CRC for Weed Management Systems
Technical Series No. 6

The CRC for Weed Management Systems: An Impact Assessment

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Front Cover: Bitou bush and Paterson’s curse. Photos courtesy of NSW Agriculture and CSIRO.

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Acknowledgements

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Summary

The CRC for Weed Management Systems is now two-thirds of the way through a comprehensive portfolio of activities aimed at achieving a significant reduction in the economic cost of weeds.

- Our review highlights the avenues through which the CRC's work will reduce weed costs over the longer term and its achievements to date toward this goal. These avenues include:
  - savings in weed control costs and yield losses in agriculture and savings in weed control costs in natural ecosystems;
  - improved sustainability of agricultural production through a movement away from current single dimension herbicide control programs, which are generating increased herbicide resistance of weeds;
  - reducing 'external' impacts on producers by reducing the scope for weed spread into 'clean' areas;
  - satisfying consumer preferences by avoiding herbicide residues;
  - enhancing knowledge and expertise among weed researchers, weed managers and the general community; and
  - reducing environmental damage and protecting biodiversity of flora and fauna, and enhancing the amenity value of natural ecosystems.

- The CRC has an impressive array of achievements to date. Many are by nature difficult to quantify though will have obvious and perhaps significant value to the community over the longer term. Such less tangible achievements include:
  - quantification of the economic costs of various weed incursions — which is providing a better understanding of the weed problem and how resources to control weeds can be better targeted;
  - contributions to policy development — on strategies to control weeds of national significance, in the development of transgenic herbicide resistant crops, on allowable herbicide dose rates etc.;
  - fostering interdisciplinary research;
  - achieving a shift toward sustainable integrated management systems for weed control; and
  - fostering education, training and dissemination of information on weeds and control technologies.

- Achievements more readily quantifiable include:
  - crop management strategies to reduce weeds such as competitive cropping techniques;
  - release of biological control agents to control weeds of pastures and natural ecosystems;
  - development of an integrated weed management strategy for control of annual weeds in pastures; and
  - development of mechanisms to help prevent entry and distribution of novel weeds.

- We have subjected five projects from different areas of the CRC's portfolio to more detailed analysis. The results are particularly revealing. They show that the expected benefits greatly exceed the spending by the CRC (around $39 million over its seven year term) across its entire portfolio of activities. For some projects the benefits are captured mainly by agricultural producers. For others the main beneficiaries are the community as a whole.
  - We estimate that the CRC's contribution in accelerating the development of competitive cropping systems has the potential to deliver $124 million of benefits in present value terms over the next 30 years compared with outlays of $4.5 million. The internal rate of return on this project is estimated to be 43 per cent.
  - CRC work in contributing to integrated pasture management techniques to control vulpia has the potential to deliver returns with a present value of $496 million over the next 30 years. This compares with spending of $2.1 million on this project. The internal rate of return for the project is estimated to be 62 per cent.
  - We calculate that the CRC's work in accelerating CSIRO's longstanding program to develop effective biological control for Paterson's curse in pastures is likely, by bringing forward significantly the expected economic gains from the program, to deliver some $253 million of gains in present value terms over the next 50 years. This compares with total CRC and partner outlays on this project of $5.9 million, since 1996, implying an internal rate of return of 45 per cent.
  - CRC work on biological control of bitou bush, a major environmental weed of coastal areas of New South Wales, has the potential to deliver $45 million of gains in present value terms over the next 30 years — through savings on control costs, improved biodiversity and improved amenity values. This compares with project costs of $2.2 million, indicating an internal rate of return from the project of 29 per cent.
  - We estimate that the CRC's systems and activities in preventing the incursion of two potential new weeds (Mexican feather grass and cotton thistle) have

generated potential benefits to the Australian economy of $83 million in present value terms — through reducing substantially the probability of incursion of these weeds and hence avoiding the potential costs they would impose.

- The clear message from the sample of projects we have analysed is that CRC research is generating a very high rate of return to the community on the funds it is spending. There are several reasons for this.
  - Weeds impose substantial economic costs — on agriculture and on natural ecosystems. These costs are incurred each year into the future. Their present value is enormous. Hence, measures which can reduce these annual costs will over time generate large benefits.
  - The CRC's integrated systems approach to achieving weed control is well targeted and extremely cost effective. This approach recognises that effective and sustainable weed control over the longer term can best be achieved by bringing about steady changes in the plant environment that favour more desirable species at the expense of weeds. Such changes can invariably be achieved without incurring significant input costs on an ongoing basis. The CRC's strong emphasis on biological control provides a good example. Once established, biological controls work indefinitely at a pace dictated largely by the size of the weed problem and environmental factors. They deliver a stream of benefits over the longer term for little costs beyond those needed to establish the control.

1. Introduction

The CRC for Weed Management Systems (hereafter CRC) was established in 1995. It brings together over 140 researchers and educators, drawn from nine member institutions:

- New South Wales Agriculture;
- CSIRO (Division of Entomology and Plant Industry);
- Charles Sturt University School of Agriculture;
- Avcare Pty Ltd;
- Agriculture Western Australia;
- the Victorian Department of Natural Resources and Environment (DNRE);
- the Grains Research and Development Corporation (GRDC);
- the University of Adelaide; and
- the University of New England.

1.1 Objectives of the CRC

The CRC's mission statement is to increase the sustainability of agriculture and protect the natural environment by developing ecologically sound, cost effective weed management systems. Specific objectives are to:

- optimise the integration of chemical, biological and ecological approaches for weed control of annual crop and pasture systems in the southern cropping zone;
- develop practical integrated weed management systems that reduce weed infestation, protect the environment and enhance sustainability and productivity of temperate perennial pasture ecosystems;
- develop integrated strategies for the sustainable management of weeds invading natural ecosystems in temperate Australia in order to maintain biological diversity of native flora and fauna, and to prevent further degradation of natural habitats;
- implement a suite of weed science and weed management education programs which (for the first time in Australia) offers a coordinated approach to educating undergraduates, postgraduates, professional land and natural resource managers, and the community; and
- interact with researchers and land managers to communicate the results of weed research and foster the adoption of resulting weed management strategies.

Key concerns behind the strong focus on sustainability through integrated weed management are:

- increasing herbicide resistance of weeds;
- a growing recognition (confirmed by subsequent CRC research) that traditional spray and kill programs will need to be supplemented by management strategies which bring about a reduction in weed seed banks over time; and
- rising consumer resistance to herbicide residues in products and demands for more organic growing methods.

The CRC initially set as its target to bring about a 10 per cent reduction in the cost of weeds. Based on an estimate at the time that weeds cost Australian agriculture about $3.3 billion per year (Anonymous 1995 referred to in Vere, Jones and Griffith 1997) this translates into an annual saving to the economy worth $330 million.

1.2 This study

The CRC is a substantial research and development (R&D) enterprise. The CRC attracts a Commonwealth program grant of around $2.2 million a year for a seven year period. Over its first four years (1995-96 to 1998-99) the program grant of $8.8 million has been added to by $4.3 million in cash, $21 million in-kind from consortium members and $1.1 million from others. Program grant funds for this CRC expire in June 2002. A new proposal for the next round of CRC funding has been submitted.

This report provides a perspective on the economic value of the CRC's achievements to date. At issue is the CRC's performance measured against its objectives and the money spent in pursuing them. The weed control systems and strategies developed by the CRC and its education and information initiatives are now delivering, and will continue to deliver well into the future, benefits to farmers and to the wider community through reducing the economic cost of weeds. Critical questions that need to be asked relate the nature of these benefits and how large they are likely to be relative to the costs incurred to achieve them. Answers to these questions are an important element of accountability for the funds spent by the CRC over the past five years. They may also provide guidance on the relative returns from different categories of weed control programs and on how the composition of expenditure in a prospective new CRC funding agreement might be changed to enhance its payoffs to the community.

1.3 Our approach

The CRC has a diverse portfolio of projects organised over five program areas. They cover basic and applied work involving CRC initiated projects and fast tracking of projects at various stages of development before the advent of the CRC. Many activities are components of integrated systems of R&D where a full picture of payoffs will not become apparent until some years into the future. This makes it difficult from today's vantage point to 'ring fence' and quantify the future stream of benefits from the CRC's contribution.

There are two main approaches to accountability of the CRC's achievements in this situation. The first is to select at random a set of projects from the portfolio of activities for quantitative evaluation. From the results the net benefits of the entire package of R&D activities might be extrapolated. The validity of this approach depends on the representative nature of the projects. A large sample size is required for extrapolation to be valid. It is more difficult to apply when only some projects are amenable to evaluation as is clearly the case here.

A second approach is to select several successful projects for analysis and see how far the returns from these projects go to covering the costs of the entire program of R&D. This approach, though more tractable than the first, generates less information. And, as before, benefits that are more difficult to quantify tend to get lost in the assessment.

We follow a compromise between the two approaches. We first develop a framework setting out the types of benefits that are likely to emerge from each project in each program area. This provides a summary picture of the expected outputs of each component of each program and their anticipated impact on agricultural profitability, sustainability, satisfying consumers' preferences, education and the more public good areas such as the preservation of biodiversity in natural ecosystems. It also allows projects to be considered as part of an integrated program rather than standalone.

If the net present value of the flow of benefits relative to costs from each project or set of projects could be estimated, it would be a simple exercise to sum these values to find the net benefits generated by the CRC. But time constraints, as well as inherent difficulties in making such benefit–cost estimates for many of the CRC's activities, make this task infeasible. Instead, we draw on analytical systems developed by economists within the CRC and additional project specific information to provide estimates of costs and benefits from a selection of projects across key program areas. We use the results to draw conclusions about the value of the CRC's contribution to reducing the economic cost of weeds relative to the funds it has spent to achieve it.

additional project specific information to provide estimates of costs and benefits from a selection of projects across key program areas. We use the results to draw conclusions about the value of the CRC's contribution to reducing the economic cost of weeds relative to the funds it has spent to achieve it.

2. Reducing the economic cost of weeds - what is at stake?

Weeds are a major management problem for farmers. They impose financial costs — through expenditure on herbicides and other control measures, and through reductions in crop and pasture yields and product quality. Farm production and profits are reduced.

Weeds also impose financial costs on governments and others with responsibility for natural ecosystems. These are in the form of control costs — herbicides, slashing, mechanical removal, etc. There is also a 'yield' loss that is borne by the wider community — the reduction in the value of biodiversity and loss in amenity value through infestation.

These financial costs and losses of amenity value and biodiversity translate into economic costs. National income, consumption prospects and living standards are reduced as a result of weed infestation of private and public land.

2.1 What is the economic cost of weeds?

Knowing just how much different weed infestations reduce living standards is important for three reasons:

- it helps determine the level of effort that should be devoted to reducing the cost of weeds;
- it helps determine priorities in weed control research; and
- it provides a baseline against which progress in the fight against weeds might be measured.

It is usual to think of the economic cost of weeds in terms of weeds which have already spread to agricultural regions and natural ecosystems where the damage from infestation is readily apparent. But there is also a constant threat of new weed incursions and an expected economic cost from this threat. Measures which reduce the probability of new weed incursions will also yield economic benefits.

Studies estimating the cost of weeds differ markedly according to their coverage and degree of intellectual rigour. Their common feature is the invariably high estimate. Jones et al. (2000) refer to estimates by Combellack (1987) of the financial cost of weeds in agricultural cropping systems of $1271 million per year, made up of $592 million in cultivation costs, $137 million in herbicides, $34 million in herbicide application costs, $422 million in yield losses and $86 million in product contamination costs. Financial losses from weed incursions in pastures, horticulture and non-crop areas were estimated at $494 million, $213 million and $119 million respectively. These estimates imply a total financial cost of $2.1 billion (based on 1981-82 statistics), which translates into $2.8 billion for 1987.

Jones et al. (2000) provide estimates of the costs of weeds in annual winter grain cropping regions. Their methodology extends the concept of financial costs to economic costs — by taking into account the effects of weeds on crop volumes and commodity prices. The results indicate annual economic costs of $1.1 billion, with 95 per cent borne by farmers as reduced profits and 5 per cent by consumers as higher crop prices.

Other studies report estimates of the costs of specific weeds in certain regions. These include an annual cost of $42 million for wild oats in grain crops in 1987-88 (Medd and Pandey 1990), an annual cost of $40 million for serrated tussock in New South Wales pastures (Jones and Vere 1998) and a current (1997) annual cost of serrated tussock control in Victoria of $5.1 million, which will increase to $15 million per year in ten years time if the weed spread is not contained (Nicholson, Patterson and Muller 1997).

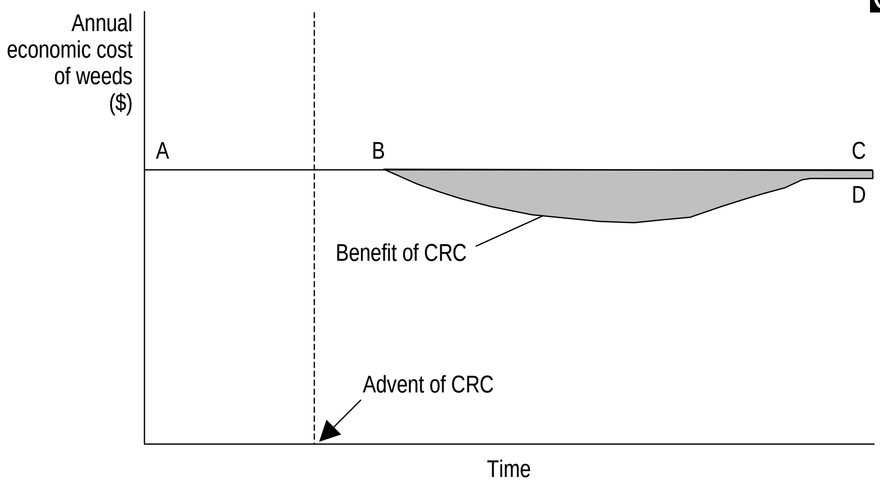
The clear message is that weed incursion is a significant economic problem. It is therefore in the community's interest for a substantial commitment of effort to be devoted to reducing the economic costs imposed by weed incursions.

2.2 How the CRC might reduce the economic cost of weeds

Chart 2.1 depicts schematically the impact of the CRC on weed costs.

The line ABC depicts the economic cost of weeds (on crops, pastures, natural ecosystems) in the absence of the CRC. For convenience, this is shown as horizontal (constant economic cost through time). Whether this curve slopes up or down is difficult to predict — there are factors at work which are tending to both increase and decrease the economic cost of weeds over time. An increasing appreciation in the community of the value of biodiversity and the amenity value derived from natural ecosystems will, other things equal, lead to an increase over time in the economic cost of environmental weeds. Declining real prices for agricultural products, other things equal, will reduce the economic cost of weeds on agriculture. The advent of internet trading may be increasing the economic costs of weeds over time by increasing the likelihood of incursions of new weeds imported through the mail by plant enthusiasts. Similarly, reductions in the effectiveness of current control strategies will, other things equal, increase the economic cost of weeds over time unless land managers have access to alternative means of control.

2.1 Measuring the payoffs from the CRC



The line ABD represents the profile of annual economic costs of weeds under the influence of the CRC. The shaded area between the two lines measures the economic value of the CRC's efforts to reduce weed costs.

Specifying the profile of ABD is also difficult. The CRC can reduce the economic costs of weeds through two pathways:

- by developing new control strategies and new components which increase the range and effectiveness of existing control strategies; and
- by decreasing the transaction costs of farmers and natural resource managers in arriving at the optimum strategy to reduce weed costs (which may lead to more or less weed control and herbicide use).

Key components of the first pathway are CRC initiatives to reduce pasture and crop yield losses, product quality and weed control costs. Control costs include current input costs such as expenditures on weedicides and cultivation. They also include any opportunity costs associated with current control measures — for example, high rates of chemical use today may have adverse implications for weed resistance and farm productivity in the future. Key components of the second pathway are the information initiatives the CRC uses to get its message across. Education and communication and adoption programs have a prominent place in the CRC's agenda (see later).

Once we have established the CRC's contribution through these two pathways, we also need to account for the likely success of projects currently under way and the profile of adoption of projects that have yielded successful findings. Some of the CRC's work has involved the speeding up of the adoption of techniques pioneered by others. And some of the CRC's accomplishments to date will not be adopted until some time down the track. Finally, we need to recognise that the effectiveness, and hence economic value, of some weed management techniques will peak then wane over time.

3. Agenda, expected outcomes and achievements

CRC activities to reduce the economic cost of weeds are organised over five program areas:

- cropping systems (program 1)
- perennial pastures (program 2)
- natural ecosystems (program 3)
- education (program 4)
- communication and adoption (program 5).

Each program has a number of subprograms and projects. The CRC has initiated new projects and has built on and fast tracked existing projects in these areas.

3.1 Allocation of resources

Table 3.1 shows the cash and in-kind contributions to the program to 1999-2000, and projected funding in the following two years. The total funding for the program to the end of 1999-2000 was $38.7 million (not discounted), of which a third was cash and the rest in-kind. Table 3.2 and chart 3.3 show the allocation of resources across programs and subprograms. Program 1 on cropping systems attracted 17.4 per cent of the funding, program 2 on pasture weeds attracted 25.5 per cent and program 3 on natural ecosystems attracted 22.7 per cent. Education and communication programs together received over 28 per cent of the funding, reflecting the strong emphasis on capacity building in the research, farming and broader community. In all programs in-kind contributions provided the major source of funds — however, cash contributions were particularly important for education. As this program provides scholarship support for students the higher share of cash is appropriate.

The combined roles of many of the personnel working in a program area across sub-programs makes division of in-kind resources at the sub-program level difficult, so chart 3.3 presents only the shares in cash allocations to 2000. The areas in programs 1 and 2 receiving the greatest funding focus are developing and extending integrated systems. This reflects the emphasis of the CRC on systems approaches to weed management in crops and pastures. The greater emphasis on biological controls in program 3 also reflects priorities as active weed control measures through herbicides and mechanical means are too expensive to be widely applied to weed problems in natural ecosystems.

3.2 Expected outcomes

Each of the CRC's projects is designed to contribute to reducing the economic cost of weeds in different ways. Tables 3.4 to 3.8 set out a framework for recording qualitatively the nature of the benefits that are anticipated

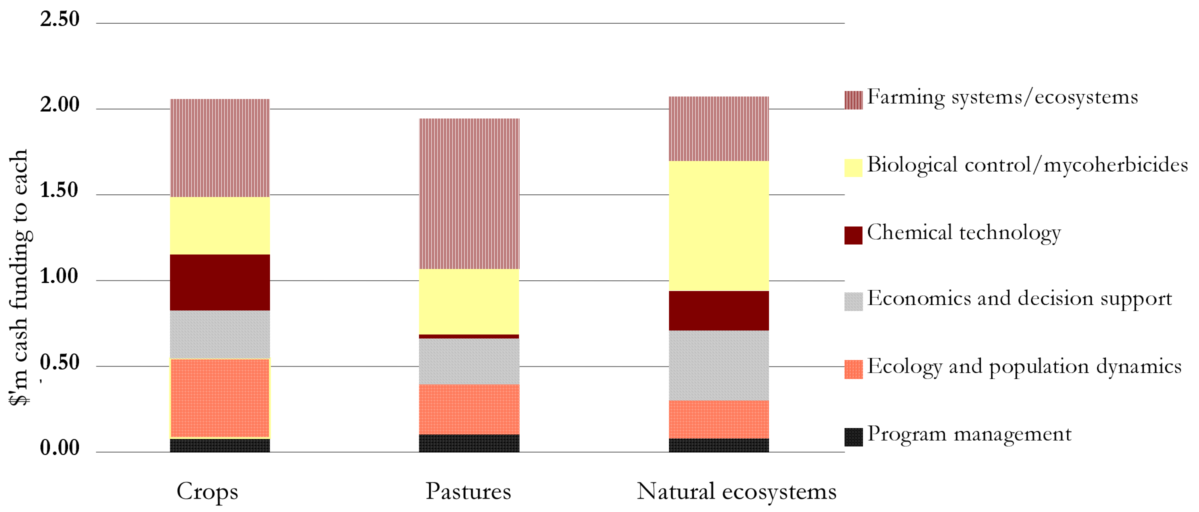
3.1 Total funding for the CRC Cash and in-kind

	1995-96	*1996-97*	*1997-98*	*1998-99*	*1999-00*	*Projected 2000–01*	*Projected 2001-02*	*Grand total*
	$ million	$ million	$ million	$ million	$ million	$ million	$ million	$ million
Total cash	1.44	2.71	3.33	2.72	2.75	2.75	2.75	18.45
Total in kind	4.75	5.11	5.30	5.98	4.59	4.59	4.59	34.92
Total	6.19	7.82	8.63	8.70	7.34	7.34	7.34	53.37

3.2 Allocation of CRC funds to 2000 between programs, cash and in-kind shares

		Total budget to 2000	*Share in cash*	*Share in-kind*
		$ million	%	%
Program 1	Annual cropping systems	6.72	30.6	69.4
Program 2	Perennial pasture ecosystems	9.86	19.7	80.3
Program 3	Natural ecosystems	8.79	23.5	76.5
Program 4	Education	2.95	46.6	53.4
Program 5	Communication and adoption	8.00	18.7	81.3
Program 7	Administration	2.37	18.7	81.3
Total ($ million)		38.69	12.9	25.7

3.3 Allocation of CRC cash expenditure by three main subprogram areas



Data Source: CRC Weed Management personal communication, September 2000

3.4 Contribution from annual cropping systems program

	Type of impact expected						
	Reduction in unit production costs	***Improved sustain-ability of production system***	***Reduced external impacts on producers***	***Satisfying consumer tastes and preferences***	***Skill development***	***Reducing environ-mental pollution***	***Protection of biodiversity***
Integration of ecological and dynamics knowledge into modelling and weed management strategies (competitive crops, selective spray topping)	M	H	M	M	H	L	L
Formulation of decision support rules for herbicide use and for herbicide resistance	M	H	M	M	M	L	L
Assessment of herbicide resistant crop cultivars	H	M	L	L	M	L	L
Assessment of pathogens with/without low rates of herbicides in glasshouse and field	H	H	M	M	H	L	L
Review and extend current known tactics for IWM strategies for wild radish	H	H	M	L	M	L	L

Note: H = high, M = medium, L = low.

for each project in each program. Some benefits are clearly of a private nature — they are captured as increased profits by commercial farmers. Others are shared more throughout the community.

The table recognises five categories of benefits as follows.

- Reduction in unit production costs. Benefits accrue to producers as production costs are reduced through lower input requirements and/or higher yields from the same level of inputs. Some of the benefits through this channel will be passed on to consumers in lower prices as more effective weed control increases crop production.
- Improved sustainability of production system. Weed incursions may threaten sustainability through increased chemical resistance to current spray programs in particular. Benefits come from maintaining or

3.5 Contribution from perennial pasture ecosystems program

	Type of impact expected						
	Reduction in unit production costs	***Improved sustain-ability of production system***	***Reduced external impacts on producers***	***Satisfying consumer tastes and preferences***	***Skill development***	***Reducing environ-mental pollution***	***Protection of biodiversity***
Integrated ecological studies of key weed species within pasture systems developed and implemented	M	M	M	L	H	L	L
Preliminary bioeconomic models of weed impacts developed	H	H	M	L	M	L	L
Level of herbicide resistance in perennial pastures identified	M	M	M	L	L	L	L
Research on factors to enhance biological control agents commenced and field tests with enhanced biological control agents done	M	H	H	M	H	M	H
Farm and industry level surveys and analyses of weed impacts and benefits–costs of improved weed management	H	H	L	L	M	L	L
Mechanisms operating between herbicide use, resistance and pasture species dynamics determined	M	H	M	L	H	M	L
Grazing management systems within industry context for weed control and enhanced productivity developed	H	H	M	M	H	L	L

Note: H = high, M = medium, L = low.

improving crop and pasture productivity against a counterfactual of declining, static or only slowly increasing productivity.

- Reduced external impacts on producers. Weed management activities (or the lack of them) on one property impact on neighbouring properties through weed transfer and perhaps also soil erosion and salinity.
- Satisfying consumer tastes and preferences. There is considerable concern in some sections of the community over herbicide residues in foods. There is also disquiet over the potential release of genetically modified crop plants, including herbicide tolerant crops. Concerned consumers will increasingly demand guarantees of safe (and lower) herbicide inputs and minimal intervention via genetic manipulation.
- Producers may benefit through premium prices on such guarantees. Consumers benefit in that they value these attributes and are prepared to pay for them, which may or may not be validated in terms of benefit to health.
- Skill development. Increasing knowledge and expertise among weeds researchers, weed managers and the general community is an important, though difficulty to quantify, part of the CRC's agenda. Research skills are inputs into future research, the payoffs coming as lower research costs and increased research effectiveness in weed control in the future. Enhanced education of weed managers in control strategies has the potential to deliver more immediate gains, enhancing production and sustainability.
- Reducing environmental pollution. Weeds have the potential to do considerable environmental damage. Better control strategies means reduced control costs. The benefits may also include enhanced tourism and non-market recreational uses such as fishing and bush walking.
- Protecting biodiversity. Encroachment of weeds has adverse effects on vulnerable species — both flora and

3.6 Contribution from natural ecosystems program

	Type of impact expected						
	Reduction in unit production costs[a]	*Improved sustain-ability of production system*	*Reduced external impacts on producers*	*Satisfying consumer tastes and preferences*	*Skill development*	*Reducing environ-mental pollution*	*Protection of biodiversity*
Development and refinement of demographic models for at least two invasive weeds (broom, St John's wort)[b]	L	M	M	L	M	M	M
Establishment of trials that combine the effects of fire, herbicide application and the release of natural enemies with revegetation strategies	H	H	M	H	M	M	H
Development of methods for impact assessment of invasive species and their implementation	M	H	H	L	M	M	H
Field release of additional agents and monitoring of their effects on reproductive output of candidate weeds (bitou bush, boneseed, bridal creeper, broom, horehound, St John's wort, blackberry)	M	H	H	H	M	M	H

[a] Production costs are interpreted as costs of natural resource management. [b] These are inputs into developing control strategies.
Note: H = high, M = medium, L = low.

fauna. Not a lot is known about the threats to biodiversity from weeds, but several examples suggest the effect could be large. While the use value of any one species is difficult to assess — stemming from genetic potential as well as uses such as garden plants, forage and food, and from the role it plays in the ecosystem — the value may be large.

Program 1: Annual cropping systems

This program encompasses weed control technologies for all small grains and for all southern cropping regions — Western Australia, South Australia, Victoria and southern New South Wales. Most of the expected impacts are concerned with enhancing profits of commercial grain growers through achieving cost reductions and improved sustainability of production.

Program 2: Perennial pastures

Research under this program is directed at improving the performance of perennial pastures in the high rainfall zone (beef, sheep meat, wool production) in southern and south eastern Australia. The expected impacts are mainly of a private commercial nature, though biological control programs can be expected to enhance biodiversity in the region.

Program 3: Natural ecosystems

Research under this program will deliver benefits overwhelmingly of a public good nature. In particular, the research is expected to make a major contribution to protecting and restoring biodiversity in natural ecosystems as well as reducing the costs of natural resource management by government authorities and regional Landcare and Dunecare groups.

Program 4: Education

The benefits from this program will accrue to both commercial farmers and the community as a whole through the variety of impacts indicated in table 3.7. In particular, the program will greatly enhance skill development in weed research and in weed management.

3.7 Contribution from education program

	Type of impact expected						
	Reduction in unit production costs	*Improved sustain-ability of production system*	*Reduced external impacts on producers*	*Satisfying consumer tastes and preferences*	*Skill development*	*Reducing environ-mental pollution*	*Protection of biodiversity*
Short courses for land managers and advisors in weeds and weed management	M	H	L	L	H	M	L
New subject in integrated weed management developed and available for full-time study at U. Adelaide, CSU, UNE, distance learning at CSU and UNE	L	M	L	L	H	L	L
Establishment of a computer network system to which information on weeds can be added from CRC research — seven list servers (contribution to date to entry prevention of Mexican feather grass, cotton thistle, alpine herb)	L	M	M	M	M	M	H
Development of a subject on integrated weed management for parks and recreational areas available to CSU students in Park management, and to students at other Universities studying natural resource and park management courses.	L	M	L	M	H	M	M
Postgraduate students engaged in research	–	–	–	–	H	–	–
Publication of a textbook on Integrated Weed Management	L	M	L	L	H	L	L

Note: H = high, M = medium, L = low.

Program 5: Communication and adoption

As indicated by the assessment in table 3.8, this program is vitally important in delivering the gains from CRC research to both commercial farmers and to the community at large.

3.3 Achievements

A snapshot of the CRC's performance four years into its term reflects much in the way of work in progress. Yet a large number of achievements are readily apparent over a range of areas (chart 3.9). Many of these achievements fall under the more difficult to quantify heading, though real financial benefits will flow from them in due course.

Achievements more difficult to quantify

Understanding the economic cost of weeds

CRC economists have developed an array of sophisticated biological–economic models to measure the cost of current weed incursions and the likely payoffs from alternative control strategies. This work is providing a better understanding of the seriousness of the weed problem and the appropriate level and prioritisation of effort to control it. In turn, it will lead to better targeted weed control programs in the future.

Policy development

The CRC has made important contributions in several areas of policy development. One contribution is its input into

3.8 Contribution from communication and adoption program

	Type of impact expected						
	Reduction in unit production costs	***Improved sustain-ability of production system***	***Reduced external impacts on producers***	***Satisfying consumer tastes and preferences***	***Skill development***	***Reducing environ-mental pollution***	***Protection of biodiversity***
Establish in-house and public communication systems	M	M	M	L	M	L	L
Participate in project design and development of ensure integration of strategies to maximise adoption	H	H	H	L	H	M	M
Establish partnership with provider groups to ensure adequate channels for feedback and servicing	H	H	H	L	H	M	H
Targeted extension activities, with particular reference to major commercial and environmental weeds	H	H	H	M	H	M	H
Provide support data so that decision making can be sympathetic to economic and environmental constraints when implementing integrated weed management systems	H	H	M	L	H	M	L

Note: H = high, M = medium, L = low.

the policy debate on the development of transgenic herbicide resistant crops. A second contribution is its input into the government's 1997 national weed strategy to identify weeds of national significance and develop coordinated actions to control them. The CRC has contributed significantly to the development of national strategies for five weeds of national significance (Chilean needle grass, serrated tussock, bridal creeper, blackberry, bitou bush – boneseed). A third contribution involves work on appropriate policies to deal with the externalities associated with weed infestations. This work has shown that, in some serrated tussock infested areas (where control costs to the farmer exceed the productivity of the land), community welfare is maximised by planting trees on the land and ceasing agricultural production.

A fourth contribution is the CRC's submission to a 1999 New South Wales government inquiry into the use and management of pesticides (Nordblom and Medd 1999). In this submission the CRC argued for the New South Wales Pesticide Act to be amended to allow flexibility where appropriate and safe for:

- users to apply herbicide dose rates below the maximum specified on the product without the need for permit approval; and
- government and private advisers to recommend sub-label herbicide does rates.

The submission noted that economic, trade and public concerns about pesticides are driving users worldwide to fine tune dose rates to match field environmental conditions observed for the specific problem being targeted. Biological, economic and social considerations were advanced to support the CRC's case. The recommendation of the CRC's submission that pesticide use be allowed at rates lower than recommended on labels, except where expressly prohibited, was incorporated in the New South Wales *Pesticide Act 1999*, which came into effect on 1 July 2000. This brings New South Wales into line with Australia's other mainland states, as well as Canada and the US

.

Fostering interdisciplinary research

A major achievement of the CRC has been to bring together professionals from different disciplines to collaborate on solving a particular problem. Resource economists, weed scientists, weed ecologists, biologists, agronomists and entomologists have benefited greatly from such interactions, which will have longer term benefits in terms of their productivity in addressing research issues well beyond weeds.

Paradigm shift in approach to weed control

The CRC's interdisciplinary approach and its focus on sustainable integrated management systems for weed control have led to a fundamental shift in how weed infestations should be managed — from a heavy emphasis on individual and static spray kill techniques to a multifaceted approach, which combines a range of technologies over time to reduce current infestations and wind back the source of future infestations.

Education, training and dissemination of information

Achievements include the development of an undergraduate subject (integrated weed management), which is now taught at three universities, the provision of opportunities for 15 post-graduate students to further their scientific education and training, the delivery of short courses for land managers, and professional development and community education initiatives. These initiatives can be expected to deliver longer term benefits to the individuals involved and the wider community.

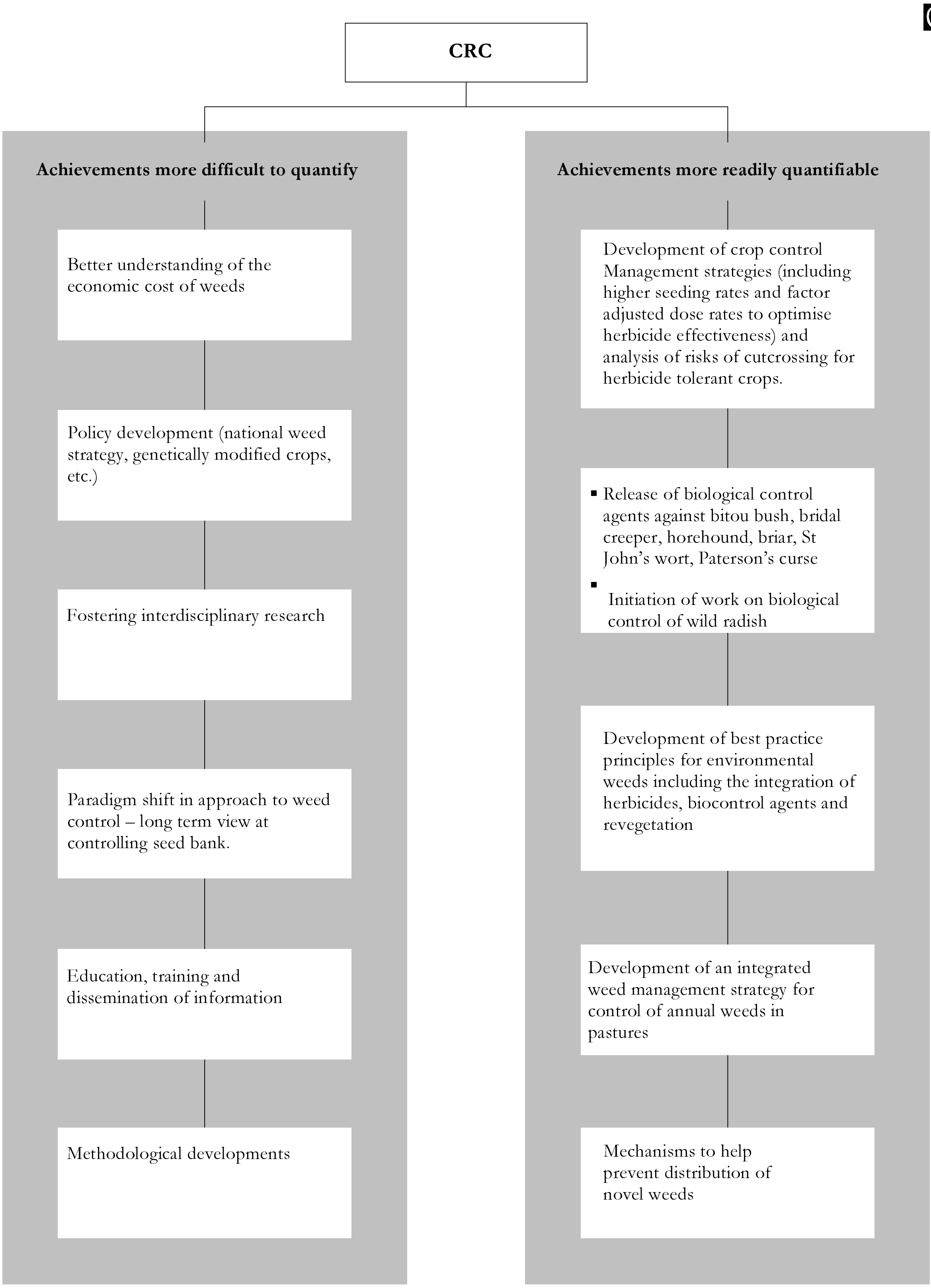
Methodological developments

A number of developments in methodology by CRC researchers will have a wider application beyond weeds. An example is the application of techniques of choice modelling and citizens juries (for valuation of non-market goods and services) to estimate the willingness to pay for control of environmental weeds in natural ecosystems. This is an important part of an assessment of the economic impact of environmental weeds.

Achievements which can be more readily quantified

Chart 3.9 contains a selection of these. In later chapters we provide more detail on specific examples.

3.9 Dimensions of the CRC's contribution to date



4. Competitive cropping for weed control: a benefit-cost analysis

4.1 Background

Weeds in winter crops have been estimated to cost over $1.1 billion a year in Australia (Jones et al. 2000). The costs arise from:

- yield loss as weeds crowd out the crop;
- contamination loss as product that contains weed seed and weed residue is often discounted;
- control costs of additional cultivation, herbicides and other treatments; and
- opportunity costs arising from losses associated with soil structure decline from cultivation and the impact of pesticide residue levels on market access and price.

4.2 Competitive cropping

Competitive cropping is the practice of increasing seeding rates and/or selecting more vigorous genetic stock to crowd out weed seedlings in the crop. It is one tool in the toolbox of techniques for the integrated management of weeds in crops. The benefits of competitive cropping arise from:

- reduced need for application of post emergent herbicides;
- increased effectiveness of such herbicide applications due to the synergies between the selective herbicide and crowding out (herbicide treatments may be less than 100 per cent effective due to weather conditions and insufficient dose rates); and
- its role in an integrated weed management system that places less emphasis on cultivation for weed control, and hence is more supportive of a minimum tillage cropping system with associated gains in long term sustainability of yields.

The costs of competitive cropping are:

- the cost of the additional seed and sowing costs and/or higher cost of more competitive varieties;
- any additional cost of harvest or other costs associated with a thicker crop; and
- until the work of the CRC demonstrated otherwise, a perceived reduction in crop yields and quality (as plant effort goes into foliage production).

Adoption of competitive cropping

Competitive cropping has not been widely adopted in the past as effective herbicides have provided lower cost weed management options. However, in estimating the cost of weed management options involving competitive cropping, farmers in general would have factored in an economic loss due to a strong perception that more vigorous varieties and/or higher plant density reduces grain yields and quality.

With increases in herbicide resistance, farmers are seeking alternative systems to minimise weed costs. Reduced applications of herbicides only delay the development of resistant weeds. However, this delay could be valuable when alternative systems of weed control carry additional costs such as yield losses from soil structure decline associated with higher levels of cultivation. Competitive cropping offers an alternative approach to increased cultivation for weed control. Included in a management system, competitive cropping may also reduce weed costs by delaying the development of resistance. Competitive cropping has also been demonstrated to improve the effectiveness of herbicide applications.

The CRC research

The CRC research program brought together most of the researchers involved in competitive cropping around Australia. Table 4.1 lists the projects involved in program 1 that have an impact on competitive cropping.

There are three main areas of R&D:

- estimation of the impact of competitive cropping on crop yields and weed numbers;
- manipulating crop agronomy to favour the crop rather than the weeds; and
- identification and breeding of more vigorous crop varieties.

4.3 The contribution of the CRC research

The findings

The research has found that competitive cropping does not result in lower yields or grain quality for any given level of weeds. This finding was corroborated for a number of different grain crops in a variety of regions. It is held to be a robust result. While research on competitive cropping was under way prior to the CRC, the collaboration provided by the CRC allowed sharing of results and coordination of trials to improve the regions and crops covered by the research.

Work on crop agronomy, identification of more vigorous equivalent varieties and breeding efforts have concentrated on more vigorous wheat varieties. Substantial improvements in terms of lower weed control costs are anticipated to result from this work, and some advance has already been made. The main saving is due to greater effectiveness of herbicides when combined with competitive cropping. This results from reducing the seed bank over

4.1 CRC projects on competitive cropping

Name of project	*Start date*	*End date*	*Researchers involved*
Previous			
Extent and physiological basis of ability of wheat cultivars to supress weeds	07/11/95	31/08/97	Makhtari, Cousens and Galwey
Early vigour wheat – its role in productivity and sustainability		30/06/97	D Sloane, G Gill, G McDonald and G Hollamby
Impact of planting arrangement and herbicides on ryegrass population dynamics		1997	J Matthews and G Gill
Understanding competition between wheat and wild radish	1997	1999	R Cousens
Potential to breed more competitive wheat and barley varieties		30/06/99	D Lemerle, P Martin and R Richards
Molecular markers for allelochemicals in wheat genotypes	1996	1999	H Wu, Pratley and D Lamerle
Reducing herbicide use – role of competitive crops	07/95	2000	R Davidson and G Gill
Modelling weed/crop competition	1997	2000	Lemerle, R Cousens, et al
Allelopathy between wheat and ryegrass			A Billinger and S Powles
Yield loss/density relationships wheat and wild oats	1997	1999	C Murphy, D Lemerle and R Medd
Current			
IWM for phalaris control and wheat competition	1998	2000	R Coleman and G Gill
Impact of increased wheat seeding rate on wheat yield, quality and ryegrass supression	1997	2000	CRC Cousens, Lemerle, Gill, Peltzer and Moerkerk
Managing weeds and crop vigour under no-till farming systems development	07/1999	06/2002	Sam Keeman and G Gill
Regional packages to make wheat strongly competitive against weeds	07/1999	2002	D Lemerle
Soil quality parameters associated with enhanced crop vigour	1999		R Gallagher, Wahri and G Gill
Reducing herbicide use – role of competitive crops	2000		R.Davidson and G Gill
Genetic control of allelopathy in wheat	09/1999	09/2002	H Wu, J Pratley and D Lemerle

Source: Lemerle personal communication (August 2000).

time. The studies undertaken relate mainly to wild radish and wild oats, although the work on wild oats is applicable to annual rye grass, which is probably the most important.

Table 4.2 provides estimates of the net benefits of including competitive cropping in a weed management regime for crops in wild oats and wild radish infested areas. The benefits are for a wheat crop with a weed free yield of 3.9 tonnes per hectare. The additional cost of the higher seeding rates of $6 a hectare is factored in to the impact on gross margins. The gains come from lower herbicide applications and higher yields. The increase in gross margins over time were estimated by Randall Jones of the CRC for the purpose of this evaluation. As the benefits depend on the cumulative impact on the seed bank, they change over time. As can be seen from the table, the impact on wild radish and wild oat weed problems are quite different. This is due to the different persistence of the seeds of the two weeds, wild radish being more persistent. The benefits peak in the seventh year for wild oats and continue to increase for the full 20 year period for wild radish.

4.4 Evaluation of the impact

Project costs

The present value of the costs of the competitive cropping program is estimated at $4.5 million over the life of the CRC. This estimate is based on data provided by the CRC on cash and in-kind contributions under the program and associated activities. One third of the funding is cash, the rest is in-kind contributions. There are a number of projects that are funded by GRDC and other organisations that have contributed to the competitive cropping research but have not fallen formally under the CRC umbrella, so the funding has not been reflected in the CRC annual reports. As these projects have been identified, we include them in the total funding for the competitive cropping program.

4.2 Projected annual net benefits — improvement in gross margins

Year	*Wild radish*	*Wild oats*
	$/ha	$/ha
1	12.63	42.79
2	15.75	43.60
3	18.81	43.45
4	21.79	42.94
5	24.72	42.38
6	27.57	41.27
7	30.34	37.96
8	33.04	32.12
9	35.65	25.51
10	38.16	18.63
11	40.58	11.60
12	42.92	5.20
13	45.16	1.52
14	47.31	0.34
15	49.37	0.00
16	51.34	0.00
17	53.22	0.00
18	55.01	0.00
19	56.71	0.00
20	58.34	0.00

Source: Jones personal communication (September 2000).

Project benefits

Improvement in gross margins

Adoption of the weed management systems developed by the CRC and associated agencies can bring substantial benefits in terms of higher gross margins. An estimate of the benefits was made for each of the three main wheat growing regions using the benefit estimates in table 4.2. These estimates were scaled by the average weed free yield in each of the regions, and were applied only in the areas prone to each of the weeds. A survey undertaken by the CRC of weeds in crops (Jones et al. 2000) provided a baseline for the area where competitive cropping was relevant. Wild radish is the predominant weed in the western region, with very little present in the northern region, while wild oats were present across all regions. There is comparatively little overlap of these weeds, and for the analysis an overlap of 10 per cent was assumed for the base case estimates. In the overlap areas the benefit of competitive cropping is assumed to be the average of the benefits for the individual weeds. This may be conservative as the benefit may be greater, but an assessment of the benefits of multiple weed control has not yet been undertaken by the CRC so the true benefits cannot be estimated.

Table 4.3 gives the initial areas of wheat crop with weeds in each of the three regions. The value of the research will depend in part on how rapid the spread of weeds is likely to be. The assumptions made about the spread of weeds is also given in the table. As the rate is not known a range of values were provided for the sensitivity analysis.

Adoption

The research has reduced the uncertainty about the impact of competitive cropping and removed the old perceptions that yield and quality would suffer under such a management system. The work by the CRC and others has provided more competitive varieties with comparable yields and quality. It has expanded the range and sophistication of weed management systems with potentially large gains for farmers in weed prone areas. An important factor influencing the impact of the research has been the growth of herbicide resistance. Over 30 per cent of farmers in the southern cropping areas now report some level of commercially damaging resistance (Lemerle personal communication, July 2000).

Recent surveys conducted on behalf of the CRC have found the integrated use of competitive cropping increasing from a very low base. It is anticipated that adoption of competitive cropping as part of a weed management strategy could easily rise from current levels of around 10 per cent to 60 per cent in the next ten to fifteen years. Three scenarios are developed for adoption. The actual scenario will depend in part on the growth of herbicide resistance and this is one trigger that will increase adoption. However, the CRC is working hard through its communication programs to encourage adoption prior to resistance development. Three adoption profiles are tested — a low adoption profile peaks at 40 per cent, the best bet profile peaks at 60 per cent and the high adoption profile peaks at 90 per cent. As resistance varies between the three regions, the adoption rates are scaled up for the western and southern regions, with adoption greatest in the western region (20 per cent higher than in northern regions).

Work on competitive cropping was under way prior to the establishment of the CRC so in the absence of the CRC it is likely that use of competitive cropping would have expanded. It is difficult to assess what the outcome would have been in the absence of the CRC as no doubt weed management systems would have improved somewhat and adoption would also have increased. After some discussion it was decided that around half the achievements would have been likely in the absence of the CRC, so the estimate of benefits attributable to the CRC are scaled back accordingly.

Results

Table 4.4 gives the results for the best bet point estimates for each of the parameters as discussed above. Based on these assumptions the competitive cropping program will bring benefits with a present value of $124 million. With

4.3 Areas of weeds, average yields and spread assumptions

Area		*Northern*	*Southern*	*Western*
		Hectares	Hectares	Hectares
Wheat	ha	2 545 000	4 071 000	3 724 000
Wild oats	ha	473 868	639 300	615 500
Wild radish	ha	500	187 500	1 381 700
Average yields	t/ha	3.1	3.1	2.4
Assumptions about changes in areas (rate of weed spread, per cent per year)				
		Minimum	*Base*	*Maximum*
Wild oats	%	0	1	5
Wild radish	%	0	1	5
Percentage overlap (area with both weed problems)	%	20	10	0
Scaling factors[a]				
		Northern	*Southern*	*Western*
Adoption		1	1.1	1.2
Weed spread		1	1.1	1.3

[a] Denotes higher rate of adoption and rate of weed spread from northern (base) because of genetic herbicide resistance in the area.
Source: Jones, et al. (2000) assumptions.

this benefit the program has a 43 per cent return on the cash and in-kind investment, and a benefit–cost ratio of 28.5.

4.4 Results of the benefit–cost analysis — competitive cropping

	Unit	*Results*
Benefits (present value)	$m	123.8
Costs (present value)	$m	4.4
Net benefits (present value)	$m	119.4
Ratio of benefits to costs	$m	28.5
Internal rate of return	%	43

Sensitivity analysis

The sensitivity analysis establishes the most likely range of benefits given the range of assumptions about growth rates of weeds and adoption profiles, which are the main areas of uncertainty. Table 4.5 gives the results for the 90 per cent confidence interval and the mean using probability distributions across the range of likely parameter values. The lower bound net benefit of $86 million, indicates that it is highly likely that the project has had and will have a substantial impact on weed costs over time.

4.5 Sensitivity analysis — competitive cropping

	Unit	*Lower bound*	*Mean*	*Upper bound*
Benefits (present value)	$m	90	128.9	184
Costs (present value)	$m	4.5	4.5	4.5
Net benefits (present value)	$m	86.0	124.5	180.5
Ratio of benefits to costs		20.8	29.6	42.5

It should be noted that the technology developed for competitive cropping is applicable to other crops and to other weeds. This analysis based on two weeds in wheat crops is likely to understate the true benefits of the technology that has been developed in the program.

5. Controlling vulpia and Paterson's curse in pastures: a benefit–cost analysis

Weeds in pastures have been estimated to cost over $792 million a year in Australia (24 per cent of the total estimated cost of $3.3 billion). The costs arise from:

- production loss as weeds crowd out more productive pasture species — animal meat and wool gain is lower per hectare grazed;
- contamination loss where the product is tainted by weed residues (such as seeds in wool) and hence discounted;
- control costs of mechanical removal, herbicides and other treatments; and
- potential opportunity costs arising from losses associated with the impact of herbicide residue levels on market access and price.

Unlike weeds in crops, pasture weeds are more likely to spread beyond the property boundary. Failure to control some of the common weeds imposes additional weed costs on neighbours and further afield.

5.1 Current vulpia and Paterson's curse control strategies

Vulpia is an annual grass of poor nutritional value. It is a prolific seeder and quickly infests bare ground and will crowd out more nutritious perennial grasses. Paterson's curse (*Echium platagineum*) is a broadleaf annual that has some nutritional value, but crowds out more productive pasture species. It may also cause liver damage in animals after prolonged grazing of it over a number of years.

Surveys over the last ten years of various parts of the temperate perennial pasture zone of south-eastern Australia (which supports about half southern Australia's sheep and cattle production) have indicated high percentages of vulpia and other low productivity annual grasses and also a significant presence of Paterson's curse and other broad leaf weeds. CRC research has established that, because of its high seed bank density and dominance in many pastures, spraying of vulpia is not an effective control option. And spray control of Paterson's curse, while effective at certain times of the year, does not by itself achieve effective control. For both weeds, spray and spray topping programs need to be supplemented by other control technologies.

5.2 CRC research

The CRC has conducted research on integrated management strategies to control these and other annual and broad leaf weeds in perennial pastures. The research has covered:

- estimating the impact of weed management on pasture nutrition;
- active grazing management involving the application of differential grazing pressure at key times in the life cycle of vulpia;
- identification and releases of biological control agents in the case of Paterson's curse; and
- analysing the effectiveness of herbicides and spray grazing.

5.3 Findings and achievements

Herbicides have been shown to provide short term control for vulpia, but need to be followed up by other management strategies to prevent reinfestation. It is important to target measures that reduce seeding recruitment for effective longer term control.

A massive increase in the number of releases of biological control agents for Paterson's curse has been achieved, the benefits from which are now becoming apparent. Models to assess the economic impact of weeds, including vulpia and Paterson's curse, have been developed. This modelling builds on work on the nutritional values of pastures under different levels of four representative pasture species (vulpia, phalaris, Paterson's curse and subterranean clover). Such models can assist farmers in decisions about the optimal level of weed control in pastures. The models can take into account industrywide costs as well as on-farm costs.

An integrated weed management approach to controlling vulpia has been developed. This centres on the judicious use of herbicides to reduce seed numbers and grazing management at different times of the year to take advantage of this and encourage perennials at the expense of annuals. Active grazing management, which increases the abundance of perennial grasses relative to annual grasses, also appears to reduce Paterson's curse dominance.

A best bet package has been formulated involving herbicides in year one, targeted grazing to reduce seed heads in year two, then summer rest, autumn fertiliser, then normal grazing, then rest the following spring. This package provides a proactive way of weakening vulpia at the expense of perennials and should be applied where annuals exceed 20 per cent of the pasture. The payoffs come through more productive pastures. There will also be external benefits through the effects of more productive pastures on reducing water runoff and dryland salinity.

5.4 Payoffs from vulpia control

Adoption of the integrated weed management techniques formulated by the CRC will lead to a reduction in vulpia area relative to improved perennial grasses such as phalaris and cocksfoot.

The extent of vulpia in pastures was measured in a recent survey by the CRC involving 160 sample points covering all of the New South Wales tablelands — from Tenterfield in the north to Cooma in the south. Randall Jones and David Vere of the CRC evaluated the payoffs from achieving an absolute 10 per cent reduction in the area of vulpia in pastures — from an average of 37 per cent in paddocks surveyed to 27 per cent. The 10 per cent absolute reduction is considered a conservative estimate of what can be achieved by implementing the integrated weed management techniques developed by the CRC for vulpia control in perennial pastures.

Table 5.1 shows the pasture composition in the base scenario (that indicated by the survey results) and the new pasture composition achievable through application of the CRC's integrated weed management approach. It is assumed that vulpia would be replaced by improved perennial grasses.

5.1 Tablelands pasture composition: base scenario and vulpia reduction scenario

Pasture type	***Base scenario***	***Vulpia reduction scenario***
	% of area	% of area
Improved perennial grasses	10.0	20.0
Native perennial grasses	17.8	17.8
Annual grasses (vulpia)	37.0	27.0
Legumes	25.0	25.0
Broad leaf weeds	10.2	10.2

Source: CRC survey (base scenario).

These scenarios were run through a grazing systems linear programming model for wool and lambs, and a livestock economic surplus model to generate estimates of the likely annual benefits to the tablelands wool and lamb industries from vulpia reduction.

The results indicate annual benefits of $70.7 million to the lamb industry and $137.7 million to the wool industry. These benefits are achievable through changes to grazing management that do not incur any significant on-farm costs. They are an underestimate of the full benefits from vulpia reduction as the benefits derived from the cattle industry have not yet been estimated.

Benefits from the CRC's research

The above estimates are those obtainable from full adoption of the CRC's research findings. The research findings are now being packaged into a grazing management system that can be adopted by farmers. We postulate an S shaped adoption profile, beginning in 2002. We assume that, after 15 years, 50 per cent of farmers through the New South Wales tablelands will have adopted the CRC's integrated pasture management package.

Finally, we assume that 50 per cent of the benefits from the research are attributable to the work of the CRC. While research work on vulpia control predates the CRC, it has been CRC research that has been the key factor behind the integrated pasture management systems approach to control which has emerged.

Benefits compared with costs

Under the above assumptions about the CRC's contribution to the research findings and the rate of adoption by farmers, the present value of benefits from vulpia control to 2030 is $495.8 million (5 per cent discount rate). The CRC has incurred only $2.1 million in research costs for the project. On this basis the project has an internal rate of return of 62 per cent.

5.5 Payoffs from control of Paterson's curse

Biological control of Paterson's curse has been a long standing project within the scientific community. In 1985, the Industries Assistance Commission (IAC, now the Productivity Commission) undertook a comprehensive benefit–cost analysis of biological control of Paterson's curse. They concluded that biological control would generate significant net benefits through increases in productivity and stocking rates in livestock industries.

Since the IAC research, biological control agents (in particular, the crown weevil) have been released and analysis of test sites has allowed careful examination of the spread of these agents. Using this information, Tom Nordblom, CRC economist at Charles Sturt University, and Matthew Smyth, Anthony Swirepik, Andy Sheppard and David Briese at CSIRO –Entomology, have constructed a detailed biological–economic model to examine the effects of biological control.

In this model, the spread of the agent varies by region according to seasonal rainfall breaks — a late break is less conducive to the spread of the agent — and the extent to which the agent removes Paterson's curse from pastures also depends on the region. Using information on current Paterson's curse coverage and stocking rates by region, the model estimates the extent to which the control agent allows increased stocking and therefore increased profit. (Appendix A, prepared by Nordblom et al., contains a summary of the model assumptions and results.)

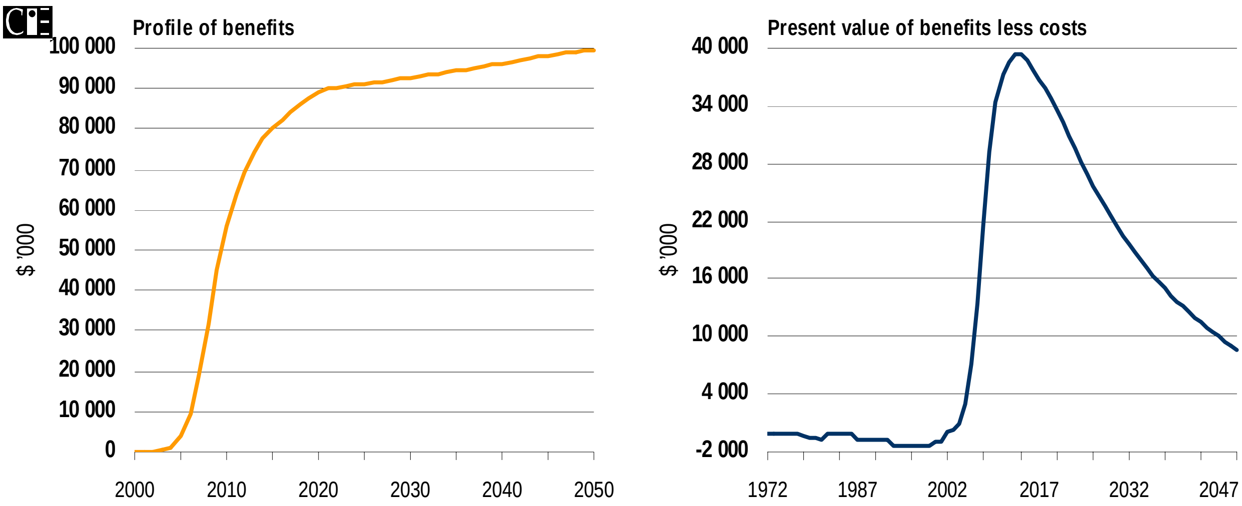
In using the model to evaluate the CRC's contribution, we have assumed a net profit margin of $9 per dry sheep equivalent (DSE), derived from a gross margin of $15 per DSE after netting off all costs other than returns to land. Nordblom et al. use $8 per DSE in a base calculation but show the effect of varying this estimate.)

Chart 5.2 shows the profile of benefits (in current dollars) arising from the release of the agent as well as the profile of the present value of benefits and costs from the project. The net present value of biological control (using a 5 per cent real discount rate and counting the benefits out to 2050) is estimated to be around $1 billion. The ratio of benefit to costs is 52 to 1. This corresponds to an internal rate of return over the entire project (from 1972 to 2050) of 22 per cent.

Of course, efforts to establish biological control have been taking place since the 1970s, and the CRC has only been involved in recent years. We can measure the contribution of the CRC by noting that its involvement has most likely brought the benefits forward (in time) from when they would otherwise have occurred. This is illustrated in the first panel of chart 5.3, which shows the effect of bringing the benefits forward by five years. Having benefits accrue earlier is a gain to the community. The present value of this gain (measured as the difference between the two lines) is shown in the second panel of chart 5.3. The second panel also shows the profile of benefits if the CRC only brought the gains forward by two years.

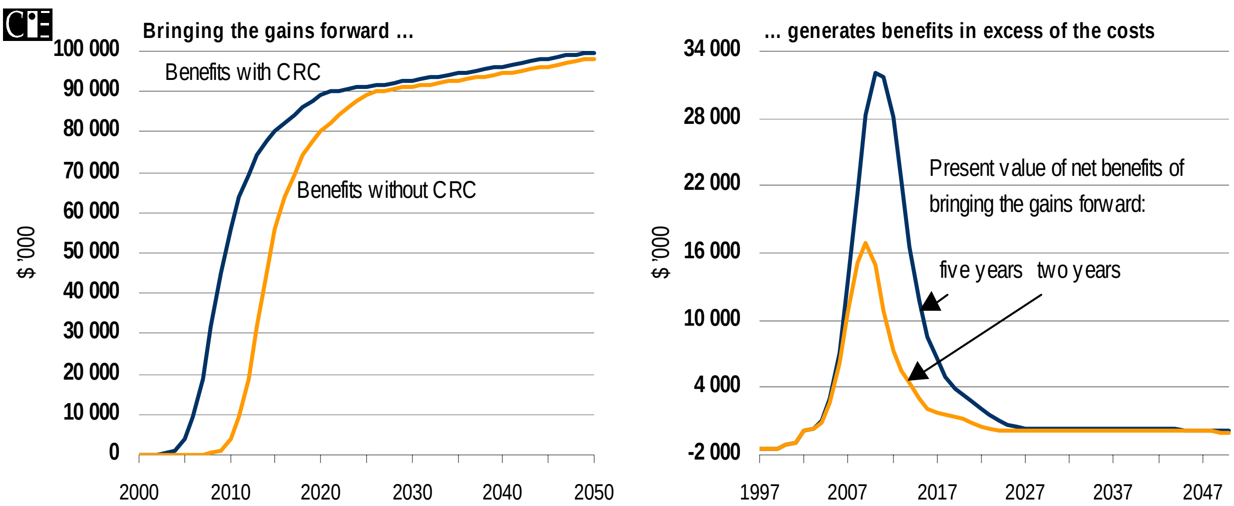
If we allocate all research costs since 1996 to the CRC, we find that by bringing the benefits forward by five years, the CRC has generated net benefits (in present value terms) of $253 million. The ratio of benefits to costs is 43 to 1 and the internal rate of return is 45 per cent. Bringing the benefits forward by two years generates net benefits of $105 million, a benefit–cost ratio of 18 to 1 and an internal rate of return of 38 percent.

5.2 Benefits of controlling Paterson's curse



Data source: CRC model and CIE estimates

5.3 Bringing the benefits forward



Data source: CIE estimates based on CRC model

6. Contribution of CRC's weed information system

The CRC's Education Program aims to improve weed management in southern Australia by increasing knowledge and expertise among researchers, weed managers and the general community. This program contains a number of initiatives including courses for university undergraduates, short courses for land managers and advisers in weeds and weed management, a scholarship program, publications and the establishment of a computer network system to which information on weeds can be added from CRC research.

The computer network system contains a series of list servers to facilitate weed information transfer to subscribers. There are seven list servers, serving different sections of the community and linking over 400 people. By enhancing vigilance through facilitating fast and comprehensive information sharing on weeds, the CRC's weed list server initiative has the potential to deliver significant community benefits. Benefits accrue through reducing the threat of entry and hence avoiding the economic costs that such entry might bring.

Despite some plants being declared noxious weeds, ignorance of this may result in such plants continuing to be sold by nurseries or kept in home gardens. Fast information flows can be critical in ensuring that the weeds are removed from the community before they become a threat to agriculture or natural ecosystems.

The computer network system has already played a vital role in preventing the establishment of two potential weeds — Mexican feather grass and cotton thistle. It has done this by conveying information quickly around the group of weed experts to alert authorities about prospects for a weed incursion and enabling the necessary steps to be taken to prevent it. The CRC has also developed a white paper (prepared at the request of the Nursery Industry Association of Australia to assist it address the spread of weeds via the horticultural industry) on options and recommendations for reducing the distribution of potential new weeds. Here we analyse the potential payoffs to the community from the prevention of the spread of weeds through the CRC's weed information system.

6.1 Interception of Mexican feather grass

Mexican feather grass (*Nassella tenuissima* — a native of Argentina, Chile, New Mexico and Texas) is closely related to serrated tussock (*Nassella trichotoma*), which is a serious weed in south-east Australia, particularly New South Wales. Mexican feather grass could, until recently, be legally imported to Australia and sold through nurseries. Hardy, low maintenance, ground cover grasses, of which Mexican feather grass is an exotic example, are popular as ornamental plantings in gardens.

McLaren et al. (1999), using Mexican feather grass as an example, document how new technologies, such as the CRC's electronic internet servers linking the 'weeds community', can alert authorities to the existence of emerging weeds. In 1998 a landscape gardener identified (through the CRC's weed server) *Nassella tenuissima* on sale at a rare plant nursery in Victoria. He alerted authorities via the Enviroweeds email network set up by the CRC, which in turn led to the removal and destruction of the plants and a review of AQIS import regulations. McLaren et al. (1999) note that the increased use of internet trading has made plants from overseas more accessible and has increased the rate of illegal plant introductions to Australia. Mexican feather grass, for example, is widely advertised for sale on the internet. The CRC's computer system to facilitate weed information transfer provides an effective means of combating the enhanced likelihood of weed entry through internet trading of plants.

Quantifying the benefits from prevention of spread of Mexican feather grass

Chart 6.1 sets out the components of a calculation of the benefits from the CRC's initiatives to prevent the spread of potential weeds that have not yet entered agricultural and natural ecosystems.

The first two components concern the costs incurred if the weed becomes established. These depend on:

- the potential area impacted
- the control costs once the weed is established
- the loss in value added once the weed is established.

Potential area impacted

Mexican feather grass is similar in taxonomy, growth and ecology to serrated tussock. It could be expected to have a similar potential distribution. A climate matching system (called CLIMATE) has been used to generate a prediction of the area of weed infestation based on the climate of its known destinations. The results (see McLaren et. al 1999) indicate that, based on South American distributions, serrated tussock has a predicted distribution of 2.4 million hectares. Serrated tussock is estimated to now cover more than 870 000 hectares in New South Wales and more than 130 000 hectares in Victoria. But, based on current Australian distributions, its potential distribution is estimated to be 3.2 million hectares, with substantial areas

6.1 Benefits from prevention of weed entry

Cost if established equals:
- loss in value added per area due to weeds after control is undertaken
- control costs per area adjusted for density of weed

- Value added threatened by weed in crops, pastures, natural ecosystems
- Value of new weed tolerant alternatives
- Cost of control – herbicides, mechanical
- Effectiveness of control

times

Potential area impacted adjusted for speed of spread

- Biological suitability
- Natural controls
- Dynamics of spread mechanism

less

Utility that would have been derived from entry

- Uniqueness of plant
- Utility from uses of plant

multiplied by

Change in the probability of successful interception

- Probability of successful interceptionpre-CRC
- Probability of successful interception post-CRC controls

of New South Wales, Victoria and Tasmania at risk of invasion.

The CLIMATE system predicts a potential distribution of Mexican feather grass of 14.1 million hectares, about six times that of serrated tussock. McLaren et al. (1999) note that the CLIMATE system does not take into account a consideration of soil type, day length or biotic factors and hence may overestimate a weed's potential distribution. Nevertheless, it appears that Mexican feather grass has the potential to infest a larger area than serrated tussock.

Potential economic costs if establishment were to occur

Because of its high fibre and low protein content, Mexican feather grass, like serrated tussock, has no grazing value. Infestation greatly reduces pasture and livestock production.

The economic costs of serrated tussock have been extensively studied over the past 20 years. The results from these studies can be used to provide estimates of the likely economic costs of Mexican feather grass. The most recent and comprehensive assessment of serrated tussock economic costs is that of Jones and Vere (1998), conducted for the CRC.

The Jones and Vere study is based on a detailed measurement of weed infestation in New South Wales and the consequences for grazing industry profitability. The economywide costs of this reduction in grazing industry profitability, measured in terms of profits lost by producers and reduced consumer surplus, were estimated at $40 million per year.

An analysis of the serrated tussock infestation in Victoria (Nicholson, Patterson and Miller 1997) estimated the weed was currently costing $5.1 million per year, primarily through lost agricultural production. The study estimated that, if no control measures are taken, the area of infestation will increase by more than 80 per cent in ten years (then costing

$15 million per year) and 250 per cent after 30 years (then costing $34 million per year).

What do these estimates mean for the potential cost of a Mexican feather grass invasion? If Mexican feather grass were to invade the same climatic area as serrated tussock, then there may be no additional cost, or only minor additional cost, to that caused by serrated tussock. The two weeds may simply compete among each other. If this is the case, most of the cost of a potential Mexican feather grass invasion is likely to be determined by the effects of infestation in areas outside of the serrated tussock infestation area, leading to reduced agricultural production and increasing control costs in these areas. This in turn will depend on how and where the invasion takes place, its anticipated rate of spread and the value of agricultural production in the areas (outside of the serrated tussock infested areas) into which it spreads. Accurate information on each of these components is not available. Our analysis is based on the following assumptions.

- The rate of spread of Mexican feather grass, assuming entry were to have taken place in 1999, is 50 per cent faster than the observed rate of spread for serrated tussock. (In New South Wales serrated tussock was first observed in pastures in 1936, and had infested 680 000 hectares by 1977 and 870 000 hectares by 1998. In Victoria serrated tussock was first observed in 1954, and had infested 30 000 hectares by 1979 and 130 000 hectares by 1998.)
- Mexican feather grass spreads initially through the area currently infested by serrated tussock, then moves out into the drier areas.
- The maximum area of spread of Mexican feather grass is twice that of serrated tussock.
- In the areas beyond the serrated tussock infested region, Mexican feather grass will incur one-third the economic cost on a per hectare basis than does serrated tussock. This reflects the lower rainfall and pasture productivity of the drier areas beyond the serrated tussock infested belt. In the areas already infested by serrated tussock, the additional economic cost of Mexican feather grass infestation is 20 per cent of the cost of serrated tussock infestation.
- The economic cost of serrated tussock infestation at its current level is $45 million per year, which is on average a cost of $46 per hectare infested. A more conservative estimate of cost of $40 a hectare is used to estimate the cost in the base case.

Based on these assumptions, the present value (at a 5 per cent discount rate) of potential economic costs of a Mexican feather grass infestation now and spreading over the next 60 years is $39 million.

This cost is significantly lower than the present value cost of serrated tussock (an annual cost of serrated tussock of $40 million represents a present value of around $800 million over 60 years) as, due to the slow initial rate of spread, it is unlikely that Mexican feather grass will spread beyond the area that is projected to be affected by serrated tussock during the next 60 years. As serrated tussock is expected to continue to spread, even with a spread rate twice that of serrated tussock, the area infested by Mexican feather grass will not exceed that of serrated tussock in the 60 year time frame of the benefit–cost analysis.

Utility that would have been derived from entry

While prevention of Mexican feather grass entry avoids potential losses in profits from agriculture, it also results in a welfare loss to the potential purchasers of the plant. The size of this loss in consumer surplus will depend on the size of the market for the plant if entry was not restricted, the price consumers would pay and the elasticity of demand for the weed — which in turn depends on the availability of close substitutes. If, for example, purchasers were largely indifferent to Mexican feather grass as a garden plant relative to, say, a native grass such as Poa tussock, then the welfare loss to potential purchasers of being denied Mexican feather grass would be small. Given the variety of exotic stipoid grasses and closely related plants available to gardeners we consider the welfare losses from prevention of entry to be negligible.

Change in the probability of successful interception

The final element in the calculation of the benefits from preventing the entry of Mexican feather grass concerns the contribution of the CRC in achieving successful interception (through its internet server and other initiatives). In the case of Mexican feather grass, it can be argued that the existence of the Enviroweeds network developed by the CRC proved to be the vital link in achieving quick removal and destruction of the plants. We assume that, as a result of the CRC's initiative, the probability of successful interception of Mexican feather grass at entry was increased from zero to 100 per cent. That is, 100 per cent of the present value of the potential economic costs of a Mexican feather grass invasion have been saved as a result of the CRC.

Benefits compared with costs of achieving them

Project costs

The cost of the prevention program in present value terms is $1.4 million. This reflects the annual cost of $152 000 over the seven years of the CRC and the value of the ongoing time and effort of the volunteers who must continue to monitor nurseries and react to entry threats. It is assumed that on average 50 volunteers spend an hour a week in the task. Costing their labour at $25 an hour gives an annual cost of $62 500 for monitoring. Such monitoring must continue for successful prevention.

Results

Table 6.2 provides the estimates of the net benefits of successful prevention of entry of Mexican feather grass.

6.2 Benefit–cost analysis base case — Interception of Mexican feather grass

	Unit	Base case
Benefits (present value)	$m	39.4
Costs (present value)	$m	1.4
Net benefits (present value)	$m	38
Ratio of benefits to costs		28
Internal rate of return	%	32

The benefits of $39 million are the avoidance of the additional costs of Mexican feather grass in serrated tussock areas. These benefits stem from higher productivity and lower weed control costs than would otherwise have been the case if Mexican feather grass had not been detected.

The internal rate of return if the CRC initiated program continues to be successful in excluding Mexican feather grass is 32 per cent. The net present value of the project is estimated as $38 million, with a benefit–cost ratio of 28 to 1.

Sensitivity analysis

Table 6.3 provides an indication of the sensitivity of the results to assumptions about spread rate and costs of Mexican feather grass relative to serrated tussock. The downside and upside estimates provide 90 per cent confidence interval around the base case estimates. The downside estimates of the potential cost of Mexican feather grass are based on a spread rate equivalent to that of serrated tussock, an additional cost of the Mexican feather grass of 10 per cent, and a cost of serrated tussock of only $30 per hectare in the future. The upside scenario is based on a spread rate twice that of serrated tussock, an additional cost where there is serrated tussock of 50 per cent, and a cost of $46 a hectare. The assumptions about the cost of Mexican feather grass outside the serrated tussock area are irrelevant as even at the higher spread rate Mexican feather grass spread does not exceed that of serrated tussock over the next 60 years.

6.3 Sensitivity analysis — Mexican feather grass

	Unit	Downside	Upside
Benefits (present value)	$m	9.9	150.9
Costs (present value)	$m	1.4	1.4
Net benefits (present value)	$m	8.5	149.5
Ratio of benefits to costs		7.0	107.3
Internal rate of return	%	17	54

The range of estimated present values of preventing the entry of Mexican feather grass is $10 million to 151 million. The return on the investment many be as high as 54 per cent or as low as 17 per cent. Even at the low end, the investment in the weed watching network is clearly one that has considerable strategic value in reducing the probability of entry of weeds that could impose significant costs on the farming community.

6.2 Quantifying the benefits from prevention of cotton thistle spread

A second example of the potential payoffs from the CRC's initiatives to help prevent the distribution of potential weeds is provided by the cotton thistle experience. Cotton thistle (*Onopordium nervosum*) has recently arrived in Australia. It is much larger than existing thistle weeds and could be expected to be more damaging to pasture productivity at similar densities to existing thistle weeds. It has the potential to spread to drier and warmer areas beyond those currently infested by thistles, so could be expected to significantly extent the area and severity of the current thistle infestation of pastures. There is also the risk of hybridisation between *O. nervosum* and those thistle species already present, which would lead to better adapted plants for the Australia environment and a bigger thistle weed problem than at present.

Cotton thistle was promoted as an ornamental garden plant on the television gardening show *Burke's Backyard* in March 1998. Through the CRC's electronic communication system the 'weeds community' was alerted and the seed on sale was quickly purchased and destroyed. The Director of the CRC wrote to the presenter of *Burke's Backyard* advising him of the dangers in promoting cotton thistle, offering the CRC's assistance to vet plants for their potential to become weeds before a decision is made to feature them in the program and requesting assistance from the program to alert the community on the dangers to agriculture and the natural ecosystem from illegal introductions of new plants.

Prevention of potential economic costs

Thistles in pastures current impose significant economic costs — through reduced stocking rates and through herbicide treatment costs. Analysis by the CRC in conjunction with Meat & Livestock Australia personnel suggests that heavy infestations can reduce pasture stocking rates by up to 25 per cent, moderate infestations by 12 per cent and light infestations by 2 per cent, and that herbicide treatment costs for heavy infestations can reach $19 per hectare. Assuming 80 000 hectares of heavy infestations, 220 000 hectares of moderate infestations and 800 000 hectares of light infestations, the economic cost of the current thistle invasion has been estimated at $14 million per year.

Our calculations of the economic cost of a potential invasion of cotton thistle are based on the following assumptions.

- Cotton thistle begins to infest agricultural land in 2000 and by 2020 has infested the same area (1.3 million hectares) as existing thistles.
- Existing thistles cost on average $11 a hectare in control costs and lost productivity on infested pastoral land.
- The additional cost of this new invasion is up to 60 per cent of the cost of the existing thistle invasion — although cotton thistle has greater potential to reduce pasture productivity than existing thistles, cotton thistle will, to some extent, outcompete existing thistles. The base case assumes an increase on current thistle costs of 30 per cent.
- From 2020 to 2040 cotton thistle will go on to infest a further 1.3 million hectares but, because this will be in drier, warmer areas, the reduction in pasture productivity will only be one-third of that from existing thistles in the existing zone of infestation.

Based on these assumptions, we calculate a net present value of potential economic costs from cotton thistle infestation to be $43 million.

Benefits compared with costs of achieving them

Project costs

The cost of the prevention program in present value terms is $1.4 million. This is the same cost as for the Mexican feather grass effort. As each weed would require the same level of effort to prevent entry, when the benefit–cost analysis is conducted on a weed by weed basis, a full cost is required. As the actual costs are shared across weeds, this approach somewhat overstates the cost of the project and hence understates the returns to the project. However, given the nature of the project, this effect is likely to be small.

Results

Table 6.4 provides the estimates of the net benefits of successful prevention of entry of cotton thistle.

6.4 Benefit–cost analysis base case — cotton thistle

	Unit	Base case
Benefits (present value)	$m	43.3
Costs (present value)	$m	1.4
Net benefits (present value)	$m	41.8
Ratio of benefits to costs		30.8
Internal rate of return	%	29

The benefits of $43 million come from the avoidance of the additional costs (control and productivity loss) of cotton thistle in thistle infested areas, and from the prevention in areas not likely to be invaded by the current thistle species. Current thistle spread is close to maximum likely spread and cotton thistle has a potentially much greater range. However, as initial infestation spread is relatively slow, a cotton thistle infestation in 2000 is not expected to spread beyond the current thistle range until 2022.

The internal rate of return if the CRC initiated program continues to be successful in excluding Mexican feather grass is 29 per cent. The net present value of the project is estimated as $42 million, with a benefit–cost ratio of 31 to 1.

Sensitivity analysis

Table 6.5 provides an indication of the sensitivity of the results to assumptions about the costs of cotton thistle relative to current thistle species, as the spread rate is expected to be the same as other thistle species. The downside and upside estimates provide a 90 per cent confidence interval around the base case estimates. The downside estimates of the potential cost of cotton thistle are based on a cost of current thistle of $5 a hectare. The cotton thistle is assumed in the downside scenario to pose no additional costs in the areas infested by other thistles, and 10 per cent of the current cost in areas outside those that would be affected by current thistle species. This low cost reflects the low gross margins on pastoral activities in the regions where cotton thistle could spread.

6.5 Sensitivity Analysis — cotton thistle

	Unit	Downside	Upside
Benefits (present value)	$m	9.1	142.5
Costs (present value)	$m	1.4	1.4
Net benefits (present value)	$m	7.7	141.1
Ratio of benefits to costs		6.5	101.3
Internal rate of return	%	16	46

The upside scenario is based on an additional cost of 50 per cent in areas affected by current thistle species and a cost of current infestations of $15 a hectare. In areas outside the range of current thistle species the cost is assumed to be 60 per cent of the cost of current species. This scenario assumes that the more marginal pastoral areas would move to higher valued pastoral production in the future than is currently the case.

The range of estimated present values of preventing the entry of cotton thistle is $9 million to $143 million. The return on the investment may be as high as 46 per cent or as low as 16 per cent. Even at the low end, the investment in the weed watching network is clearly one that has considerable strategic value in reducing the probability of entry of weeds that could impose significant costs on the farming community.

7. Control of bitou bush: a benefit–cost analysis

7.1 Background

Bitou bush (*Chrysanthemoides monilifera* subspecies *rotundata*) is a native to coastal South Africa, probably introduced accidentally to Australia in ship ballast early in the 20th century. From 1946 to 1968 it was planted along coastal areas by the Soil Conservation Service of New South Wales to facilitate erosion control and mine area rehabilitation. This greatly enhanced its spread. Bitou bush is a prolific seeder. Dispersal occurs primarily by animals ingesting the seeds. Bitou bush has now heavily infested eastern coastal ecosystems. Where infestation occurs, it rapidly becomes the dominant species. It covers over a 1200 kilometre range of coastline from Rainbow Beach in southern Queensland to Tathra in southern New South Wales. More than 70 000 hectares are currently infested, overwhelmingly in New South Wales. In Queensland, after 20 years of a spray control program, bitou bush has been virtually eradicated, though constant vigilance is needed to prevent reinfestation from the few plants that re-establish each year.

Infestation has led to a decline in the biodiversity of flora and fauna in coastal areas, and reduced access and amenity value of coastline areas.

The introduced weed boneseed (*Chrysanthemoides monilifera*, subspecies *monilifera*) is a close relative. Boneseed is a problem weed in coastal ecosystems in Victoria and South Australia in much the same way as is bitou bush in New South Wales. One of the biological control agents for bitou bush being researched by the CRC also attacks boneseed.

7.2 CRC research to control bitou bush

The CRC has identified bitou bush as a major environmental weed of natural ecosystems. Bitou bush is also listed by the National Weeds Strategy as one of the 20 weeds of national significance. CRC research to control the weed has built on an existing biological control program, which began with the release of the shoot-tip moth in 1989. This moth has had only limited success in controlling the bush. In 1996, after CRC research, the seed fly (*Mesoclanis polana*) was released and within two years had established throughout the entire distribution of bitou bush. The seed fly feeds off the seeds and is capable of reducing seed production by around 40 per cent on average, though in some situations up to 95 per cent seed reduction is occurring. It is anticipated that the seed fly will slow the rate of spread, but not kill existing infestations.

In April 2000 a leaf rolling moth was released by CRC. It is anticipated that the leaf rolling moth in conjunction with the seed fly will gradually kill existing plants. This in turn will allow native plants to recolonise, increasing biodiversity.

7.3 Potential benefits from the CRC's research

These are set out in chart 7.1. The chart shows four categories of benefits:

- reduction in control costs;
- increase in biodiversity in currently infested areas;
- increased amenity values due to a reduction in invasion in infested areas; and
- improved outcomes (prevention of infestation and hence prevention of loss of biodiversity) in areas suitable for infestation but where infestation is not yet present.

Reduction in control costs

The bush can be controlled through herbicidal sprays, slashing then spraying and hand pulling. Mechanical control techniques are expensive and often impractical for large infestations in areas which are difficult to access. Spray techniques are also expensive. Aerial spraying by helicopter has been developed by New South Wales Agriculture. Costs range from $120–200 per hectare, depending on the size of the area sprayed. Bitou bush seeds can survive for up to seven years in the soil. Reinvasion is a major problem. Up to three spray treatments per site over a seven year period are recommended to prevent reinfestation.

Government authorities in New South Wales undertake significant expenditure on bitou bush control, mainly through spraying. The level of government spending on control is determined by the availability of funds rather than a plan to achieve a certain rate of reduction in infestation. Funds must be available for a sequence of years to allow respraying of the same area several times. For this reason, the control program cannot afford to be too ambitious. In addition to expenditure by government authorities, local dune care groups spend significant amounts of time and effort controlling bitou bush in their communities.

It is estimated that annual expenditure in New South Wales on bitou bush control — spray costs, labour costs and the value of labour in kind provided by voluntary groups — is

7.1 Benefits from control of bitou bush

Benefits	Estimates
Reduction in control costs	■ Current levels of control (ha) ■ Current cost of control ($/ha) ■ Reduction in spread (ha) – Reduced control activity (ha) – Cost saing ($)
Improved outcomes in controlled areas (no infestation, but suitable for infestation)	■ Likelihood that infestation will occur if no controls on current infestation ■ Value placed on amenity in controlled areas (no infestation) ■ Extent to which amenity is improved by biological rather than current control methods – Value on additional amenity
Increase in biodiversity due to less crowding out	■ Value placed on coastal biodiversity ■ Extent to which biodiversity was threatened ■ Extent to which control methods promoted/reduced biodiversity ■ Extent to which biological control promotes biodiversity – Relative improvement in biodiversity compared with prior control – Value placed on this improvement
Increased amenity values due to reduction in invasion in uncontrolled areas (infestation present)	■ Value placed on amenity in affected areas ■ Extent to which this value is reduced due to invasion (limited access, aesthetics due to biological control reduction) ■ Improvement in access, aesthetics, due to biological control reduction – Value on this improvement

around $2 million per year. At this level of effort, the area dominated by bitou bush infestation is still increasing. While there are no measures of its rate of spread, anecdotal evidence is that the spread rate at the current level of control could be around 1 to 5 per cent per year. In Queensland, about $20 000 per year is spent to ensure that isolated breakouts of the weed are controlled. Control costs can be expected to decline over time as biological control takes effect.

Prevention of infestation in areas currently unaffected

Colonisation by bitou bush is incomplete. Climate maps suggest that bitou bush has the potential to at least treble its current area of infestation if not controlled. By controlling the rate of spread and eventually reducing new infestation, the biological control agent has the potential to save the costs of infestation (loss of amenity value, loss of biodiversity and requirement for larger spray costs) from areas currently free of the weed that are suitable for infestation.

Increase in biodiversity in currently infested areas

Bitou bush displaces the dominant plants in communities it invades, leading to a decline in biodiversity of flora and fauna. In 1999 bitou bush was listed as a key threat to biodiversity in coastal New South Wales. The distribution of bitou bush overlaps with some rare and endangered plant species. Effective biological control is expected to lead over time to a re-emergence of the biodiversity present in uninfested coastal ecosystems.

Increased amenity values due to a reduction in invasion in currently infested areas

Removal of bitou bush will enhance access to coastal areas and improve the aesthetics of these areas. Some people place a value on such improvements, and studies suggest that many people value access to the beach with quite high willingness to pay for continued access.

7.4 Estimating the benefits from biological control

In the analysis that follows we estimate the benefits of biological control of bitou bush arising from:

- reduced spray and labour costs of control;
- enhanced amenity values through protecting access to the beach, campgrounds and picnic grounds; and
- reduced threat to biodiversity in south-eastern coastal regions.

Against these benefits must be weighed any increased costs of dune stabilisation required as bitou bush is reduced.

Savings in control costs

The main reasons for control are to prevent the spread of the bush to areas not currently affected and to provide access to the beach and facilities in affected areas. An effective biological control agent should greatly reduce the efforts required to prevent spread, and will reduce the area that needs to be treated in order to ensure adequate access to the beach and facilities.

Without biological control, it is anticipated that at the current control efforts bitou bush will continue to spread at around 1 per cent in area a year. To develop the without biological control scenario it is assumed that budget constraints would limit the level of control. The control budget is assumed to remain constant in real dollars at $2 million a year.

With an effective biological control the area that needs to be treated will decline. It is assumed that 10 per cent of the affected area will continue to be treated as the minimum area necessary to provide adequate access to the beach and facilities in affected areas. Cost savings in control reflect the difference between this annual cost and $2 million a year.

Table 7.2 provides details of the potential savings in control costs from successful biological control. Column 1 shows the area likely to be still affected in the without biological control scenario and column 2 shows the area that will be affected with the biological control after 15 years. At this point in time the extent of control and the rate at which control can be achieved by the biological control agent remains unknown. Assumptions need to be made. We assume that the rate of bitou bush control follows an S shaped expansion path, reaching a steady state of around 50 per cent control after 15 years. The third column gives the cost of control required to ensure that 10 per cent of the remaining area is treated to allow beach access. The final column gives the cost saving from biological control. Under these assumptions a steady state saving of $980 000, just under half the current control costs, is achieved on an annual basis.

Amenity values

Work undertaken by the CRC to assess the value of controlling bitou bush — willingness to pay by visitors and residents — found that there appeared to be little or no willingness to pay for the removal of bitou bush. This is very likely to be due to the fact that beach access is currently provided by the control efforts of the various state governments, rather than Australians not valuing access to their beaches.

7.2 Savings in control costs from biological control of bitou bu

	Area infested current	Area of infestation with biological control	Control cost with biological control	Cost savings in control
	ha	ha	$m	$m
2000	70 000	70 000	2.00	0.00
2001	70 700	69 946	2.00	0.00
2002	71 407	69 804	1.99	0.01
2003	72 121	69 446	1.98	0.02
2004	72 842	68 639	1.96	0.04
2005	73 571	67 139	1.92	0.08
2006	74 306	64 946	1.86	0.14
2007	75 049	62 304	1.78	0.22
2008	75 800	59 446	1.70	0.30
2009	76 558	56 500	1.61	0.39
2010	77 324	53 520	1.53	0.47
2011	78 097	50 527	1.44	0.56
2012	78 878	47 530	1.36	0.64
2013	79 667	44 531	1.27	0.73
2014	80 463	41 532	1.19	0.81
2015	81 268	38 532	1.10	0.90
2016	82 081	35 532	1.02	0.98
2017	82 901	35 532	1.02	0.98
2018	83 730	35 532	1.02	0.98
2019	84 568	35 532	1.02	0.98
2020	85 413	35 532	1.02	0.98
2021	86 267	35 532	1.02	0.98
2022	87 130	35 532	1.02	0.98
2023	88 001	35 532	1.02	0.98
2024	88 881	35 532	1.02	0.98
2025	89 770	35 532	1.02	0.98
2026	90 668	35 532	1.02	0.98
2027	91 575	35 532	1.02	0.98
2028	92 490	35 532	1.02	0.98
2029	93 415	35 532	1.02	0.98
2030	94 349	35 532	1.02	0.98

Source: CIE estimates.

Evidence in Australia and abroad suggests that people place a very high value on beach access. Estimates of willingness to pay in the United States range widely. Some relevant estimates are $4.50 (US$2.64 in 1995) for access to nine Hawaii beaches (Moncur 1975), $5.29 (US$3.06 in 1995) for access to New England beaches (Kline and Swallow 1998), and $15.86 (US$9.36 in 1995) for access to California beaches (Dornbusch et al. 1986). A study on the NSW north coast found a willingness to pay for beach and dune maintenance per visit of $0.30 in 1990 (Pitt 1992), with an estimated 10.3 million visitors a year. Further studies in the same area estimated willingness to pay for dune and beach maintenance of $4.67 per resident household per month in 1992 (Pitt 1993).

The Moncur and Dornbusch et al. studies used the travel cost method to estimate the consumer surplus associated with visiting the beach. The other studies cited above used contingent valuation, which asks respondents about their willingness to pay or accept compensation under different scenarios. Given the differences in the locations and scenarios, none of the values provides an appropriate measure of the value of bitou bush control. However, they do provide a guide to a sensible range for the likely value.

An estimate of $1 per visitor day is used in making the base case evaluation. A reasonable range of estimates is $0.50 to $5 a visitor day. The number will be on the higher side if access is very limited by the infestations, forcing people to travel further to access beaches and reducing the quality of the experience due to increased crowding. Based on the Pitt (1992) estimate of 10.3 million visitor days per year to the New South Wales north coast, a conservative base line estimate of twice this level for the larger area of New South Wales infested with bitou bush in 2000 is used. In the base case, visitor numbers are assumed to grow at 2 per cent a year. It is assumed that, at a minimum, visitor numbers will grow at 1 per cent a year and, at a maximum, around 3 per cent a year.

Under the 'without biological control' scenario the limited budget for control results in restricted access to the beach and facilities. A directly proportional relationship is assumed between restrictions on access and loss of amenity. Under the 'with biological control' scenario the public budget remains sufficient to ensure at least 10 per cent of the infested area is cleared providing adequate access to maintain amenity values.

Table 7.3 provides the estimates of amenity value under the base case, maximum and minimum scenarios for the growth in visitor numbers.

Biodiversity values

To date little work has been done estimating biodiversity values, and none associated with biodiversity in coastal areas of south east Australia. That there are biodiversity values is undoubtedly true, but it is very difficult to separate these values from amenity values held by visitors and options values held by those who may use the resource in the future. The estimate of willingness to pay for dune restoration by Pitt is a good example as some of this value might be for stabilisation to protect biodiversity. A better estimate on existence values is the study by Bennett (1984) which tried to focus on non-use values of the Nadgee nature reserve to ACT residents. This study found an annual willingness to pay of $2.00 per adult to preserve the reserve as a non-use conservation area.

7.3 Improvement in amenity values with biological control

	Increase in amenity values		
	Minimum	***Base case***	***Maximum***
	$m	$m	$m
2000	0.00	0.00	0.00
2001	0.01	0.02	0.11
2002	0.02	0.04	0.22
2003	0.03	0.06	0.33
2004	0.04	0.09	0.45
2005	0.05	0.11	0.58
2006	0.06	0.13	0.71
2007	0.07	0.16	0.85
2008	0.09	0.18	1.00
2009	0.10	0.21	1.15
2010	0.11	0.24	1.31
2011	0.12	0.27	1.48
2012	0.13	0.29	1.65
2013	0.14	0.32	1.84
2014	0.15	0.35	2.03
2015	0.17	0.38	2.22
2016	0.18	0.42	2.43
2017	0.19	0.45	2.65
2018	0.20	0.48	2.88
2019	0.21	0.52	3.11
2020	0.23	0.55	3.36
2021	0.24	0.59	3.61
2022	0.25	0.63	3.88
2023	0.26	0.66	4.16
2024	0.28	0.70	4.45
2025	0.29	0.74	4.75
2026	0.30	0.79	5.06
2027	0.32	0.83	5.39
2028	0.33	0.87	5.73
2029	0.34	0.92	6.08
2030	0.36	0.96	6.45

Note: Base case scenario assumes willingness to pay for full access to the beach of $1 per visitor day with visitor number increasing by 2 per cent per year. Minimum scenario assumes willingness to pay of $0.50 per visitor day with visitor number increasing by 1 per cent per year. Maximum scenario assumes willingness to pay of $8 per visitor day with visitor number increasing by 3 per cent per year.

Source: CIE estimates.

A study currently under way (van Beuren and Bennett for the National Land and Water Resources Audit) to assess the relative contributions of factors such as biodiversity and willingness to pay will provide a base line estimate for Australia on willingness to pay for protecting biodiversity. Early results indicate there is a significant willingness to pay, but the magnitude has yet to be determined. An earlier study (CIE 1997), using choice modelling in the ACT, found that there was a significant willingness to pay in the ACT community to protect the habitat of uncommon species in the region ($24 a year per household to reduce habitat loss for five uncommon species).

These values provide only a guide to possible biodiversity values associated with biological control of bitou bush. The impact on biodiversity of infestations of bitou bush is considered by scientists to be significant, although it has not been measured. A measure of this impact would be required to appropriately frame a choice modelling survey to assess the values placed on the biodiversity.

As the value of biodiversity is clearly not zero, indicated by the efforts of bush regeneration groups to control the weed, a value of $1 per household a year is assumed as a base case. This is around a quarter of the existence value estimate for Nadgee in the ACT. An upper limit for the value is $8, which is similar to the current value of Nadgee (per household), and a lower limit of $0.50 is assumed. While all Australians may have existence values for biodiversity, the estimates are for households living in areas within 50 kilometres of areas that are currently infested or are likely to be infested. The base case assumes 4.6 million households within this area. The number of households is assumed to be growing at 2 per cent a year in the region.

The willingness to pay for protection of biodiversity is assumed to be directly proportional to the restored and

7.4 Improvement in biodiversity values with biological control

	Increase in value of biodiversity protected		
	Minimum	***Base case***	***Maximum***
	$m	$m	$m
2000	0.00	0.00	0.00
2001	0.02	0.10	0.39
2002	0.05	0.21	0.83
2003	0.09	0.34	1.37
2004	0.13	0.53	2.13
2005	0.20	0.81	3.22
2006	0.29	1.16	4.64
2007	0.39	1.56	6.26
2008	0.50	1.99	7.96
2009	0.60	2.41	9.67
2010	0.71	2.84	11.36
2011	0.81	3.25	13.03
2012	0.92	3.67	14.68
2013	1.02	4.07	16.29
2014	1.11	4.46	17.88
2015	1.21	4.85	19.44
2016	1.31	5.23	20.97
2017	1.32	5.27	21.13
2018	1.33	5.31	21.30
2019	1.34	5.35	21.46
2020	1.35	5.39	21.62
2021	1.36	5.43	21.78
2022	1.37	5.47	21.94
2023	1.37	5.51	22.09
2024	1.38	5.55	22.25
2025	1.39	5.59	22.40
2026	1.40	5.62	22.55
2027	1.41	5.66	22.70
2028	1.42	5.70	22.85
2029	1.43	5.73	23.00
2030	1.44	5.76	23.15

Note: Assumes biodiversity value of $2 per household (base case), $0.50 per household (minimum) and $8 per household (maximum).
Source: CIE estimates.

protected area relative to what would otherwise have been infested. This assumption takes a middle path between those who think that every thing must be protected and those who think that biodiversity is protected as long as there is some representative of a species alive.

Table 7.4 shows the estimates of biodiversity value under the biological control relative to the without biological control situation.

Additional costs

Bitou bush was introduced for dune stabilisation and it performs this function well. Removal of bitou bush is likely to lead to additional expenditure for dune stabilisation in areas where the biological control reduces the bush to levels where access is too easy and erosion becomes a problem. We were not able to get an estimate of these costs and so were unable to include them in the analysis. If they are significant, the benefit estimates generated below would need to be scaled down accordingly.

7.5 Estimating net benefits

Cost of CRC projects

An estimate of the annual cost of the program was made using an assessment of the share of the effort in each of the natural ecosystems sub-programs attributable to work on bitou bush and boneseed. The total discounted cost of the work estimated using this approach is $2.17 million over the life of the CRC. This takes into account cash funds committed under the program for the remaining years of the CRC. The cost of spreading the biological agent is minimal compared to the research costs in selecting, evaluating and monitoring the control agent.

Results

The results of the benefit–cost analysis are presented in table 7.5 for the base case scenario. The project on bitou bush control is estimated to have yielded a return of 29 per cent on the CRC investment under the base case scenario. For a cost of $2.2 million the benefits to the Australian public in cost saving, improved amenity and biodiversity are worth almost $45 million, a benefit–cost ratio of 21 to 1.

7.5 Benefits relative to costs (Baseline scenario)

Benefits	***$m***
Savings in control costs	6.1
Increased amenity value	3.7
Increased biodiversity value	35.2
Total	**45.0**
Costs	2.2
Benefit/cost ratio	20.7
Internal rate of return	29%

Source: CIE estimates.

Sensitivity analysis

The results are most sensitive to assumptions about the willingness to pay for amenity and for protecting biodiversity. They are also sensitive to the growth rate assumptions in visitor numbers. Table 7.6 provides the worst case and best case scenarios based on the combinations of these assumptions. As it was very difficult to put probabilities on these scenarios arising, a full risk analysis was not undertaken. Rather, they should be taken to provide a guide to the range of values within which the true range of benefits of the research are likely to fall.

7.6 Sensitivity analysis — Bitou bush

	Unit	***Downside***	***Upside***
Benefits (present value)	$m	16.4	169.2
Costs (present value)	$m	2.2	2.2
Net benefits (present value)	$m	14.2	167.0
Ratio of benefits to costs		7.5	77.9
Internal rate of return	%	19	47

The range of likely values is large, with estimates of benefits ranging from $14 million to $167 million, with a base case scenario of benefits of $45 million. This large range stems more from the uncertainty about the values people place on biodiversity than from values from access to the beach. As more accurate estimates of the value placed on biodiversity become available, the reliability of benefit–cost estimates of this kind will improve. However, it is clear that even if the minimum estimates (which are very conservative) are adopted, the project on biological control of bitou bush will provide benefits well in excess of project costs, delivering to the public a rate of return on their investment of 19 per cent.

References

Anonymous 1995, 'Introduction', *Weed Watch Newsletter*, Cooperative Research Centre for Weed Management Systems, no. 1, CSIRO Entomology, Canberra.

Bennett 1984, 'Using direct questioning to Value the Existence Benefits of Preserved Natural Areas, *Australian Journal of Agricultural Economics*, vol. 28 (2-3) August/December.

Combellack, JH 1987, 'Weeds in cropping — their cost to the Australian economy', *Plant Protection Quarterly*, vol. 2, no. 2.

CIE (Centre for International Economics) 1997, *A Study to Assess Environmental Values Associated with Water Supply Options*, prepared for ACTEW Corporation, Canberra.

Dornbusch, D et al. 1986, *OCS Impacts on California Coastal Recreation: Vol 3, Detailed Methodology*, US Department of the Interior, Minerals Management Service Pacific OCS Office, Los Angeles.

IAC (Industries Assistance Commission) 1985, *Biological control of Echium species (including Paterson's curse/Salvation Jane)*. IAC Report no. 371, 30 September 1985, Australian Government Publishing Service, Canberra, ACT.

Jones, RJ, Alemseged, Y, Medd, R and Vere, D 2000, *The Distribution, Density and Economic Impact of Weeds in Australian Annual Winter Cropping Systems*, Economics Research Report 4, Cooperative Research Centre for Weed Management Systems.

Jones, RE and Vere, DT 1998, The economics of serrated tussock in New South Wales, *Plant Protection Quarterly*, vol. 13, no. 2, pp. 70–6.

Kline, JD and Swallow, SK 1998, 'The demand for local access to coastal recreation in southern New England', *Coastal Management*, vol 26, pp. 177–90.

McLaren, DA, Stajsic, V and Gardner, MR 1998, 'The distribution and impact of South/North American stipoid grasses (Poacceae: Stipeae) in Australia', *Plant Protection Quarterly*, vol. 13, no. 2, pp. 62–70.

McLaren, DA, Whattam, M, Blood, K, Stajsic, V and Hore, R 1999, 'Mexican feather grass (Nasella tenuissima): a potential disaster for Australia', *12th Australian Weeds Conference, 12–16 September*, Hobart, pp. 658–62.

Medd, RW and Pandey, S 1990, 'Estimating the cost of wild oats (*Avena* spp.) in the Australian wheat industry', *Plant Protection Quarterly*, vol. 5, no. 4, pp. 142–44.

Moncur, JET 1975, 'Estimating the value of alternative outdoor recreation facilities within a small area', *Journal of Leisure Research*, vol. 7, pp. 301–11.

Nicholson, C, Patterson, A and Miller, L 1997, *The Cost of Serrated Tussock Control in Central Western Victoria*, Department of Natural Resources and Environment, Victoria.

Nordblom, TL and Medd, RW 1999, *Submission by the Cooperative Research Centre for Weed Management Systems to the Parliament of New South Wales,* Legislative Council Standing Committee on State Development, Inquiry into the use and management of pesticides in New South Wales.

Pitt, M 1992, 'The value of beach and dune maintenance to tourism: a contingent valuation study on the north coast of New South Wales', in Lockwood, M and DeLacy, T (eds), *Valuing Natural Areas: Applications and Problems of the Contingent Valuation Method*, Johnstone Centre of Parks, Recreation and Heritage, Charles Sturt University, Albury, Australia.

Pitt, MW 1993, The contingent value of maintaining natural vegetation on beach dunes, paper presented to the 37th Annual Conference of the Australian Agricultural Economics Society, Sydney, 9–11 February.

Seaman, JT, Turvey, WS, Ottaway, SJ, Dixon, RJ, Gilmour, AR 1989, Investigations into the toxicity of *Echium plantagineum* in sheep 1. Field grazing experiments. *Australian Veterinary Journal* no. 66**,** pp. 279-85.

Sheppard, AW, Smyth, MJ, Swirepik, A 1999, Impact of the root-crown weevil (*Mogulones larvatus*) and other BIOCONTROL AGENTS on Paterson's curse in Australia: AN UPDATE. Australia Weeds Conference, Hobart September 1999.

Vere, DT, Jones, RE and Griffith, GR 1997, 'Evaluating the farm and industry impacts of weeds and the benefits of improved weed control in agricultural production systems', *Plant Protection Quarterly*, vol. 12, no. 3, pp. 145–50.

Appendix A

Benefit–cost analysis for biological control of *Echium* Weed Species(Paterson's curse/Salvation Jane)

[*updated by T. Norblom - A contributed paper to the 45th Annual Conference of the Australian Agricultural and Resource Economics Society (AARES), Adelaide, 23-25 January 2001]*

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Benefit–cost analysis for biological control of *Echium* Weed Species(Paterson's curse/Salvation Jane)

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Key words: biological control, benefit cost analysis, Paterson's curse, *Echium* spp., weed, pasture, Australia

Abstract

Based on the timing and location of 400 successful releases of insects specifically targeting *Echium* species of weeds including Paterson's curse / "Salvation Jane" since 1992 across southern Australia, and estimates of insect attack and spread rates according to dates of weed germination, a benefit / cost analysis is developed for the biological control research and development program begun by CSIRO in 1972. Australian meat and wool industries have also contributed funding to the program, in addition to in-kind contributions of the NSW, Victorian, South Australian and Western Australian state departments, and since 1995 the Weeds CRC. Total R&D expenditures by CSIRO and the partners mentioned above will reach $14 million by 2001. Annual benefits in terms of increased productivity of grazing lands are projected to rise from near-zero in 2000 to some $73 million by 2015, based on a value of $8/DSE. These sums do not include savings due to reduced spray costs as offsetting expenses will arise with management practices required to maximise the success of bio-control agents, and to limit reinvasion by other pasture weeds. The discounted (5%) net present value (NPV) of the benefit-cost stream from 1972 to 2015 is projected at $259 million, for a B/C ratio of 14:1 and an internal rate of return exceeding 17%. Because lower attack and spread rates of the insects are observed in regions with late autumn breaks, a slow build-up of benefits is expected to continue over many years. The discounted NPV for the 1972-2050 period is estimated to be $916 million, with a B/C ratio of 47:1 and an internal rate of return exceeding 19%.

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Introduction

Echium plantagineum (commonly known as Paterson's curse, salvation Jane or Riverina bluebell) is an introduced winter annual pasture weed of Mediterranean origin. Free of native Mediterranean plant and insect communities, it has become one of the dominant pasture weeds of temperate Australia. Other introduced *Echium* species (*E. vulgare* , *E. italicum* , and *E. simplex*) also occur as weeds in Australia (Parsons & Cuthbertson, 1992). Keeping in mind that *E. plantagineum* is the most important Australian pasture weed in the genus, henceforth in this paper we refer to the four species collectively as '*Echium*'. Although relatively nutritious in terms of digestible nutrients, and valued as a pasture plant in some places, *Echium* contains pyrrolizidine alkaloids that are poisonous to livestock, reducing weight gain and wool clip and in severe cases leads to death (Cullen, 1993; Culvenor *et al.*, 1984; Macneil, 1993; Piggin, 1977; Seaman *et al.* 1989; Seaman & Dixon, 1989). *Echium* is estimated to occur on over 30 million hectares in Australia (IAC Report 1985).

Echium was first suggested as a candidate for biological control at the Australian Weeds Council in 1971. CSIRO Entomology started surveys in its native range in 1972 from its base in Montpellier, France. Of the hundred or more insect species recorded on *Echium*, eight were selected as possible biological control agents, with the first imported into quarantine, Canberra, by 1979. In 1980, a small group of graziers and apiarists lodged an injunction in the Supreme Court of South Australia to stop the biological control program as they considered the loss of *Echium* a threat to their livelihoods. The Biological Control Act 1984 established procedures for assessing and authorising biological control programs in Australia (Cullen and Delfosse 1985); a subsequent inquiry and benefit-cost analysis was conducted by the Industries Assistance Commission (IAC), which concluded with the judgement that a biological-control program on *Echium* should go ahead (IAC Report 1985).

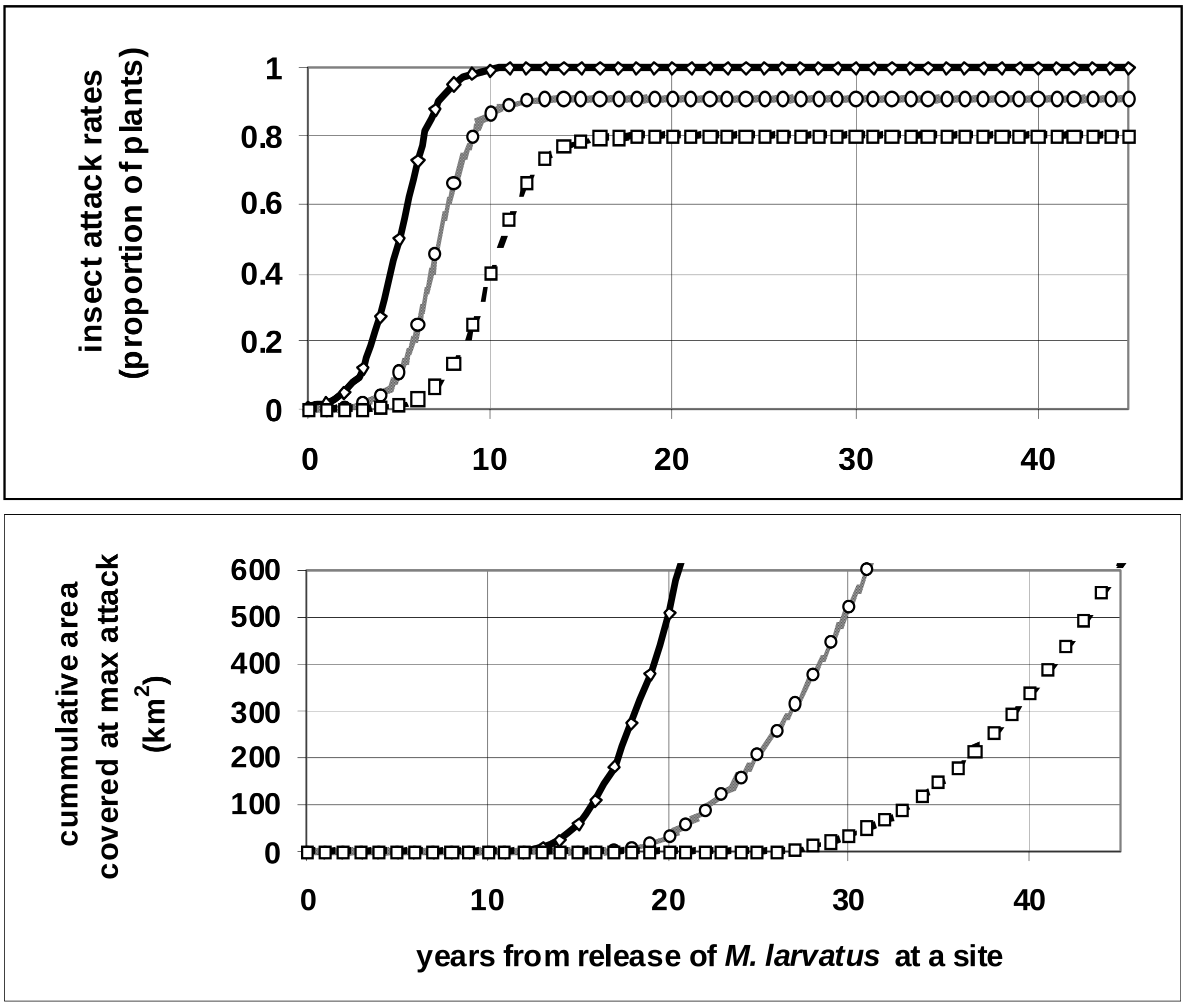
The Supreme Court injunction was eventually lifted and the importation of insects into Australia resumed. Since then six insect species have been successfully released: a leaf mining moth, *Dialectica scalariella*, crown and root weevils, *Mogulones larvatus* and *Mogulones geographicus*, a root beetle, *Longitarsus echii*, a stem boring beetle, *Phytoecia coerulescens* and a pollen beetle *Meligethes planiusculus*. Of these insects *D. scalariella* and *M. larvatus* were introduced first and have been released across the geographic range of the weed. *M. larvatus* is known to be limiting the *Echium* population at two of the earliest release sites (Sheppard *et al.* 1999) and approaching control at many of the younger release sites.

Based on the positive population trend of *M. larvatus* and its ability to limit the weed at an increasing number of sites, the economic analysis of the IAC report was revisited so projected economic gains from biological control could be quantified. Unlike previous cost-benefit analysis of biological control, where an insect is given an arbitrary impact and rate of spread, the current analysis incorporates observed values based on the biology and ecology of *M. larvatus* and its' weedy host, *Echium*, over the last eight years.

Methods

Of some 1000 releases of *M. larvatus*, 400 have been confirmed successful in terms of insect survival to subsequent seasons. Of these successful releases, 189 were in NSW, 143 were in Victoria, while SA and WA had only 34 each. The development of insect attack rates on *Echium*, based on field data, and the geographic spread of the insects, based on field observations by scientists on the project, are described as logistic functions of time. Function parameters differ according to the date of the autumn season break; both attack and spread rates are highest with an early autumn break (March) and lowest with a late break (May). This variation occurs because late breaks tend to decouple the occurrence synchrony of *Echium* and *M. larvatus* (Sheppard *et al.* 1999). The geographic spread of *M. larvatus* is considered to reach maximum rates of 1.7, 1.0 and 0.8 km per year in the cases of March, April and May autumn breaks, respectively (Figure 1).

Figure 1. Insect attack and spread by year from release, according to month of autumn break



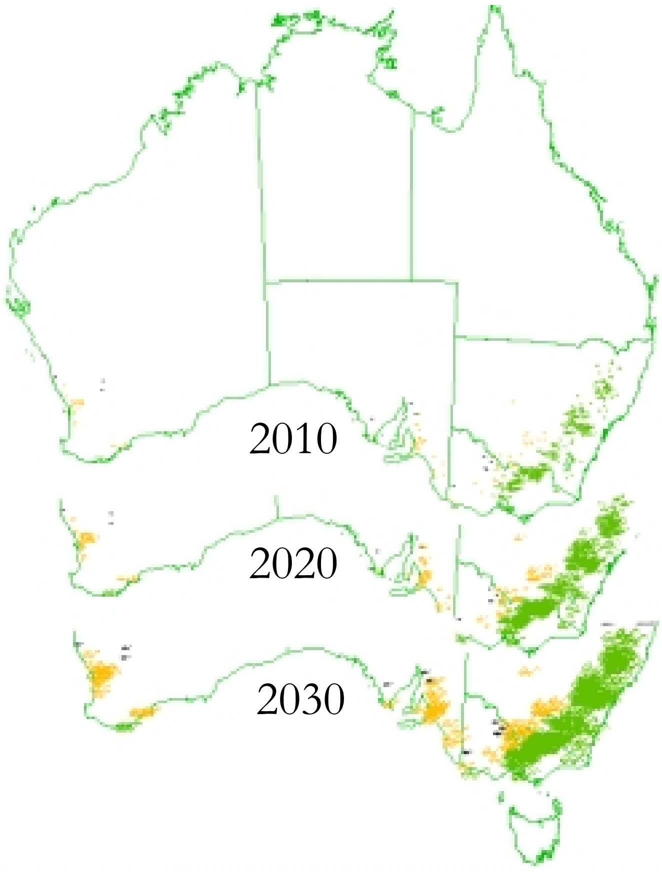
The present study uses the district location, grazing area, and stocking rate information supplied by the IAC (1985) report, overlaying the new insect release location and date data. Autumn break date classifications were assigned to districts according to the month in which greater than 25 mm median rainfall is received, based on long-term monthly median rainfall maps from the Bureau of Meteorology (BOM, 2000). Combining the attack and spread functions in a simulation model allowed prediction of surface areas covered by insects at different densities over time. The projected infestation fronts of insects spreading out from the 400 successful release sites are simulated in Figure 2 for the years 2010, 2020, and 2030.

It was assumed for districts in which there was more than one release, the maximum spread of insects from each release was to the area defined as the district total divided by the number of releases in the district. This is a conservative assumption given the fact that the earliest insect releases (say in 1993 versus 2000) will have spread over greater surface areas and reached greater densities than later releases, and the fact that insects are not limited by administrative boundaries. These conservative assumptions were made to limit the computational burden posed by 400 insect releases distributed over a seven-year period across 44 districts of varying size. The 400 releases and 44 districts define 130 sub-districts, depending on year of release, for which year-by- year sequences of areas with partial relief are simulated. These are aggregated back to the 44 districts as area equivalents with full economic loss relief.

There are several other conservative assumptions in our analysis. One is that all long-term biological control of *Echium* will result only from the activity of *M. larvatus*, the crown weevil; there is good reason to anticipate complementary successes of the other agents released against the weed. The model conservatively assumes no further releases beyond the 400 successful establishments; in reality, state departments of agriculture will continue to respond to farmers' requests (Shepherd, 1993), and the Wool Mark Company and Meat and Livestock Australia continue important support for releases of bio-control agents against *Echium*. The model focuses on the valuation of increased pasture productivity and ignores reductions in conventional spraying costs which formed a significant share of the anticipated benefits calculated in the IAC Report (1985) and that of CSIRO (1998). While reductions in pasture spray costs may be anticipated, these are likely to

Figure 2. Simulated spreading fronts of *M. larvatus* populations released on Paterson's curse from 1993-2000 at 2010, 2020 and 2030.

Source: Anthony Swirepik (CSIRO Entomology/Canberra) and collaborators in respective states.



be replaced with the costs of measures taken by farmers to facilitate the success of the biological control agents and to limit reinvasion by other pasture weeds (Taylor & Sindal, 2000). The model also ignores control costs and losses attributable to *Echium* as a weed in crops; these amount only to some $1.2 million annually (Jones *et al.*, 2000) and may be assumed to continue indefinitely.

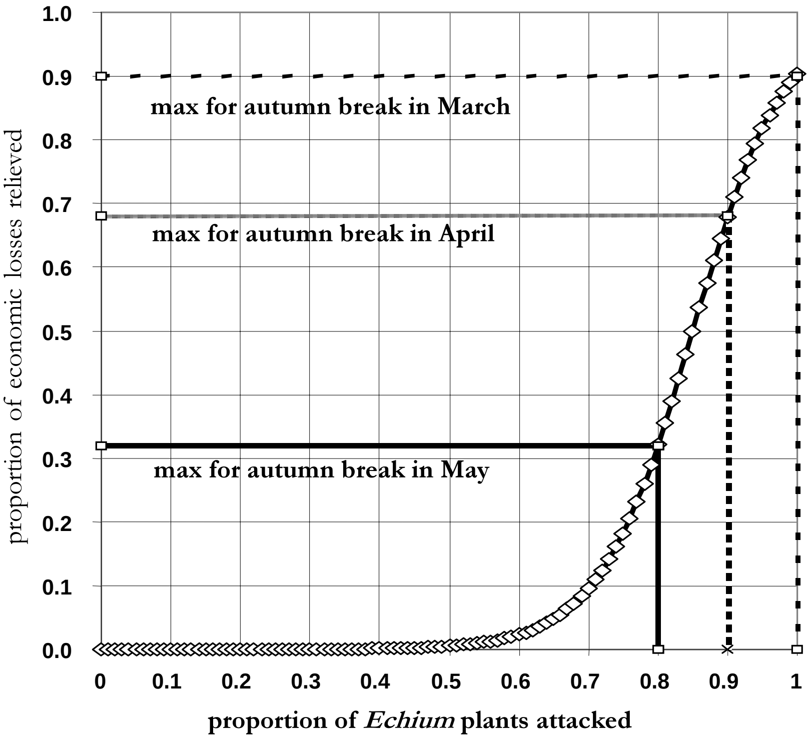
The economic damage caused by *Echium* in pastures is assumed to remain unaffected by *M. larvatus* at attack levels below 50%. Attack levels above this are assumed to result in increasing reductions in economic loss. In the case of areas with late autumn breaks (May), for example, the maximum attack rate is 80%, resulting in a maximum of only a 32% reduction in economic loss. In the case of April autumn breaks, the maximum attack rate is 90%, giving a maximum of 68% reduction in losses due to *Echium*. The earliest autumn breaks (March) are associated with ultimate attack rates of 100% but only 90% reductions in economic loss from the weed (Figure 3).

The attack and spread simulation model, set for the particular size, release dates and autumn break parameters of each sub-district, was used to generate a time series of areas with varying degrees of partial economic relief from *Echium*. Maximum relief over a course of years would reach 90%, 68%; and 32% in the March-break, April-break and May-break districts, respectively. The time required to reach these limits differed according to district size and number of releases. For each year in each district, a ratio was calculated of the (weighted) relieved area to the total area. These ratios were multiplied times the maximum proportions by which total stocking rates were assumed to be increased in the absence of *Echium* in the IAC report, district by district (these ranged from a maximum of 0.2 to a minimum of –0.1). Total stocking rates for each district were expressed as dry sheep equivalents (DSE) where 1 DSE relates to 1 wool sheep, 1.5 DSE for each meat sheep, 10 DSE for each beef animal and 15 DSE for each dairy cow.

In order to express the aggregate economic relief in dollar terms a conservative value per added DSE was wanted. The lowest gross margin per DSE in NSW is $8.80 for wethers. A value of $8/DSE was chosen as a conservative base for modeling, though values double this are recorded for sheep and cattle enterprises in NSW, where the greatest infestations of *Echium* occur. The year-by-year estimates of dollar value loss relief were aggregated across districts by state. The simulated time paths of these benefits for each state are given in Figure 4. The greatest benefits from bio-control of Echium are anticipated in NSW, followed by Victoria and South Australia. Comparatively little benefit is expected for Western Australia, where the late autumn breaks put *M. larvatus* at a disadvantage.

The biological control research and development program on *Echium* was begun by CSIRO in 1972. Australian meat and wool industries have also contributed funding to the program, in addition to in-kind contributions of the NSW, Victorian, South Australian and Western Australian state

Figure 3. Economic loss reduction with insect attack on *Echium*



departments, and since 1995 the Cooperative Research Centre for Weed Management Systems (Weeds CRC). Total R&D expenditures by CSIRO and the partners mentioned above will reach $14 million by 2001. The derivation of this sum is given in Table 1.

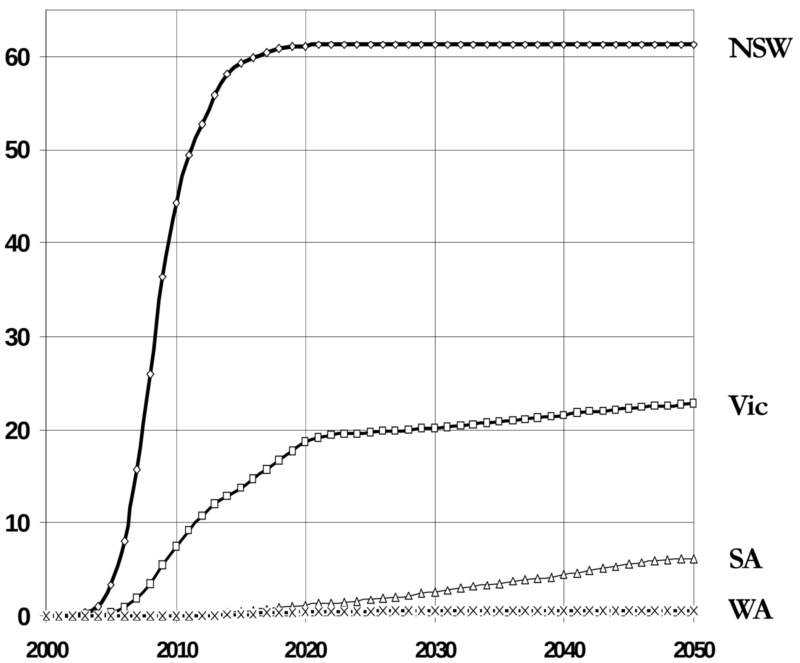
The projected four-state aggregate benefit stream, minus the cost stream, derives the time series of un-discounted net annual benefits in Table 2. The series was subjected to discounting at various rates for the case of $8/DSE. Sums of the discounted net present values for the 1972-2015 and 1972-2050 periods were calculated along with benefit cost ratios. To save space, values are shown only for selected years in Table 2: every five years during the R & D phase, every year from 2000 to 2015 when benefits are expected to increase most rapidly, and every five years thereafter to 2050. Likewise, only values for odd discount rates (1%, 3%, … 19%) are shown.

A fuller exploration of the affects of discount rates and values of DSEs on the present value of the bio-control program for *Echium* is found in Table 3. This puts the base model projections in perspective and shows their sensitivity to changes in these key assumptions.

Results and Discussion

Annual benefits in terms of increased productivity of grazing lands are projected to increase from near-zero in 2000 to some $73 million by 2015 (Table 2). The discounted (5%) net present value (NPV) of the benefit-cost stream from 1972 to 2015 is projected at $259 million, for a B/C ratio of 14.1:1 and yielding an internal rate of return exceeding 17%. Because lower attack and spread rates of the insects are observed in regions with late autumn breaks, a slow build-up of benefits is expected to continue over many years. The discounted NPV for the 1972-2050 period is estimated to be $916 million, with a B/C ratio of 47.5:1 and an internal rate of return above 19%. These estimates do not explicitly take into account reductions in costs of current *Echium* control measures that are expected with the successful spread of the bio-control agents. This is because we recognise that land managers (graziers) will have to make some changes in grazing and spraying practices in order to maximise the success of the bio-control agents and to avert reinvasion by other pasture weeds. To the extent that these changes are not costless, they will tend to balance somewhat the benefits from reduced control costs.

Figure 4. Projected annual benefits from biocontrol of *Echium* by state, undiscounted $ millions, based on $8/DSE



For the future

The authors feel a more complete analysis should be done to take in the question of the payoffs likely (a) from additional targeted insect releases, beyond the 400 successful ones already achieved, and (b) from extension program developments in integrated pest management to increase the success rates of future releases. These are activities most likely to speed up the effective benefits of the bio-control program on *Echium* and, therefore, likely to produce benefits well beyond those expected otherwise. The analysis required for that purpose must handle the simulation of geographic spread of insects differently than the current model. A GIS-based model would allow representing the spread and overlapping build up of insects from neighbouring release locations. With this information it should be possible to search for geographic gaps in insect coverage to target the locations of new releases optimally. That is, it should be possible to determine a priority list of release locations, ranked according to expected economic payoffs. In order to enhance the confidence of such a GIS model, field monitoring work is first required to test and correct the current assumptions on rates of geographic spread of insects, rates of attack and rates of economic relief from suppression of *Echium*, under the different climatic regimes in the weed's range. These three rates are not only functions of climate, however, but may be reduced locally by inappropriate management practices of graziers /farmers. It is through this connection that quantitative values may be simulated for effective extension programs. Such monitoring, modeling and extension work is in the interest, particularly, of the meat and wool industry groups who stand to benefit most.

Conclusion

The success story projected for biological control of *Echium* in Australia will likely be at a slower pace than envisaged by the IAC report of 1985. Nevertheless, the return on investments is expected to be very respectable. The role of the Weeds CRC in funding the *Echium* bio-control program has been small relative to those of CSIRO and the meat and wool industries over the years. The Weeds CRC worked with its partners to speed the release program and support development of essential extension material. Keeping in mind that just over $14 million has been spent on the bio-control program for *Echium*, the high net present values anticipated with all but the most extreme combinations of low DSE values and high discount rates (lower left corner of Table 3) give strong assurance of success. Part of a key to this success will be the effectiveness of the extension program developed with the Weeds CRC's help, allowing farmers to improve their own chances of benefiting from bio-control and at the same time speeding the geographic spread of agents to other *Echium*-infested areas.

GIS-based analysis is needed to answer questions of (a) the value of further releases where there are geographic gaps in insect populations that will take many years to fill, and (b) the value of further extension programs for integrated pest management for wider success of bio-control.

References

BOM (Bureau of Meteorology), 2000. http://www.bom.gov.au/

CIE (Centre for International Economics), 2000. *The CRC for Weed Management Systems, An impact assessment.* CIE, Canberra & Sydney. September 2000.

CSIRO, 1998. *MRC Project CS 209 Biological control of Paterson's curse, Echium plantagineum,Phase III Final Report*, Unpublished contracted research report. CSIRO Entomology, Canberra

Cullen, J.M., 1993. Biological control of weed, invertebrate and disease pests of Australian sheep pastures. In Delfosse, E.S. (ed.). 1993. *Pests of pastures: weed, invertebrate and disease pests of Australian sheep pastures.* CSIRO Information Services, Melbourne. pp. 293-312.

Cullen, J.M., Delfosse, E.S. 1985. *Echium plantagineum*: catalyst for conflict and change in Australia. In Delfosse, E.S. (ed.). 1985. *Proceedings of the VI International Symposium on biological control of weeds*. Canadian Government Publishing Centre, Ottawa. pp. 249-292.

Culvenor, C.C.J., Jago, M.V., Peterson, J.E., Smith, L.W., Payne, A.L., Campbell, D.G., Edgar, J.A., Frahn, J.L., 1984. Toxicity of *Echium plantagineum* (Paterson's curse). 1 Marginal toxic effects in Merino wethers from long-term feeding. *Australian Journal of Agricultural Research* **35**, 293-304.

IAC (Industries Assistance Commission), 1985. *Biological control of Echium species (including Paterson's curse / Salvation Jane).* IAC Report No. 371. 30 September 1985. Australian Government Publishing Service, Canberra, ACT

Jones, R.E., Alemseged, Y., Medd, R.W., Vere, D., 2000. *The distribution, density and economic impact of weeds in the Australian annual winter cropping system.* Cooperative Research Centre for Weed Management Systems (Australia). Technical Series No. 4. August 2000.

Macneil, A., 1993. Priorities for control of pests in the sheep-wheat zone of Australia: a farmer's perspective. In Delfosse, E.S. (ed.). 1993. *Pests of pastures: weed, invertebrate and disease pests of Australian sheep pastures.* CSIRO Information Services, Melbourne. pp. 29-33.

Parsons, W.T., Cuthbertson, E.G., 1992. *Noxious weeds of Australia.* Inkata Press, Melbourne & Sydney.

Piggin, C.M., 1977. The nutritive value of *Echium plantagineum* L. *and Trifolium subterraneum* L.. *Weed Research* **17**, 361-365.

Table 1. Research and development costs for *Echium* bio-control ($thousands)

Year	BCA Year	Total	In-Kind* Contributions	Meat**	Wool**	Weeds CRC
1972	-28	$35	$6.9	$7.2	$21.1	$0.0
1973	-27	$53	$24.8	$7.2	$21.1	$0.0
1974	-26	$30	$1.7	$7.2	$21.1	$0.0
1975	-25	$51	$22.4	$7.2	$21.1	$0.0
1976	-24	$59	$30.7	$7.2	$21.1	$0.0
1977	-23	$68	$39.3	$7.2	$21.1	$0.0
1978	-22	$99	$70.4	$7.2	$21.1	$0.0
1979	-21	$177	$148.6	$7.2	$21.1	$0.0
1980	-20	$208	$180.1	$7.2	$21.1	$0.0
1981	-19	$287	$258.6	$7.2	$21.1	$0.0
1982	-18	$77	$48.4	$7.2	$21.1	$0.0
1983	-17	$28	$0.0	$7.2	$21.1	$0.0
1984	-16	$28	$0.0	$7.2	$21.1	$0.0
1985	-15	$28	$0.0	$7.2	$21.1	$0.0
1986	-14	$28	$0.0	$7.2	$21.1	$0.0
1987	-13	$401	$200.0	$99.9	$101.0	$0.0
1988	-12	$405	$200.0	$102.3	$102.3	$0.0
1989	-11	$423	$209.9	$155.4	$106.3	$0.0
1990	-10	$434	$229.9	$102.0	$102.0	$0.0
1991	-9	$540	$252.9	$155.4	$131.4	$0.0
1992	-8	$512	$230.0	$161.4	$120.2	$0.0
1993	-7	$947	$674.8	$126.9	$145.5	$0.0
1994	-6	$1,087	$772.1	$166.7	$148.7	$0.0
1995	-5	$1,113	$789.8	$170.4	$152.4	$0.0
1996	-4	$1,160	$797.0	$195.3	$167.3	$0.0
1997	-3	$1,206	$849.4	$162.1	$169.7	$25.00
1998	-2	$1,258	$856.8	$188.8	$187.7	$25.00
1999	-1	$1,324	$860.3	$193.5	$244.9	$25.00
2000	0	$1,049	$628.5	$99.8	$239.7	$81.0
2001	1	$915	$491.6	$91.1	$222.3	$110.0
TOTALS		**$14,029**	**$8,874.8**	**$2,230.1**	**$2,658.4**	**$266.0**

Source Cost data assembled by Matthew Smyth, CSIRO Entomology

Note* In-kind contributions include CSIRO funds and those of NSW, Vic, SA and WA

Note** Contributions from Meat and Wool industries include amounts of $108077 and $317115, respectively between the years 1972 and 1986; we assume the amounts were divided equally among these years

Seaman, J.T., Turvey, W.S., Ottaway, S.J., Dixon, R.J., Gilmour, A.R., 1989. Investigations into the toxicity of *Echium plantagineum* in sheep 1. Field grazing experiments. *Australian Veterinary Journal* **66,** 279-85.

Seaman, J.T., Dixon, R.J., 1989. Investigations into the toxicity of *Echium plantagineum* in sheep 2. Pen feeding experiments. *Australian Veterinary Journal* **66**, 286-292.

Shepherd, R.C.H., 1993. Paterson's curse: "I want some grubs" versus research releases. In Delfosse, E.S. (ed.). 1993. *Pests of pastures: weed, invertebrate and disease pests of Australian sheep pastures.* CSIRO Information Services, Melbourne. pp. 337-341.

Sheppard, A.W., Smyth, M.J., Swirepik, A., 1999. Impact of the root-crown weevil (*Mogulones larvatus*) and other biocontrol agents on Paterson's curse in Australia: An update. In Bishop, A.C., Boersma, M. and Barnes, C.D. (eds.) 1999. *12th Australian Weeds Conference, Papers and Proceedings*. Tasmanian Weed Society, Devonport. pp. 343-346.

Taylor, U., Sindal, B., 2000. *The Pasture Weed management Kit. A guide to managing weeds in Southern Australian perennial pasture*. CRC for Weed Management Systems ISBN: 095 870 105 9 TN9

Table 2. Benefit-Cost analysis for biocontrol of *Echium* with various discount rates and DSEs valued at $8

Selected Years Year	BCA Year	TOTAL Un-discounted Benefits-Costs	Costs of Bio-Control R & D	Aggregate Benefits to Grazing		1%	3%	5%	7%	9%	11%	13%	15%	17%	19%
					B/C ratio to 2015	29.2	20.4	14.1	9.7	6.6	4.4	2.9	1.9	1.2	0.8
					B/C ratio to 2050	173.5	88.6	47.5	26.5	15.2	8.9	5.3	3.2	1.9	1.1
					NPV ($M) to 2015	$421	$330	$259	$202	$155	$116	$81	$49	$16	-$19
					NPV ($M) to 2050	$2,572	$1,491	$916	$591	$394	$267	$180	$115	$61	$12
					Discount rate:	1%	3%	5%	7%	9%	11%	13%	15%	17%	19%
		(un-discounted $ millions)				discounted present values (2000) in $ millions									
1972	-28	-$0.04	-$0.04			-$0.05	-$0.08	-$0.14	-$0.23	-$0.39	-$0.65	-$1.08	-$1.76	-$2.86	-$4.60
1977	-23	-$0.07	-$0.07			-$0.09	-$0.13	-$0.21	-$0.32	-$0.49	-$0.75	-$1.12	-$1.68	-$2.50	-$3.70
1982	-18	-$0.08	-$0.08			-$0.09	-$0.13	-$0.18	-$0.26	-$0.36	-$0.50	-$0.69	-$0.95	-$1.30	-$1.76
1987	-13	-$0.40	-$0.40			-$0.46	-$0.59	-$0.76	-$0.97	-$1.23	-$1.56	-$1.96	-$2.47	-$3.09	-$3.85
1992	-8	-$0.51	-$0.51			-$0.55	-$0.65	-$0.76	-$0.88	-$1.02	-$1.18	-$1.36	-$1.56	-$1.80	-$2.06
1997	-3	-$1.21	-$1.21			-$1.24	-$1.32	-$1.40	-$1.48	-$1.56	-$1.65	-$1.74	-$1.83	-$1.93	-$2.03
2000	0	-$1.05	-$1.05	$0.00		-$1.05	-$1.05	-$1.05	-$1.05	-$1.05	-$1.05	-$1.05	-$1.05	-$1.05	-$1.05
2001	1	-$0.91	-$0.91	$0.01		-$0.90	-$0.88	-$0.86	-$0.85	-$0.83	-$0.82	-$0.80	-$0.79	-$0.77	-$0.76
2002	2	$0.06		$0.06		$0.05	$0.05	$0.05	$0.05	$0.05	$0.05	$0.04	$0.04	$0.04	$0.04
2003	3	$0.28		$0.28		$0.27	$0.26	$0.24	$0.23	$0.22	$0.20	$0.19	$0.18	$0.17	$0.17
2004	4	$1.11		$1.11		$1.07	$0.99	$0.91	$0.85	$0.79	$0.73	$0.68	$0.64	$0.59	$0.55
2005	5	$3.53		$3.53		$3.35	$3.04	$2.76	$2.51	$2.29	$2.09	$1.91	$1.75	$1.61	$1.48
2006	6	$8.82		$8.82		$8.31	$7.39	$6.58	$5.88	$5.26	$4.72	$4.24	$3.81	$3.44	$3.11
2007	7	$17.53		$17.53		$16.35	$14.25	$12.46	$10.92	$9.59	$8.44	$7.45	$6.59	$5.84	$5.19
2008	8	$29.48		$29.48		$27.22	$23.27	$19.95	$17.16	$14.79	$12.79	$11.09	$9.64	$8.39	$7.33
2009	9	$41.74		$41.74		$38.16	$31.99	$26.91	$22.70	$19.22	$16.32	$13.89	$11.87	$10.16	$8.72
2010	10	$51.71		$51.71		$46.81	$38.48	$31.74	$26.29	$21.84	$18.21	$15.23	$12.78	$10.76	$9.08
2011	11	$58.64		$58.64		$52.56	$42.36	$34.29	$27.86	$22.73	$18.61	$15.29	$12.60	$10.43	$8.65
2012	12	$63.62		$63.62		$56.46	$44.62	$35.42	$28.25	$22.62	$18.18	$14.68	$11.89	$9.67	$7.89
2013	13	$67.97		$67.97		$59.73	$46.29	$36.05	$28.21	$22.17	$17.50	$13.88	$11.05	$8.83	$7.08
2014	14	$71.38		$71.38		$62.10	$47.19	$36.05	$27.68	$21.36	$16.56	$12.90	$10.09	$7.92	$6.25
2015	15	$73.58		$73.58		$63.38	$47.23	$35.39	$26.67	$20.20	$15.38	$11.76	$9.04	$6.98	$5.41
2020	20	$81.32		$81.32		$66.65	$45.03	$30.65	$21.01	$14.51	$10.09	$7.06	$4.97	$3.52	$2.51
2025	25	$83.17		$83.17		$64.85	$39.72	$24.56	$15.32	$9.65	$6.12	$3.92	$2.53	$1.64	$1.07
2030	30	$84.53		$84.53		$62.72	$34.83	$19.56	$11.10	$6.37	$3.69	$2.16	$1.28	$0.76	$0.46
2035	35	$86.10		$86.10		$60.78	$30.60	$15.61	$8.06	$4.22	$2.23	$1.19	$0.65	$0.35	$0.20
2040	40	$87.85		$87.85		$59.01	$26.93	$12.48	$5.87	$2.80	$1.35	$0.66	$0.33	$0.16	$0.08
2045	45	$89.65		$89.65		$57.29	$23.71	$9.98	$4.27	$1.86	$0.82	$0.37	$0.17	$0.08	$0.04
2050	50	$90.93		$90.93		$55.29	$20.74	$7.93	$3.09	$1.22	$0.49	$0.20	$0.08	$0.04	$0.02

Nordblom, Smyth, Swirepik, Sheppard & Briese (Weeds CRC / 2000)
Model: **Benefit-Cost Analysis for *Echium* Bio-Control 809.xls**

Table 3. Net present value (in $millions) for *Echium* biocontrol, 1972-2050, as function of discount rate and value per DSE of pasture productivity gain.

		$1 DSE	$2 DSE	$3 DSE	$4 DSE	$5 DSE	$6 DSE	$7 DSE	$8 DSE	$9 DSE	$10 DSE
	1%	308	632	955	1279	1602	1925	2249	2572	2895	3219
	2%	229	474	719	964	1208	1453	1698	1943	2188	2433
	3%	172	360	549	737	926	1114	1303	1491	1680	1868
	4%	129	277	424	571	719	866	1014	1161	1309	1456
Discount	5%	97	214	331	448	565	682	799	916	1034	1151
	6%	73	167	261	355	449	544	638	732	826	920
	7%	54	130	207	284	360	437	514	591	667	744
	8%	38	101	164	228	291	354	418	481	544	607
	9%	25	78	130	183	236	289	341	394	447	499
	10%	14	58	102	147	191	236	280	324	369	413
	11%	4	41	79	117	154	192	230	267	305	342
	12%	-5	27	59	91	123	156	188	220	252	284
	13%	-14	13	41	69	97	124	152	180	208	235
	14%	-23	1	25	49	73	97	121	145	169	193
	15%	-32	-11	10	31	52	73	94	115	136	157
	16%	-42	-23	-5	13	32	50	69	87	105	124
	17%	-52	-36	-20	-4	13	29	45	61	77	94
	18%	-64	-49	-35	-21	-6	8	22	37	51	65
	19%	-77	-64	-51	-39	-26	-13	0	12	25	38
	20%	-92	-80	-69	-58	-46	-35	-24	-12	-1	11

Source: Bio-economic simulation by Nordblom, Smyth, Swirepik, Sheppard & Briese (Weeds CRC / 2000)
Model: **Benefit-Cost Analysis for Echium Bio-Control 809.xls**