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BENEFIT- COST ANALYSIS FOR BIOLOGICAL CONTROL OF *ECHIUM* WEED SPECIES (Paterson's curse / Salvation Jane)

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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).

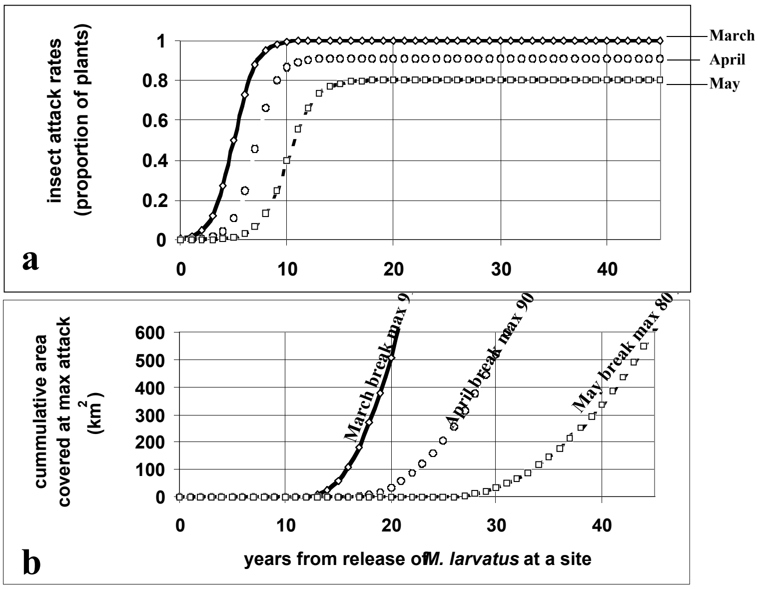
The Supreme Court injunction was eventually lifted and the importation of insects into Australia resumed. Since then six insect species have been successfully released: a leaf mining moth, *Dialectica scalariella*, crown and root weevils, *Mogulones larvatus* and *Mogulones geographicus*, a root beetle, *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).

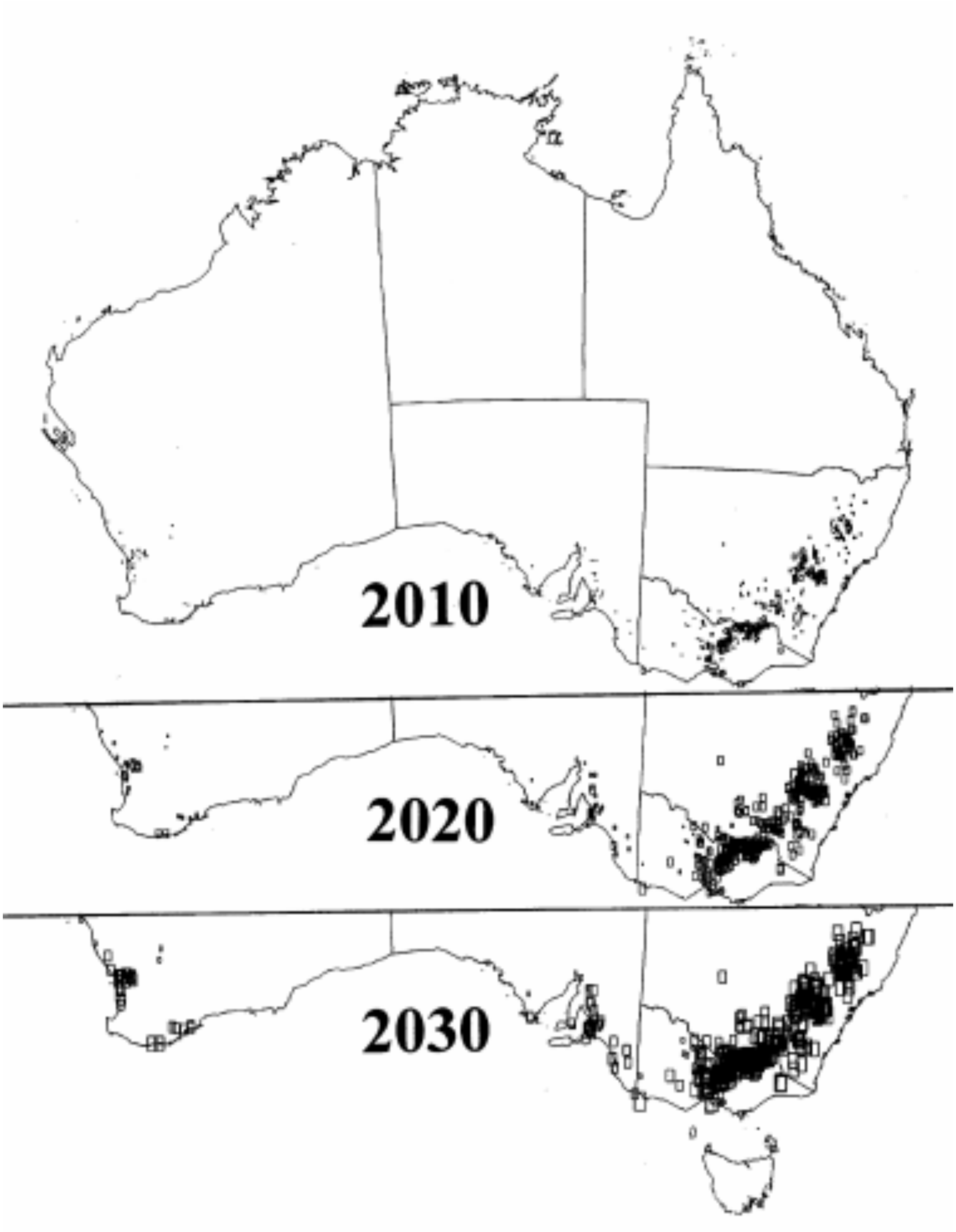
Figure 1. Insect attack and spread by year from release, according to month of autumn break



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.

Figure 2. Simulated spreading fronts of 400 ***M. Larvatus*** populationsreleased on Paterson's curse from 1993-2000, at 2010, 2020 and 2030

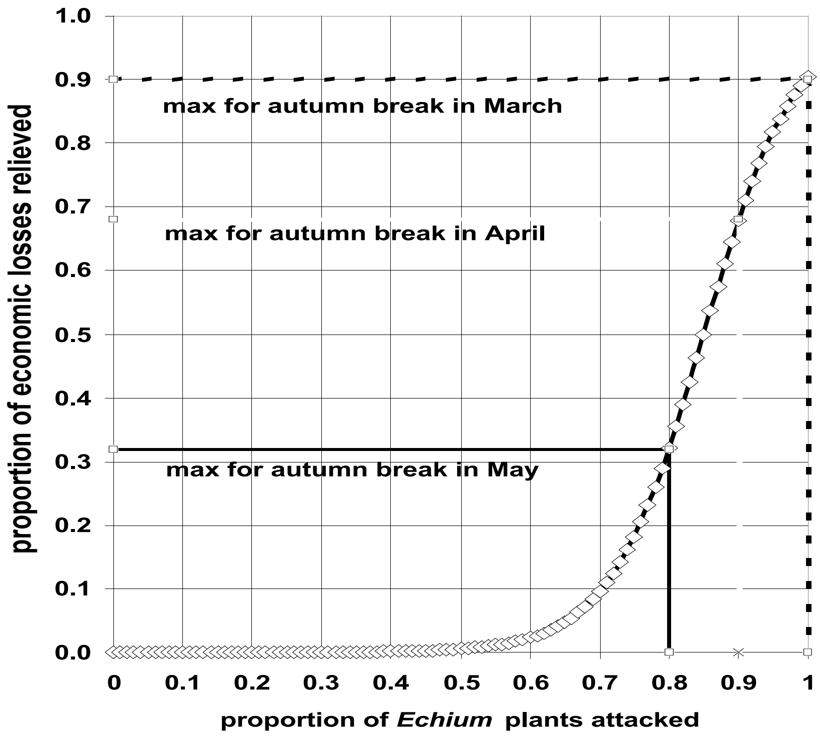


Source: Anthony Swirepik **(CSIRO-**Entomology/Canberra) and collaborators in the respective states

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 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).

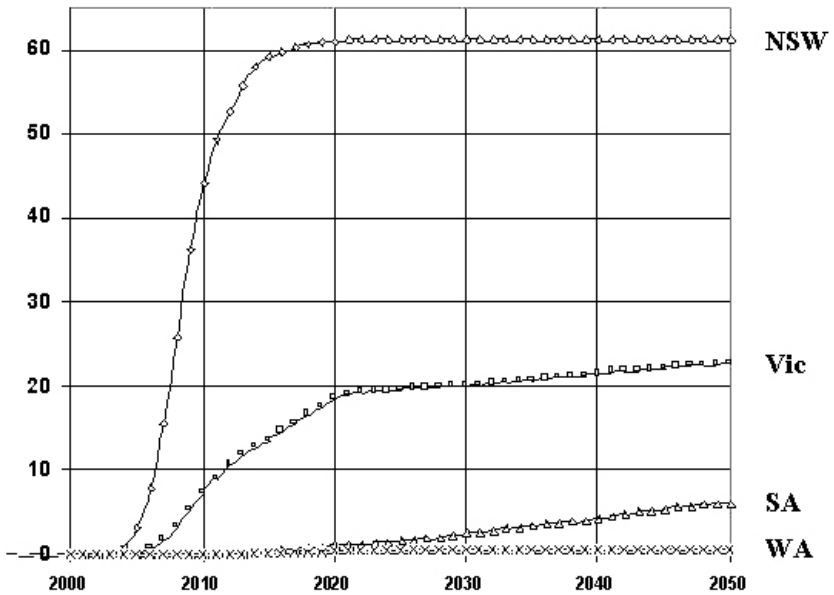
Figure 3. Economic loss reduction with insect attack on *Echium*



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.

Figure 4. Projected annual benefit from Bio-control of *Echium* by state, un-discounted $ millions, based on $8/DSE



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 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.

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	$106.3	$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	$25.0
1998	**-2**	**$1,258**	$856.8	$188.8	$187.7	$25.0
1999	**-1**	**$1,324**	$860.3	$193.5	$244.9	$25.0
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

Table 2. Benefit-Cost Analysis for bio-control 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											
					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* bio-control, 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**

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.

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.

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