have cost $9.6 million.

7.5 Cost benefit analysis

7.5.1 Data inputs

Cost of chemical control

The Queensland Government is estimated to have been spending approximately $4.2 million per annum on control of groundsel bush in 1977.

Distribution of biocontrol

The distribution of biocontrol is unclear. In this analysis it is estimated to have taken 25 years to reach its equilibrium effectiveness level and that biocontrol is 20% effective at maximum distribution. This is probably a severe underestimation, but in the absence of quantified information, a conservative value has been used.

7.5.2 Model

A CBA model was used in this analysis as described in Section I. The analysis examined the benefits and costs that accrue due to replacement of pre-research control of groundsel bush with biocontrol. The net impact was identified by comparing the benefits and costs of the previous control with the benefits and costs since biocontrol. The net benefit of the program is estimated by the equation below:

$$NB = CS - RC$$

Where:

NB = The net benefit from the biocontrol of groundsel bush program ($)

CS = The cost savings to the Queensland Government following adoption of biocontrol measures ($)

RC = The cost of research ($)

The cost savings to the Queensland Government following adoption of biocontrol is calculated using the equation below:

$$CS = \sum_{n=50}^{1} CG \times D_n$$

Where:

CG = The annual cost to the Queensland Government for groundsel bush control prior to biocontrol ($/annum)

D = The distribution of biocontrol (%)

n = Year

The cost of undertaking the research is calculated using the equation below:

$$RC = \sum_{n=50}^{1} CR_n \times CI_n$$

Where:

CR = The research costs incurred in year *n* ($)

CI = An index for inflation to convert research costs to 2004/05 dollars

7.5.3 Results

The analysis examined the benefits to the Queensland Government in terms of control cost savings following the release of biocontrol agents. The results of the analysis are presented in **Table 7.1**. The biocontrol program provides a positive return on investment at discount rates below 5.4% but a negative return on investment above 5.5%, with a NPV of -$0.9 million and a BCR of 0.7 at a discount rate of 8.0%.

Table 7.1. Results of analysis

Real discount rate	NPV ($ million)	BCR
4.0%	$1.4	1.3
6.0%	-$0.3	0.9
8.0%	-$0.9	0.7
10.0%	-$1.1	0.5

7.5.4 Sensitivity

Biocontrol of groundsel bush is believed to be achieving some control, although the degree of control is unknown. **Table 7.2** outlines the expected NPV and BCR at an 8.0% discount rate over a range of control efficacies between 5% and 50%. The breakeven maximum distribution for biocontrol of groundsel bush is 28.8%. This is a significant level of control required for this program to breakeven and as such this variable is considered to be critical to the analysis.

Table 7.2. NPV and BCR of groundsel bush at 8% discount rate, distribution range 5–50%

Distribution	NPV ($ million)	BCR
5%	-$2.5	0.2
10%	-$2.0	0.3
15%	-$1.5	0.5
20%	-$0.9	0.7
25%	-$0.4	0.9
30%	$0.1	1.0
40%	$1.2	1.4
50%	$2.3	1.7

7.5.5 Limitations of the analysis

The degree of control that biocontrol is achieving on groundsel bush is unknown, which limits the capacity of the analysis to identify the actual benefit of the program.

This analysis only applies the benefits from reduced costs of control. It is expected that biocontrol also provides the following, unquantified benefits:

- Improved stock and machinery movement, through reduced vigour and spread of groundsel bush;
- Reduced production losses through reduced toxicity to stock and greater land availability;
- Reduced health problems.

Quantification of these benefits would result in an increase in the NPV and BCR of the biocontrol program.

7.6 Summary

The groundsel bush biocontrol program resulted in the testing of 35 insect species, with six insects and one pathogen becoming established. The program is estimated to have cost a total of $9.6 million, resulting in an estimated NPV of -$1.0 and BCR of 0.7 at a discount rate of 8.0%.

Table 7.3. Summary of program benefits / costs

Type of benefit	Benefit / Cost	Detail
Economic	Reduced cost of chemical control	While the level of control that biocontrol has achieved is uncertain, it is believed that there has been a positive impact which provides a benefit in terms of reduced need for chemical control. The breakeven maximum distribution for biocontrol of groundsel bush is 28.8%.
	Improved stock and machinery movement	Reduced vigour and spread of the weed, improving stock and machinery movement.
	Reduced production losses	Reduced toxicity to cattle, sheep and chickens, and increased pasture availability.
Social	Health benefit	Fewer groundsel bush-related allergies.

8. *Carduus nutans* (nodding thistle)

8.1 References

Sindel, B.M. (1991)

Swirepik, A. and Smyth, M. (2002)

Woodburn, T.L. and Briese, D.T. (1996)

Young, R. and Woodburn, T. (2002)

8.2 Background and biology

Carduus nutans (nodding thistle) is a biennial prickly herb, growing a prostrate rosette of leaves in its first year and flowers and seeds on erect prickly stems in the second year. Rosette diameter can be greater than one metre with stems to two metres high.

Nodding thistle grows in open situations in temperate regions, where it prefers soils of moderate to high fertility and an annual rainfall of approximately 500–900 millimetres.

8.3 Establishment and impact

Nodding thistle was first recorded in the central tableland of NSW in 1950 and was probably transported in contaminated seed from New Zealand. It is mainly a problem in NSW where it is an important weed of improved pastures. By 1996 it infested 1.1 million hectares of improved pastures in NSW. In Victoria, Tasmania, South Australia and Western Australia it has been confined to isolated scattered colonies.

Further potential distribution areas include southeast Queensland, southwest Victoria, the Adelaide Hills, and southwest Western Australia.

Fecundity in Australia is between 285 to 5,578 seeds/plant, or up to 32,500 seeds/square metre. Seed longevity in the field (based on seedling emergence) is approximately 7–13 years. Measured seed banks in Australia range between 3,000–13,000 seeds/square metre.

Mortality of seedlings and rosettes is usually high and as such establishment is relatively rare in dense native perennial pasture. However, nodding thistle readily invades fertile pastures of introduced annuals, particularly where the ground has been disturbed.

The impact of nodding thistle upon the pastoral industry has not been quantified. It grows in dense patches (approximately 10 mature plants/square metre), competes with pasture plants for resources and is not readily grazed because of its spiny leaves. It reduces access to useful fodder by stock and seriously reduces carrying capacity. Spiny heads also contribute to vegetable fault in wool with dense patches often harbouring pest animals. It can also cause physical injury to stock.

Proliferation is encouraged by nitrogen enrichment under continuous heavy grazing. Sheep and cattle rarely eat foliage, but often consume seed heads, which may possibly aid dispersal. While nodding thistle is primarily a pasture pest it is also commonly found on roadsides, waste land, lucerne crops, hill country and grasslands. Nodding thistle is rarely found in cropping regions.

The root of the nodding thistle can be eaten as a vegetable and the flowers yield good honey.

8.4 Biological control program

The underlying philosophy of biological control for nodding thistle is to limit seed production. Because seed banks are large and long-lived, this is a long-term approach although the spread may also be reduced in the short term. Effective biocontrol can be expected to generate three categories of economic benefits for graziers in the NSW Tablelands:

- Reduction in expenditure on chemical control;
- Reduced loss of production from pasture; and
- Improved wool quality due to reduction in vegetable fault.

There will also be environmental benefits as nodding thistle has allelopathic effects on beneficial species and can out-compete native plant species.

Rhinocyllus conicus thistle head weevil (released 1988) has not been effective as it is not well synchronised with flowering of the plant.

Urophora solstitialis seed fly (released 1991) and *Trichosirocalus mortadelo* (imported as *T. horridus*) rosette weevil (released 1993) are established in NSW and seed production has been reduced at some sites by greater than 70%. At two sites the soil seed bank has significantly declined from 9,500 seeds/square metre in 1989 to 397 seeds/square metre in 2001. Plant densities have also significantly declined. It is expected that heavy and medium levels of infestation will be eliminated by 2005.

8.4.1 Development cost

No research costs have been provided for nodding thistle, although Young and Woodburn (2002) estimate that the research costs of the biocontrol program, when converted to 2004/05 dollar terms, have a PV of $11.9 million between 1986 and 2000 (at a 5% discount rate).

8.5 Cost benefit analysis

Young and Woodburn (2002) estimate that the PV of benefits (when converted to 2004/05 dollar terms) from the nodding thistle biocontrol program is $81.3 million at a 5% discount rate. This equates to a NPV of $69.4 million and a BCR of 6.9.

These figures ignore benefits associated with improved wool quality resulting from reduced vegetable fault, and environmental benefits. Therefore the benefits identified are considered conservative estimates.

8.6 Summary

The nodding thistle biocontrol program resulted in the release of two biocontrol agents that have become established and effectively control infestations of the weed. Young and Woodburn (2002) estimate that, when expressed in 2004/05 dollar terms, the program cost $11.9 million (5% discount rate), resulting in a NPV of $69.4 and a BCR of 6.9.

Table 8.1. Summary of program benefits / costs

Type of benefit	Benefit / Cost	Detail
Economic	Increased productivity	The annual benefit from biocontrol in terms of increased productivity is estimated to be $8.8M, comprised of: • Increased carrying capacity of pasture; and • Improved wool quality (reduced vegetable fault).
	Control cost savings	Reduced control costs of approximately $2.7M per annum.
	Loss to honey industry	Nodding thistle flowers have some value to the honey industry. Reduced plant populations may have a negative impact on this industry, although it is likely to be small relative to the benefits.
Environmental	Increased biodiversity and environmental sustainability	Increased biodiversity and environmental sustainability: • Allelopathic effects on beneficial species; • Out-compete native plant species; and • Forms dense patches harbouring pest animals.
	Reduced chemical toxicity	Improved environmental health and reduced non-targeted impacts to plants and animals.

9. *Carduus pycnocephalus* and *Carduus tenuiflorus* (slender thistles)

9.1 References

Australian Bureau of Statistics (2005b)

Australian Bureau of Statistics (1998)

Bruzzese, E. and Cullen J.M. (1995)

D. Briese, CSIRO Division of Entomology, *pers. comm.*, 2005

R. Kwong, Victorian Department of Primary Industries, *pers. comm.*, 2005

Reserve Bank of Australia (2005)

Sindel, B.M. (1991)

Victorian Department of Sustainability and Environment

Woodburn, T.L. and Briese, D.T. (1996)

9.2 Background and biology

Carduus pycnocephalus and *Carduus tenuiflorus* (slender thistles) are upright prickly plants, unbranched or heavily branched and can grow to 1–2 metres high. They grow in warm temperate regions with winter rainfall and favour establishment on disturbed sites.

9.3 Establishment and impact

Slender thistles were established in South Australia in 1881 and Victoria in the 1880s. They now occur in all states except Northern Territory.

Slender thistles occur over approximately 8.25 million hectares in Victoria and are widely distributed in NSW and Tasmania. They are widespread but do not have a significant impact in Western Australia or Queensland.

Slender thistles are mainly weeds of pastures but, in higher rainfall areas, also impact crops. They are not grazed by stock due to prickles and discourage grazing of palatable plants in their vicinity, reducing pasture productivity. They may also be toxic to stock.

Early growth characteristics give them a competitive advantage over more desirable pasture plants with seeds remaining dormant for approximately 10 years.

Slender thistles have some value to the honey industry.

9.4 Biological control program

The rust fungus *Puccinia cardui-pycnocephali* has been in Australia for many years, but in 1993 two new strains were introduced and released. They are established and early results are promising.

Since 1995 there has been anecdotal evidence of reduced plant biomass, with fewer flowers and seeds produced. Research has shown that the rust can reduce plant size and flower production but, for most years, these reductions will be insufficient to permanently reduce thistle densities. The rust, however, may provide an additional negative impact on the weeds in their competition with pasture grasses.

9.4.1 Development cost

The slender thistle biocontrol program ran from 1987 to 1997 and is estimated to have cost a total of $2.1 million. The program was partly funded by the Australian Wool Industry.

9.5 Cost benefit analysis

9.5.1 Data inputs

Gross value of wool industry in Victoria

The gross value of the wool industry in Victoria was estimated to be $489.4 billion in 2003/04.

Land area used for sheep in Victoria

Approximately 2.46 million hectares of pasture land was used for sheep-rearing in Victoria in 1997.

Land area infested

Approximately 36% of Victoria's total land area is infested with slender thistle. This proportion has been applied as a conservative estimate to the sheep industry to estimate the area of land used for sheep-rearing that is infested, as slender thistles are predominantly a weed of grazing pastures.

Distribution of biocontrol

Biocontrol is estimated to reduce the impact of slender thistle by approximately 2.5%. It is assumed that the efficacy of biocontrol has built up gradually to its current level since the first release in 1993.

9.5.2 Model

A CBA model was used in this analysis as described in Section I. The analysis examined the benefits and costs that accrue due to replacement of pre-research control of slender thistle with biocontrol. The net impact was identified by comparing the benefits and costs of the previous control with the benefits and costs since biocontrol. The net benefit of the program is estimated by the equation below:

$$NB = WI - RC$$

Where:

NB = The net benefit from the biocontrol of slender thistle program ($)

WI = The savings to the wool industry following adoption of biocontrol measures ($)

RC = The cost of research ($)

The savings to the wool industry following adoption of biocontrol is calculated using the equation below:

$$WI = \sum_{n=50}^{1} GV \times AI \times D_n$$

Where:

GV = The gross value of the Victorian wool industry per hectare of land used for sheep rearing ($/ha)

AI = The area of the sheep industry that is infested with slender thistle (ha)

D = The distribution of biocontrol (%)

n = Year

The cost of undertaking the research is calculated using the equation below:

$$RC = \sum_{n=50}^{1} CR_n \times CI_n$$

Where:

CR = The research costs incurred in year *n* ($)

CI = An index for inflation to convert research costs to 2004/05 dollars

9.5.3 Results

The analysis examined the benefits to the Victorian wool industry in terms of increased production following the release of biocontrol agents. The results of the analysis are presented in **Table 9.1**. The biocontrol program provides a positive return on investment at all discount rates, with a NPV of $20.9 million and a BCR of 14.1 at a discount rate of 8.0%.

Table 9.1. Results of analysis

Real discount rate	NPV ($ million)	BCR
4.0%	$53.4	30.7
6.0%	$32.7	20.4
8.0%	$20.9	14.1
10.0%	$13.8	10.1

9.5.4 Sensitivity

Distribution of biocontrol

The breakeven value with respect to the distribution of biocontrol ranges from 0.1% (4% discount rate) to 0.2% (10% discount rate), *ceteris paribus*. The distribution does not significantly alter the findings of the analysis.

Area infested

The breakeven value with respect to the area infested by slender thistles ranges from 1.2% (4% discount rate) to 3.6% (10% discount rate) of the land used by the wool industry in Victoria, *ceteris paribus*. This is significantly lower than the 36.3% of land infested used in this analysis. This variable does not significantly alter the findings of this analysis and, as such, is not considered to be a critical variable.

Table 9.2. Sensitivity analysis

Variable	Units	Base case	Breakeven point at 4% discount rate [(a)]	Breakeven point at 10% discount rate [(a)]
Distribution of biocontrol	%	2.5%	0.1%	0.2%
Area infested	%	36.3%	1.2%	3.6%

Note: [(a)] The breakeven value is the value of the input where the NPV for the specified discount rate equals 0.

9.5.5 Limitations of the analysis

While it is known that approximately 36.3% of Victoria is infested with slender thistle it is unknown to what extent land used for sheep is infested. It has been assumed in this analysis to be the same proportion as for Victoria as a whole (36.3%). Ideally, specific data on the loss to the wool industry from slender thistle would be known in order to determine the benefits received by the industry from biocontrol. Also, due to data limitations, infested land in NSW has not been included in the analysis.

This analysis only examined the losses to the wool industry. While the wool industry is considered to be the industry most severely affected by slender thistle infestations, other grazing enterprises are also affected. The benefits to these enterprises has not been included due to data limitations and, as such, the benefits identified in this analysis are considered an underestimate.

9.6 Summary

The slender thistle biocontrol program has resulted in the release of one agent which has become established. The program is estimated to have cost a total of $2.1 million, resulting in a NPV of $20.9 million and a BCR of 14.1 at a discount rate of 8.0%.

Table 9.3. Summary of program benefits / costs

Type of benefit	Benefit / Cost	Detail
Economic	Improved productivity	Biocontrol is estimated to reduce production losses in Victoria by approximately $4.4M per annum through the following channels: • Increased carrying capacity of land; • Improved stock access to useful fodder; • Reduced vegetable fault in wool; • Reduced physical injury to stock; and • Reduced toxicity to stock.
	Loss to honey industry	Reduced plant populations may have a negative impact on the honey industry, although it is likely to be small relative to the benefits of the biocontrol program.

10. *Chondrilla juncea* (skeleton weed)

10.1 References

CSIRO (1987)

Cullen, J.M. (1978)

Cullen, J.M. (1984)

Hanley, M.E. and Groves, R.H. (2002)

Marsden, J.S., Martin, G.E., Parham, D.J., Ridsdill Smith, T.J. and Johnston, B.J. (1980)

Scott, P. and Dodd, J. (1996)

10.2 Background and biology

Chondrilla juncea (skeleton weed) is a relatively long-lived perennial rosette-forming plant. It occurs over a wide range of climatic conditions but prefers semi-arid Mediterranean climates. It is able to establish on a wide range of soil types while preferring well-drained sandy soils with deep profiles for taproot development.

10.3 Establishment and impact

Skeleton weed was accidentally introduced to Australia some time before 1918. The rate of spread through wheat growing regions of southeast Australia was approximately 24 kilometres/year between 1920 and 1960 and it appears to have reached the limits of its distribution in southeast Australia. Skeleton weed is found through virtually the entire cereal growing area of NSW and Victoria and is still spreading in South Australia and Western Australia.

Skeleton weed is a prolific seed producer with approximately 70,000 seeds/square metre produced in a dense infestation. Seed survival is very short-term, approximately six months, and there is no seed accumulation over time. Extremely high plant densities (approximately 500 plants/square metre) can be found under favourable conditions.

Skeleton weed is a weed of cultivation and open disturbed areas. Prior to biocontrol, it was often found as dense stands in cultivated paddocks, and formed tall, dense thickets on roadsides and overgrazed pastures. It was also a problem in some vineyards, citrus orchards and crops.

Native vegetation is rarely affected, however in the absence of biocontrol it is highly competitive with cereals and crops, seriously reducing yields by up to 50% in wet years and up to 80% in dry years. The tall wiry stems also provide an additional harvesting cost as they choke harvesting machinery.

During the 1930s skeleton weed caused cereal growing to be abandoned in many parts of the Riverina. It was widely recognised as the most serious weed of the Australian wheat growing regions. It reduces soil nitrogen, and competes for soil moisture. It causes choking and loss of condition in dairy cattle.

Skeleton weed is a palatable and nutritious sheep fodder in the rosette stage and during flowering, but must be continuously grazed to prevent bolting. It can also be beneficial for honey production.

The cost of the unsuccessful eradication campaign in Western Australia was $1.4 million in 1995/96.

10.4 Biological control program

The skeleton weed biocontrol program resulted in the release of four agents, three of which established.

Puccinia chondrillina rust fungus and *Aceria chondrillae* gall mite caused a reduction in the spread of the narrow-leaf form and greatly reduced its impact in crops. By 1975 there were annual savings to farmers of approximately $18 million and by 2000 the saving is estimated to have been approximately $290 million. However, in some areas the narrow-leaf form of skeleton weed can be replaced by broad-leaf forms, which have increased their distributions and abundances in response to reduced competition from the narrow-leaf form. A new strain of the rust fungus may be effective in reducing the biomass of intermediate-leaved plants, but it is too early to identify this conclusively. Nevertheless, by 2005 skeleton weed is no longer considered a serious weed in cropping areas of southeast Australia, and this is one of the most successful biocontrol programs of a weed of broadacre crops.

10.4.1 Development cost

Marsden *et al.* (1980) state that CSIRO spent a total of $2.3 million in research on biocontrol of skeleton weed (10% discount rate, in 1975 dollar terms). In 2004/05 dollar terms this equates to a total cost of approximately $12.7 million.

10.5 Cost benefit analysis

Marsden *et al.* (1980) estimated that biocontrol of skeleton weed would provide a benefit, expressed in 2004/05 dollar terms, of $1,425.5 million over the length of the analysis[5] at a 10% discount rate. The NPV for skeleton weed biocontrol is estimated to be approximately $1,412.8 million for the biocontrol project, while the BCR is estimated to be 112.1 at a 10% discount rate (192.2 at a 5% discount rate) and the IRR is estimated to be 141.0%.

It is noted by Cullen (1984) that these benefits could be inflated as the actual effectiveness of biocontrol was less than the level of effectiveness predicted by Marsden *et al.* in their *ex ante* analysis due to the potential replacement of the narrow-leaf form with broad-leaf forms. Even so, Cullen suggests that biocontrol was very effective in reducing the problem caused by skeleton weed and that the accumulated benefits were sufficiently large to make the difference between the actual level of effectiveness and the level of effectiveness predicted by Marsden *et al.* insignificant. This is supported by anecdotal evidence that skeleton weed is no longer a major weed of cropping areas in southeast Australia, suggesting that the level of effectiveness of biocontrol is not significantly different from the level predicted by Marsden *et al*.

10.6 Summary

The skeleton weed biocontrol program resulted in the release of four agents, three of which have become established. Marsden *et al.* (1980) estimate the cost of the program, when converted to 2004/05 dollar terms, to be $12.7 million (10% discount rate), resulting in a NPV of $1,412.8 million and a BCR of 112.1.

Table 10.1. Summary of program benefits / costs

Type of benefit	Benefit / Cost	Detail
Economic	Increased productivity	The benefits of increased wheat yield from biocontrol are estimated to be approximately $70M/annum (in 2004/05 dollar terms). Other production benefits include: • Reduced harvesting cost; • Increased soil nitrogen; • Increased soil moisture uptake; • Improved condition of dairy cattle; and • Reduction in management and machinery problems in vineyards and citrus orchards.
	Control cost savings	Control cost saving of approximately $10.5M/annum (in 2004/05 dollar terms).
	Loss to honey industry	Reduced plant populations may have a negative impact on the honey industry, although it is likely to be small relative to the benefits of the biocontrol program.

[5] The Marsden *et al.* (1980) analysis is for the period from 1960 to 2000, and includes a stream of benefits from 1972 to 2000.

11. *Chrysanthemoides monilifera* subspecies (boneseed/bitou bush)

11.1 References

CIE (2001)

J. Ireson, Tasmanian Institute of Agricultural Research, *pers. comm.*, 2005

R. Holtkamp, NSW Department of Primary Industries, *pers. comm.*, 2005

R. Kwong, Victorian Department of Primary Industries, *pers. comm.*, 2005

11.2 Background and biology

Chrysanthemoides monilifera subspecies (boneseed/bitou bush) are erect or sprawling perennial woody shrubs 1–3 metres in height. They occur in temperate and sub-tropical climates, and prefer sandy or medium-textured soils in disturbed places, often near the coast. They are tolerant to saline conditions.

11.3 Establishment and impact

Chrysanthemoides monilifera was first grown in Australia in the 1850s and was naturalised by 1910. It was planted for sand stabilisation along the New South Wales coast from 1946–1968 and now forms almost pure stands in coastal areas.

Subspecies *rotundata* (bitou bush) occurs on coastal areas. By 1982 it infested 660 kilometres (60%) of the NSW coast including many National Parks and Reserves, and was the dominant species along a 220 kilometre stretch.

Subspecies *monilifera* (boneseed) is widespread and severe in Victoria. In 1981 boneseed covered approximately 72,000 hectares of Victoria with scattered plants, 3,000 hectares of moderate infestation and 3,000 hectares with dense cover. Boneseed is also found in the Mount Lofty Ranges in South Australia and the north and east coast of Tasmania.

Boneseed/bitou bush has the potential to spread much more widely. Most of southern Australia, including Tasmania, is under threat. Virtually all of Victoria is a suitable habitat.

It has a rapid growth rate and enormous seed production (up to 50,000 seeds/plant) and soil seed banks (800–2,500 seeds/square metre for boneseed, 2,000–5,000 seeds/square metre for bitou bush). Seeds are dispersed by birds, foxes, rabbits and cattle and can remain dormant for more than 10 years.

Boneseed/bitou bush does not affect agriculture as it is rarely found in pasture. However, it establishes readily in native vegetation communities, out-competing and eliminating native species, and is considered a threat to some rare native plants, ecological communities and other significant areas, including World Heritage areas. It forms dense stands that affect the habitat of native fauna, replaces important nectar and pollen species for apiarists, and responds quickly after fire. It also creates a favourable environment for other highly invasive weeds.

It is sometimes grown for sand stabilisation and as a garden ornamental.

11.4 Biological control program

Comostolopsis germana tip moth was released in 1989 and targets stem tips of bitou bush, destroying developing leaves, buds and flowers and reducing seed production. It is now widely established in the field but suffers from heavy predation and parasitism at some sites. The *Mesoclanis polana* seed fly (released in 1997) is also widely established and is having a significant impact on seed production and reducing plant vigour of bitou bush.

The *Tortrix* sp. leaf-rolling moth was first released in 2001 and is established on bitou bush in NSW, but it is too early to determine its effectiveness. The leaf rolling moth is very damaging in its native range but has suffered high predation in Australia and failed to establish on boneseed.

The cost of biocontrol in Tasmania has averaged approximately $30,000/annum since 1991. No agents have become established in Tasmania.

11.4.1 Development cost

The boneseed/bitou bush biocontrol program began in 1990 and is ongoing. It is estimated to have cost a total of approximately $7.1 million in 2004/05 dollar terms.

11.5 Cost benefit analysis

CIE (2001) conducted an *ex ante* CBA on bitou bush biocontrol over a 40 year period between 1990 and 2030. The analysis indicated that the program, if successful, would provide in PV terms (at a 5% discount rate and expressed in 2004/05 dollar terms) a saving in control costs of $7.2 million, an increase in amenity worth $4.4 million and an increase in biodiversity worth $41.5 million (which equates to a total benefit of $53.0 million from the biocontrol program).

Anecdotal evidence indicates that the bitou bush biocontrol program has achieved about 5% of the impact projected by CIE. This equates to a total benefit in PV terms of approximately $2.7 million. The PV of research costs at a 5% discount rate (expressed in 2004/05 dollar terms) is approximately $5.1 million, resulting in a NPV of -$2.5 million and a BCR of 0.5.

11.6 Summary

The boneseed/bitou bush biocontrol program has resulted in the release of seven agents, with three becoming established. The program is estimated, once converted to 2004/05 dollar terms, to have cost a total of $7.1 million, resulting in a NPV of -$2.5 million and a BCR of 0.5 at a 5% discount rate.

Table 11.1. Summary of program benefits / costs

Type of benefit	Benefit / Cost	Detail
Economic	Control cost saving	Control cost savings, with chemical control costs ranging from $120–$200/hectare, worth approximately $0.4 million (at 5% discount rate in 2004/05 dollar terms) between 1990 and 2030.
Environmental	Increased biodiversity	Increased biodiversity worth approximately $2.1 million (at a 5% discount rate in 2004/05 dollar terms) between 1990 and 2030.
Social	Increased amenity	Amenity values worth approximately $0.2 million (at a 5% discount rate in 2004/05 dollar terms) between 1990 and 2030 from enhanced access to coastal areas and improved aesthetics of these areas.

12. *Cryptostegia grandiflora* (rubber vine)

12.1 References

Chippendale, J.F. (1991)

Franco-Dixon, M. (2003)

Mackey, A.P. (1999)

Reserve Bank of Australia (2005)

Tomley, A.J. and Evans, H.C. (2004)

Vogler, W. and Lindsay, A. (2002)

12.2 Background and biology

Cryptostegia grandiflora (rubber vine) is a scrambling sub-shrub. It is a vigorous climber which can grow unsupported as an untidy, many-branched shrub to approximately two metres in height and is known to have grown to 30 metres as a climber in trees.

Rubber vine grows in semi-arid tropics along watercourses amongst low shrubs, open areas and edges of forests. Rubber vine is intolerant of shade, but tolerant of a wide range of soil types.

12.3 Establishment and impact

Rubber vine was introduced to Queensland in the 1860s and by 1944 had infested 1,200 hectares. It now occurs along much of the Queensland coast extending into the Gulf, and is a common component of riparian vegetation and floodplains.

By 1973 there were 120,000 hectares infested, increasing at the rate of 1%–3% per annum. In 1989 it was conservatively estimated that there were 600,000 hectares of dense infestations adjacent to rivers and creeks. In 1991 the area densely infested was estimated as approximately 700,000 hectares, with the weed present across 34 million hectares.

Potential distribution for rubber vine is approximately 32,000–160,000 square kilometres of reasonably dense infestation in northern Australia. Dense infestations have 2,000–5,000 plants/hectare. Individual plants can live for greater than 80 years. However, few seeds survive for more than one year in the soil.

Rubber vine has a number of impacts, it:

- Smothers tall trees and pastures;
- Forms impenetrable thickets along streams;
- Restricts access to water;
- Reduces grazing;
- Increases mustering problems;
- Is toxic to cattle, goats, sheep, horses and humans but is quite unpalatable so it is rarely eaten; and
- Increases erosion due to decreased ground cover.

Dense infestations of rubber vine can reduce carrying capacity by almost 100%. The cost to the cattle industry in 1991 was estimated to be greater than $8 million and by 2001 the cost was estimated to be approximately $18.3 million.

Rubber vine seriously damages native plant communities, especially gallery forests and dry rain forests. It poses a threat to four vulnerable animal species, 13 threatened plant communities, one Ramsar site, 13 important wetlands and 48 Reserves in Queensland. It also harbours feral animals such as pigs.

The weed can be used to produce commercial quality rubber but this is uneconomic to harvest and extract.

12.4 Biological control program

The moth *Euclasta whalleyi* was released 1988–91 and the rust *Maravalia cryptostegiae* in 1995–97. They have both become widespread throughout all areas infested with rubber vine. The moth was initially effective in defoliating rubber vine, but parasitism has reduced its effect. It persists at low levels with occasional outbreaks. The rust has had a significant impact, but is less effective in dryer, western areas.

The rust is most effective when integrated with fire. Rust infection causes leaf drop, allows grass growth and decreases flowering and seeding. A fire in mid-spring in rust-infected plants killed 80% of plants, and follow-up one year later increased plant mortality to 99%.

Four years after the rust release very few seedlings were present amongst heavily-infested plants and rubber vine populations had decreased 25–65%. Pod numbers were reduced by 85%, above ground biomass by 74%, leaf cover by 73% and flower production by 48%. The rust also prevents re-colonisation and, subsequently, reduces its invasive ability.

Long-term monitoring sites were established in 1997. By 2001 there has been at least a 40% reduction in the number of live plants and stems/hectare and a reduction in seedling recruitment from 178/hectare in 1998 to approximately zero in 2001. Biocontrol provides the opportunity for the removal of existing infestations with little follow-up required, as subsequent seedling recruitment is minimal.

12.4.1 Development cost

The rubber vine biocontrol program is estimated to have cost a total of $3.6 million between 1984 and 2004.

12.5 Cost benefit analysis

Chippendale (1991) in an *ex ante* analysis estimated the benefits of a successful biocontrol program at between $295 million and $528 million. The following CBA is based on data used in the Chippendale analysis.

12.5.1 Data inputs

Costs of rubber vine

The costs of rubber vine, when converted to 2004/05 dollar terms, are outlined below:

- Cost of control prior to biocontrol is estimated to be $10.32/hectare;
- Cost from reduced carrying capacity is estimated to be $16.56/hectare;
- Increased mustering costs are estimated to be $4.81/hectare; and
- Cattle losses are estimated to be valued at $4.40/hectare.

Area infested

The area infested with rubber vine was estimated to be approximately 378,500 hectares in 1984. Without biocontrol rubber vine was predicted to spread at a rate of 6% per annum, while biocontrol, introduced in 1995, is estimated to reduce the level of infestation by 3% per annum.

12.5.2 Model

A CBA model was used in this analysis as described in Section I. The analysis examined the benefits and costs that accrue due to the release of biocontrol agents to control rubber vine. The net impact was identified by comparing the benefits and costs of the previous control with the benefits and costs since biocontrol. The net benefit of the program is estimated by the equation below:

$$NB = CS + CC + MC + LC - RC$$

Where:

NB = The net benefit from the biocontrol of rubber vine program ($)

CS = The control cost savings following adoption of biocontrol measures ($)

CC = The benefit from increased carrying capacity ($)

MC = The reduction in mustering costs ($)

LC = The reduction in cattle losses from rubber vine ($)

RC = The cost of research ($)

The control cost savings following adoption of biocontrol is calculated using the equation below:

$$CS = \sum_{n=50}^{1} CE \times \left(A_n^{WBC} - A_n^{BC}\right)$$

Where:

CE = The control expenses prior to biocontrol ($/ha)

A = The area infested with rubber vine in year *n* (ha)

WBC = Without biocontrol

BC = With biocontrol

n = Year

The benefit from increased carrying capacity is estimated using the following equation:

$$CC = \sum_{n=50}^{1} CRC \times \left(A_n^{WBC} - A_n^{BC}\right)$$

Where:

CRC = The cost of rubber vine from reduced carrying capacity ($/ha)

The reduction in mustering costs is estimated by the equation below:

$$MC = \sum_{n=50}^{1} IMC \times \left(A_n^{WBC} - A_n^{BC}\right)$$

IMC = The increase in mustering costs caused by rubber vine ($/ha)

The reduction in cattle losses is calculated using the following equation:

$$LC = \sum_{n=50}^{1} LCR \times \left(A_n^{WBC} - A_n^{BC}\right)$$

Where:

LCR = The loss of cattle due to rubber vine ($/ha)

The cost of undertaking the research is calculated using the equation below:

$$RC = \sum_{n=50}^{1} CR_n \times CI_n$$

Where:

CR = The research costs incurred in year *n* ($)

CI = An index for inflation to convert research costs to 2004/05 dollars

12.5.3 Results

The analysis examined the benefits from biocontrol in terms of reduced cost of control and increased productivity. The results of the analysis are presented in **Table 12.1**. The biocontrol program provides a positive return on investment at all discount rates, with a NPV of $232.5 million and a BCR of 108.8 at a discount rate of 8.0%.

Table 12.1. Results of analysis

Real discount rate	NPV ($ million)	BCR
4.0%	$833.8	307.8
6.0%	$430.2	179.5
8.0%	$232.5	108.8
10.0%	$131.3	68.6

12.5.4 Sensitivity

Distribution of biocontrol

The breakeven value with respect to the distribution of biocontrol[6] ranges from 0.2% (4% discount rate) to 0.7% (10% discount rate), *ceteris paribus*. This is significantly lower than the 9.3% estimated in this analysis based on historical data regarding the efficacy of biocontrol. As such this variable is not considered critical to the findings of the analysis.

12.5.5 Limitations of the analysis

The analysis does not include any environmental and social benefits of biocontrol due to data limitations surrounding these benefits. Environmental and social benefits of biocontrol include:

- Reduced threat to native plant communities, especially gallery forests and dry rain forests;
- Improved access to streams;
- Reduced erosion;
- Reduced toxicity from chemical control; and
- Reduced health risk from rubber vine, which is toxic to humans.

All of these benefits, if quantified, would result in an increase in the NPV and BCR of the rubber vine biocontrol program.

12.6 Summary

The rubber vine biocontrol program resulted in the release of two agents, both of which have become established. The program is estimated to have cost a total of $3.6 million, resulting in a NPV of $232.5 million and a BCR of 108.8 at a discount rate of 8.0%.

Table 12.2. Sensitivity analysis

Variable	Units	Base case	Breakeven point at 4% discount rate [(a)]	Breakeven point at 10% discount rate [(a)]
Distribution of biocontrol	%	9.3%	0.2%	0.7%

Note: [(a)] The breakeven value is the value of the input where the NPV for the specified discount rate equals 0.

[6] In this case the distribution of biocontrol refers to the difference in the growth rate of rubber vine pre and post biocontrol agent release.

Table 12.3. Summary of program benefits / costs

Type of benefit	Benefit / Cost	Detail
Economic	Control cost saving	Control cost saving of $10.32/ha, resulting in a benefit of $8.9M in 2005.
	Increased carrying capacity	The estimated carrying capacity increase from biocontrol was valued at $16.56/ha, resulting in a benefit of approximately $14.3M in 2005.
	Decreased mustering costs	Reduced mustering costs of $4.81/ha, resulting in an estimated benefit of $4.2M in 2005.
	Reduced loss of cattle	Reduced loss of cattle of $4.41/ha, resulting in a benefit of approximately $3.8M in 2005.
Environmental	Improved biodiversity and sustainability of natural environments	Biocontrol of rubber vine: • Reduces damage to native plant communities, especially gallery forests and dry rain forests; • Reduces smothering of tall trees and pastures; • Aids in the prevention of impenetrable thickets forming along streams; • Reduces erosion from decreased ground cover; and • Decreases the area available to harbour feral animals such as pigs. Rubber vine currently poses a threat to: • 4 vulnerable animal species; • 13 threatened plant communities; • 1 Ramsar site; • 13 important wetlands; and • 48 Reserves in Queensland.
	Reduced chemical toxicity	Improved environmental health and reduced impacts to non-targeted plants and animals.
Social	Reduced health risk to humans	Reduced potential for harm and health risks to humans.

13. *Echium plantagineum* (salvation Jane/Paterson's curse)

13.1 References

CIE (2001)

IAC (1985)

Nordblom, T.L., Smyth, M.J., Swirepik, A., Sheppard, A.W. and Briese, D.T. (2002a)

Nordblom, T.L., Smyth, M.J., Swirepik, A., Sheppard, A.W. and Briese, D.T. (2002b)

Swirepik, A. and Smyth, M. (2002)

13.2 Background and biology

Echium plantagineum (Paterson's curse) is a winter annual, initially growing as a rosette that later supports one to many erect flowering branches. It grows in warm-temperate regions with winter rainfall on a wide range of soil types.

13.3 Establishment and impact

Paterson's curse was first recorded in Sydney in 1843 and by 1900 was well established throughout southeast Australia. Paterson's curse now occurs as the dominant species across large areas of grazing land in southern Australia, however it is not as important in cropping areas. In northern South Australia it provides some value as sheep fodder.

In the early 1980s Paterson's curse infested approximately 918,000 hectares in Victoria, four million hectares in South Australia and 296,000 hectares in Western Australia, with these areas expected to have increased since then. Based on herbarium records Paterson's curse is also found over most of NSW and much of southeastern Queensland. Its range is currently close to its limit and further expansion is unlikely.

Paterson's curse out-competes other plants, especially under light grazing. It is grazed by sheep but displaces other more desirable species as well as other weeds. It is not generally grazed by cattle or horses and is poisonous to pigs and horses. It is also thought to cause hay-fever and rigid hairs on the plant cause skin irritation.

Paterson's curse is valued by apiarists and is of value as pasture in semi-arid country.

In 1985 it was estimated to cause an annual net loss of between $9 and $27 million in NSW, $2.3 million in Vic, and $2.3 million in SA. A report by the Industries Assistance Commission (1985) found that detrimental effects outweigh benefits by 10:1 and that potential benefits of biological control could be as high as $30 million/annum.

13.4 Biological control program

CSIRO began surveys for agents to control Paterson's curse in 1972.

Dialectica scalariella leaf-mining moth was first released in 1980 but failed to establish. In 1989 it was re-released and is now widely distributed but usually does not provide significant control. *Mogulones larvatus* crown weevil released in 1992 makes infested plants less vigorous and kills heavily-infested plants. It is the most effective in the absence of grazing. *M. larvatus* reduces plant survival by 43%, plant size of survivors by 58% and seed weight by 74%.

Mogulones geographicus root weevil was released in 1993 and *Longitarsus echii* flea beetle was released in 1995. Both are having a significant and increasing effect but no data has been collected to quantify the impact of these agents. The pollen beetle *Meligethes planiusculus*, first released in 1998, is widely established but its impact is unknown.

The use of biological control along with reasonable pasture management should greatly reduce the weed problem.

13.4.1 Development cost

Total research costs for the Paterson's curse biocontrol program have not been provided, although CIE (2001) estimate the PV of research costs (when converted to 2004/05 dollar terms) to be approximately $23.1 million between 1972 and 2000 (at a 5%).

13.5 Cost benefit analysis

CIE (2001) conducted an *ex ante* analysis on biocontrol of Paterson's curse and estimate that the NPV of projected benefits from biological control (using a 5% discount rate and counting the benefits out from 1972 to 2050), when converted to 2004/05 dollar terms, is approximately $1.2 billion, with a BCR of 52.0. The IRR over the period is approximately 22%. Anecdotal evidence indicates that the observed impact of biocontrol is similar to the impact projected by CIE in their analysis.

13.6 Summary

The Paterson's curse biocontrol program resulted in the release of seven agents, with five becoming established. When converted to 2004/05 dollar terms the program, including ongoing releases of the agents, was estimated to cost approximately $23.1 million (5% discount rate), resulting in a NPV of $1.2 billion and a BCR of 52.0 between 1972 and 2050.

Table 13.1. Summary of program benefits / costs

Type of benefit	Benefit / Cost	Detail
Economic	Increased productivity	Increased productivity by: • Increasing the carrying capacity of pasture; • Reducing the displacement of other, more desirable, species of pasture plants; • Reduced poisoning of stock; and • Reduced expenditure on chemical control. The estimated NPV of the biocontrol program, based on increased productivity, is approximately $1.2 billion (at a 5% discount rate) between 1972 and 2050.
	Loss to honey industry	Reduced plant populations may have a negative impact on the honey industry, although it is likely to be small relative to the benefits of the biocontrol program.
	Reduced fodder in semi-arid country	Paterson's curse has some value as pasture in semi-arid country. Biocontrol will have a negative impact in these areas by reducing pasture options.
Social	Health benefits	• Reduction in hay-fever; and • Reduced skin irritation.

14. *Emex australis* and *Emex spinosa* (spiny emex, three-corner jack and lesser jacks)

14.1 References

M. Julien, CSIRO Division of Entomology, *pers. comm.*, 2005

Shepherd, R.C.H. (1990)

14.2 Background and biology

Emex australis and *Emex spinosa* (spiny emex) are vigorous annual herbs with fleshy stems and strong taproot that forms a rosette at the early stages of growth. Normally prostrate, they may assume a semi-erect habit in dense pasture to less than 30 centimetres high.

They grow in semi-arid tropical, subtropical and temperate regions and prefer sandy or loamy soils.

14.3 Establishment and impact

First recorded in Western Australia in 1830, South Australia in approximately 1840, NSW and Victoria in approximately 1883 and in Queensland in 1911, they are now common in all agricultural areas of mainland States except in the tropics. They are a particular problem in northern and central wheatbelt of Western Australia, where greater than one million hectares of pasture and 500,000 hectares of cereal crops are infested.

They are important weeds throughout NSW and are still spreading. In Victoria and South Australia they are common along the Murray River irrigation area and some cereal areas, and in Queensland are economically significant in cereals and lucerne throughout the southeast region.

The predicted potential range of the weeds covers most of the southern half of the country (excluding inland desert and mountain ranges). They are mainly weeds of disturbed areas such as agricultural, horticultural and industrial areas and are serious weeds of the dried fruit industry through product contamination. They are rarely found in natural ecosystems or areas of conservation.

Infestations can be extremely dense, for example one infestation in Western Australia had greater than 900 plants and 5,000 seeds/square metre, and as such competed with cereal crops and pastures. Their prostrate growth smothers other species. Eleven plants/square metre can reduce wheat yield by 40%. They are not readily eaten by stock and impacts include:

- Stock poisoning;
- Discomfort from spines;
- Health problems for humans and animals, especially dogs; and
- Punctures in bicycle tyres.

In non-agricultural areas they are not an aggressive competitor and are mainly a nuisance due to their spiny fruit. Natural areas invaded include edges of creeks, riverine flats, alluvial flats and granite rocks, which are sites of biological diversity and refuge in Western Australia.

In 1980 agricultural production in Western Australia was estimated to have been reduced by greater than $20 million annually with crop losses of greater than $15/hectare and animal production losses approximately $13/hectare. In 1993 the annual loss from spiny emex in Western Australia were estimated to have increased to $40 million.

In Western Australia spiny emex has become a major source of food for Major Mitchell and inland red-tailed black cockatoos.

14.4 Biological control program

Perapion antiquum weevil, which can reduce the competitive ability of the plant and reduce seed production, was released in 1982, however it is not known to have established.

14.4.1 Development cost

The spiny emex biocontrol program ran for five years between 1974 and 1978 at an estimated total cost of approximately $2.0 million.

14.5 Cost benefit analysis

No CBA has been conducted as the biocontrol program is not believed to have provided any benefits.

14.6 Summary

The spiny emex biocontrol program resulted in the release of one agent, the *Perapion antiquum* weevil which did not establish. As such this program has delivered no benefits.

15. *Harrisia* spp. (harrisia cactus)

15.1 References

Armstrong, T.R. (1976)

McFadyen, R.E. (1986)

McFadyen, R.E. and Tomley, A.J. (1981)

R. McFadyen, Weeds CRC, *pers. comm.*, 2005

Reserve Bank of Australia (2005)

Walton, C. (2005)

15.2 Background and biology

Harrisia spp. (harrisia cactus) grows in subtropical, semi-arid scrublands and prefers deep fertile clays. It produces red, fleshy fruits and the seeds are dispersed by birds, pigs, cattle and people. Plants produce numerous large underground root storage tubers which make chemical control difficult. Harrisia cactus can form dense impenetrable thickets up to 1–2 metres high and covering 80–90% of the land area, which significantly reduces productivity. Harrisia cactus is not readily grazed due to spines and mature plants are highly drought-resistant.

15.3 Establishment and impact

Harrisia cactus was first introduced to Queensland between 1885–1890. It infests several widely scattered sites in Queensland and NSW and has been recorded in Western Australia.

Herbicide control operations began in 1951 and by 1958 several thousand acres of dense cactus growth had been treated with herbicides and reduced to light or relatively light regrowth at a cost of approximately £175,000.

In 1976 the cost of aerial or boom-spraying dense patches of harrisia cactus was $66–$80/hectare, and for spot spraying small patches from $15–$30/hectare. For boom-spraying and ploughing, prior mechanical clearing of woody plants was required at an additional cost of $8–30/hectare. In the 1970s, the Queensland Lands Department was spending greater than $500,000 per year treating the weed across 68,000 hectare in the Collinsville region. Individual holdings were also spending up to $60,000 per year on control. The maximum loss in productivity due to cactus infestations was the market value of the land where it was rendered unsuitable for agricultural production of any kind.

By 1978/79 the Queensland Government was spending up to $700,000 per annum on control, which resulted in a total expenditure between 1965 and 1980 of approximately $7 million. The total cost incurred from harrisia cactus between 1950 and 1982 was estimated in 1982 to be approximately $18.4 million, which in 2004/05 dollar terms represents a cost of $49.5 million.

15.4 Biological control program

The Queensland Government initiated a three-year biological control program in 1973.

Biological control has been highly successful. Other methods of control, chiefly herbicides, ceased after 1979 at a saving to the Government of at least $2.3 million/annum. There are also savings to individual landholdings of up to $200,000/annum.

Hypogeococcus festerianus mealybug (released 1975) established immediately and was very successful. In 1956 after herbicide treatment, there was regrowth of 140,000 plants/hectare. Following mealybug establishment this was reduced to 190 plants/hectare with a total stem length of 16 metres.

Harrisia cactus in north Queensland was costing the Government greater than $2.9 million in direct costs from mid-1960s until biocontrol was achieved in 1980. The biological control campaign cost approximately $1.4 million in total.

15.4.1 Development cost

A three year biocontrol project for harrisia cactus between 1974 and 1976, plus exploration in 1959 and 1972, is estimated to have cost a total of approximately $1.0 million.

15.5 Cost benefit analysis

15.5.1 Data inputs

Annual government expenditure on control

The annual government expenditure on control prior to biocontrol is estimated to have been approximately $2.3 million per annum on average.

Distribution of biocontrol

It is estimated that biocontrol took six years to reach full efficacy.

15.5.2 Model

A CBA model was used in this analysis as described in Section I. The analysis examined the benefits and costs that accrue due to replacement of pre-research control of harrisia cactus with biocontrol. The net impact was identified by comparing the benefits and costs of the previous control with the benefits and costs since biocontrol. The net benefit of the program is estimated by the equation below:

$$NB = CS - RC$$

Where:

NB = The net benefit from the biocontrol of harrisia cactus program ($)

CS = The control cost savings to the Government following adoption of biocontrol measures ($)

RC = The cost of research ($)

The control cost savings to the Government following adoption of biocontrol is estimated using the equation below:

$$CS = \sum_{n=50}^{1} GE \times D_n$$

Where:

GE = Annual Government expenditure on controlling harrisia cactus prior to biocontrol ($/annum)

D = The efficacy of biocontrol in year *n* (%)

n = Year

The cost of undertaking the research is calculated using the equation below:

$$RC = \sum_{n=50}^{1} CR_n \times CI_n$$

Where:

CR = The research costs incurred in year *n* ($)

CI = An index for inflation to convert research costs to 2004/05 dollars

15.5.3 Results

The analysis examined the benefits to the Queensland Government in terms of control cost savings following the release of biocontrol agents. The results of the analysis are presented in **Table 15.1**. The biocontrol program provides a positive return on investment at all discount rates, with a NPV of $18.6 million and a BCR of 23.5 at a discount rate of 8.0%.

Table 15.1. Results of analysis

Real discount rate	NPV ($ million)	BCR
4.0%	$38.4	43.1
6.0%	$26.1	31.0
8.0%	$18.6	23.5
10.0%	$13.8	18.4

15.5.4 Sensitivity

Cost Saving to the Government

The breakeven value with respect to the cost saving to the Government from biocontrol ranges from $52,800/annum (4% discount rate) to $123,400/annum (10% discount rate), *ceteris paribus*. This is significantly lower than the $2.3 million/annum that the Government is estimated to have been spending on controlling harrisia cactus in the 1970's. As such this variable is not considered critical to the findings of the analysis.

Table 15.2. Sensitivity analysis

Variable	Units	Base case	Breakeven point at 4% discount rate [(a)]	Breakeven point at 10% discount rate[(a)]
Cost saving to government	$/annum	$2.3 million	$52,800	$123,400

Note: [(a)] The breakeven value is the value of the input where the NPV for the specified discount rate equals 0.

15.5.5 Limitations of the analysis

This analysis has only included the benefits received by the Queensland Government in terms of cost savings. These benefits are considered to be an underestimate of the actual benefits received, as the following benefits were not included:

- Increased productivity for grazing and cropping enterprises through increased carrying capacity of land, improved access to land and reduced injury to stock that was not previously controlled by chemical or mechanical means;
- Restored biodiversity in areas previously infested by harrisia cactus by reducing the competitiveness of the weed; and
- The reduction in chemical control has an added benefit in terms of reduced off-target chemical damage to the environment. This provides a benefit in terms of improved environmental health and reduced non-targeted negative impacts to humans, animals and plants.

While all of these benefits exist no data is available with which to quantify them. The benefits of the harrisia cactus biocontrol program are expected to be understated in this analysis as there is presently insufficient data to quantify these additional impacts.

15.6 Summary

The harrisia cactus biocontrol program resulted in the release of four agents, three of which became established. The program is estimated to have cost a total of approximately $1.0 million, resulting in a NPV of $18.6 million and a BCR of 23.5 at a discount rate of 8.0%.

Table 15.3. Summary of program benefits / costs

Type of benefit	Benefit / Cost	Detail
Economic	Control cost saving	Control cost reduction of approximately $2.3M per annum.
	Improved productivity [(a)]	Increased carrying capacity of land, increasing access to land and reducing injury to stock.
Environmental	Improved biodiversity [(a)]	Reduced competitiveness allowing native fauna and flora to return.
	Reduced chemical toxicity	Improved environmental health and reduced impacts to non-targeted plants and animals.

Note: [(a)] These benefits/costs were already provided to some degree by control methods used prior to the biocontrol program, thus these benefits/costs can not be solely attributed to biocontrol. Due to data limitations the impact of biocontrol in relation to these benefits/costs has not been separated from the impact of prior control methods.

16. *Heliotropium europaeum* (common heliotrope)

16.1 References

J. Cullen, CSIRO Division of Entomology, *pers. comm.*, 2005

16.2 Background and biology

Heliotropium europaeum (common heliotrope) grows in temperate regions in disturbed areas on a wide range of soils.

16.3 Establishment and impact

Common heliotrope was first recorded in Australia in 1880 and is now found in all mainland States except the Northern Territory. It is now widespread north and west of Great Dividing Range as well as the lower southwest of Western Australia with the heaviest infestations in Riverina and Murray Valley, with common heliotrope occupying several thousand square kilometres of northern Victoria and south central NSW.

Common heliotrope acts as an ephemeral plant, producing several generations in one season. It is not aggressive, is susceptible to competition and its presence is an indicator of past overgrazing or cropping. Common heliotrope is toxic to sheep, cattle and horses, but is not very palatable and is rarely eaten by Merino sheep. However, other breeds of sheep as well as cattle are more susceptible and it causes considerable stock mortality and reduces productive life of survivors.

16.4 Biological control program

Biocontrol research started in 1972 by CSIRO and resulted in the release of two biocontrol agents, with both becoming established. However, it is believed that neither have had any success in controlling common heliotrope.

16.4.1 Development cost

The common heliotrope biocontrol program ran from 1973 to 1991 and is estimated to have cost approximately $4.4 million in total.

16.5 Cost benefit analysis

No CBA has been conducted as the biocontrol program is not believed to have provided any benefits.

16.6 Summary

Two agents have been released and established however neither have been successful in controlling common heliotrope. As such the common heliotrope biocontrol program is considered to have provided no benefits.

17. *Hypericum perforatum* (St John's wort)

17.1 References

Briese, D.T. (1997)

Campbell, M.H., Briese, D.T. and Delfosse, E.S. (1995)

Culvenor, C.C.J. (1985)

D. Briese, CSIRO Division of Entomology, *pers. comm.*, 2005

Mahr, F.A., Mayo, G., Ainsworth, N. and Jupp, P. (1999)

McLaren, D.A., Bruzzese, E. and Pascoe, I.G. (1997)

Shepherd, R.C.H. (1985)

17.2 Background and biology

Hypericum perforatum (St John's wort) is a perennial herb that grows to between 30–120 centimetres high. It reproduces from crowns, lateral roots and seeds. St John's wort grows in temperate regions on drier sites at elevations of 500–1,000 metres. It prefers rainfall of greater than 750 millimetres and is able to establish on a wide range of soil types.

St John's wort forms dense stands in NSW and Victoria, but the short growing season in South Australia and Western Australia restricts it to scattered open communities.

17.3 Establishment and impact

St John's wort was first recorded in Melbourne in 1857 and rapidly spread throughout northeast Victoria. It was also recorded in Hobart in 1865. By 1900 St John's wort was found in NSW and South Australia and now occurs in all States except the Northern Territory.

The most heavily infested areas are the Central and Southern Tablelands and Slopes of NSW, with a total of approximately 188,000 hectares covered in 1976.

Early spread was rapid in Victoria between and between 1900–1932 approximately 130,000 hectares had become infested. This declined from 1932–1957 to approximately 50,000 hectares as a result of biocontrol and pasture improvement. However, St John's wort resumed spreading rapidly in the 1960s and by 1982 northeast Victoria had an area of infestation of approximately 175,200 hectares, which continued to spread.

The total distribution in Australia in 2000 was approximately 400,000 hectares with greater than 80% of this in natural vegetation (mainly open woodlands). Scattered infestations were identified over approximately 150,000 hectares of mainly non-arable land in Mount Lofty Ranges, Eyre Peninsula and Kangaroo Island in South Australia, but this area has remained static for over 40 years. St John's wort occupies less than 10 hectares in each of Queensland, Western Australia and Tasmania.

In 1978 a survey determined that approximately 90% of weed infestations occurred in native forests and sown forest plantations under semi-shaded and shaded conditions, whereas only 7% occurred in agricultural or open conditions. The largest infestations occur in water catchment reserves; infestations on farms are mainly on non-arable land.

Seedling establishment is promoted by bare soil, disturbance (rabbit scratches, fire) and wet summers. Once the plant has survived the first year it can overtop competing vegetation and develop an extensive root system.

All livestock that are forced to graze pastures dominated by St John's wort will experience health problems and production losses.

Impacts of St John's wort include:

- Poisonous to stock (sheep, cattle and horses);
- Causes photosensitisation;
- Contact rash in humans;
- Dry stems cause fire hazard in summer; and
- Strongly competes with, and displaces, other plants.

St John's wort is mainly a problem in pasture and has led to the abandonment of formerly productive properties in Victoria and NSW. There is generally dense seedling growth following fire and St John's wort is a problem in national parks, bushland and other rarely used land.

Annual losses on St John's wort-infested pastures in NSW were estimated by Campbell *et al.* (1995) to be approximately $22.5 million (in 1994/95 dollars). In 1994/95 approximately $82,000 was spent on control of the weed in NSW National Parks.

17.4 Biological control program

Biocontrol for St John's wort has proceeded in four distinct phases:

- 1928–1939 exploration in England;
- 1935–1942 exploration in southern France;
- 1940–1956 redistribution of agents on a large scale; and
- 1978–present searches in climatically more suitable areas and targeting particular plant parts.

Biocontrol with *Chrysolina* beetles has achieved long-term effective control of extensive infestations in sunny open sites but has been unsuccessful in shaded sites.

In 1984 no other insects other than *C. quadrigemina* appeared to cause significant damage to the weed. Because of the less aggressive nature of the weed in shady areas the lack of effective biocontrol in these areas may not be overly significant, however the weed still poses a management cost for forestry.

Biocontrol can be effective when integrated with other management tools. Many areas have been practically cleared of the weed by the application of superphosphate after successful beetle attack, provided grazing is carefully managed. This management regime is not as effective in shallow soils.

Gall midge *Zeuxidiplosus giardi* has become widespread but has little impact. *Aphis chloris* and the mite *Aculus hyperici*, which established and spread rapidly, reduce root growth and, subsequently, the competitiveness of St John's wort. The mite appears to be the most promising agent but plants are variable in their susceptibility to attack. There is some evidence that the mite can cause substantial reduction in the vigour of St John's wort populations and might improve the overall level of biocontrol.

17.4.1 Development cost

The total research cost for the St John's wort biocontrol program is unclear, with the cost of research from 1928 to 1956 (covering the initial identification of biocontrol agents through exploration in England and France and the subsequent successful releases of *Chrysolina* beetles) unknown. There is also limited detail available for the research costs for more targeted biocontrol agents starting in 1978.

17.5 Cost benefit analysis

Due to the limited data available on costs of the St John's wort biocontrol program no CBA has been conducted for this program.

17.6 Summary

The St John's wort biocontrol program has resulted in the release of eleven agents, six of which have become established. The cost of the program is unknown, although they are believed to be insignificant in comparison to the benefits which are estimated to be as high as $20.6 million per annum since the 1970's.

Table 17.1. Summary of program benefits / costs

Type of benefit	Benefit / Cost	Detail
Economic	Increased productivity	Annual production benefit of approximately $20.6M per annum since the 1970's through the following channels: • Reduced stock health problems and poisoning; • Reduced photosensitisation; • Increased pasture productivity and carrying capacity.
Environmental	Reduced fire hazard risk	Reduced fire risk and intensity of burn.
Social	Contact rash in humans	Decreased incidence of contact rash in humans.

18. *Lantana camara* (lantana)

18.1 References

Bartholomew, B.L. and Armstrong, T.R. (1978)

Broughton, S. (2000)

Clark, A. (2004)

CSIRO (1964)

Culvenor, C.C.J. (1985)

Day, M.D., Broughton, S. and Hannan-Jones, M.A. (2003)

Day, M.D., Wiley, C.J., Playford, J. and Zalucki, M.P. (2003)

M. Day, Queensland Department of Natural Resources and Mines, *pers. comm.*, 2005

Walton, C. (2005)

Willson, B.W. (1985)

18.2 Background and biology

Lantana camara (lantana) is a brittle, much-branched, thicket-forming shrub, normally 2–4 metres tall but capable of scrambling over other vegetation to 15 metres high. It is an aggregate species derived from natural and horticultural hybridisation.

Lantana grows in both dry and humid climates in warm regions, mainly on richer soils, from sea level to approximately 2,000 metres, and prefers moist conditions. It is frost-sensitive, and has a low tolerance of soil salinity but tolerates partial shading.

18.3 Establishment and impact

Lantana was first recorded in Australia at Adelaide in 1841. It spread rapidly along eastern coast of Australia and is now a prominent coastal and sub-coastal weed from Cairns to Bega, and is also found on both Lord Howe and Norfolk Islands. Lantana is generally considered to have reached its potential distribution range, but continues to invade new habitats within the range as well as increasing in density. The seeds are generally distributed by fruit-eating birds and mammals.

The main economic damage is to the productivity of pastures but lantana is also considered a serious weed of the plantation and native timber and orchard industries. Lantana infests greater than four million hectares of pasture in eastern Australia, shades out useful species and reduces productivity. The impacts of the weed include:

- Being unpalatable and poisonous to stock (mainly cattle);
- Providing haven and alternate host for pests and pathogens; and
- Exotic birds feed on the fruits.

Annual losses in pastures are estimated at approximately $7.7 million (made up of approximately 1,500 stock deaths, reduced performance, loss of pasture and control costs). Total control costs by primary industries in Queensland are estimated as greater than $10 million/year. The costs of lost production in Australia due to lantana has been conservatively estimated as greater than $22 million. Lantana readily invades uncultivated pastures.

Lantana is a serious invader of plantation forestry, causing economic loss through competition with young trees, interference with access for management and harvesting and creating a fire hazard. In 1964 approximately four million hectares of Queensland pasture and forest were infested. Approximately £10,000/annum was spent on controlling lantana in native pine plantations to reduce fire risks, while the control of 250,000 hectares of lantana present in NSW State Forests in the 1960s was estimated to cost approximately £100,000/annum. Annual costs to forestry were approximately $0.5 million in 1984. The total cost when combined with the costs incurred by landholders, Local Government Authorities, and other bodies was estimated as greater than $7 million.

Lantana is also a serious invader of disturbed natural ecosystems, such as rainforests where it can increase the impact of fires on the margins. It infests all rainforest remnants on the north coast of NSW and in southeast Queensland, although it mainly invades areas of open eucalypt woodland, where it forms dense monospecific thickets, greatly reducing conservation value and increasing the fire hazard.

One entire ecological community in north NSW (lowland rainforest on floodplains) and 20 flora species are under threat specifically from lantana. In Queensland it is present in five threatened plant communities, 165 Reserves, one Ramsar site and poses a potential threat to at least 60 plant and animal species of conservation significance. Lantana is also considered a major threat to the Wet Tropics World Heritage Area.

Examples of expenditure on lantana control include:

- NSW National Parks – greater than $100,000/year;
- Ergon Energy Mackay region – $46,000/year to clear lines and easements;
- Queensland Parks and Wildlife Monto and Wide Bay-Burnett region – greater than $50,000/year; and
- Maroochy Shire Council, Queensland – greater than $30,000/year.

Lantana provides benefits in the form of food and shelter to a number of native birds, animals and insects, forms a useful temporary buffer along forest edges for bush regeneration projects, prevents soil erosion on steep slopes and stream banks, and suppresses some weeds considered to have a greater ecological impact. It is extensively grown as a garden ornamental, but is now banned from sale in all States and Territories.

18.4 Biological control program

Despite a significant international effort on biological control, lantana remains a major weed worldwide. Biocontrol agents have in many cases, at least seasonally, decreased the size of individual plants, making other control methods considerably easier.

A total of thirty biocontrol agents have been introduced to Australia since 1914, of which seventeen have become established, and four of these are effectively reducing the vigour and competitiveness of lantana in certain areas. The effectiveness of agents varies depending on their spread and impact.

A complete list of biological control agents released is published in Day *et al*. (2003).

- First biocontrol releases in Australia occurred in 1914 and 1917 by the Queensland Department of Agriculture and Stock (QDAS);
- In 1936 CSIRO introduced the lace bug *Teleonemia scrupulosa* and redistribution by the QDAS continued until 1947;
- In 1953–65 the Queensland Department of Public Lands conducted overseas exploration and releases;
- From 1965–78 a joint project between CSIRO, Queensland Department of Primary Industries, Lands and Forestry (later Queensland Department of Lands), and NSW Department of Agriculture was carried out, with further overseas exploration and releases. All agents were reared and released from the Sherwood labs;
- From 1988 to the present, Queensland Department of Natural Resources & Mines has continued overseas exploration in North and Central America, and cooperated with the Republic of South Africa, resulting in the release of several additional agents.

18.4.1 Development cost

The lantana biocontrol program began in 1914 and is ongoing, although prior to 1953 research was sporadic with only 12 years of research being conducted between 1914 and 1952. Over this period (1914–52) the program is estimated to have cost approximately $1.2 million in total. Since 1953, research into biocontrol for lantana is estimated to have cost approximately $12.4 million, making the overall cost of the lantana biocontrol program $13.6 million.

Each new species costs approximately 3–5 scientist years in host-specificity testing, mass rearing and releases.

18.5 Cost benefit analysis

18.5.1 Data inputs

Production losses

The annual loss to production in Australia due to lantana is estimated to be approximately $23.2 million, inclusive of cattle deaths, loss of pasture, loss of performance, control costs and costs to forestry.

Distribution of biocontrol

It is estimated that biocontrol is presently about 10% effective in the warmer half of the lantana range (therefore overall distribution of 5%), with four agents causing significant damage to the weed. These four agents were released in 1914, 1936 and two in 1966. The build-up to full efficacy has been based on the timing of the release of these four agents, with a ramp-up period of 10 years for each one.

18.5.2 Model

A CBA model was used in this analysis as described in Section I. The analysis examined the benefits and costs that accrue due to the control of lantana with biological agents. The net impact was identified by comparing the benefits and costs prior to biocontrol with the benefits and costs since biocontrol. The net benefit of the program is estimated by the equation below:

$$NB = IP - RC$$

Where:

NB = The net benefit from the biocontrol of lantana program ($)

IP = The increase in production following the release of biocontrol agents ($)

RC = The cost of research ($)

The increase in production following the release of biocontrol agents is estimated using the equation below:

$$IP = \sum_{n=100}^{1} PL \times D_n$$

Where:

PL = Annual production losses caused by lantana prior to biocontrol ($/annum)

D = The efficacy of biocontrol in year *n* (%)

n = Year

The cost of undertaking the research is calculated using the equation below:

$$RC = \sum_{n=100}^{1} CR_n \times CI_n$$

Where:

CR = The research costs incurred in year *n* ($)

CI = An index for inflation to convert research costs to 2004/05 dollars

18.5.3 Results

The analysis examined the benefits in terms of increased production following the release of biocontrol agents. Given the length of the program (starting in 1914 and ongoing) a 100 year analysis has been conducted. The results of the analysis are presented in **Table 18.1**. The biocontrol program provides a positive return on investment at all discount rates, with a NPV of $2.5 million and a BCR of 5.6 at a discount rate of 8.0%.

Table 18.1. Results of analysis

Real discount rate	NPV ($ million)	BCR
4.0%	$7.7	5.5[(a)]
6.0%	$4.0	5.7
8.0%	$2.5	5.6
10.0%	$1.6	5.1

Note: [(a)] The counter intuitive increasing BCR with increasing discount rate is due to the timing of the costs and benefits and their relative values once discounted.

Two distinct phases of lantana biocontrol research can be identified:

- Pre-1953, which encompasses the sporadic rearing and releasing of biocontrol agents imported from Hawaii and Fiji between 1914 and 1952; and
- Post-1953, which saw the beginning of a period of continued effort into biocontrol research.

Separate fifty year CBAs have been conducted for each of these periods (one from 1914 and the other from 1953). These periods have been analysed as separate programs, with the costs and benefits accruing in one CBA not included in the other. Both CBAs include the release of two agents that are successfully reducing the vigour of lantana plants.

Pre-1953

This analysis examined the benefits in terms of increased production from the release of biocontrol agents in 1914 and 1936 against the costs of the biocontrol program between 1914 and 1952. The results of the analysis are presented in **Table 18.2**. The rearing and release of biocontrol agents between 1914 and 1952 provides a positive return on investment at all discount rates, with a NPV of $2.4 million and a BCR of 6.9 at a discount rate of 8.0%.

Table 18.2. Results of analysis, pre-1953

Real discount rate	NPV ($ million)	BCR
4.0%	$5.7	10.4
6.0%	$3.6	8.5
8.0%	$2.4	6.9
10.0%	$1.6	5.7

Post-1953

This analysis examined the benefits accruing from research into biocontrol of lantana since 1953, which resulted in the release of two agents in 1966 that are successfully reducing the vigour of lantana plants. The results of the analysis are presented in **Table 18.3**. Since 1953, the lantana biocontrol program has provided a negative return on investment at all discount rates, with a NPV of -$1.3 million and a BCR of 0.6 at a discount rate of 8.0%.

Table 18.3. Results of analysis, post-1953

Real discount rate	NPV ($ million)	BCR
4.0%	-$0.2	1.0
6.0%	-$1.0	0.7
8.0%	-$1.3	0.6
10.0%	-$1.3	0.4

18.5.4 Sensitivity[7]

Distribution

The breakeven value with respect to the distribution of biocontrol ranges from 0.9% (4% discount rate) to 1.0% (10% discount rate), *ceteris paribus*. Expert opinion is that biocontrol is currently 10% effective over 50% of the lantana range (overall distribution of 5.0%), which is considerably higher than the breakeven values. As such this variable is not considered critical to the findings of the analysis.

[7] This sensitivity analysis refers to the 100 year CBA only.

Table 18.4. Sensitivity analysis

Variable	Units	Base case	Breakeven point at 4% discount rate [(a)]	Breakeven point at 10% discount rate [(a)]
Distribution	%	5%	0.9%	1.0%

Note: [(a)] The breakeven value is the value of the input where the NPV for the specified discount rate equals 0.

18.5.5 Limitations of the analysis

The analysis assumes that each of the four successful biocontrol agents reduce the losses in productivity caused by lantana by an equal amount. However, there is no evidence to verify the accuracy of this assumption. Given the considerable time lags between releases of agents, the actual level of control achieved by each separate agent can affect the results of the analysis. However, sensitivity analysis shows that even at an overall distribution of 1.0% (which assumes each agent provides a level of control of 0.25%) the biocontrol program would return a positive return on investment.

18.6 Summary

The lantana biocontrol program has resulted in the release of thirty biocontrol agents, with seventeen of these becoming established and four effectively reducing the vigour and competitiveness of lantana in at least some areas. It is estimated that biocontrol is causing at least 10% reduction in the density of lantana infestations in the northern half of its range. The program is estimated to have cost a total of $13.6 million, resulting in a NPV of $2.5 million and a BCR of 5.6 at a discount rate of 8.0%.

When breaking the program down to pre-1953 and post-1953, it is seen that the research, rearing and release of biocontrol agents prior to 1953 provided a positive return on investment while research post-1953 has actually provided a negative return on investment. This is largely due to the following factors:

- **Timing of benefits and costs**: The initial release of biocontrol agents (1914) occurred in the same year as the initial expenditure on biocontrol, meaning that benefits were accruing immediately. Research starting in 1953, however, took 13 years to produce any benefits with the release of agents in 1966; and
- **Magnitude of costs and benefits of research**: Research expenditure prior to 1953 was sporadic and considerably lower than post-1953. However, it is assumed that the overall benefits from the two agents released in 1914 and 1936 is the same as that for the two released in 1966.

Table 18.5. Summary of program benefits / costs

Type of benefit	Benefit / Cost	Detail
Economic	Increased productivity	Productivity is estimated to have increased by approximately $1.2 million/annum, or $290,000/annum per biocontrol agent released.
Environmental	Reduced threat to natural habitat	In Queensland lantana is present in five threatened plant communities, 165 Reserves, one Ramsar site and poses a potential threat to greater than 60 plant and animal species of conservation significance. It is considered a major threat to the Wet Tropics World Heritage Area. Biocontrol is believed to be having some impact on controlling the weed, reducing the threat to these native species.
	Improved environmental health and biodiversity	Lantana provides a haven and alternate host for various pests and pathogens, while exotic birds feed on the fruit. By reducing the vigour and competitiveness of the weed, biocontrol would improve environmental health.

19. *Lantana montevidensis* (creeping lantana)

19.1 References

W.A.. Palmer, Queensland Department of Natural Resources and Mines, *pers. comm.*, 2005

19.2 Background and biology

Lantana montevidensis (creeping lantana) grows in the semi-arid tropics and subtropics, especially on shallow stony soils, and occurs mostly in coastal and sub-coastal Queensland and northern NSW.

19.3 Establishment and impact

It reduces pasture productivity, is an extremely efficient pioneer species especially in times of drought, and is suspected of poisoning cattle.

19.4 Biological control program

Two biocontrol agents were released during this program with both failing to establish.

19.4.1 Development cost

The creeping lantana biocontrol program is estimated to have cost approximately $200,000 over a five year period between 1996 and 2000.

19.5 Cost benefit analysis

No CBA has been conducted as the biocontrol program did not provide any benefits.

19.6 Summary

The creeping lantana biocontrol program has provided no benefit with the two agents released failing to establish.

20. *Marrubium vulgare* (horehound)

20.1 References

Bruzzese, E. and Cullen J.M. (1995)

J.L. Sagliocco, Victorian Department of Primary Industries, *pers. comm.*, 2005

J. Weiss, Victorian Department of Primary Industries, *pers. comm.*, 2005

R. Kwong, Victorian Department of Primary Industries, *pers. comm.*, 2005

Reserve Bank of Australia (2005)

Sloane, Cook and King Pty Ltd (1988)

20.2 Background and biology

Marrubium vulgare (horehound) is an erect perennial herb, 30–75 centimetres high that grows in Mediterranean climatic regions, on well-drained soils and is relatively drought-tolerant.

20.3 Establishment and impact

Horehound was first recorded in South Australia in 1841 and was considered naturalised by 1848. It has become one of the most widespread weeds in southern Australia and now occurs in all States except the Northern Territory, being found on at least 26 million hectares.

Horehound generates the greatest problems in northwest Victoria and southeast South Australia where semi-arid conditions contribute to the decreased vigour of competing plant species. In 1980 the total infestation was approximately six million hectares in Victoria and approximately 20 million hectares in South Australia. It is considered to have reached its maximum potential distribution in Australia, but not its maximum density, and the major spread of horehound is through seeds adhering to wool on sheep.

Horehound is not palatable to stock and its establishment is encouraged by heavy grazing. It taints meat if animals are forced to eat it. Horehound establishes quickly under favourable conditions, however seedlings do not establish in dense pastures.

Due to its spreading habit, each plant occupies a large area, and where established can significantly reduce pasture productivity. The weed can also cause vegetable fault in wool.

Horehound invades natural ecosystems if these have been disturbed or previously grazed, but is not invasive in undisturbed native vegetation. There are two plant species at risk in Victoria due to horehound invasion.

A report by Sloane, Cook and King Pty Ltd (1988) estimated the cost of horehound to the wool industry at $680,000, although the overall economic impact on agriculture has not been calculated. A 1996 survey of Victoria Parks estimated 78,200 hectares of public lands were infested, which resulted in approximately $19,000 and 1,900 work-hours/annum in control costs.

20.4 Biological control program

The horehound plume leaf-feeding moth (*Wheeleria spilodactylus*) was imported into quarantine in 1991 and released in 1994. It weakens the plant and reduces the number of flowers and seeds produced. After 3–5 years at a location the moths can cause severe damage to the infestation. Population increase of the moth is rapid, over 100 fold per year, but spread is very slow and the moth requires active redistribution.

Rearing and release of the moth was primarily carried out in Victoria from 1993–96 and in 1996 the Weeds CRC began rearing at the University of New England in Armidale. In 1997 the Tasmania Institute of Agriculture Research also began rearing, and in 1998 a grant from the Weeds CRC enabled monitoring of release sites. Releases were also made in South Australia and the moth is now widely established.

The clearwing root-boring moth (*Chamaesphecia mysiniformis*) was tested by CSIRO in Europe in 1994. Mass rearing was undertaken at Keith Turnbull Research institute (KTRI) in Victoria and at the Weeds CRC in South Australia. The moth is now established at sites in South Australia and Victoria.

20.4.1 Development cost

The horehound biocontrol program ran from 1989 to 2001 at an estimated cost of approximately $1.8 million.

20.5 Cost benefit analysis

20.5.1 Data inputs

Decrease in value of the Australian wool clip due to horehound

Prior to biocontrol, the Australian wool clip is estimated to have lost approximately $1.17 million dollars per annum through vegetable fault in wool due to horehound.

Efficacy of biocontrol

Biocontrol is estimated to have led to a 5–10% reduction in losses to the Australian wool clip over approximately 50% of the area affected by horehound since 2000. Biocontrol is still improving as the two agents continue to spread and increase, and losses from horehound are expected to reduce even further in the future.

Distribution of biocontrol

Biocontrol is estimated to have taken six years to reach current levels of efficacy.

20.5.2 Model

A CBA model was used in this analysis as described in Section I. The analysis examined the benefits and costs that accrue to the wool industry due to the control of horehound with biocontrol. The net impact was identified by comparing the benefits and costs to the wool industry prior to biocontrol with the benefits and costs since biocontrol. The net benefit of the program is estimated by the equation below:

$$NB = WC - RC$$

Where:

NB = The net benefit from the biocontrol of horehound program ($)

WC = The increase in value of the Australian wool clip following adoption of biocontrol measures ($)

RC = The cost of research ($)

The increase in value of the Australian wool clip following adoption of biocontrol is estimated using the equation below:

$$WC = \sum_{n=50}^{1} LW \times D_n$$

Where:

LW = Annual loss to the Australian wool clip from horehound prior to biocontrol ($/annum)

D = The efficacy of biocontrol in year *n* (%)

n = Year

The cost of undertaking the research is calculated using the equation below:

$$RC = \sum_{n=50}^{1} CR_n \times CI_n$$

Where:

CR = The research costs incurred in year *n* ($)

CI = An index for inflation to convert research costs to 2004/05 dollars

20.5.3 Results

The analysis examined the benefits to the Australian wool industry in terms of increased value of the Australian wool clip following the release of biocontrol agents. The results of the analysis are presented in **Table 20.1**. The biocontrol program provides a negative return on investment at all discount rates, with a NPV of -$0.9 million and a BCR of 0.2 at a discount rate of 8.0%. However, this is considered an underestimate of the benefits of the biocontrol program (see **Section 20.5.5**).

Table 20.1. Results of analysis

Real discount rate	NPV ($ million)	BCR
4.0%	-$0.8	0.4
6.0%	-$0.9	0.3
8.0%	-$0.9	0.2
10.0%	-$0.9	0.2

20.5.4 Sensitivity

Reduction in value

The breakeven value with respect to the reduction in value to the wool industry from horehound ranges from $2.67 million/annum (4% discount rate) to $6.63 million/annum (10% discount rate), *ceteris paribus*. The estimated loss to the wool industry, as provided by Sloane, Cook and King Pty Ltd (1988), is $1.17 million/annum, which is less than half the breakeven value at a 4% discount rate and approximately one quarter the breakeven value at a 10% discount rate. This implies that, based on available data regarding production gains to the wool industry, the benefits of the horehound biocontrol program do not cover the costs.

However, the wool industry is not the only industry to suffer losses due to horehound, as horehound is an aggressive invader of any heavily grazed lands. **Table 20.2** shows that, at an 8% discount rate, an annual saving of approximately $5.0 million would be sufficient for the horehound biocontrol program to breakeven.

This is clearly a critical variable of the analysis, however there is insufficient data available to accurately identify the benefits of biocontrol.

Table 20.2. NPV and BCR of horehound at 8% discount rate, annual saving $1 million–$10 million

Annual saving ($M/annum)	NPV ($ million)	BCR
$1.0	-$1.0	0.2
$2.0	-$0.7	0.4
$3.0	-$0.5	0.6
$4.0	-$0.3	0.8
$5.0	$0.0	1.0
$6.0	$0.2	1.2
$7.0	$0.5	1.4
$8.0	$0.7	1.6
$9.0	$0.9	1.8
$10.0	$1.2	2.0

Reduction in lost value due to biocontrol

The breakeven value with respect to the reduction in lost value due to biocontrol ranges from 8.6% (4% discount rate) to 21.2% (10% discount rate), *ceteris paribus*. This is between 2.3 and 5.7 times higher than the 3.8% reduction in lost value used in this analysis. While a 21.2% reduction in lost value is significantly higher than the 3.75% used in this analysis, an 8.6% reduction is conceivable given that the reduction in lost value is estimated to be between 5% and 10% where biocontrol agents have established[8]. It is probable that a level of 22% reduction in lost value will be reached or even exceeded in the future, as the two biocontrol agents increase in density and distribution. As such this variable is considered critical to the analysis.

20.5.5 Limitations of the analysis

This analysis has been limited to the inclusion of the benefits received by the wool industry in terms of reduced vegetable fault in wool. These benefits are considered to be an underestimate of the actual benefits received, as the following benefits were not included:

- Increased pasture productivity through increased grazing area and reduced tainting of meat; and
- Reduced risk to two plant species in Victoria and increased biodiversity.

No data is available to quantify these benefits. As such the benefits of the horehound biocontrol program are expected to be understated in this analysis.

20.6 Summary

The horehound biocontrol program resulted in the release of two biocontrol agents, both of which have successfully established. The program is estimated to have cost a total of $1.8 million, resulting in a NPV of -$0.9 million and a BCR of 0.2 at a discount rate of 8.0%. The benefits of the horehound biocontrol program are expected to be understated in this analysis as they do not include any increase in production in pasture (aside from the benefits to the wool industry), market impacts of tainted meat or environmental benefits. It has been identified that an annual benefit of approximately $5.0 million is required for this program to breakeven at an 8% discount rate.

Table 20.3. Sensitivity analysis

Variable	Units	Base case	Breakeven point at 4% discount rate [(a)]	Breakeven point at 10% discount rate [(a)]
Reduction in value	$/annum	$1.17 million	$2.67 million	$6.63 million
Reduction in lost value due to biocontrol	%	3.75%	8.6%	21.2%

Note: [(a)] The breakeven value is the value of the input where the NPV for the specified discount rate equals 0.

[8] Anecdotal evidence indicates that biocontrol agents are established across approximately 50% of the total horehound infestation. This is expected to increase in the future.

Table 20.4. Summary of program benefits / costs

Type of benefit	Benefit / Cost	Detail
Economic	Increased productivity	• Reduced vegetable fault losses of approximately $44,000 per annum; • Increased grazing area; and • Reduced market impacts from tainted meat.
Environmental	Reduced threat to natural ecosystems	Reduced exposure to species loss for the two plant species at risk in Victoria due to horehound invasion.

21. *Mimosa diplotricha* (giant sensitive plant)

21.1 References

McFadyen, P.J. (1982)

Reserve Bank of Australia (2005)

Willson, B.W. and Garcia, C.A. (1992)

21.2 Background and biology

Mimosa diplotricha (previously known as *Mimosa invisa*) (giant sensitive plant) is a shrubby or sprawling prickly annual, although in some circumstances it behaves as a perennial vine. It grows in wet places in tropical regions and is sensitive to shade.

21.3 Establishment and impact

Giant sensitive plant is a serious weed of tropical crops (especially sugarcane), orchards, plantations and pastures. It is known to have been present in Australia since approximately 1929 but remains restricted to the coast of north Queensland.

The prickly stems of giant sensitive plant smother crops and impede harvesters. It is unpalatable to stock and forms dense, tangled thickets that can cause injury and death to trapped animals.

Estimates of control costs, expressed in 2004/05 dollar terms, range from approximately $270,000/year (incurred in 1982) to $3.3 million/year (in 1992). From 1983/84 to 1987/88 there were six men and three vehicles employed on *Mimosa diplotricha* control in northern Queensland. From 1989/90 to 1991/92 there were two men and two vehicles.

Giant sensitive plant can be used as a green manure in some situations and seeds can remain dormant for many years.

21.4 Biological control program

Two biocontrol agents were released, one of which, the psyllid *Heteropsylla spinulosa*, established. Biological control with the psyllid has significantly reduced the vigour and seeding of the plant. It can reduce stem elongation by 72% and seed production by 80%. It increases in population quickly and spreads rapidly. The psyllid controls the plant in non-crop areas, and usually in crops and pastures as well. Attack by the psyllid makes plants less spiny and more readily grazed by stock in pastures, which further assists in control.

The psyllid was released in 1988 and established immediately. Control costs rapidly reduced to approximately zero from an estimated $3.3 million annually.

21.4.1 Development cost

The giant sensitive plant biocontrol program ran from 1982 to 1992 at an estimated total cost of approximately $1.7 million.

21.5 Cost benefit analysis

21.5.1 Data inputs

Cost of chemical control

The cost of controlling giant sensitive plant with chemicals prior to biocontrol is estimated to have been $3.3 million per annum.

Distribution of biocontrol

Chemical control costs are estimated to have been reduced to effectively zero five years after the introduction of biocontrol. A linear efficacy growth rate of biocontrol was assumed over this period.

21.5.2 Model

A CBA model was used in this analysis as described in Section I. The analysis examined the benefits and costs that accrue due to replacement of pre-research control of giant sensitive plant with biocontrol. The net benefit of the program is estimated by the equation below:

$$NB = CS - RC$$

Where:

NB = The net benefit from the biocontrol of Giant Sensitive plant program ($)

CS = The control cost savings following adoption of biocontrol measures ($)

RC = The cost of research ($)

The control cost saving following adoption of biocontrol is estimated using the equation below:

$$CS = \sum_{n=50}^{1} CC \times D_n$$

Where:

CC = The cost of controlling giant sensitive plant with chemicals ($/annum)

D = The efficacy of biocontrol in year *n* (%)

n = Year

The cost of undertaking the research is calculated using the equation below:

$$RC = \sum_{n=50}^{1} CR_n \times CI_n$$

Where:

CR = The research costs incurred in year *n* ($)

CI = An index for inflation to convert research costs to 2004/05 dollars

21.5.3 Results

The analysis examined the benefits in terms of control cost savings following the release of biocontrol agents. The results of the analysis are presented in **Table 21.1**. The biocontrol program provides a positive return on investment at all discount rates, with a NPV of $20.2 million and a BCR of 18.0 at a discount rate of 8.0%.

Table 21.1. Results of analysis

Real discount rate	NPV ($ million)	BCR
4.0%	$46.7	34.4
6.0%	$30.1	24.4
8.0%	$20.2	18.0
10.0%	$14.1	13.8

21.5.4 Sensitivity

Cost savings

The breakeven value with respect to the control cost savings from biocontrol ranges from $95,500/annum (4% discount rate) to $239,000/annum (10% discount rate), *ceteris paribus*. This is significantly lower than the $3.3 million/annum that is estimated to have been spent on controlling giant sensitive plant. As such this variable is not considered critical to the findings of the analysis.

21.5.5 Limitations of the analysis

Due to limited data availability, the benefits of this analysis do not include productivity gains due to the improved control of giant sensitive plant from biocontrol. Production benefits are expected to include:

- Reduced injury and death to animals trapped by dense thickets of giant sensitive plant;
- Increased carrying capacity of land; and
- Improved stock and machinery movement.

The analysis does not include the reduced spread of giant sensitive plant, which could potentially spread to larger areas of the wet tropics of Australia, including the Northern Territory.

The analysis also does not include any potential costs from the reduction in giant sensitive plant in terms of the weed's ability to be used as a green manure. This cost however is likely to be minimal.

It is considered that if these benefits and costs were quantified it would lead to a net increase in the benefits of the giant sensitive plant biocontrol program.

21.6 Summary

The giant sensitive plant biocontrol program resulted in the release of two agents, one of which became established. The program is estimated to have cost a total of $1.7 million, resulting in a NPV of $19.7 million and a BCR of 17.6 at a discount rate of 8.0%. This is considered to be an underestimate of the benefits of the program as potential productivity gains are not included due to data limitations.

Table 21.2. Sensitivity analysis

Variable	Units	Base case	Breakeven point at 4% discount rate [(a)]	Breakeven point at 10% discount rate [(a)]
Cost savings	$/annum	$3.3 million	$95,500	$239,000

Note: [(a)] The breakeven value is the value of the input where the NPV for the specified discount rate equals 0.

Table 21.3. Summary of program benefits / costs

Type of benefit	Benefit / Cost	Detail
Economic	Control cost saving	Control cost savings of approximately $3.2M per annum.
	Improved productivity [(a)]	• Reduction in density of thickets that can trap animals, causing injury and death; • Increased carrying capacity of land; and • Improved stock and harvester movement.
	Reduced fertilizer options [(a)]	Loss of option to green manure.

Note: [(a)] These benefits/costs were already provided to some degree by control methods used prior to the biocontrol program, thus these benefits/costs can not be solely attributed to biocontrol. Due to data limitations the impact of biocontrol in relation to these benefits/costs has not been separated from the impact of prior control methods.

22. *Mimosa pigra* (mimosa)

22.1 References

Buckley *et al.* (2004)

Flanagan, G.J. (1995)

Heard, T.A. and Pettit, W. (2005)

Paynter, Q. and Flanagan, G.J. (2004)

Paynter, Q. (2005)

R. McFadyen, Weeds CRC, *pers. comm.*, 2005

Reserve Bank of Australia (2005)

Sinden *et al.* (2004)

T. Heard, CSIRO Division of Entomology, *pers. comm.*, 2005

22.2 Background and biology

Mimosa pigra (mimosa) is a leguminous thorny shrub that grows up to six metres in height. It prefers to grow in seasonally-flooded open environments throughout the tropics.

22.3 Establishment and impact

Mimosa was first recorded at Darwin in 1891. It spread rapidly from 1975 and covered approximately 80,000 hectares by 1983. Spread has slowed since the late 1980s due to control of water buffaloes that were facilitating the spread of the weed, herbicidal control and public awareness.

Mimosa has the potential to infest much greater areas of northern Australia wherever rainfall is greater than 750 millimetres. A new outbreak was discovered at Proserpine in Queensland in 2001.

Mature plant density in dense stands is between 1–3 plants/square metre, while seed densities in the soil average approximately 12,000/square metre. Typical annual seed production is approximately 9,000 seeds/plant, but can reach 220,000 seeds/plant for an isolated individual in an ideal location. Seeds can remain viable for many years in the soil.

Light penetration to ground level in a dense stand can be as low as 1–5%, which effectively suppresses the growth of all other plant species.

The rate of population increase within a river system is rapid, with infestations doubling every 1.2 years. Across the Northern Territory doubling time was estimated to be 6.7 years.

Mimosa is an enormous problem for conservation as it forms impenetrable monospecific thickets of 4–5 metres in height, making areas inaccessible by animals or people. Mimosa has a number of economic, social and environmental impacts as it:

- Interferes with:
  - Stock mustering;
  - Stock watering;
  - Irrigation; and
  - Recreational use of waterways (including fishing);
- Smothers pastures, reducing productivity;
- Displaces native waterbirds (including the magpie goose) and other fauna;
- Suppresses all other vegetation;
- Threatens traditional cultural practices; and
- Threatens tourism (especially in Kakadu).

Mimosa has the ability to colonise large areas of wetlands quickly and threatens several plants of conservation significance, and several wetlands of national and international significance.

Mimosa has potential use as fuel for electricity production.

22.4 Biological control program

The first releases of biocontrol agents were made in 1983. By 2005, biological control agents are beginning to reduce the vigour and seed production of mimosa. Several agents have established, with two having a significant impact. New agents are still being released and benefits are increasing each year.

Neurostrota gunniella, a tip-boring moth, has reduced seed production by 58–78%, reduced radial canopy growth by 14% in one season, and one generation of larvae reduced seedling growth by 30%. However, it is unlikely to control mimosa on its own.

Carmenta mimosa, the stem-boring moth, is very damaging locally and is predicted to cause widespread reductions in mimosa populations. Field experiments identified that expansion of mimosa stands only occurred

where the moth was absent and the grass had been burnt. Competing vegetation increased beneath stands colonised by the moth, which should increase fuel loads and lead to more intense fires. By altering the susceptibility of mimosa to fire, *C. mimosa* has the potential to dramatically reduce the abundance of mimosa on Northern Territory floodplains, provided overgrazing does not reduce fuel loads. *C. mimosa* alone can regulate mimosa populations, however it is likely that *Neurostrota gunniella* herbivory is also damaging, particularly to isolated plants.

The benefits of reduced chemical usage due to biological control are:

- In national parks and reserves, two herbicide applications at $40/hectare with biocontrol agents present as compared to three applications at $60/hectare without biocontrol; and
- For cattle grazing, where bulldozing followed by fire is used, costs are approximately $130/hectare without biocontrol or approximately $110/hectare with biocontrol.

22.4.1 Development cost

The mimosa biocontrol program operated between 1981 and 2004 and is estimated to have cost a total of approximately $21.6 million.

22.5 Cost benefit analysis

22.5.1 Data inputs

Control costs

The cost of controlling mimosa in productive land pre and post biocontrol are estimated to be $130/ha and $110/ha, respectively. The cost of controlling mimosa in park land pre and post biocontrol are estimated to be $180/ha and $80/ha, respectively.

Proportion of mimosa-infested park land that is actively controlled

Sinden *et al.* (2004) report that over the seven year period between 1996–97 and 2002–03, $10.455 million was spent on controlling mimosa in and around Kakadu National Park, equating to an annual expenditure of $1.494 million. Based on the above control cost estimates, the cost of controlling a mimosa infestation in the entire park lands would be $8.64 million/annum. It is estimated, then, that approximately 17% of park land is infested and actively controlled.

Distribution of biocontrol

Biocontrol is estimated to have taken 20 years from first release to build up to current control levels (resulting in the control costs provided).

22.5.2 Model

A CBA model was used in this analysis as described in Section I. The analysis examined the benefits and costs that accrue due to replacement of pre-research control of mimosa with biocontrol. The net impact was identified by comparing the benefits and costs of the previous control with the benefits and costs since biocontrol. The net benefit of the program is estimated by the equation below:

$$NB = PL + NP - RC$$

Where:

NB = The net benefit from the biocontrol of mimosa program ($)

PL = The control cost savings for productive land following adoption of biocontrol measures ($)

NP = The control cost savings for park land following adoption of biocontrol measures ($)

RC = The cost of research ($)

The control cost savings for productive land following adoption of biocontrol is estimated using the equation below:

$$PL = \sum_{n=50}^{1} \left(CPL^{PB} - CPL^{WB}\right) \times APL \times D_n$$

Where:

CPL = The cost of controlling mimosa in productive land ($/ha)

PB = Pre-biocontrol

WB = With biocontrol

APL = Area of productive land infested with mimosa (ha)

D = The efficacy of biocontrol in year *n* (%)

n = Year

The control cost savings for park land following adoption of biocontrol is estimated using the equation below:

$$NP = \sum_{n=50}^{1} \left(CNP^{PB} - CNP^{WB}\right) \times ANP \times D_n$$

Where:

CNP = The cost of controlling mimosa in park land ($/ha)

ANP = Area of park land infested with mimosa (ha)

The cost of undertaking the research is calculated using the equation below:

$$RC = \sum_{n=50}^{1} CR_n \times CI_n$$

Where:

CR = The research costs incurred in year *n* ($)

CI = An index for inflation to convert research costs to 2004/05 dollars

22.5.3 Results

The analysis examined the benefits in terms of control cost savings following the release of biocontrol agents. The results of the analysis are presented in **Table 22.1**. The biocontrol program provides a positive return on investment at all discount rates, with a NPV of -$1.5 million and a BCR of 0.8 at a discount rate of 8.0%.

Table 22.1. Results of analysis

Real discount rate	NPV ($ million)	BCR
4.0%	$3.7	1.3
6.0%	$0.1	1.0
8.0%	-$1.5	0.8
10.0%	-$2.2	0.6

22.5.4 Sensitivity

Control cost savings (park land)

The breakeven value with respect to the control cost savings from biocontrol for park land ranges from $492,100/annum (4% discount rate) to $1.6 million/annum (10% discount rate), *ceteris paribus*. The control cost savings from biocontrol for park land is estimated to be approximately $829,800/annum, which assumes that 17% of the park land was infested with mimosa and controlled prior to biocontrol. However, there is limited data with which to confirm the accuracy of this estimate.

Table 22.2. Sensitivity analysis

Variable	Units	Base case	Breakeven point at 4% discount rate [(a)]	Breakeven point at 10% discount rate [(a)]
Control cost savings (Park Land)	$/annum	$829,800	$492,100	$1.6 million

Note: [(a)] The breakeven value is the value of the input where the NPV for the specified discount rate equals 0.

Table 22.3 outlines the NPV and BCR of the mimosa program for a range of control cost savings based on the proportion of park land controlled using chemical spraying in the absence of biocontrol at an 8% discount rate. The breakeven value at an 8% discount rate is 24.9% of park land controlled using chemical spraying, equating to a cost saving of approximately $1.2 million. As such this variable, and subsequently the control cost savings, has some influence on the results and findings of the analysis.

Table 22.3. NPV and BCR of mimosa, park land control, 8% discount rate

Proportion of park land controlled using chemical spraying in the absence of biocontrol	Control cost saving ($/annum)	NPV ($ million)	BCR
10%	$480,000	-$3.0	0.6
20%	$960,000	-$1.0	0.9
30%	$1,440,000	$1.0	1.1
40%	$1,920,000	$3.0	1.4
50%	$2,400,000	$5.0	1.7
60%	$2,880,000	$7.0	1.9
70%	$3,360,000	$9.0	2.2
80%	$3,840,000	$11.0	2.4
90%	$4,320,000	$12.0	2.7
100%	$4,800,000	$15.0	3.0

22.5.5 Limitations of the analysis

This analysis has only included the benefits already received in terms of reduced control costs, and does not take into account probable improvements in the level of biocontrol as newly-established agents increase and spread. Further, the measured benefits are considered to be an underestimate of the actual benefits received, as the following benefits were not included:

- Productivity is improved through the control of the weed by decreasing the competitiveness of the weed in infested areas and reducing the size of infestations, which reduces interference with stock mustering, watering and irrigation and the smothering of pastures;
- Reduced threat to other areas (northeast WA and much of Queensland) from reduced seed production which reduces risk of seed transport on vehicles, stock and fishing and camping gear;
- Reduced threat to tourism (especially in Kakadu) by reducing the competitiveness of mimosa and, subsequently, reducing its ability to invade natural ecosystems and reduce their attractiveness;
- Reduced competitiveness also improves biodiversity by allowing displaced native fauna and flora to re-establish;
- The reduction in chemical control due to biocontrol provides an additional benefit in terms of reduced toxicity, improved water quality, improving environmental health and reducing non-target impacts to plants and animals;
- Improved access to, and recreational use of, waterways (including fishing) through reduced vigour and seed production of mimosa; and
- Reduced threat to, and maintenance of, cultural values.

No data is available to quantify these benefits. As such the benefits of the mimosa biocontrol program are expected to be understated in this analysis.

22.6 Summary

The mimosa biocontrol program resulted in the release of thirteen agents, nine of which became established. The program is estimated to have cost a total of $21.6 million, resulting in a NPV of -$1.5 million and a BCR of 0.8 at a discount rate of 8.0%. This is considered to be an underestimate of the benefits of the program as it does not include:

- Improved biocontrol as recently-established agents increase and spread;
- Any potential productivity gains;
- Any potential gains to the tourism industry;
- Any environmental benefits; and
- Any recreational or cultural benefits.

Table 22.4. Summary of program benefits / costs

Type of benefit	Benefit / Cost	Detail
Economic	Reduced cost of control in productive land	Control cost saving in productive land of $640,000 per annum.
	Reduced cost of control in park land	Control cost saving in park land of $829,800 per annum.
	Improved productivity [(a)]	• Improved stock mustering; • Improved stock watering; • Reduced interference with irrigation; and • Increased carrying capacity.
	Reduced threat to tourism (especially in Kakadu) [(a)]	Improved attractiveness of natural ecosystems, reducing the threat the tourism industry.
Environmental	Improved biodiversity [(a)]	• Reduced displacement of native waterbirds (including the magpie goose) and other fauna; and • Reduced suppression of other vegetation.
	Reduced chemical toxicity	Improved environmental health and reduced impacts to non-targeted plants and animals.
Social	Improved recreational enjoyment [(a)]	Improved access to, and recreational use of, waterways (including fishing).
	Increased cultural sustainability [(a)]	Reduced threat to, and maintenance of, cultural values.

Note: [(a)] These benefits/costs were already provided to some degree by control methods used prior to the biocontrol program, thus these benefits/costs can not be solely attributed to biocontrol. Due to data limitations the impact of biocontrol in relation to these benefits/costs has not been separated from the impact of prior control methods.

23. *Onopordum* spp. (scotch, stemless and Illyrian thistles)

23.1 References

Allan, C.J. and Holst, P.J. (1996)

D. Briese, CSIRO Division of Entomology, unpublished data (2002)

Briese, D.T., Pettit, W.J. and Walker, A. (2004)

M. Smyth, CSIRO Division of Entomology, *pers. comm.*, 2005

Sindel, B.M. (1991)

Woodburn, T.L. and Briese, D.T. (1996)

23.2 Background and biology

Onopordum spp. (scotch, stemless and Illyrian thistles) grow in temperate or warm-temperate winter rainfall areas.

23.3 Establishment and impact

These thistles were first recorded as weeds in Victoria in the 1850s and are now established on grazing lands throughout southern Australia.

Scotch and Illyrian thistles infest an area of approximately 1.1 million hectares, with scotch thistle covering approximately 80,000 hectares in Victoria, while stemless thistles infest approximately 1.6 million hectares in total. Stemless thistles are worst in Western Australia and southern Australia.

These thistles are competitive weeds of pasture, are not eaten by stock, reduce the carrying capacity of pastures and cause vegetable fault in wool.

23.4 Biological control program

The scotch, stemless and Illyrian thistle biocontrol program resulted in the release of seven agents, four of which have become established, and two cause significant damage. *Larinus latus* seed-weevil significantly reduces seed production at some sites with seed suppression increasing over time. If this continues, a reduction in soil seed bank will result.

Lixus cardui stem-boring weevil (released 1993) can, at very high densities, reduce plant height by greater than 60% and seed production by greater than 80%.

23.4.1 Development cost

The scotch, stemless and Illyrian thistle program began in 1988 and is ongoing. It is estimated to have cost a total of approximately $3.7 million.

23.5 Cost benefit analysis

Briese (2002) estimates that the scotch, stemless and Illyrian thistle biocontrol program provides a positive return on investment at all discount rates from 4% to 10%, with a NPV of $18.0 million and a BCR of 9.6 at a discount rate of 8%[9].

Table 23.1. Results of analysis

Real discount rate	NPV ($ million)	BCR
4.0%	$56.0	21.6
6.0%	$31.3	14.2
8.0%	$18.0	9.6
10.0%	$10.6	6.7

23.6 Summary

The scotch, stemless and Illyrian thistle biocontrol program resulted in the release of seven agents, four of which have become established. The program is estimated to have cost a total of $3.7 million, resulting in a NPV of $18.0 million and a BCR of 9.6 at a discount rate of 8.0%.

[9] A CBA for this biocontrol program was conducted by D. Briese in 2002. The model used has been updated with additional research and expenditure through to 2005 and all data inflated to 2004/05 dollar terms.

Table 23.2. Summary of program benefits / costs

Type of benefit	Benefit / Cost	Detail
Economic	Improved productivity	At full distribution (estimated to occur in 2017) biocontrol will reduce productivity losses by approximately $7.4M per annum, comprised of: • Increased carrying capacity of land; and • Reduced vegetable fault in wool.

24. *Opuntia* spp. (prickly pears)

24.1 References

Coyle, P.H. (1990)

Dodd, A.P. (1958)

Government Statisticians Office (2004)

Hosking, J.R. and Deighton, P.J. (1979)

Hosking, J.R., McFadyen, R.E. and Murray, N.D. (1988)

Hosking, J.R., Sullivan, P.R. and Welsby, S.M. (1994)

J. Hosking, NSW Department of Primary Industries, *pers. comm.*, 2005

Johnston, W.R. (1982)

Reserve Bank of Australia

Walton, C. (2005)

White, G.G. (1980)

24.2 Background and biology

As there are several species of pest prickly pear, this section will provide an overview of some of these and then examine the impact of the genus overall.

24.2.1 *Opuntia aurantiaca*

Opuntia aurantiaca grows in warm-temperate to subtropical semi-arid areas, particularly along streams. It was first noted in NSW in 1883 and was recognised as a problem in NSW and Queensland in 1911. *Opuntia aurantiaca* is also naturalised in Victoria. By 1932 thousands of hectares were infested in southern Queensland and northern NSW. By 1988 it covered approximately 200,000 hectares in NSW.

Opuntia aurantiaca is drought resistant and not usually grazed due to spines. It forms dense thickets creating an impenetrable barrier. Spines on this cactus may cause injury to humans and animals.

Biocontrol using the cochineal insect, *Dactylopius austrinus*, was effective in Queensland and NSW. *Opuntia aurantiaca* is now only a minor problem in Queensland and NSW.

24.2.2 *Opuntia stricta* (including a form previously known as *Opuntia inermis*)

Opuntia stricta grows in semi-arid savannas in warm-temperate, subtropical and tropical regions. It is capable of growing in both exposed and semi-shaded situations.

Opuntia stricta was first recorded in NSW in 1839 and by 1900 covered four million hectares in NSW and Queensland. In 1920 *Opuntia stricta* was forcing approximately 400,000 hectares of land out of production each year and by 1926 had covered 24 million hectares, with at least half of this area totally abandoned for grazing. The worst areas were central and southern Queensland, northern NSW inland from the Great Dividing Range and the Hunter Valley. At its peak *Opuntia stricta* was spreading at approximately 100 hectares/hour.

The cactoblastis moth *Cactoblastis cactorum* was introduced in 1925. By 1933 more than 90% of prickly pear in Queensland and NSW had been destroyed by the moth. In parts of NSW *Opuntia stricta* is not controlled by cactoblastis but in these areas another cochineal, *Dactylopius opuntia*, provides adequate control. There are also a number of small *Opuntia stricta* infestations in Victoria, South Australia and Western Australia.

24.2.3 *Opuntia monacantha* (previously known as *Opuntia vulgaris*)

Opuntia monacantha grows in moist and semi-arid warm temperate to subtropical and tropical regions and was probably introduced with the First Fleet in 1788. It is widespread but not present over large areas in Australia. *Opuntia monacantha* occurs in all mainland States but is not a major weed anywhere.

Biocontrol using a cochineal, *Dactylopius ceylonicus*, has been effective in parts of Australia and has probably restricted the spread and establishment of *Opuntia monacantha*.

24.2.4 Other *Opuntia* spp. and *Cylindropuntia imbricata*

Opuntia dillenii also occupied large areas in Queensland and was controlled by cactoblastis. *Opuntia streptacantha*, *Opuntia tomentosa* and *Cylindropuntia imbricata* (previously *Opuntia imbricata*) were three other species targeted for biocontrol. These cacti are controlled using a combination of biocontrol agents and manual control. *Dactylopius opuntiae* will control *Opuntia streptacantha* and *Opuntia tomentosa* as long as the plants are first cut down, and cactoblastis causes some damage to small plants of both species. A fourth cochineal species, *Dactylopius tomentosus*, will destroy *Cylindropuntia imbricata* if plants are cut down.

A number of other cactus species have subsequently been controlled by agents brought in to control the afore mentioned cactus species.

24.3 Biological control program

24.3.1 Development cost

The prickly pear biocontrol program began with some overseas exploration in 1903, however research costs have been provided from 1919 only. Between 1919 and 1939 a total of approximately $18.1 million was spent on biocontrol, while approximately a further $3.0 million was spent between 1978 and 1987.

24.4 Cost benefit analysis

24.4.1 Data inputs

Value added of agricultural production

The value added of agricultural production in the Darling Downs from control of *Opuntia stricta* and *Opuntia dillenii* is estimated to be approximately $841.7 million in 2004/05.

Area opened up for agricultural production

It is estimated that approximately 70% of productive land currently used for agricultural purposes in the Darling Downs was previously infested by prickly pear and cleared by biocontrol.

Reduction in benefit from mechanisation

The development of new machinery in the 1960s capable of farming even dense prickly pear infested areas reduced the benefit received from biocontrol beyond this point in time. It is estimated that this reduction is approximately 50% of the benefit received prior to mechanisation, which implies that 50% of the area that would have been infested would have been able to be utilised from the 1960s on. This is an estimate based on the following:

- The heavy tractors could plough dense infestations to use the land for cropping; and
- Control of dense prickly pear infestations for pastoral production land would still have been uneconomic.

Distribution of biocontrol

Biocontrol is estimated to have taken 5 years to build up to 90% efficacy and a further 15 years to build up to 100% efficacy (where 100% is equal to the current level of control).

24.4.2 Model

A CBA model was used in this analysis as described in Section I. The analysis examined the benefits and costs that accrue due to replacement of pre-research control of prickly pear with biocontrol. The net impact was identified by comparing the benefits and costs of the previous control with the benefits and costs since biocontrol. The net benefit of the program is estimated by the equation below:

$$NB = BA - RC$$

Where:

NB = The net benefit from the biocontrol of prickly pear program ($)

BA = The benefit to agricultural production in the Darling Downs following adoption of biocontrol measures ($)

RC = The cost of research ($)

The benefit to agricultural production in the Darling Downs following adoption of biocontrol is estimated using the equation below:

$$BA = \sum_{n=50}^{1} (VA \times AO) \times (1 - MC_n) \times D_n$$

Where:

VA = The agricultural value added production in the Darling Downs ($/annum)

AO = The total proportion of the Darling Downs agricultural production area opened up by biocontrol (%)

MC = The reduction in benefits due to mechanisation (%)

D = The efficacy of biocontrol in year *n* (%)

n = Year

The cost of undertaking the research is calculated using the equation below:

$$RC = \sum_{n=50}^{1} CR_n \times CI_n$$

Where:

CR = The research costs incurred in year *n* ($)

CI = An index for inflation to convert research costs to 2004/05 dollars

24.4.3 Results

The analysis examined the benefits to agricultural production in the Darling Downs following the release of biocontrol agents. The results of the analysis are presented in **Table 24.1**. The biocontrol program provides a positive return on investment at all discount rates, with a NPV of approximately $3.1 billion and a BCR of 312.3 at a discount rate of 8.0%.

Table 24.1. Results of analysis

Real discount rate	NPV ($ million)	BCR
4.0%	$7,180.3	552.2
6.0%	$4,626.3	410.0
8.0%	$3,100.4	312.3
10.0%	$2,148.6	243.0

24.4.4 Sensitivity

Area opened up for agricultural production

Biocontrol is known to have opened up large tracts of previously heavily-infested and unusable land in the Darling Downs that is now used for agricultural production. However, exact figures on the amount of land that was reclaimed for agriculture is unknown.

This analysis has used an estimate that 70% of the current Darling Downs agricultural land area was previously unusable due to prickly pear infestation. **Table 24.2** provides estimates of the NPV and BCR of the prickly pear biocontrol program for changes in the area of land opened up for agriculture in the Darling Downs ranging between 30% and 90% of the current production area.

Even at a level of just 30% (considered a very low estimate since nearly the entire Darling Downs was previously heavily infested by prickly pear) the biocontrol program provides a NPV of approximately $1.3 billion and a BCR of 133.9. As such this variable is not considered critical to the findings of the analysis.

Table 24.2. NPV and BCR of prickly pear, area opened up for agricultural production, 8% discount rate

Area opened up for agricultural production	NPV ($ million)	BCR
30%	$1,323.0	133.9
35%	$1,545.2	156.2
40%	$1,767.4	178.5
45%	$1,989.5	200.8
50%	$2,211.7	223.1
55%	$2,433.9	245.4
60%	$2,656.0	267.7
65%	$2,878.2	290.0
70%	$3,100.4	312.3
75%	$3,322.5	334.6
80%	$3,544.7	356.9
85%	$3,766.9	379.2
90%	$3,989.0	401.6

24.4.5 Limitations of the analysis

The benefits in this analysis refer to production benefits achieved in the Darling Downs following the release of biocontrol agents. This is considered an underestimate of the production gains as prickly pear infested and led to the abandonment of land used for agriculture in other areas of Queensland and in NSW. However, there is limited data available identifying how much previously infested land has been opened up for agriculture in areas other than the Darling Downs. Ideally, this information would be available in order to provide a more accurate analysis.

This analysis also does not include environmental benefits of biocontrol, such as improved biodiversity and reduced toxicity of chemical control, or any health benefits in terms of reduced risk of injury from prickly pear spines.

All of these benefits, if quantified, would be expected to lead to an increase in the NPV and BCR of the prickly pear biocontrol project.

24.5 Summary

The prickly pear biocontrol program resulted in the release of twenty biocontrol agents, with fourteen established some of which have since disappeared. The program is estimated to have cost a total of $21.1 million, resulting in a NPV of $3.1 billion and a BCR of 312.3 at a discount rate of 8.0%. This is considered to be an underestimate of the total benefits of the program, largely because it does not include productivity gains in areas outside of the Darling Downs.

Table 24.3. Summary of program benefits / costs

Type of benefit	Benefit / Cost	Detail
Economic	Improved productivity	Increased productivity in the Darling Downs of approximately $589.2M per annum at full distribution (1947 onward). This benefit is considered to be reduced by approximately 50% since the 1960's due to improved mechanisation.
Environmental	Improved biodiversity	Improved biodiversity due to reduced competitiveness of prickly pear, allowing native flora to re-establish.
	Reduced chemical toxicity	Improved environmental health and reduced impacts to non-targeted plants and animals due to the reduction in arsenic pentoxide use.
Social	Injuries from spines	Fewer injuries caused by prickly pear spines.

25. *Parkinsonia aculeata* (parkinsonia)

25.1 References

R. McFadyen, Weeds CRC, *pers. comm.*, 2005

R. van Klinken, CSIRO Division of Entomology, *pers. comm.*, 2005

van Klinken, R. (2005)

25.2 Background and biology

Parkinsonia aculeata (parkinsonia) is a many-branched, thorny, spreading shrub or small tree that can grow to 2–8 metres high. It grows in semi-arid tropics and subtropics on a wide range of soils near water, yet it is relatively drought-tolerant.

25.3 Establishment and impact

Parkinsonia was introduced to Australia in the late 1800s and was planted by pastoralists around dams, bores and homesteads. It has since become widespread across Western Australia, Northern Territory, Queensland and northern NSW. It currently infests approximately 1 million hectares, but has the potential to spread much further.

Parkinsonia produces a large number of seeds that can remain viable in the soil for many years. Pods are dispersed by floating on water. Seeds are probably also spread in mud on animals and machinery. Mass germination events follow rainfall.

Parkinsonia is extremely hardy and forms dense thickets especially along creeks and rivers. It reduces pasture productivity, hinders mustering, restricts access to water and is not readily browsed by cattle.

25.4 Biological control program

Research on biological control was a joint project between Western Australia, Northern Territory and Queensland beginning in 1983. Only one insect, the seed weevil *Penthobruchus germaini*, has become widely established. In some cases it destroyed up to 99% of seeds but it has a high egg mortality from native parasitoids. No agents are having a significant impact on parkinsonia survival or reproduction at present.

25.4.1 Development cost

The parkinsonia biocontrol program ran for eight years from 1983 and the research is estimated to have cost a total of approximately $1.6 million.

25.5 Cost benefit analysis

No CBA has been conducted as there is believed to have been no significant economic benefits from the released biocontrol agents.

25.6 Summary

It is estimated that biocontrol has had no significant economic benefits.

26. *Parthenium hysterophorus* (parthenium)

26.1 References

Adamson, D. and Bray, S. (1999)

AEC*group* (2002)

Armstrong, T.R. (1978)

Auld, B.A., Hosking, J. and McFadyen, R.E. (1983)

Chippendale, J.F. and Panetta, F.D. (1994)

Dhileepan, K. (2001)

Dhileepan, K. (2003)

Dhileepan, K., Setter, S.D. and McFadyen, R.E. (2000)

Kloessing, K. (1994)

Tana, T. and Navie, S. (2001)

26.2 Background and biology

Parthenium hysterophorus (parthenium) is an erect and multi-branched ephemeral herb known for its vigorous growth, to 1.5 metres tall (occasionally to 2 metres). The young plant forms a basal rosette.

Parthenium grows in the tropics and subtropics on a wide range of soils but prefers heavier, fertile clay soils and does not tolerate heavy shade. In Australia it grows predominantly in pasture areas.

26.3 Establishment and impact

Parthenium was probably introduced in southeast Queensland during WWII but the major infestations resulted from contaminated pasture seed imported from the USA in 1958. It was recognised as a serious pest in Queensland in 1974 after a series of wet years. During the 1970s it spread at an exceptional rate and has since become a dominant weed over thousands of hectares of grazing land in sub-coastal districts of Queensland.

Parthenium has the potential to spread greatly throughout the warm and temperate-humid and sub-humid regions of Australia. By 1991 it was present throughout 170,000 square kilometres of Queensland (10% of State) causing annual losses to beef producers of approximately $16.5 million through reduced stocking rates, reduction in daily live weight gain and additional production and control costs. It was estimated in 1996 that if it continued to spread throughout its potential distribution range in Australia it could cost the beef industry between $109–$129 million per year.

It is an aggressive coloniser of disturbed land and has the ability to disperse long distances in mud and other debris adhering to machinery, vehicles and livestock. Parthenium is a prolific seed producer, capable of producing up to 15,000 seeds/plant, with a soil seed bank in Australia measured between 3,000–40,000 seeds/square metres. Seeds remain viable in the soil for greater than six years. Parthenium rapidly becomes the dominant plant species and excludes other species resulting in a monoculture, especially in overgrazed pastures.

Parthenium is normally unpalatable to stock, is poisonous and may taint meat (particularly mutton) if eaten. Parthenium also poses a potential threat to cropping and creates market access problems for producers in regions where it is present.

Other impacts of parthenium include:

- Allelopathic effects on other plants;
- Can be an alternate host for some pest species;
- Can contaminate other produce (eg: seed, grain and forage) with subsequent restrictions on sale and movement; and
- Has required the construction of expensive wash-down facilities for vehicles and machinery.

It is a major health threat to humans due to allergenic dermatitis and asthma (10% of property workers in infested areas are affected).

It is a significant environmental weed, which can cause total habitat change in native grasslands, the herbaceous layer in woodlands, floodplains and along rivers.

26.4 Biological control program

The parthenium biocontrol program began in 1977 and finished in 2004. A total of nine insects and two rust diseases were released, all of which established except one insect. Effective biocontrol is largely due to the impact of three insects and the rusts.

Zygogramma bicolorata leaf beetle was released in 1980 and became abundant from 1990. It causes 91–100% defoliation, which resulted in reductions in:

- Weed density by 32–93%;
- Plant height by 18–65%;
- Plant biomass by 55–89%;
- Flower production by 75–100%;
- Soil seed bank by 13–86%; and
- Seedling emergence in following season by 73–90%.

From these factors it is expected that there will be a reduced density of parthenium weed in 6–7 years.

Epiblema strenuana stem-galling moth (released 1982) reduces plant vigour and flower production which is reducing the soil seed bank. *Smicronyx lutulentus* seed feeding weevil (released 1980) became widely established by 1992 and is reducing the seed production in at least the southern areas of infestation.

Other agents released between 1980 and 1996 have established and are increasingly reducing the vigour of the weed.

Data on soil seed banks by Navie and Adkins (2001) show a continuing decline in parthenium seed bank over the 5 years to 2000, most probably due to the activity of biocontrol agents. This decline has continued since.

26.4.1 Development cost

The parthenium biocontrol program began in 1977 and exploration and new releases finished in 2004. It is estimated to have cost a total of approximately $11.0 million.

26.5 Cost benefit analysis

It is estimated that parthenium biocontrol program provides a positive return on investment at all discount rates from 4% to 10%, with a NPV of $33.3 million and a BCR of 7.2 at a discount rate of 8%[10].

Table 26.1. Results of analysis

Real discount rate	NPV ($ million)	BCR
4.0%	$7,180.3	552.2
6.0%	$4,626.3	410.0
8.0%	$3,100.4	312.3
10.0%	$2,148.6	243.0

26.6 Summary

The parthenium biocontrol program resulted in the release of eleven agents, ten of which have become established. The program is estimated to have cost a total of $11.0 million, resulting in a NPV of $33.3 million and a BCR of 7.2 at a discount rate of 8.0%.

Table 26.2. Summary of program benefits / costs

Type of benefit	Benefit / Cost	Detail
Economic	Allelopathic effects on other plants (pasture)	Annual average benefit to sown pasture of approximately $380,000 and $986,000 to native pastures.
	Contaminate other produce (seed, grain and forage)	Market restrictions, price penalties for sellers and price premiums in some areas that are clear.
	Led to the construction of expensive wash-down facilities	Capital construction and operating costs of the facility as well as the time of users.
Environmental	Change in native flora and fauna	Can cause total habitat change in native grasslands, woodlands, along rivers and floodplains.
	Alternate host for some pest species	Changing the natural balance of the area and encouraging exotics into the region.
Social	Health threat to humans due to allergenic dermatitis and asthma	10% of property workers in infested areas affected, average annual cost in medical treatment of approximately $8.0 million.

[10] A CBA for this biocontrol program was conducted by AEC*group* in 2002 based on data from Adamson and Bray (1999). The model used has been updated with additional research and expenditure through to 2005 and all data inflated to 2004/05 dollar terms.

27. *Prosopis* spp. (mesquite)

27.1 References

AEC*group* (2002)

W.A. Palmer, Queensland Department of Natural Resources and Mines, *pers. comm.*, 2005

R. McFadyen, Weeds CRC, *pers. comm.*, 2005

R. Van Klinken, CSIRO Division of Entomology, *pers. comm.*, 2005

Reserve Bank of Australia (2005)

Van Klinken, R.D., Fichera, G. and Cordo, H. (2003)

27.2 Background and biology

Prosopis spp. (mesquite) is either a thorny multi-stemmed shrub 3–5 metres high, with branches drooping to ground level or a single-stemmed tree to 15 metres in height. It can be extremely long-lived (greater than 170 years).

Mesquite grows in semi-arid tropics and subtropics and becomes most dense where it has ready access to the water table. Established plants are very drought-tolerant having one of the most extensive root systems of any plant in the world. It also has large carbohydrate reserves in roots and can actively grow even during prolonged drought. It has the ability to defoliate to survive adverse conditions and produce rapid growth during favourable conditions.

27.3 Establishment and impact

Mesquite was first introduced to Australia around 1900 and quickly spread. In Western Australia an infestation originating from two trees planted at Mardie Station in the 1930s now covers 30,000 hectares of dense mesquite and 120,000 hectares of scattered plants, over a total area of infestation of greater than 250,000 hectares.

In other States the spread has been less rapid but has the potential to be much greater if control efforts ceased. In Queensland there is a core infestation in the southwest of the state of 4,000 hectares and scattered plants over 300,000 hectares. In NSW mesquite occurs as scattered plants over approximately 27,000 hectares. Current infestations in Australia cover approximately 800,000 hectares.

All Australian mainland States and Territories have favourable conditions for growth of mesquite, except for very wet or very cold areas. Semi-arid or arid areas are at greatest risk of invasion. In Western Australia alone, potential distribution is greater than 25 million hectares in the Pilbara and Kimberley regions, and greater than 500,000 hectares near Derby.

The spread of mesquite is usually through stock or other animals ingesting and voiding seeds with rapid spread occurring after significant rain events. Mesquite also has substantial seed production with seed dormancy of several years. Mesquite is an aggressive competitor in rangelands and forms dense thickets resulting in:

- Complete loss of grass cover;
- Reduced available grazing area;
- Mustering difficulties;
- Damage to fencing and other infrastructure;
- Restricted access to water;
- Erosion;
- Tyre punctures; and
- Human injuries (approximately $20,000/year is spent on medical treatment of injuries caused by the thorns).

Environmental problems caused by mesquite include lost biodiversity, damage to watercourses and providing cover for feral animals. Production losses in northwest Queensland were estimated at approximately $25,000/year.

Mesquite also provides shade for stock, produces good timber and fuel and the pods make good fodder.

In Queensland the Strategic Weed Education and Eradication Program (SWEEP) spent $3.98 million on mesquite control between 1995 and 2000, which was supplemented by over $614,000 spent by landholders. In Western Australia approximately $80,000–$90,000 per year was spent on control prior to biocontrol.

27.4 Biological control program

The mesquite biocontrol program began in 1992 and is ongoing. Several insects were released but only one is having any significant impact.

The leaf-tying moth *Evippe* sp. is causing significant damage in the Pilbara of Western Australia where it can result in the death of 50–100% of leaves and prolonged defoliation across the 150,000 hectare infestation.

Mesquite is no longer seen as an intractable problem in the Pilbara, with seed production and seedling recruitment down to almost zero. However, the situation is complicated by a prolonged drought, with the full impact of the biocontrol program only apparent once

the full climatic cycle has been observed. Herbicide usage is increasing as landowners see some hope of significantly reducing existing populations once the vigour of plants is reduced by the biocontrol.

27.4.1 Development cost

The mesquite biocontrol program began in 1992 and is ongoing. It is estimated to have cost a total of $2.3 million.

27.5 Cost benefit analysis

27.5.1 Data inputs

Cost of control

The cost of controlling mesquite in Western Australia is estimated to have averaged $85,000/annum prior to biocontrol, while prior to biocontrol the SWEEP program in Queensland was estimated and expected to spend the following:

- $1.0 million in 1999 to 2005;
- $0.5 million in 2006 to 2010;
- $0.25 million in 2011 to 2020; and
- $0.1 million in 2021 onwards.

Medical expenses

The annual cost of medical treatment due to mesquite is estimated to be $20,000.

Distribution of biocontrol

Biocontrol is estimated to be 25% effective in controlling mesquite, with efficacy building up over an eight year period from initial release.

27.5.2 Model

A CBA model was used in this analysis as described in Section I. The analysis examined the benefits and costs that accrue due to replacement of pre-research control of mesquite with biocontrol. The net impact was identified by comparing the benefits and costs of the previous control with the benefits and costs since biocontrol. The net benefit of the program is estimated by the equation below:

$$NB = QCS + WCS + HB - RC$$

Where:

NB = The net benefit from the biocontrol of mesquite program ($)

QCS = The control cost savings in Queensland following adoption of biocontrol measures ($)

WCS = The control cost savings in Western Australia following adoption of biocontrol measures ($)

HB = The cost saving on medical treatment following adoption of biocontrol measures ($)

RC = The cost of research ($)

The control cost savings in Queensland following adoption of biocontrol is estimated using the equation below:

$$QCS = \sum_{n=50}^{1} SW_n \times D_n$$

Where:

SW = The estimated cost of the SWEEP program in year *n* ($/annum)

D = The efficacy of biocontrol in year *n* (%)

n = Year

The control cost savings in Western Australia following adoption of biocontrol is estimated using the equation below:

$$WCS = \sum_{n=50}^{1} WS_n \times D_n$$

Where:

WS = The estimated cost of control in WA in year *n* ($/annum)

The cost saving on medical treatment following adoption of biocontrol is estimated using the equation below:

$$HB = \sum_{n=50}^{1} ME \times D_n$$

Where:

ME = The estimated annual cost of medical treatment due to mesquite ($/annum)

The cost of undertaking the research is calculated using the equation below:

$$RC = \sum_{n=50}^{1} CR_n \times CI_n$$

Where:

CR = The research costs incurred in year *n* ($)

CI = An index for inflation to convert research costs to 2004/05 dollars

27.5.3 Results

The analysis examined the benefits to the Queensland and Western Australian Governments in terms of control cost savings following the release of biocontrol agents. The results of the analysis are presented in **Table 27.1**. The biocontrol program provides a negative return on investment at all discount rates, with a NPV of -$0.8 million and a BCR of 0.5 at a discount rate of 8.0%. This is considered an underestimate of the benefits of the program (see **Section 27.5.5**).

Table 27.1. Results of analysis

Real discount rate	NPV ($ million)	BCR
4.0%	-$0.3	0.8
6.0%	-$0.6	0.6
8.0%	-$0.8	0.5
10.0%	-$0.9	0.4

27.5.4 Sensitivity

Reduction in control costs

The breakeven value with respect to the reduction in control costs, in percentage terms, ranges from 30.1% (4% discount rate) to 62.2% (10% discount rate), *ceteris paribus*. The estimated level of control is 25.0%: this may reach as high as 50.0% over the next 10 years, although there is insufficient data to accurately identify this. As such this variable is considered critical to the findings of the analysis. Ideally more information would be available on both the exact reduction in seeding caused by biocontrol and the link between seeding reduction and expenditure on control, in order to provide a more accurate estimate on the benefits of biocontrol.

27.5.5 Limitations of the analysis

This analysis has only included the benefits received in terms of reduced control costs. These benefits are considered to be an underestimate of the actual benefits received, as the following benefits were not included:

- Increased productivity by:
  - Increasing the available grazing area;
  - Decreasing mustering costs;
  - Reducing damage to fences and other infrastructure;
  - Improving access to water; and
  - Fewer tyre punctures; and
- Reduced negative environmental impacts such as:
  - Erosion;
  - Loss of biodiversity;
  - Damage to watercourses; and
  - Provision of shelter for feral animals.

No data is available to quantify these benefits. As such the benefits of the mesquite biocontrol program are expected to be understated in this analysis.

27.6 Summary

The mesquite biocontrol program has resulted in the release of four biocontrol agents, all of which have become established. The program is estimated to have cost a total of $2.3 million, resulting in a NPV of -$0.8 million and a BCR of 0.5 at a discount rate of 8.0%. However, due to the significant level of benefits that were not able to be quantified and were subsequently excluded it is expected that the overall benefits of the mesquite biocontrol program would outweigh its cost.

Table 27.2. Sensitivity analysis

Variable	Units	Base case	Breakeven point at 4% discount rate [(a)]	Breakeven point at 10% discount rate [(a)]
Reduction in control costs	%	25%	30.1%	62.2%

Note: [(a)] The breakeven value is the value of the input where the NPV for the specified discount rate equals 0.

Table 27.3. Summary of program benefits / costs

Type of benefit	Benefit / Cost	Detail
Economic	Control cost savings	Control cost saving in Queensland of approximately: • $125,000 per annum between 2006 and 2010; • $62,500 per annum between 2011 and 2020; and • $25,000 per annum thereafter. Control cost saving in WA of approximately $21,250 per annum from 2006 onwards.
	Improved productivity [(a)]	• Increasing the available grazing area; • Reducing mustering costs; • Reducing damage to fences and other infrastructure; • Improving access to water; and • Reducing the number of tyre punctures.
	Reduced benefits from mesquite [(a)]	Reduced/lost: • Shade for stock; • Options for timber; • Fuel sources; and • Fodder options.
Environmental	Improved biodiversity and environmental sustainability [(a)]	Decreased: • Erosion; • Loss of biodiversity; • Damage to watercourses; and • Shelter for feral animals.
Social	Reduction in injury [(a)]	Reduced cost of medical treatment due to injury from thorns of approximately $5,000/annum.

Note: [(a)] These benefits/costs were already provided to some degree by control methods used prior to the biocontrol program, thus these benefits/costs can not be solely attributed to biocontrol. Due to data limitations the impact of biocontrol in relation to these benefits/costs has not been separated from the impact of prior control methods.

28. *Rubus fruticosus* agg. (blackberry)

28.1 References

E. Bruzzese, Victorian Department of Primary Industries, *pers. comm.*, 2005

James, R. and Lockwood, M. (1998)

R. Kwong, Victorian Department of Primary Industries, *pers. comm.*, 2005

Reserve Bank of Australia (2005)

28.2 Background and biology

Rubus fruticosus agg. (blackberry) are perennial, scrambling, prickly shrubs that often form large clumps 1–7 metres high. They mostly grow in humid temperate regions on fertile soils with rainfall greater than 750 millimetres, but will also grow in drier areas alongside streams. There are at least 14 taxa of blackberry in Australia.

28.3 Establishment and impact

The earliest record of blackberry in Australia was in 1842 in Adelaide. Blackberry was promoted by acclimatisation societies in the 1860s and was recognised as an important weed in the 1880s. Blackberry occurs in all States except the Northern Territory and is of particular importance in NSW, Victoria and Tasmania. It is considered to have reached the climatic limits of its potential range in Australia, but within this range many large areas of bushland are still free of blackberry infestation.

Blackberry is a prolific seed producer with a single plant producing between 170,000–400,000 seeds/year and thickets producing 7,000–13,000 seeds/square metre. These seeds are dispersed widely by birds and foxes.

In 1958 there were approximately 146,000 hectares of infested land in Victoria and by 1975 there were approximately 663,000 hectares. By 1984 this had grown to approximately 3 million hectares of blackberry in Victoria with:

- 460,000 hectares of dense infestation;
- 380,000 hectares of medium infestation; and
- 2,200,000 hectares of sparse infestation.

In 1984 there were approximately 5,000 hectares of blackberry in Western Australia and 5.6 million hectares in NSW with:

- 151,000 hectares of dense infestation;
- 1,220,000 hectares of medium infestation; and
- 4,383,000 hectares of sparse infestation.

Overall, there was approximately 2.5 million hectares of dense or medium infestation in Australia in 1984 and this was estimated to increase to 8.8 million hectares in Australia by 2003.

Blackberry is a major weed of pastures, native forests and along streams and gullies. In 1984 the annual production loss and cost of control to NSW, Victoria and Tasmania was estimated to total $42.1 million (without taking into account social or biodiversity costs). In contrast, the benefits provided by blackberry were estimated to be just $660,000/annum. By 1990 losses and costs had increased to at least $70 million/year.

Blackberry is highly invasive and covers large areas with a dense canopy, which completely dominates all vegetation in an area in a very short time. It reduces natural diversity of vegetation in natural ecosystems and subsequently reduces recreational values of public land. It is not eaten by sheep or cattle and sheep can become tangled in thickets and die. It affects wildlife habitats and provides an important food source for undesirable exotic, as well as native, birds, restricts access to land and water, harbours pest animals and poses a serious fire hazard. Blackberry also causes access and competition problems in forestry operations.

Benefits of blackberry include fruit that are consumed by humans and by native animals, flowers that have value to apiarists and plants that provide safe nesting sites for many native birds. Blackberry is also grazed by goats and, when young, by sheep.

28.4 Biological control program

The rust fungus *Phragmidium violaceum* was first recorded in Australia in 1984, probably brought in illegally. It is now widely established. New more virulent strains were released in 2004 and are slowly spreading. The rust will reduce extensive infestations, slow down invasion of clean areas and generally make blackberry less competitive. However, this may take a number of years with mature infestations.

One of the main effects of the rust is to cause repeated defoliation that allows light penetration and germination of other plants. This continuous attack depletes root reserves and impacts on the weed's ability to compete. Rust epidemics result in fewer fruit and seeds, shorter canes and fewer new plants. On two blackberry taxa, a reduction in total biomass from the rust of respectively 56.2% and 38% and a reduction in daughter plant production of 95.8% was recorded as a result of rust infection.

However, on a population scale the changes are slow and gradual and may take more than 10 years for other plants to out-compete the weed. The rust is severe only in areas with annual rainfall greater than 800 millimetres and average daily summer temperatures of approximately 20ºC.

Each blackberry taxon has a different level of susceptibility to the rust fungus. The rust has been very effective on some, but these have been quickly overtaken by other, less competitive taxa that are resistant to the rust.

28.4.1 Development cost

The blackberry biocontrol program began in 1977 and is ongoing. The biocontrol program is estimated to have cost a total of approximately $4.9 million to date.

28.5 Cost benefit analysis

28.5.1 Data inputs

Infested area

Blackberry is estimated to infest approximately 8.8 million hectares in Australia.

Loss of production and cost of control

Blackberry is estimated to result in a loss of production and cost of control of between $95.1 million and $102.8 million. This equates to a loss of between $10.81/ha and $11.69/ha. In this analysis a conservative cost of $10.81/ha has been used.

Benefits of blackberry

Blackberry is estimated to provide a benefit of approximately $1.5 million per annum, equating to a benefit of $0.17/ha.

Distribution of biocontrol

The distribution of biocontrol is unclear. In this analysis it is estimated to have taken 10 years to reach its equilibrium effectiveness level and that biocontrol is 2.5% effective at maximum distribution (10% effectiveness over 50% of the weed's spread in 50% of years)[11].

28.5.2 Model

A CBA model was used in this analysis as described in Section I. The analysis examined the benefits and costs that accrue due to replacement of pre-research control of blackberry with biocontrol. The net impact was identified by comparing the benefits and costs of the previous control with the benefits and costs since biocontrol. The net benefit of the program is estimated by the equation below:

$$NB = BB - CB - RC$$

Where:

NB = The net benefit from the biocontrol of blackberry program ($)

BB = The benefit from biocontrol in terms of increased production and control cost savings following adoption of biocontrol measures ($)

CB = The cost of biocontrol in terms of lost benefit from blackberry following adoption of biocontrol ($)

RC = The cost of research ($)

The benefit from biocontrol in terms of increased production and control cost savings following adoption of biocontrol is calculated using the equation below:

$$BB = \sum_{n=50}^{1} LP \times D_n$$

Where:

LP = The loss of production and cost of control of blackberry prior to biocontrol ($/ha)

D = The distribution of biocontrol (%)

n = Year

The cost of biocontrol in terms of lost benefit from blackberry following adoption of biocontrol is calculated using the equation below:

$$CB = \sum_{n=50}^{1} IB \times D_n$$

[11] Expert opinion is that biocontrol of blackberry is realising at least a 10%–20% level of control over 50% of blackberry's range in 50% of years. A conservative figure of 10% has been used in this analysis.

Where:

IB = The benefit from blackberry prior to biocontrol ($/ha)

D = The distribution of biocontrol (%)

n = Year

The cost of undertaking the research is calculated using the equation below:

$$RC = \sum_{n=50}^{1} CR_n \times CI_n$$

Where:

CR = The research costs incurred in year *n* ($)

CI = An index for inflation to convert research costs to 2004/05 dollars

28.5.3 Results

The analysis examined the benefits in terms of control cost savings and increased productivity following the release of biocontrol agents. The results of the analysis are presented in **Table 28.1**. The biocontrol program provides a positive return on investment at all discount rates, with a NPV of $3.7 million and a BCR of 2.5 at a discount rate of 8.0%.

Table 28.1. Results of analysis

Real discount rate	NPV ($ million)	BCR
4.0%	$15.8	5.5
6.0%	$7.8	3.7
8.0%	$3.7	2.5
10.0%	$1.5	1.7

28.5.4 Sensitivity

Expert opinion is that biocontrol of blackberry is achieving some level of control, with the level and benefits outlined above considered to be a conservative estimate. **Table 28.2** outlines the expected NPV and BCR at an 8.0% discount rate over a range of control efficacies between 2.5% and 20%. The breakeven distribution for biocontrol of blackberry is 1.0%, which is below the conservative estimate of 2.5% used in this analysis. As this breakeven value is so low this variable is not considered to impact on the findings of the analysis of the program, however it does significantly alter the level of benefits provided by the program.

Table 28.2. NPV and BCR of blackberry at 8% discount rate, distribution range 2.5–20%

Biocontrol efficacy	NPV ($ million)	BCR
2.5%	$3.7	2.5
5%	$9.7	4.9
10%	$21.8	9.1
15%	$33.8	12.7
20%	$45.9	15.9

28.5.5 Limitations of the analysis

This analysis is limited mainly by the lack of data identifying the level of control that biocontrol has achieved. Anecdotal evidence indicates that at least between 10% and 20% control has been achieved over half the blackberry range in approximately 50% of years. A conservative estimate of 2.5% (10% control x 50% of range x 50% of years) has been used in this analysis, and even at this level of control the biocontrol program provides a positive return on investment. Without more detailed information it is unclear what level of success the biocontrol program has achieved from a financial viewpoint, although sensitivity analysis provides some indication of the range of these benefits.

Due to data limitations the analysis does not include environmental benefits such as increased biodiversity and social benefits such as improved recreational enjoyment of land. Quantification of these benefits would be expected to result in an increase in the NPV and BCR of the blackberry biocontrol program.

28.6 Summary

The blackberry biocontrol program has resulted in the release of one agent which has become widely established. The program is estimated to have cost a total of $4.9 million, with conservative estimates indicating that the program returns a NPV of $3.7 million and a BCR of 2.5 at a discount rate of 8.0%.

Table 28.3. Summary of program benefits / costs

Type of benefit	Benefit / Cost	Detail
Economic	Increased productivity	• Increasing the carrying capacity of land; • Reducing stock losses; • Improving access to land and water; and • Reducing access, competition and harvesting problems in forestry operations. Biocontrol is conservatively estimated to result in reduced losses to productivity of approximately $2.4M.
	Reduced benefits to honey industry	Reduced plant populations may have a negative impact on the honey industry, which receives annual benefits from blackberry worth approximately $1.5M, although it is likely to be small relative to the benefits of the biocontrol program.
Environmental	Increased biodiversity	Reduced vigour and competitiveness of blackberry allows light to penetrate otherwise dense thickets, allowing other plants to survive and increasing biodiversity.
	Provides safe nesting for many native birds	Reduced food and shelter for many native birds.
Social	Increased recreational values of public land	Increased recreational value of public land.

29. *Rumex* spp. (docks)

29.1 References

Bruzzese, E. and Cullen J.M. (1995)

G. Spunner, self employed dairy farmer, *pers. comm.*, 2005

J.K. Scott, CSIRO Division of Entomology, *pers. comm.*, 2005

R. Kwong, Victorian Department of Primary Industries, *pers. comm.*, 2005

29.2 Background and biology

Rumex spp. (docks) are weeds of arable, horticultural and pastoral lands as well as recreation areas, particularly in southwest Western Australia, generating a production loss of approximately $400,000 in 1975.

As there are a number of species of docks, this section will provide an overview of each and then examine the impact of the genus overall.

29.2.1 *Rumex brownii* (swamp dock/slender dock)

Rumex brownii (swamp dock/slender dock) is native to and widespread on the wetter, low lying areas of eastern Australia, and has become weedy in Western Australia.

Fruits readily attach to wool, fur, bags, clothing and other items, and can be toxic to stock. However, it is generally unpalatable and usually occurs as scattered individuals rather than dense stands.

29.2.2 *Rumex crispus* (curly dock) and *Rumex obtusifolius* (bitter dock)

Rumex crispus (curly dock) and *Rumex obtusifolius* (bitter dock) grow in cool to mildly warm temperate to subtropical regions across a wide range of fertile areas and prefer moist or wet soils. They are able to establish in grasslands, woodlands, riverbanks, and low-lying areas.

They are well established in the wetter areas of southern Australia and the fruits are well equipped for dispersal by wind, water, animals or humans.

Curly dock and bitter dock have a large crown and dense leaf growth that crowd out more desirable species and they can occur in a wide range of environments from coastal and tidal mudflats to occasionally subalpine areas. They are prolific seeders and aggressive colonisers generating approximately 60,000 seeds/plant.

29.2.3 *Rumex pulcher* (fiddle dock)

Rumex pulcher (fiddle dock) grows in warm temperate regions on a wide range of moist soils. At present it is confined to the southern quarter of Australia and is most serious in southwestern Western Australia where in some districts it is the dominant weed species on 80% of properties. It can seriously reduce productivity.

29.3 Biological control program

The biocontrol program ran between 1982 and 1998. One agent, the clearwing moth *Pyropteron doryliformis*, has established widely and provides a good level of control. The biocontrol of docks in Western Australia is considered successful, but no follow up evaluation has been done. A total of 30 benchmark sites were established in infested areas approximately five years ago for future monitoring.

A dairy farmer at Berrigan in the Riverina reported savings of approximately $10,000/year as a result of dock clearwing moth initially released in 1996. It is estimated that the majority of the farmers in the region are all saving several thousand dollars/year in reduced control costs and increased pasture productivity. Dock clearwing moth is also established in Victoria and prevalent on curly dock in the northern part of the state. No impact studies have been conducted.

29.3.1 Development cost

The docks biocontrol program ran between 1982 and 1998 and is estimated to have cost a total of approximately $1.3 million. This is considered an underestimate as research costs between 1990 and 1996 are unknown.

29.4 Cost benefit analysis

No CBA has been conducted as there is limited data available regarding the benefits of the docks biocontrol program.

29.5 Summary

The docks biocontrol program resulted in the release of one agent which has become established. The program is estimated to have cost a total of $1.3 million but due to data limitations regarding the actual impact of the weed and the level of control achieved it is not possible to quantify the benefits of the program. However, the

docks biocontrol program is considered to have been successful and anecdotal evidence indicates that farmers in the Riverina region are saving several thousands of dollars annually.

Table 29.1. Summary of program benefits / costs

Type of benefit	Benefit / Cost	Detail
Economic	Increased productivity	• Increased carrying capacity of land; • Reduced toxicity to stock; and • Reduced vegetable fault in wool. The production benefit from biocontrol is unknown due to the lack of preliminary data with regards to the impacts of docks. However, biocontrol is believed to have achieved almost total control in Western Australia and good control in approximately 50% of infested areas in Victoria and New South Wales.
Environmental	Improved biodiversity	Biocontrol is believed to have reduced weed populations in many locations throughout Australia, increasing biodiversity in these areas.

30. Water weeds – *Salvinia molesta* (salvinia), *Eichhornia crassipes* (water hyacinth) and *Pistia stratiotes* (water lettuce)

30.1 References

Axelson, S. (1987)

Harley, K.L.S., Kassulke, R.C., Sands, D.P.A. and Day, M.D. (1990)

M. Julien, CSIRO Division of Entomology, *pers. comm.*, 2005

R. Carter, NSW Agriculture, *pers. comm.*, 2005

Reserve Bank of Australia (2005)

Room, P.M. (1980)

Walton, C. (2005)

30.2 Background and biology

These three floating water weeds are considered together because it is not possible to separate their individual economic impacts. All occur in similar water bodies across the same climatic zones, and have similar harmful impacts. However, these are not additive, as it makes little difference whether a water surface is covered by a single species or by a combination of species, and removal or control of any one species can lead to replacement by another. Therefore their economic impact is analysed as a single item.

30.2.1 *Salvinia molesta* (salvinia)

Salvinia molesta (salvinia) is a free floating, entirely sterile, perennial aquatic fern. It grows in slowly moving fresh water in tropical, subtropical and warm-temperate regions.

Salvinia was probably introduced to Australia soon after World War II and was first recorded as naturalised in 1952. It has become widely established in dams, lagoons, ponds and rivers mainly along the east coast and has significant potential for further spread. There is no evidence of spread between water bodies by agents other than people, either deliberately or on boots, vehicles, etc.

Biomass in some localities in Australia is greater than 400 tonnes/hectare, with the plant able to double dry weight in 2.2 days in good growing conditions throughout summer in Queensland.

Dense infestations restrict river navigation, fishing and recreation. The plant also:

- Interferes with the operation of engineering structures;
- Obstructs or prevents irrigation;
- Exacerbates the impacts of flooding,
- Impedes access of stock to water;
- Seriously degrades native aquatic ecosystems through:
  - Preventing light penetration;
  - Reducing oxygen levels;
  - Reducing pH;
- Degrades the quality of drinking water; and
- Harbours disease vectors such as mosquitoes.

Salvinia has some potential benefits in the purification of waste water as well as its use for mulch.

30.2.2 *Eichhornia crassipes* (water hyacinth)

Eichhornia crassipes (water hyacinth) is an erect, floating perennial herb, reproducing from stolons or from seed. It grows in slow-moving freshwater in tropical, subtropical and warm-temperate regions, especially areas with elevated nutrients. It also has the capacity to grow in mud giving it the potential to grow in most freshwater bodies in mainland Australia.

Water hyacinth was introduced to Australia in the 1890s and is now common in the coastal rivers of Queensland and northern NSW. Up till 1975, mats of water hyacinth brought downriver in floods regularly choked the city reaches of the Brisbane river, preventing ferry crossings and hindering boat traffic. The most significant recent infestation in Australia occurred recently in northern NSW affecting approximately 10,000 hectares of the waterways of the Gingham Watercourse near Moree (headwaters of the Darling River system). An infestation in the Fitzroy River dam in Queensland covered an area stretching up to 50 kilometres upstream.

One plant can grow to cover 600 square metres in a year. Plant mass can reproduce at greater than one tonne/hectare/day, plant doubling time varies from approximately 5 to 15 days. Seeds can remain viable for 5 to 20 years and the plant is dispersed by water, birds and humans.

Water hyacinth can:

- Make waterways impassable;
- Choke irrigation, blocking pumps and turbines;
- Cause massive loss of water through transpiration (7.8 times the loss by evaporation from an open water surface);
- Remove oxygen;
- Reduce pH levels;
- Impact fish stocks;
- Foul water with decaying plant matter;
- Reduce habitat for water birds;
- Change the natural biotic community;
- Provide a haven for mosquitoes and an alternate host for other pests; and
- Rafts of water hyacinth can damage infrastructure in floods.

Water hyacinth also has the potential to provide some minor benefits such as:

- Stock feed;
- Green manure;
- Mulch and compost;
- Particle board and packaging; and
- Production of biogas (1 kilogram of plant gives 370 litres of gas, 69% of which is methane).

The most common use of water hyacinth is as a remover of pollutants including sewage, heavy metals, pesticides and industrial and mining waste.

30.2.3 *Pistia stratiotes* (water lettuce)

Pistia stratiotes (water lettuce) is a free-floating aquatic herb, rapidly forming dense mats. Water lettuce is probably native to the wetlands of the Northern Territory. It also exists in scattered colonies along the east coast north of Sydney and inland waterways in Queensland.

Water lettuce quickly spreads to cover entire the water surface of freshwater lakes, rivers and canals. Water lettuce infestations:

- Impede traffic;
- Impede water flow;
- Destroy habitat for fish and birds by:
  - Reducing light penetration;
  - Reducing oxygen;
  - Changing the pH of water;
- Increase water loss by transpiration; and
- Provide shelter for disease-spreading mosquitoes.

Water lettuce has some potential benefits as a stock feed and for methane production.

30.3 Biological control program

Biocontrol of salvinia with the weevil *Cyrtobagous salviniae* is considered to have been highly successful in northern Australia. Exploration for natural enemies began in Brazil in January 1978 and the weevil was introduced in 1980. A study in Sri Lanka estimated returns from biocontrol at 53:1 in terms of money, and 1,671:1 in terms of labour.

Biocontrol of water hyacinth using the weevils *Neochetina eichhorniae*, *Neochetina bruchii* and the moth *Sameodes albiguttalis* has considerably reduced many infestations in Queensland and NSW. The weevils have been most successful and have played a key role in removing large infestations in tropical and sub-tropical areas of Queensland.

Exploration for natural enemies of water lettuce began in Brazil in January 1978. The weevil *Neohydronomus pulchellus* was released in 1982 and within seven months of release cleared water lettuce from a dam near Bundaberg in Queensland and significantly reduced infestations in other dams near Brisbane.

The weevil effectively controls the plant in tropical regions. However, its effectiveness fluctuates with seasonal conditions in cooler regions.

30.3.1 Development cost

The water hyacinth biocontrol program ran between 1974 and 1991 and is estimated to have cost a total of $636,600 over the period.

Research for the salvinia biocontrol program is estimated to have cost a total of approximately $4.2 million over the periods 1978 to 1985 and 1991 to 1993.

The biocontrol program for water lettuce is estimated to have cost a total of $306,900 over a five year period between 1978 and 1982.

The total cost of the water weed biocontrol programs was approximately $5.1 million and ran between 1974 and 1993.

30.4 Cost benefit analysis

30.4.1 Data inputs

Cost of control

Control of the water weeds salvinia, water hyacinth and water lettuce (water weeds) prior to biocontrol is estimated to have cost approximately $890/ha. Chemical control is still occasionally used in controlling water weeds, at approximately 5% of the level prior to biocontrol.

Area infested

Approximately 12,000 hectares of water ways are estimated to have been infested with water weeds each year prior to biocontrol. This is based on an average of 75 hectares of infestation per waterway infested, over 160 infested waterways. This is considered a conservative estimate given that:

- Water weeds are common in the coastal rivers of Queensland and northern NSW; and
- An estimated 900 hectares of the Hawkesbury was infested by salvinia in 2004. This has not been used as an average because the majority of waterways that would have been infested are significantly smaller than the Hawkesbury, especially in northern Queensland.

Distribution of biocontrol

Biocontrol for water weeds is estimated to have been effective within the first year of release for all three species of weed.

30.4.2 Model

A CBA model was used in this analysis as described in Section I. The analysis examined the benefits and costs that accrue due to replacement of pre-research control of water weeds with biocontrol. The net impact was identified by comparing the benefits and costs of the previous control with the benefits and costs since biocontrol. The net benefit of the program is estimated by the equation below:

$$NB = CS - RC$$

Where:

NB = The net benefit from the biocontrol of water weeds program ($)

CS = The control cost savings following adoption of biocontrol measures ($)

RC = The cost of research ($)

The control cost savings following adoption of biocontrol is estimated using the equation below:

$$CS = \sum_{n=50}^{1} \{(OC \times A) - CC\} \times \left(\frac{SA_n \times WL_n \times WH_n}{3} \right)$$

Where:

OC = The estimated cost of control prior to biocontrol ($/ha)

A = The area infested with water weeds (ha)

CC = The current cost of control ($/annum)

SA = The efficacy of biocontrol of salvinia in year *n* (%)

WL = The efficacy of biocontrol of water lettuce in year *n* (%)

WH = The efficacy of biocontrol of water hyacinth in year *n* (%)

n = Year

The cost of undertaking the research is calculated using the equation below:

$$RC = \sum_{n=50}^{1} CR_n \times CI_n$$

Where:

CR = The research costs incurred in year *n* ($)

CI = An index for inflation to convert research costs to 2004/05 dollars

30.4.3 Results

The analysis examined the benefits in terms of control cost savings following the release of biocontrol agents for the water weeds salvinia, water hyacinth and water lettuce. The results of the analysis are presented in **Table 30.1**. The biocontrol program provides a positive return on investment at all discount rates, with a NPV of $76.5 million and a BCR of 27.5 at a discount rate of 8.0%.

Table 30.1. Results of analysis

Real discount rate	NPV ($ million)	BCR
4.0%	$162.2	44.0
6.0%	$108.7	34.1
8.0%	$76.5	27.5
10.0%	$56.0	22.9

30.4.4 Sensitivity

Cost of control

The breakeven value with respect to the cost of control prior to biocontrol ranges from $20/ha (4% discount rate) to $39/ha (10% discount rate), *ceteris paribus*. This is significantly lower than the estimated cost of controlling the water weeds salvinia, water hyacinth and water lettuce. This variable does not significantly alter the findings of the analysis.

Table 30.2. Sensitivity analysis

Area impacted by water weeds (ha)	Units	Base case	Breakeven point at 4% discount rate [(a)]	Breakeven point at 10% discount rate [(a)]
Cost of control	$/ha	$890	$20	$39
Area impacted	Ha	12,000	273	523

Note: [(a)] The breakeven value is the value of the input where the NPV for the specified discount rate equals 0.

Area impacted

The breakeven value with respect to the area infested by water weeds each year ranges from 273 hectares (4% discount rate) to 523 hectares (10% discount rate), *ceteris paribus*. Whilst the actual area impacted is not known an area of 12,000 hectares was utilised and is considered to be a conservative estimate given the ecological range of the weeds. The breakeven area infested is significantly below the estimated area infested at all discount rates between 4% and 10%, and as such this variable is not considered critical to the findings of the analysis.

As mentioned above, an area of 12,000 hectares is considered a conservative estimate of the area impacted by water weeds each year. The table below shows that at 20,000 hectares the NPV of biocontrol would be approximately $129.4 million with a BCR of 45.9, while at 100,000 hectares biocontrol is estimated to provide a NPV of $658.5 million with a BCR of 229.3.

Table 30.3. NPV and BCR of water weeds biocontrol at 8% discount rate

Real discount rate	NPV ($ million)	BCR
12,000	$76.5	27.5
20,000	$129.4	45.9
30,000	$195.5	68.8
50,000	$327.8	114.7
75,000	$493.1	172.0
100,000	$658.5	229.3

30.4.5 Limitations of the analysis

Due to data limitations the benefits examined in the analysis were limited to reduced control costs. These benefits are considered to underestimate the actual benefits received, as the following benefits were not included:

- Increased productivity through:
  - Improved operation of engineering structures;
  - Improved irrigation;
  - Improved access of stock to water;
  - Reduced exacerbation of flooding impacts;
  - Increased fish stocks; and
  - Improved travel on waterways.

Biocontrol effectively reduces the negative impact of water weeds on production to zero. Chemical control of water weeds was effective but use of chemicals in waterways is increasingly restricted, and repeated chemical use was very expensive. Biocontrol also supplies the following additional benefits:

- Improved sustainability of native aquatic ecosystems by:
  - Increasing light penetration;
  - Increasing oxygen levels in water;
  - Increasing pH levels of water;
  - Reducing water loss through reduced transpiration;
  - Increased natural habitat for water birds and fish;
  - Reduced production of biogas;
  - Reduced exacerbation of flooding impacts;
  - Improved potable water supplies; and
  - Reduced habitat for harbouring disease vectors such as mosquitoes;
- The reduction in chemical control provides an environmental benefit in terms of reduced toxicity, improving the environmental health of waterways and reducing non-targeted impacts to plants and animals; and
- Increased recreational use of waterways by removing water weeds from waterways that impede navigation and travel.

These benefits, if quantified, would be expected to lead to an increase in the NPV and BCR of the water weeds biocontrol project.

30.5 Summary

The biocontrol program for the three water weeds salvinia, water hyacinth and water lettuce has resulted in the release of seven biocontrol agents, six of which have become established. The program is estimated to have cost a total of $5.1 million, resulting in a NPV of $76.5 million and a BCR of 27.5 at a discount rate of 8.0%.

Table 30.4. Summary of program benefits / costs

Type of benefit	Benefit / Cost	Detail
Economic	Reduced cost of control	Control cost saving of approximately $10.1M per annum.
	Increased productivity [(a)]	• Improved operation of engineering structures; • Improved irrigation; • Improved access of stock to water; • Reduced exacerbation of flooding impacts; • Improved quality of drinking water supplies; • Increases fish stocks; and • Improves travel on waterways.
	Reduced benefit of weed [(a)]	Reduced options for: • Stock feed; • Green manure; • Mulch and compost; and • Particle board and packaging.
Environmental	Improved native aquatic ecosystems [(a)]	• Increased light penetration; • Increased oxygen levels in water; • Increased pH levels of water; • Reduced water loss through reduced transpiration; • Increased natural habitat for water birds and fish; • Reduced production of biogas; • Reduced exacerbation of flooding impacts; and • Reduced habitat for harbouring disease vectors such as mosquitoes.
	Reduced chemical toxicity	Improved environmental health and reduced impacts to non-targeted plants and animals.
Social	Increased recreational use of waterways [(a)]	Increased recreational use of waterways by removing impediments to travel and navigation.

Note: [(a)] These benefits/costs were already provided to some degree by control methods used prior to the biocontrol program, thus these benefits/costs can not be solely attributed to biocontrol. Due to data limitations the impact of biocontrol in relation to these benefits/costs has not been separated from the impact of prior control methods.

31. *Senecio jacobaea* (ragwort)

31.1 References

D. Briese, CSIRO Division of Entomology, *pers. comm.*, 2005

Ireson, J. (2000)

J. Cullen, CSIRO Division of Entomology, *pers. comm.*, 2005

J. Ireson, Tasmanian Institute of Agricultural Research, *pers. comm.* and unpublished data, 2005

McLaren, D.A. *et al* (1999)

McLaren, D.A. and Micken, F. (1997)

R. Kwong, Victorian Department of Primary Industries, *pers. comm.*, 2005

R. McFadyen, Weeds CRC, *pers. comm.*, 2005

Reserve Bank of Australia (2005)

31.2 Background and biology

Senecio jacobaea (ragwort) grows in humid temperate regions where rainfall is greater than 750 millimetres and prefers heavy soils.

31.3 Establishment and impact

Ragwort was present in the Melbourne Botanical Gardens in 1852 and there are now approximately 820,000 hectares infested in Victoria. It is widely distributed in the high rainfall areas of Tasmania, particularly in the north, with approximately 16,000 hectares of cattle grazed pasture infested in Tasmania in the mid-1980s. Ragwort tends to occur in marginal agricultural country.

Ragwort impacts mainly on the dairy and other pasture industries as it is poisonous to grazing animals. It taints honey and the pollen causes allergies in people. In areas where ragwort establishes it can dominate to the exclusion of all other plants. Ragwort causes a 5–20% reduction in pasture production and is an occasional weed in cropping areas.

Ragwort was estimated to cause production losses of approximately $9.3 million in 1985 in Tasmania and is estimated to cost the Victorian community between $3 and 5 million annually.

31.4 Biological control program

Seven biological control species have been released since the 1930s, with five species established. The ragwort flea beetle *Longitarsus flavicornis* was first released in Tasmania in 1979. It is now widely established and has been an effective biological control agent at many sites in Tasmania, although variations in site conditions and incompatible land management practices have limited its efficacy at some sites.

The establishment of the ragwort stem and crown-boring moth *Cochylis atricapitana* (first released in Victoria in 1987 and Tasmania in 1995) and the ragwort plume moth *Platyptilia isodactyla* (first released in Victoria in 1995 and Tasmania in 2000) are now complementing the impact of the flea beetle. Surveys show that both these additional agents are becoming widely established and, in combination with the ragwort flea beetle, have significantly reduced the ragwort problem. A survey in 2005 showed that only 14% of Tasmanian grazing property managers still considered ragwort to be a major problem. Biological control of ragwort in Tasmania is already considered to be a major success and will have permanent financial benefits for grazing industries. Production losses from ragwort are estimated to be approximately one-twentieth of the losses in 1985.

In Victoria biological control of ragwort has not been as successful, although positive impacts are being noticed. Additional time and monitoring is required to evaluate the success of biocontrol in Victoria.

31.4.1 Development cost

The biocontrol program for ragwort began in 1977 and is ongoing. To date, a total of approximately $7.9 million has been spent on the biocontrol program.

31.5 Cost benefit analysis

31.5.1 Data inputs

Costs of ragwort

It is estimated that, prior to biocontrol, ragwort was responsible for annual losses of approximately $20.2 million in the dairy and beef industries in Tasmania. This figure is derived from the production losses of $9.3 million in 1985, converted to 2004/05 dollars. For Victoria, the estimate of between $3 to $5 million is used, though this is known to be a significant understatement of the true losses caused to the grazing and dairy industry in Victoria.

Distribution of biocontrol

Biocontrol using the flea beetle is estimated to have reduced pasture production losses from ragwort in Tasmania by approximately 84% between 1979 and 1995. The subsequent release of other biocontrol agents in 1995 and 2000 is estimated to have improved the efficacy of biocontrol by a further 11% in Tasmania[12], building up to full efficacy over a 10 year period. In Victoria, biocontrol is estimated to be 10%, building up over a 15 year period.

31.5.2 Model

A CBA model was used in this analysis as described in Section I. The analysis examined the benefits and costs that accrue following the release of biocontrol agents for ragwort. The net impact was identified by comparing the benefits and costs prior to biocontrol with the benefits and costs since biocontrol. The net benefit of the program is estimated by the equation below:

$$NB = IP + CS - RC$$

Where:

NB = The net benefit from the biocontrol of ragwort program ($)

IP = The increase in productivity in Tasmania following adoption of biocontrol measures ($)

CS = The reduction in costs to the Victorian community following adoption of biocontrol measures ($)

RC = The cost of research ($)

The increase in productivity in Tasmania following adoption of biocontrol is estimated using the equation below:

$$IP = \sum_{n=50}^{1} LDB \times DT_n$$

Where:

LDB = The loss to the Tasmanian dairy and beef industries due to ragwort prior to biocontrol ($/annum)

DT = The efficacy of biocontrol in Tasmania in year *n* (%)

n = Year

The reduction in costs to the Victorian community following adoption of biocontrol is estimated by the following equation:

$$CS = \sum_{n=50}^{1} CV \times DV_n$$

Where:

CV = The cost to the Victorian community due to ragwort prior to biocontrol ($/annum)

DV = The efficacy of biocontrol in Victoria in year *n* (%)

The cost of undertaking the research is calculated using the equation below:

$$RC = \sum_{n=50}^{1} CR_n \times CI_n$$

Where:

CR = The research costs incurred in year *n* ($)

CI = An index for inflation to convert research costs to 2004/05 dollars

31.5.3 Results

The analysis examined the benefits to Tasmania in terms of increased productivity and to Victoria in terms of reduced costs to the community following the release of biocontrol agents. The results of the analysis are presented in **Table 31.1**. The biocontrol program provides a positive return on investment at all discount rates, with a NPV of $94.2 million and a BCR of 32.4 at a discount rate of 8.0%.

Table 31.1. Results of analysis

Real discount rate	NPV ($ million)	BCR
4.0%	$232.6	50.5
6.0%	$144.6	39.8
8.0%	$94.2	32.4
10.0%	$64.0	26.9

31.5.4 Sensitivity

Increased productivity, Tasmania

The breakeven value with respect to the annual increase in productivity in Tasmania between 1985 and 2005 from biocontrol of ragwort ranges from $120,200 (4% discount rate) to $538,000 (10% discount rate), *ceteris paribus*. This is significantly less than the estimated increase in production in Tasmania over the period of approximately $19.2 million. This variable does not significantly alter the findings of the analysis and as such is not considered a critical variable.

12 Based on survey results on the proportion of affected properties rating ragwort as a serious weed of pasture (Ireson, unpublished data 2005).

Table 31.2. Sensitivity analysis

Variable	Units	Base case	Breakeven point at 4% discount rate [(a)]	Breakeven point at 10% discount rate [(a)]
Increased productivity, Tasmania	$/annum	$19.2 million	$120,200	$538,000

Note: [(a)] The breakeven value is the value of the input where the NPV for the specified discount rate equals 0.

31.5.5 Limitations of the analysis

The analysis is considered to be an underestimate of the benefits provided by the ragwort biocontrol program as data from Victoria is known to be inadequate. Furthermore, the analysis does not include any environmental benefits from an increase in biodiversity or social benefits in terms of reduced allergies. Due to data limitations these benefits were not identifiable. Ideally these benefits would be quantified, which would result in an increase in the NPV and BCR of the ragwort biocontrol program.

31.6 Summary

The ragwort biocontrol program resulted in the release of seven biocontrol agents, of which five are established and three are having significant impact on the weed. The program is estimated to have cost a total of $7.9 million, resulting in a NPV of $94.2 million and a BCR of 32.4 at a discount rate of 8.0%.

Table 31.3. Summary of program benefits / costs

Type of benefit	Benefit / Cost	Detail
Economic	Increased productivity in Tasmania	Approximately $19.2M per annum.
	Reduced cost to Victorian community	Approximately $400,000 per annum.
Environmental	Increased biodiversity	Removal of weed populations that out-compete nearly all other plants.
Social	Reduction in allergies and other human health issues	Reduced ragwort induced allergies in the community. Reduced risk of human alkaloid poisoning from unblended milk from affected animals, especially goats.

32. *Senecio madagascariensis* (fireweed)

32.1 References

L. Smith, NSW Department of Agriculture, *pers. comm.*, 1989, quoted in Sindel & Michael

R. McFadyen, Weeds CRC, *pers. comm.*, 2005

Sindel, B.M. and Michael, P.W. (1988)

32.2 Background and biology

Senecio madagascariensis (fireweed) is an erect, much-branched bush or herb that grows to approximately 60 centimetres tall. It grows in subtropical temperate pastures in high rainfall areas on a wide range of soils and is frost-sensitive.

32.3 Establishment and impact

Fireweed was first collected in the Hunter Valley in 1918 and has since spread along the coast, northern tablelands and western slopes of NSW and into southeast Queensland. Fireweed is still spreading rapidly but is expected to remain restricted to southeast Australia.

Seed banks in field infestations average approximately 12,000 seeds/square metre and dense infestations have been observed with approximately 5,000 plants/square metre.

Fireweed invades disturbed areas and reduces pasture productivity. It is generally unpalatable to stock but if eaten causes death or poor growth and condition of stock (cattle and horses) through poisoning. It rapidly forms dense infestations that displace productive pasture species.

A survey by Sindel and Michael (1988) estimated that the costs to the dairy industry alone in NSW from fireweed were 100,000 man hours plus $250,000 per annum in 1985. Based on the results of this survey, fireweed was estimated to cost NSW farmers approximately $3.4 million annually in 1989.

32.4 Biological control program

No biocontrol agents have been developed for controlling fireweed in Australia. Natural enemies found in Madagascar could attack other native plants in Australia and were rejected for use in Australia on these grounds.

32.4.1 Development cost

The fireweed biocontrol program ran for five years between 1989 and 1994 at an estimated total cost of $377,000.

32.5 Cost benefit analysis

The fireweed biocontrol program did not result in the release of any biocontrol agents due to lack of specificity, and as such did not result in any benefits. However, a CBA has been conducted to demonstrate the level of benefits that needed to be achieved had biocontrol agents been released for the program to provide a positive return on investment.

32.5.1 Data inputs

Costs of fireweed

Based on results of a survey conducted by Sindel and Michael (1988), it is estimated that the costs of fireweed to NSW farmers was $5.4 million annually. However, fireweed is only a serious weed under certain weather conditions, and these costs are likely to be achieved in approximately 1 in every 5 years. In other years, costs would be proportionately less, down to nil in 1 year in 5. As a result, the average cost of fireweed is estimated to be half the figure estimated from the Sindel and Michael (1988) survey at $2.7 million per annum.

Distribution of biocontrol

Based on the distribution build-up rate achieved by other biocontrol agents, a building-up period of 10 years to full efficacy has been used for the hypothetical release of biocontrol agents for fireweed.

32.5.2 Model

A CBA model was used in this analysis as described in Section I. The analysis examined the potential benefits and costs that could have accrued had biocontrol agents with the required specificity for control of fireweed been released following the completion of the research program. The net impact was identified by comparing the benefits and costs of fireweed prior to the research program with the benefits and costs of a hypothetical release of biocontrol agents following the research program. The net benefit of the program is estimated by the equation below:

$$NB = IP - RC$$

Where:

NB = The net benefit from the release of biocontrol agents for fireweed following the research program ($)

IP = The increase in productivity in NSW following the release of biocontrol agents ($)

RC = The cost of research ($)

The increase in productivity in NSW following the hypothetical release of biocontrol agents is estimated using the equation below:

$$IP = \sum_{n=50}^{1} LP \times DT_n$$

Where:

LP = The loss to NSW farmers due to fireweed prior to the biocontrol research program ($/annum)

DT = The projected efficacy of biocontrol in NSW in year *n* (%)

n = Year

The cost of undertaking the research is calculated using the equation below:

$$RC = \sum_{n=50}^{1} CR_n \times CI_n$$

Where:

CR = The research costs incurred in year *n* ($)

CI = An index for inflation to convert research costs to 2004/05 dollars

32.5.3 Results

The analysis examined the potential benefits to NSW in terms of increased productivity had biocontrol agents specific to the control of fireweed been released. The breakeven distributions for discount rates between 4% and 10% are presented in **Table 32.1**. The breakeven value with respect to the distribution of biocontrol of fireweed ranges from 0.9% (4% discount rate) to 2.8% (10% discount rate), *ceteris paribus*.

Table 32.1. Results of analysis

Real discount rate	Distribution Required to Breakeven
4.0%	0.9
6.0%	1.4
8.0%	2.1
10.0%	2.8

The table below outlines the benefits that could have been achieved (at an 8% discount rate) had the biocontrol program resulted in the successful release of biocontrol agents. The breakeven distribution at an 8% discount rate is 2.1%, while a 10% reduction in fireweed would have resulted in a NPV of $1.3 million and a BCR of 4.9.

Table 32.2. NPV and BCR of fireweed, hypothetical distribution, 8% discount rate

Distribution	NPV ($ million)	BCR
1%	-$0.2	0.5
2%	$0.0	1.0
5%	$0.5	2.4
10%	$1.3	4.9
15%	$2.1	7.3
20%	$2.9	9.8
30%	$4.4	14.6
40%	$6.0	19.5
50%	$7.6	24.4
75%	$11.6	36.6
100%	$15.6	48.8

32.6 Summary

The fireweed biocontrol program failed to identify any suitable agents for controlling the weed, and as such did not provide any benefits. However, CBA shows that had any biocontrol agents specific to the control of fireweed been released, the distribution of biocontrol would have only needed to be 2.1% to break even. This highlights the low level of benefits generally required by biocontrol programs in order to provide a positive return on investment. This is due to the low costs of these programs relative to the costs of the weed.

33. *Senna obtusifolia* (sicklepod)

33.1 References

Mackey, A.P., Miller, E.N. and Palmer, W.A. (1997)

33.2 Background and biology

Senna obtusifolia (sicklepod) is an annual or short-lived erect, perennial herb or woody sub-shrub that grows to approximately one half to two metres in height. It grows in the tropics and subtropics on well-aerated or sandy soils and grows well on floodplain margins in the Northern Territory.

33.3 Establishment and impact

Sicklepod was introduced to Australia during WWII and is presently confined to higher rainfall districts of coastal Queensland and the Northern Territory. In 1996 it infested approximately 600,000 hectares in northern Queensland and it is still rapidly expanding its range. Sicklepod's final distribution is likely to include the entire eastern coastal strip of Queensland and NSW and the northern parts of the Northern Territory.

Sicklepod can produce approximately 8,000 seeds/plant. It competes with tropical crops and pastures and is a serious weed of sugar cane. It produces dense thickets and reduces the available grazing area, which significantly reduces stock numbers. Sicklepod is unpalatable but can cause stock poisoning. It also invades National Parks and forestry areas.

The cost to the sugar cane industry in Queensland is estimated at greater than $600,000/year, mainly as chemical control costs. The cost to individual beef properties in Queensland is estimated to range from $2,000 to $31,000/year. The annual cost to Local Government Areas, National Parks and the Queensland Department of Primary Industries is estimated to be approximately $175,000.

33.4 Biological control program

The biocontrol program did not result in the release of any agents.

33.4.1 Development cost

The sicklepod biocontrol program ran between 1992 and 2000 at an estimated total cost of $736,800.

33.5 Cost benefit analysis

No CBA has been conducted as no biocontrol agents were released.

33.6 Summary

The sicklepod biocontrol program did not result in the release of any agents.

34. *Sida acuta* and *Sida rhombifolia* (spinyhead sida, Paddy's lucerne)

34.1 References

A. Cameron, Pasture Development Northern Territory Government, *pers. comm.*, 2005

Flanagan, G.J., Hills, L.A. and Wilson, C.G. (2000)

Lonsdale, W.M., Farrell, G. and Wilson, C.G. (1995)

Reserve Bank of Australia (2005)

34.2 Background and biology

34.2.1 *Sida acuta* (spinyhead sida)

Sida acuta (spinyhead sida) grows in open scrublands in tropical regions on a wide range of soil types. It is a widespread weed of pastures and sugarcane in central and northern coastal Queensland as well as one of worst weeds of pastures in the northern parts of the Northern Territory.

Spinyhead sida competes strongly with crops and pastures and is usually left ungrazed by stock. Its deep taproot gives it a competitive advantage in dry periods and it is a prolific seed producer with long dormancy periods.

The cost of treating spinyhead sida infestations with herbicides is $38.78/hectare for chemical (Starane at 1.5 litres/hectare) plus the cost of application with a boomspray, approximately $5–$7/hectare in the Northern Territory.

34.2.2 *Sida rhombifolia* (Paddy's lucerne)

Sida rhombifolia (Paddy's lucerne) grows in warm temperate to tropical savannas on a wide range of soil types. It is now common along the whole eastern and northern coasts of Australia, and is also found inland in small areas.

Paddy's lucerne is a serious competitor with crops and pastures, is not readily grazed and has little nutritional value. Its deep taproot gives it a competitive advantage in dry periods.

34.3 Biological control program

Calligrapha pantherina beetle was first released in the Northern Territory in 1989 and had a significant impact within three years, with spinyhead sida and Paddy's lucerne densities reduced by 84–99% at sites in the Darwin region.

In the Darwin area alone there is approximately 1,250 hectares of improved pasture. Following establishment of *Calligrapha pantherina* beetle there was approximately a 50% increase in production from these pastures, with cattle production increasing to 150 kilograms/hectare/year or $225/hectare/year. Approximate annual production benefit from these areas is $140,000.

Biocontrol in the Northern Territory, especially in northern coastal regions, has had significant success. Approximately 25% of the improved pastures received chemical treatment each year for control of sida prior to biocontrol, whereas now little treatment is needed. Approximate annual savings on herbicide treatment costs in the Darwin region is between $60,000 and $85,000. The beetle has also spread across northern Queensland but no data is available for economic impacts in this region.

34.3.1 Development cost

The sida biocontrol program ran for 16 years between 1984 and 1999 and is estimated to have cost approximately $4.2 million in total.

34.4 Cost benefit analysis

34.4.1 Data inputs

Cattle production

Cattle production in Darwin pre and post biocontrol is estimated to be $150/ha/annum and $225/ha/annum, respectively.

Cost of control

The cost of using herbicides to control sida was estimated to be between $60,000 and $85,000 per annum. The mid-point of $72,500 has been used in this analysis.

Distribution of biocontrol

Biocontrol is estimated to be approximately 90% effective in controlling sida[13].

34.4.2 Model

A CBA model was used in this analysis as described in Section I. Due to data limitations the analysis was applied only to the Darwin area and examined the benefits and costs that accrue due to replacement of pre-research control of sida with biocontrol. The net impact was identified by comparing the benefits and costs of the previous control with the benefits and costs since biocontrol. The net benefit of the program is estimated by the equation below:

$$NB = IP + CS - RC$$

Where:

NB = The net benefit from the biocontrol of sida program ($)

IP = The increase in productivity in Darwin following adoption of biocontrol measures ($)

CS = The control cost savings in Darwin following adoption of biocontrol measures ($)

RC = The cost of research ($)

The increase in productivity in Darwin following adoption of biocontrol is estimated using the equation below:

$$IP = \sum_{n=50}^{1} \left(CP^{B} - CP^{PB}\right) \times A \times D_n$$

Where:

CP = Cattle production in Darwin ($/ha/annum)

B = With biocontrol

PB = Prior to biocontrol

A = Area infested in Darwin (ha)

D = The efficacy of biocontrol in year *n* (%)

n = Year

The control cost savings in Darwin following adoption of biocontrol is estimated by the following equation:

$$CS = \sum_{n=50}^{1} HS \times A \times D_n$$

Where:

HS = The control cost saving from reduced herbicide usage ($/ha/annum)

The cost of undertaking the research is calculated using the equation below:

$$RC = \sum_{n=50}^{1} CR_n \times CI_n$$

Where:

CR = The research costs incurred in year *n* ($)

CI = An index for inflation to convert research costs to 2004/05 dollars

34.4.3 Results

The analysis examined the benefits in Darwin in terms of increased productivity and control cost savings following the release of biocontrol agents. The results of the analysis are presented in **Table 34.1**. The biocontrol program provides a negative return on investment at all discount rates, with a NPV of -$1.3 million and a BCR of 0.5 at a discount rate of 8.0%. This is considered to be an underestimate of the total benefits of the biocontrol program (see **Section 34.4.5**).

Table 34.1. Results of analysis

Real discount rate	NPV ($ million)	BCR
4.0%	-$0.7	0.8
6.0%	-$1.1	0.6
8.0%	-$1.3	0.5
10.0%	-$1.4	0.4

34.4.4 Sensitivity

Area of improved pasture

The breakeven value with respect to the increase in area of productive pasture as a result of biocontrol ranges from 1,842 hectares (4% discount rate) to 5,116 hectares (10% discount rate), *ceteris paribus*. While the estimated area of improved pasture in Darwin of 1,250 hectares is less than the breakeven range, biocontrol is known to also be having a significant impact on productive land in the Adelaide River, Douglas/Daly and Katherine regions, as well as parts of northern Queensland. It is unknown how much productive pasture has been made available through the clearing of sida from these areas with biocontrol, but it is likely that the increase in productive land falls within (or is greater than) the breakeven range of 1,842 hectares to 5,116 hectares.

Assuming that the increase in productivity and reduction in control costs are similar to those experienced in Darwin for these regions, this variable can significantly affect the findings of the analysis and as such is considered a critical variable. Ideally additional information regarding the impact of sida in other regions would be available to better estimate the impacts of the biocontrol program, however, in lieu of this data, a conservative estimate using only data for Darwin was deemed appropriate.

[13] When applying the distribution to cattle production and cost of control an efficacy of 100% has been used, building up over five years, since the cattle production and cost of control data provided for post biocontrol is for a 90% level of biocontrol effectiveness.

Table 34.2. Sensitivity analysis

Variable	Units	Base case	Breakeven point at 4% discount rate [(a)]	Breakeven point at 10% discount rate [(a)]
Area of improved pasture	Ha	1,250	1,842	5,116

Note: [(a)] The breakeven value is the value of the input where the NPV for the specified discount rate equals 0.

34.4.5 Limitations of the analysis

This analysis is considered to be an underestimate of the benefits of the sida biocontrol program as it only includes benefits achieved in the Darwin area only. Biocontrol is known to also be having a significant impact on productive land in the Adelaide River, Douglas/Daly and Katherine regions in the Northern Territory and in northern Queensland, however, no data is available regarding its impact in these areas.

The analysis also does not include any environmental benefits received from the reduction in chemical control. The reduction in chemical control provides an environmental benefit in terms of reduced toxicity, improving the environmental health of the land and reducing non-targeted impacts to plants and animals.

If these benefits of biocontrol were quantified it would result in an increase in the NPV and BCR of the sida biocontrol program.

34.5 Summary

The sida biocontrol program resulted in the release of three agents, all of which have become established. The program is estimated to have cost a total of $4.2 million, resulting in a NPV of -$1.3 million and a BCR of 0.5 at a discount rate of 8.0%. This analysis is considered to underestimate the benefits of the sida biocontrol program as it only includes benefits received in the Darwin area.

Table 34.3. Summary of program benefits / costs

Type of benefit	Benefit / Cost	Detail
Economic	Increased production	Increased productivity in Darwin by approximately $93,750 per annum due to increased carrying capacity.
	Control cost saving	Reduced the need for chemical control in Darwin, saving approximately $72,500 per annum.
Environmental	Reduced chemical toxicity	Improved environmental health and reduced impacts to non-targeted plants and animals.

35. Other thistles – *Cirsium vulgare* (spear thistle) and *Silybum marianum* (variegated thistle)

35.1 References

Bruzzese, E. (1996)

Bruzzese, E. and Cullen J.M. (1995)

R. Kwong, Victorian Department of Primary Industries, *pers. comm.*, 2005

Sindel, B.M. (1991)

35.2 Background and biology

35.2.1 *Cirsium vulgare* (spear thistle)

Cirsium vulgare (spear thistle) is an annual or biennial prickly herb, initially developing a prostrate rosette of leaves followed by an erect flowering spike. Dead plants can remain standing for up to two years, impeding stock movement and access.

Spear thistle grows in cool-temperate regions on exposed, warm sites with good fertility.

Spear thistle was identified in Tasmania as early as the 1830s and in South Australia prior to 1841. It occurs in all States except the Northern Territory and is widespread in NSW. It is found through approximately 9.7 million hectares in Victoria and across the fertile soils of southeast Queensland. Spear thistle is also widespread in South Australia and is of most importance in wetter areas. It is widespread in the wetter areas of Western Australia and is found across all farming areas of Tasmania.

A large rosette can cover 0.3 square metres and is not readily grazed as animals avoid the spines which reduces the carrying capacity of pastures. Spear thistle contaminates hay, competes with cereal crops, harbours pests, and is an important component of vegetable fault in wool.

It provides some limited value to the honey industry.

35.2.2 *Silybum marianum* (variegated thistle)

Silybum marianum (variegated thistle) grows in warm-temperate regions on fertile soils.

Variegated thistle was identified in:

- Tasmania from 1832;
- South Australia in 1840s; and
- Victoria from the 1850s.

It currently occurs in all States except the Northern Territory. There are approximately 4.8 million hectares infested in Victoria and approximately 3,000 hectares in Western Australia. It is still spreading in Tasmania.

Variegated thistle forms thickets so dense that all other vegetation is excluded. It is competitive in pastures and not readily eaten by stock as it can be toxic. It can also harbour pest animals. Seeds remain viable in soil for up to 9 years.

Variegated thistle provides some value to the honey industry.

35.3 Biological control program

For spear thistle:

- *Urophora stylata* gall fly was released in 1994 and is established;
- *Rhinocyllus conicus* receptacle weevil was first released in 1990, which failed, with subsequent releases in 1991 and 1992; and
- *Trichosirocalus mortadelo*, a crown weevil, was first released on spear thistle in 1996. The weevil is established on *Carduus nutans* (nodding thistle) in NSW.

The aim of the biological control program was to reduce seed production. From Victorian data, to achieve significant control of the weeds, seed production would need to be reduced by at least 78% and up to 96% in some areas. Although the above biological agents were released and established, there was no significant impact because spear thistle was not the preferred host plant for any of the agents released.

For variegated thistle, *R. conicus* from variegated thistle in France was released in Australia between 1991 & 1993 but its current status is unknown.

35.3.1 Development cost

The spear and variegated thistle biocontrol programs ran between 1988 and 2002 and the research is estimated to have cost a total of approximately $3.0 million.

35.4 Cost benefit analysis

No CBA has been conducted as there is believed to have been no benefits from the released biocontrol agents.

35.5 Summary

The spear and variegated thistle biocontrol program has resulted in the release of three agents for spear thistle and one for variegated thistle, with all becoming at least locally established. However, the program is not believed to have provided any measurable benefits, due to low population levels of the agents, possibly because these thistles were not the preferred host.

36. *Xanthium occidentale* (Noogoora burr)

36.1 References

Chippendale, J.F. (1992)

Julien, M.H., Broadbent, J.E. and Matthews, N.C. (1979)

Morin, L., Auld, B.A. and Smith, H.E. (1996)

Van Klinken, R.D. and Julien, M.H. (2003)

36.2 Background and biology

Xanthium occidentale (Noogoora burr) is a stout, single-stemmed or much-branched annual with a well-developed taproot that reaches a maximum height of 2.5 metres high. It grows in tropical and subtropical regions and in warm situations in temperate regions. It prefers deep fertile soils and can establish in arid regions near water sources. Noogoora burr is flood and salinity-tolerant.

36.3 Establishment and impact

Noogoora burr was introduced into Queensland in the 1850s and quickly spread through much of the sheep grazing country of western and central Queensland and NSW. It is widespread in Queensland and was described as the State's most common weed. It is also established along several rivers in the Northern Territory and northern Western Australia, with the total distribution area in Western Australia being approximately 50,000 hectares.

The total area encompassed in Australia is approximately 2 million hectares with total species dominance in some areas. However the density and spread of the weed varies considerably with seasonal conditions.

Prior to biocontrol, Noogoora burr occured most densely and consistently in the coastal and sub-coastal regions of Queensland and northern NSW. In drier regions it is confined to courses of ephemeral streams and dense infestations depend upon favourable wet summers.

Burrs are readily dispersed in wool, fur, bags and other items and cause major problems during shearing of sheep. In 1978–79 wool contamination cost producers approximately $1.7 million. It was estimated that approximately 10% of the 1976 wool clip from the Western Division of NSW received a price penalty of $0.05/kilogram due to vegetable fault. Noogoora burr is also dispersed by water and will float for up to 30 days.

The impacts of the weed include:

- Increased inspection time and cost for travelling stock;
- Burrs in hooves cause lameness; and
- Burrs in manes, tails and legs cause discomfort to stock and often completely mat wool.

Plants compete strongly with pastures and crops and dense infestations (approximately 30 plants/square metre) have the capacity to deny stock access to water. Seeds and seedlings are poisonous to stock (especially cattle and pigs) and the weed has also been found to cause contact dermatitis and hay-fever.

36.4 Biological control program

Biocontrol with the illegally introduced rust *Puccinia xanthii* is effective in much of central and eastern Queensland, but less effective elsewhere. The rust has been found on sunflower crops growing near burr infestations, but crop yield was not affected. The rust was proposed as a potential biocontrol agent prior to its illegal introduction.

The moth *Epiblema strenuana*, introduced in 1982 against parthenium, also provides substantial control in most areas.

36.4.1 Development cost

No research costs have been provided for the Noogoora burr biocontrol program, although Chippendale (1992) estimates the total cost of the program, when converted to 2004/05 dollar terms, to be approximately $10.1 million over the period between the early 1930's and mid-1970's.

36.5 Cost benefit analysis

Due to data limitations no CBA has been conducted for the Noogoora burr biocontrol program. However, an analysis by Chippendale (1992) estimates that the annual benefit from biocontrol, expressed in 2004/05 dollar terms, is approximately $1.2 million, providing a PV of $23.4 million at a 5% discount rate[14]. However, due to a lack of data identifying the timing of research costs a NPV and BCR of the Noogoora burr biocontrol program cannot be calculated with this data.

[14] The PV provided by Chippendale is for a 50 year analysis of the benefits of biocontrol only and does not take into consideration the timing of research costs (ie the analysis does not start in the early 1930's when research began but rather in 1983 when the first benefits of biocontrol were identified).

36.6 Summary

The Noogoora burr biocontrol program resulted in the release of four agents, three of which have become established. The total cost of the program, expressed in 2004/05 dollar terms, was estimated to be approximately $10.1 million, while the annual production benefit from reduced vegetable fault in wool due to biocontrol was estimated to be $1.2 million, resulting in a PV of benefits of $23.4 million (5% discount rate).

Table 36.1. Summary of program benefits / costs

Type of benefit	Benefit / Cost	Detail
Economic	Increased pasture productivity	• Increased carrying capacity of pastures and crops; • Reduced contamination of wool; • Reduced lameness in stock; • Lower inspection time and cost of travelling stock; • Improved stock access to water; and • Reduced toxicity to stock. Chippendale (1992) estimates that the annual benefit of biocontrol in terms of reduced vegetable fault in wool is $1.2M.
Social	Health benefits	Reduced contact dermatitis and hay-fever.

37. Bibliography

Adamson, D. and Bray, S. (1999). *The Economic benefit from Investing in Insect Biological Control of Parthenium Weed (Parthenium hysterophorus)*. RDE Connections, NRSM, University of Queensland. August, 1999.

AECgroup (2002) *Economic impacts of state and local government expenditure on weed and pest animal management in Queensland*, report by the AEC*group* to the Local Government Association of Queensland.

Allan, C.J. and Holst, P.J. (1996) *Longevity of soil based seeds of Onopordum illyricum*. Plant Protection Quarterly **11** (Supplement 2): 242.

ARMCANZ (2001) *Weeds of National Significance strategic plans*, NWSEC, Launceston.

Armstrong, T.R. (1976) *Comparison of costs of alternative methods of controlling Harrisia cactus*. Proceedings of the Xth Australian Weeds Conference, Melbourne. pp 2(b)6–2(b)8.

Armstrong, T.R. (1978) *Herbicidal control of Parthenium hysterophorus L.* Proceedings of the 1st Conference of the Council of Australian Weed Science Societies, Melbourne: 157–164.

Auld, B.A., Hosking, J. and McFadyen, R.E. (1983) *Analysis of the spread of tiger pear and parthenium weed in Australia*. Australian Weeds **2**(2): 56–60.

Auld, B.A., Menz, K.M. and Medd, R.W. (1979) *Bioeconomic model of weeds in pastures*. Agro-Ecosystems 5: 69–84.

Australian Bureau of Statistics (2005) *DoHa SLA population projections.*

Australian Bureau of Statistics (2005) *Value of principal agricultural commodities produced, Australia*, ABS catalogue number 7501.0.

Australian Bureau of Statistics (2004) *Regional population growth*, ABS catalogue number 3218.0.

Australian Bureau of Statistics (1998) *Agriculture Victoria*, ABS catalogue number 7113.2.

Australian Bureau of Statistics (1997) *Census of population and housing*, ABS catalogue number 2035.0.

Australian Society of Clinical Immunology and Allergy Inc. (ASCIA) (2002) *Hay fever treatment*, http://www.allergy.org.au/month/hayfever.htm

Australian Weeds Committee (2001) *Mesquite WONS strategy* 2001, National Weeds Strategy Executive Committee, Launceston.

Axelson, S. (1987) *A cost/benefit analysis of clearing ponded areas of water storages for control of floating aquatic weeds.* Proceedings of the North Australian Weeds Conference: 12–16.

Bartholomew, B.L. and Armstrong, T.R. (1978) *A new look at lantana control.* Advisory Leaflet No. 1428, Division of Plant Industry, Department of Primary Industries. Reprinted from Queensland Agricultural Journal July–August 1978. 7 pp.

Briese, D.T. (1997) *Biological control of St. John's wort: past, present and future.* Plant Protection Quarterly **12**(2): 73–80.

Briese, D.T., Pettit, W.J. and Walker, A. (2004) *Evaluation of the biological control agent, Lixus cardui, on Onopordum thistles: experimental studies on agent demography and impact.* Biological Control **31**: 165–171.

Broughton, S. (2000) *Review and evaluation of lantana biocontrol programs.* Biological Control **17**: 272–286.

Bruzzese, E. (1996) *Ecology of Cirsium vulgare and Silybum marianum in relation to biological control.* Plant Protection Quarterly 11 (Supplement 2): 245–249.

Bruzzese, E. and Cullen J.M. (1995) *Biological control of weeds of importance to the wool industry in southern Australia,* in: Proceedings of the VIIIth International Symposium on Biological Control of Weeds, 2–7 February 1992, Canterbury, New Zealand (eds. Delfosse, E.S. and Scott R.R.) CSIRO/DSIR.

Buckley, Y.M., Rees, M., Paynter, Q. and Lonsdale, M. (2004) Modelling integrated weed management of an invasive shrub in tropical Australia. Journal of Applied Ecology **41**: 547–560.

Campbell, M.H., Briese, D.T. and Delfosse, E.S. (1995) *Hypericum perforatum L.*, in: Groves, R.H., Shepherd, R.C.H. and Richardson, R.G. (eds.) (1995) The biology of Australian weeds, Vol (1) R.G. and F.J Richardson, Melbourne, 149–167.

Centre for International Economics (CIE) (2001) *The CRC for Weed Management Systems: an impact report,* report by CIE for the CRC for Weed Management Systems.

Chippendale, J.F. (1992) The biological control of Noogoora burr in Queensland: an economic perspective, in: Proceedings of the VIIIth International Symposium on Biological Control of Weeds, February, 1992, Lincoln University, New Zealand.

Chippendale, J.F. (1991) *The potential returns to research into rubber vine* (Cryptostegia grandiflora R.BR) *in northern Queensland,* Master of Agricultural Studies Thesis, University of Queensland.

Chippendale, J.F. and Panetta, F.D. (1994) *The cost of parthenium weed to the Queensland cattle industry.* Plant Protection Quarterly **9**(2): 73–76.

Clark, A. (2004) *Review of progress towards the lantana strategic plan (2001–2004).* National Lantana Management Group, 34 pp.

Coyle, P.H. (1990) *The effect of biological control agents on weedy cacti in Western Australia.* Proceedings of the 9th Australian Weeds Conference, Adelaide, South Australia: 490–492.

CSIRO (1964) *Biological control of lantana.* Unpublished minutes of meeting held at Division of Entomology, CSIRO, Canberra, Tuesday 15th December 1964.

CSIRO (1987) *Review of Biological Control of Weeds Section,* CSIRO Division of Entomology. Unpublished Report, 50pp.

Cullen, J.M. (1978) *Evaluating the success of the programme for the biological control of Chondrilla juncea.* Proceedings of the IV International Symposium on Biological Control of Weeds, Gainsville, Florida USA 1976: 117–121.

Cullen, J.M. (1984) *Bringing the cost benefit analysis of biological control of Chondrilla juncea up to date,* in: Proceedings of the VIth International Symposium on Biological Control of Weeds, 19–25 August 1984, Vancouver, Canada (ed. Delfosse, E.S.).

Cullen, J.M. and Whitten, M.J. (1995) *Economics of classical biological control: a research perspective.* In: Hokkanen and Lynch (eds) Biological control: benefits and risks. Cambridge Uni Press, Chapter 26.

Culvenor, C.C.J. (1985) *Economic loss due to poisonous plants in Australia.* In: Plant Toxicology. Proceedings of the Australia – USA Poisonous Plants Symposium, Brisbane, Australia, May 14–18 1984. pp 3–13.

Day, M.D., Broughton, S. and Hannan-Jones, M.A. (2003) *Current distribution and status of Lantana camara and its biological control agents in Australia, with recommendations for further biocontrol introductions into other countries.* Biocontrol News and Information 24(3): 63N–76N.

Day, M.D., Wiley, C.J., Playford, J. and Zalucki, M.P. (2003) *Lantana: current management status and future prospects.* ACIAR, Canberra. 128 pp.

Dhileepan, K. (2001) *Effectiveness of introduced biocontrol insects on the weed Parthenium hysterophorus (Asteraceae) in Australia.* Bulletin of Entomological Research 91: 167–176.

Dhileepan, K. (2003) *Seasonal variation in the effectiveness of the leaf-feeding beetle Zygogramma bicolorata (Coleoptera: Chrysomelidae) and stem-galling moth Epiblema strenuana (Lepidoptera: Tortricidae) as biological control agents on the weed Parthenium hysterophorus (Asteraceae).* Bulletin of Entomological Research **93**: 393–401.

Dhileepan, K., Setter, S.D. and McFadyen, R.E. (2000) *Impact of defoliation by the biocontrol agent Zygogramma bicolorata on the weed Parthenium hysterophorus in Australia.* Biocontrol **45**: 501–512.

Dodd, A.P. (1958) *Cactus pest wastes good land.* The Living Earth, Autumn 1958: 25–27.

Dodd, A.P. (1961) *Biological control of* Eupatorium adenophorum *in Queensland,* Australian Journal of Science, **23**: 356–365.

Drea, J.J. (1991) *The philosophy, procedures and cost of developing a classical biological control of weeds project.* Natural Areas Journal **11**(3): 143–147.

Flanagan, G.J. (1995) *The economics of Mimosa pigra control in the Top End of the Northern Territory.* Unpublished Manuscript, Northern Territory Department of Primary Industry and Fisheries.

Flanagan, G.J., Hills, L.A. and Wilson, C.G. (2000) *The successful biological control of spinyhead sida, Sida acuta (Malvaceae), by Calligrapha pantherina (Col.: Chrysomelidae) in Australia's Northern Territory.* Proceedings of the X International Symposium on Biological Control of Weeds, Bozeman, Montana USA: 35–41.

Franco-Dixon, M. (2003) *Economic Impact of Biological Control of Rubber Vine* (Cryptostegia grandiflora), internal review, Queensland Department of Natural Resources and Mines

Government Statisticians Office (1996) Regional Input-Output Tables Queensland, 1989–90, Government Statisticians Office, Queensland Government

Greer, G. (1992) *Economics and the biological control of weeds.* Proceedings of the VIII International Symposium on Biological Control of Weeds, Canterbury New Zealand: 177–184.

Groves, R.H., Shepherd R.C.H. and R.G. Richardson (1995) *Biology of Australian Weeds Volume 1,* R.G and F.J.Richardson Publications, Melbourne.

Hanley, M.E. and Groves, R.H. (2002) *Effect of the rust fungus Puccinia chondrillina TU 788 on plant size and plant size variability in Chondrilla juncea.* Weed Research **42**: 370–376.

Harley, K.L.S., Kassulke, R.C., Sands, D.P.A. and Day, M.D. (1990) *Biological control of water lettuce, Pistia stratiotes (Araceae) by Neohydronomus affinis (Coleoptera: Curculionidae).* Entomophaga **35**(3): 363–374.

Harley, K.L.S. and Wright, A.D. (1987) *A summary of costs and results of biological control of weeds projects in Australia.* Proceedings of the 8th Australian Weeds Conference (eds: D. Lemerle and A.R. Leys), Weeds Society of NSW, Sydney. Pp. 85–88.

Haseler, W.H. (1963) *Biological studies of the crofton weed gall fly* Procecidochares utilis *stone,* MSc thesis, University of Queensland.

Heard, T.A., Pettit, W., 2005. *A review of the surveys for natural enemies of Mimosa pigra: what does it tell us about surveys for broadly distributed hosts?* Biological Control **32**, 252–262.

Hosking, J.R. and Deighton, P.J. (1979) *The distribution and control of Opuntia aurantiaca in New South Wales.* Proceedings of the 7th Asian-Pacific Weed Science Society Conference: 195–200.

Hosking, J.R., McFadyen, R.E. and Murray, N.D. (1988) *Distribution and biological control of cactus species in eastern Australia.* Plant Protection Quarterly **3**(3): 115–123.

Hosking, J.R., Sullivan, P.R. and Welsby, S.M. (1994) *Biological control of Opuntia stricta (Haw.) Haw. var. stricta using Dactylopius opuntiae (Cockerell) in an area of New South Wales, Australia, where Cactoblastis cactorum (Berg) is not a successful biological control agent.* Agriculture, Ecosystems and Environment **48**: 241–255.

Industries Assistance Commission (IAC) (1985) *Biological control of Echium species (including Paterson's curse/Salvation Jane).* Canberra, ACT; Australian Government Publishing Service, IAC Report No. 371.

Ireson, J.E. (2000) *Biological control of ragwort in Tasmania.* Final report to Dairy Research and Development Corporation, Tasmanian Institute of Agricultural Research, Sept. 2000. 135 pp.

James, R. and Lockwood, M. (1998) *Economics of blackberries: current data and rapid valuation techniques.* Plant Protection Quarterly **13**(4): 175–179.

Johnston, W.R. (1982) *The fight against cacti pests in Queensland.* Queensland Agricultural Journal, July–August 1982: 215–221.

Julien, M.H. (1980) *Control of aquatic Alternanthera philoxeroides in Australia; another success for Agasicles hygrophila.* Proceedings of the V International Symposium on Biological Control of Weeds, Brisbane, Australia. Pp 583–588.

Julien, M.H. and Bourne, A.S. (1988) *Alligator weed is spreading in Australia.* Plant Protection Quarterly **3**(3): 91–96.

Julien, M.H., Broadbent, J.E. and Matthews, N.C. (1979) *Effects of Puccinia xanthii on Xanthium strumarium (Compositae).* Entomophaga **24**(1): 29–34.

Julien, M.H. and Chan, R.R. (1992) *Biological control of alligator weed: unsuccessful attempts to controlterrestrial growth using the flea beetle Disonycha argentinensis (Col.: Chrysomelidae).* Entomophaga **37**(2): 215–221.

Julien, M.H., Schooler, S. and Coventry, R. (eds.) (2004) Proceedings of the 2nd Alligator Weed Workshop, April 20–21 2004, Raymond Terrace NSW.

Kennedy, J.O.S. (1987) *The economics of weed control.* Plant Protection Quarterly **2**(3): 118–123.

Kloessing, K. (1994) *Estimating the financial loss caused by parthenium weed in the Queensland grazing industry.* CRC for Tropical Pest Management, Brisbane.

Kritikos, D., Brown, J., Radford, I. and Nicholas, M. (1999) *Plant population ecology and biological control: Acacia nilotica as a case study.* Biological Control **16**: 230–239.

Kularatne, D., Holland-Clift, H., Kwong, R. and Morfe, T.A. (2005) *Biological control of bridal creeper in citrus orchards of the Murray Valley region,* Victorian Department of Primary Industries.

Lonsdale, W.M., Farrell, G. and Wilson, C.G. (1995) *Biological control of a tropical weed: a population model and experiment for Sida acuta.* Journal of Applied Ecology **32**: 391–399.

Mackey, A.P. (ed.) (1996) *Rubber vine* (Cryptostegia grandiflora) *in Queensland.* Pest Status Review, Land Protection, Queensland Department of Natural Resources & Mines, 25 pp.

Mackey, A.P. (1997) *The biology of Australian weeds 29. Acacia nilotica sp. Indica (Benth.) Brenan.* Plant Protection Quarterly 12: 7–17.

Mackey, A.P., Miller, E.N. and Palmer, W.A. (1997) *Sicklepod (Senna obtusifolia) in Queensland.* Queensland Department of Natural Resources. 39 pp.

Mahr, F.A., Mayo, G., Ainsworth, N. and Jupp, P. (1999) *Monitoring the impact of the biological control agent Aculus hyperici on Hypericum perforatum across south eastern Australia.* Proceedings of the 12th Australian Weeds Conference, pp 335–338.

Marsden, J.S., Martin, G.E., Parham, D.J., Ridsdill Smith, T.J. and Johnston, B.J. (1980) *Returns on Australian agricultural research,* CSIRO.

McFadyen, P.J. (1978) *A review of the biological control of groundsel bush (Baccharis halimifolia L.) in Queensland.* Proceedings of the 1st Conference of the Council of Australian Weed Science Societies, Melbourne. pp 123–125.

McFadyen, P.J. (1982) *The necessity for the biological control of giant sensitive plant (Mimosa invisa).* Unpublished report, Queensland Department of Lands. 6 pp.

McFadyen, R.E. (1984) *Annual ragweed in Queensland,* Proceedings of the 7th Australian Weeds Conference, Perth, 205–209.

McFadyen, R.E. (1986) *Harrisia cactus in Queensland,* in: The ecology of exotic animals and plants in Australia (ed. Kitching, R.), 240–261.

McFadyen, R.E. and Tomley, A.J. (1981) *The successful biological control of harrisia cactus (Eriocereus martini) in Queensland.* Proceedings of the 6th Australian Weeds Conference, Gold Coast, Queensland, volume 1, pp 139–143.

McLaren, D.A., Ireson, J.E. and Kwong, R.M. (1999) *Biological control of ragwort* (Senecio jacobaea L.) *in Australia*. Proceedings of X International Symposium on Biological Control of Weeds, Montana, Neal R. Spencer (ed), pp 67–79.

McLaren, D.A and Micken, F. (1997) *The ragwort management handbook*, Department of Natural Resources and Environment, pp 1–76.

McLaren, D.A., Bruzzese, E. and Pascoe, I.G. (1997) *The potential of fungal pathogens to control Hypericum species in Australia.* Plant Protection Quarterly **12**(2): 81–90.

Morin, L., Auld, B.A. and Smith, H.E. (1996) *Rust epidemics, climate and control of Xanthium occidentale.* Proceedings of the IX International Symposium on Biological Control of Weeds, Stellenbosch, South Africa: 385–391.

Nordblom, T.L., Smyth, M.J., Swirepik, A., Sheppard, A.W. and Briese, D.T. (2002a) *Spatial economics of biological control: investing in new releases of insects for earlier limitation of Paterson's curse in Australia.* Agricultural Economics **27**: 403–424.

Nordblom, T.L., Smyth, M.J., Swirepik, A., Sheppard, A.W. and Briese, D.T. (2002b) *Benefit-cost analysis for biological control of Echium spp. (Paterson's curse and related species) in Australia,* 1972–2050. Proceedings of the 13th Australian Weeds Conference: 753–756.

Panetta, F.D., Groves, R.H. and Shepherd R.C.H. (1998) *Biology of Australian Weeds Volume 2,* R.G and F.J.Richardson Publications, Melbourne.

Parsons, W.T. and Cuthbertson, E.G. (2001) *Noxious weeds of Australia,* Inkata Press, Melbourne.

Patterson, D. (1993) *The role of funding in biological control: from the public purse.* Plant Protection Quarterly **8**(4): 150–151.

Paynter, Q. and Flanagan, G.J. (2004) *Integrating herbicide and mechanical control treatments with fire and biological control to manage an invasive wetland shrub, Mimosa pigra.* Journal of Applied Ecology **41**: 615–629.

Paynter, Q. (2005) *Evaluating the impact of a biological control agent* Carmenta mimosa *on the woody wetland weed* Mimosa pigra *in Australia.* Journal of Applied Ecology **42**: 1054-1062.

Radford, I., Nicholas, D.M. and Brown, J.R. (2001) *Assessment of the biological control impact of seed predators on the invasive shrub Acacia nilotica (prickly acacia) in Australia.* Biological Control **20**: 261–268.

Reserve Bank of Australia (2005) *Consumer Price Index, Table G02,* Bulletin Statistical Tables.

Room, P.M. (1980) *Biological control of weeds – modest investments can give large returns.* Proceedings of the Australian Agronomy Conference "Pathways to Productivity" (ed.: I.M. Wood):291.

Scott, P. and Dodd, J. (1996) *Skeleton weed: the current situation.* WA Journal of Agriculture **37**: 76–81.

Shepherd, R.C.H. (1985) *The present status of St. John's wort (Hypericum perforatum L.) and its biological control agents in Victoria, Australia.* Agriculture, Ecosystems and Environment **12**: 141–149.

Shepherd, R.C.H. (1990) *Past Victorian work on Emex australis Stenheil and Tribulus terrestris L.* Plant Protection Quarterly **5**(3): 100–102.

Sindel, B.M. (1991) *A review of the ecology and control of thistles in Australia.* Weed Research **31**: 189–201.

Sindel, B.M. and Michael, P.W. (1988) fireweed

Sinden, J.A. and Thampapillai, D.J. (1995) *Introduction to Benefit Cost Analysis,* Longman House, Melbourne, Australia

Sinden, J., Jones, R., Hester, S., Odom, D., Kalisch, C., James, R. and Cacho, O. (2004) *The economic impact of weeds in Australia.* CRC for Weed Management Systems Technical Series 8: 55 pp.

Sloane, Cook & King Pty Ltd (1988) *The economic impact of pasture weeds, pests and diseases in the Australian wool industry,* Australian Wool Corporation.

Swirepik, A. and Smyth, M. (2002) *Biological control of broad-leafed pasture weeds (Paterson's curse, Onopordum and nodding thistles): what have we achieved and where to from here?* Proceedings of the 13th Australian Weeds Conference. Pp. 373–376.

Tana, T. and Navie, S. (2001) *The soil seed bank of parthenium infested pastures II. A study conducted on behalf of the Queensland Department of Natural Resources and Mines.* Unpublished Report, 10 pp.
Tisdell, C.A. (1987) Economic evaluation of biological weed control. Plant Protection Quarterly **2**(1): 10–12.

Tisdell, C.A. (1988) *Economic impact of biological control of weeds and insects.* Research Report/ Occasional Paper, Department of Economics University of Newcastle, Australia 153: 24pp.

Tisdell, C.A. (1988) *Economics of weed control on public conservation and recreation land: assessing costs and benefits.* Research Report/Occasional Paper, Department of Economics University of Newcastle, Australia 156: 15pp.

Tisdell, C.A. (1990) *Economic impact of biological control of weeds and insects.* Critical Issues in Biological Control (eds: M. Mackauer, L.E. Ehler and J. Roland), Andover, Hants, UK: Intercept Ltd. Pp. 301–316.

Tisdell, C.A. and Auld, B.A. (1990) *Evaluation of biological control projects.* Proceedings of the VII International Symposium on Biological Control of Weeds, Rome: 93–100.

Tisdell, C.A., Auld, B.A. and Menz, K.M. (1984) *On assessing the value of biological control of weeds.* Protection Ecology **6**(2): 169–179.

Tomley, A.J. and Evans, H.C. (2004) *Establishment of, and preliminary impact studies on, the rust, Maravalia cryptostegiae, of the invasive alien weed, Cryptostegia grandiflora in Queensland, Australia.* Plant Pathology **53**: 475–484.

Tutt, H.S. and Douglas, N.J. (1964) *Two chapters of the groundsel bush story.* Queensland Agricultural Journal, August 1964, 8 pp.

van Klinken, R.D. (2005) *Total annual seed loss on a perennial legume through predation by insects: the importance of within-season seed and seed-feeder dynamics,* Austral Ecology **30**, pp 414–425.

van Klinken, R.D., Fichera, G. and Cordo, H. (2003) *Targeting biological control across diverse landscapes: the release, establishment, and early success of two insects on mesquite (Prosopis spp.) in Australian rangelands.* Biological Control **26**: 8–20.

van Klinken, R.D. and Julien, M.H. (2003) *Learning from past attempts: does classical biological control of Noogoora burr (Asteraceae: Xanthium occidentale) have a promising future?* Biocontrol Science and Technology **13**: 139–153.

Vere, D.T. & Auld, B.A. (1982) *The cost of weeds.* Protection Ecology 4: 29–42.

Victorian Department of Sustainability and Environment (2005) http://www.dse.vic.gov.au/dse/

Vogler, W. and Lindsay, A. (2002) *The impact of the rust fungus Maravalia cryptostegiae on three rubber vine (Cryptostegia grandiflora) populations in tropical Queensland.* Proceedings of the 13th Australian Weeds Conference, pp 180–182.

Walton, C. (2005) *Reclaiming Lost Provinces – A Century of Weed Biocontrol in Queensland,* Department of Natural Resources and Mines: Land Protection, Brisbane.

White, G.G. (1980) *Current status of prickly pear control by Cactoblastis cactorum in Queensland.* Proceedings of the V International Symposium on Biological Control of Weeds, Brisbane: 609–616.

Willson, B.W. (1985) *The biological control of lantana – proposal for a renewed programme of exploration for and evaluation of control agents in northern South America.* Agenda paper, Noxious Plants Consultative Committee Meeting, Thursday 14 November 1985. 9 pp.

Willson, B.W. and Garcia, C.A. (1992) *Host specificity and biologicy of Heteropsylla spinulosa (Hom.: Psyllidae) introduced into Australia and Western Samoa for the biological control of Mimosa invisa.* Entomophaga 37: 293–299.

Woodburn, T.L. and Briese, D.T. (1996) *The contribution of biological control to the management of thistles.* Plant Protection Quarterly **11** (Supplement 2): 250–253.

Young, R. and Woodburn, T. (2002) *Evaluation of research on the biological control of nodding thistle* (C. nutans), CSIRO Division of Entomology.

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