The World's Largest Open Access Agricultural & Applied Economics Digital Library

This document is discoverable and free to researchers across the globe due to the work of AgEcon Search.

Help ensure our sustainability.

Give to AgEcon Search

AgEcon Search
http://ageconsearch.umn.edu
aesearch@umn.edu

*Papers downloaded from **AgEcon Search** may be used for non-commercial purposes and personal study only. No other use, including posting to another Internet site, is permitted without permission from the copyright owner (not AgEcon Search), or as allowed under the provisions of Fair Use, U.S. Copyright Act, Title 17 U.S.C.*

Economics of controlling a spreading environmental weed

Morteza Chalak[a*] David J. Pannell[a]

[a]Centre for Environmental Economics and Policy, School of Agricultural and Resource Economics, The University of Western Australia,
Crawley, WA 6009, Australia

*E-mail address: morteza.chalak@uwa.edu.au

26 June 2011
Working Paper 1114
School of Agricultural and Resource Economics
http://www.are.uwa.edu.au

Citation: Morteza Chalak[a*] David J. Pannell[a] (2011) *Economics of controlling a spreading environmental weed,* Working Paper 1114, School of Agricultural and Resource Economics, University of Western Australia, Crawley, Australia.

© Copyright remains with the authors of this document.

Abstract:

Weeds can cause significant problems to natural ecosystems. Although there have been numerous studies on the economics of weed control, relatively few of these studies have focused on natural ecosystems. This paper addresses this gap in the literature by assessing the cost-effectiveness of a comprehensive range of control strategies for blackberry (*Rubus anglocandicans*) in natural environments in Australia. We developed a stochastic dynamic simulation model and a deterministic dynamic optimisation model. The stochastic model calculates the expected net present value (NPV) of a range of control strategies, including any combination of treatment options. The optimisation model identifies the treatment combination that maximises NPV. Both models represent the costs and efficacies of control options over 25 years. The results indicate that using rust (*Phragmidium violaceum*) as a biological control agent only marginally increases NPV and excluding rust does not affect the optimal choice of other control options. The results also show for a wide range of parameter values that a strategy which combines the herbicide grazon (Triclopyre and picloram) and mowing is optimal. If chemical efficacy decreases by 20 percent it becomes optimal to include grazing blackberry by goats in the control strategy.

Keywords: environment, economics, weed, stochastic, optimisation, management

Introduction

In many environments, invasive species are significant threats to biodiversity and agriculture. The majority of natural ecosystems suffer from invasive species. Weeds are the most costly invasive species, leading to huge worldwide economic damages (Sheppard et al. 2003). Weeds reduce water management efficiency and natural biodiversity (Tyser and Key 1988; Lacey and Fay 1989; Monaco et al. 2001).

Blackberry is categorised as a Weed of National Significant in Australia (WoNS) and due to its large invasiveness, environmental and economic impacts it is considered as one of the worst weeds in Australia (Reid 2008). Vere and Dellow (1984) estimated that, in central western NSW, the value of the lost production plus the cost of controlling blackberry was \$4.7m. James and Lockwood (1998) estimated that, across Austalia, the cost of controlling blackberry plus the lost agricultural production was \$41.5m.

There have been a number of studies evaluating management strategies for weeds and other pests. Wu (2001) used dynamic optimal weed control decision rules to find the optimal management for weed. Similar approach has been used by Taylor and Burt (1984); Kennedy (1987); McConnachie et al. (2003); Chalak-Haghighi (2008). Most of these studies have focused on weed control for agricultural benefits. Studies that have considered the economics of environmental weeds and pests include Cacho et al. 2006; Panetta 2006 and Cacho et al. 2008. These studies have generally examined only a small number of discrete control strategies, often only one.

This paper extends the previous studies by identifying the optimal integrated strategy for cost-effective control of blackberry in Australian environments. In doing so, it evaluates all possible combinations of individual treatment options. In other words, it applies the concept of Integrated Weed Management (IWM) (Miller et al.

1992; Buckley et al. 2004; Pannell et al. 2004; Chalak-Haghighi et al. 2008;) to natural ecosystems.

Two different models are developed and applied to the problem: (a) a stochastic dynamic simulation model that represents weed infestation as a stochastic process and allows comparison of the NPVs of different integrated strategies, and (b) a deterministic dynamic optimisation model that finds the optimal integrated management strategies. The dynamic model includes technical relationships estimated from the simulation model. Both models include estimates of the non-market (intangible) environmental and social benefits of weed management in natural ecosystems.

The two models have different strengths: the stochastic simulation model is spatially explicit and can represent an area of the land and accounts for stochastic elements such as introduction of new infestations and probability of blackberry being removed by control strategy. The strength of dynamic optimisation model is that it finds the optimal solution for any infestation. The use of two models allows us to verify the accuracy of each model, through the comparison of results for the same scenarios.

The objectives of the paper are to identify which combination of control options is likely to be optimal in different circumstances, to estimate the economic benefits of biological control is an element of the control strategy, and to determine how changes in model parameters affect the optimal control strategy.

Method

Blackberry's tend to infest areas adjacent to rivers and streams in relatively high-rainfall regions. Once established, they spread at a rate of around 1 to 2 metres per year. The models represent the impact of blackberry on social welfare within 100m of a river in a region to which blackberry is well-adapted. Blackberry causes losses of social welfare in at least three ways: by obstructing people who wish to swim in the river from using some of the river bank, by obstructing fishers from using some of the river bank, and by competing with native plants and degrading native habitat.

The following defines the annual net benefit obtained from the river:

$$B_t = B_{veg}(w_t) + B_{fish}(w_t) + B_{swim}(w_t) - c_t(u_t) \tag{1}$$

where u_t is the control strategy (i.e. the combination of treatments) adopted in year t and c_t is the cost of that control strategy. B_{veg}, B_{fish}, and B_{swim} are the benefits obtained from healthy vegetation, fishable river side and swimmable river sides, respectively. All prices and costs are expressed in Australian dollars ($).

Benefit obtained from healthy vegetation is calculated from the following formula (Yeoh et al. 2009):

$$B_{veg} = v_{veg} Exp(-0.1455w) \tag{2}$$

where w is the percentage cover of blackberry and v_{veg} is the value of healthy vegetation per hectare.

We assume that the relationship between the fishable and swimmable river side and percentage coverage of blackberry (w) is linear and follows the below function:

$$B_{fish} + B_{swim} = (v_{fish} + v_{swim}) \cdot (1 - w) \tag{3}$$

where v_{fish} and v_{swim} are dollar values representing the non-market values that fishers and swimmers obtain from using the river.

Non-market values of blackberry impacts

Morrison and Bennet (2004) reported that, on average, households in NSW are prepared to pay, as a one-off lump-sum, \$1.98 per ha to protect the habitat of healthy native vegetation, \$29.93 to retain the entire Gwydir River in a fishable state and \$59.98 to keep the entire it swimmable. We use these values to calculate the social benefits from biodiversity, fishing and swimming for an area of land that abuts a 330 km length of river and is 100m wide. Conservatively, value we multiply the elicited values by the respondent rate to the survey (0.396). For 2.65 million households in NSW, the total value of the entire Gwydir river comes to \$2,078,000 for healthy vegetation and \$31,409,000 for fishing and \$62,943,000 swimming. To calculate the area that can be infested by blackberry on the river side the length of the river (330 km) is multiplied by the average width on both sides of the river that has potential to be infested by blackberry on the both side of the river: estimated to be 100 metres on both sides (Grammie 2009). To calculate the values per hectare of land, the total value is divided by the estimated area of river side within the relevant area (6600 ha). This results in a value of \$315 for healthy vegetation, \$4759 for fishable river side and \$9537 for swimmable river side per hectare. Calcualting annuity values, this turns out to be \$19 $ha^{-1}yr^{-1}$ for healthy vegetation, \$286 $ha^{-1}yr^{-1}$ for fishable river side and \$573 $ha^{-1}yr^{-1}$ for swimmable river side.

Blackberry dynamics

As noted earlier, the establishment of a new blackberry infestation is modelled as a stochastic event. Blackberry seeds can be introduced to an un-infested area by birds. It is estimated that the probability of a new infestation occurs in each m^{-2} of land unit is

0.0016 for the land that is within 5 meters of the river and 0.000021 for land that is 5-100 metres from the river (John Moore pers. Comm. 2009).

It is assumed that within 5 meters from the river, blackberry spreads two metres per year, while in the range of 5-100 metres from the river side, the rate of spread decreases to 1 meter a year due to decreased soil moisture (John Moore, pers. Comm. 2009). As the density of blackberry increases, the competition between blackberry individuals increases and the growth rate decreases. Based on discussion with a weeds scientist, it was assumed that blackberry cannot infest more than 75 percent of the relevant land area.

Based on these assumptions, the simulation model is used to generate the transition function for the density of blackberry between year t and year t+1 (Figure 1). A cubic function is fitted to the data to estimate the function for use in the optimisation model.

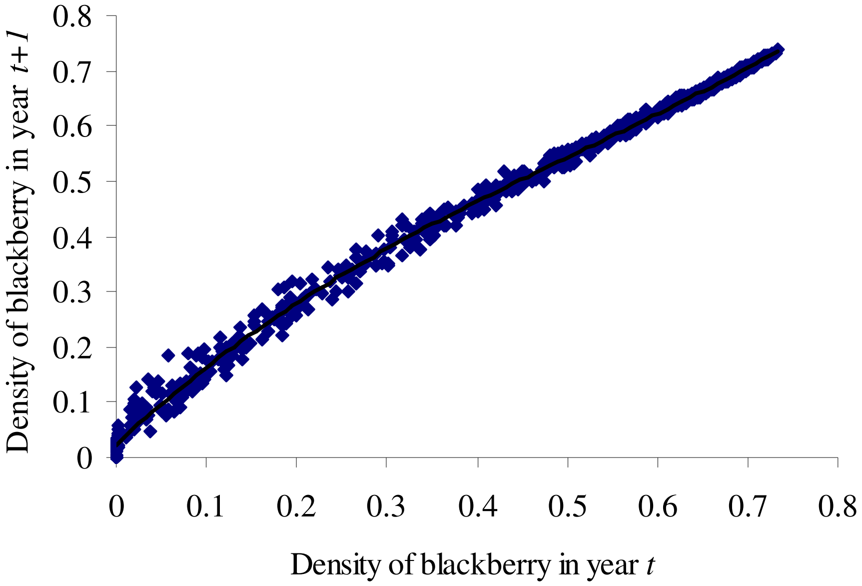

Figure 1. Transition density of blackberry in year *t* and *t+1*.

$$w_{t+1} = (0.945w_t^3 - 1.46w_t^2 + 1.53w_t + 0.023) \cdot M(u_t) \qquad (4)$$

where w_{t+1} is percentage coverage of blackberry in year t+1 and $M(u_t)$ is a multiplier that presents the effect of control strategies (u_t) on the weed population density.

Control Strategies

There are 8 control options considered for the control of blackberry: introduction of rust (Phra*gmidium violaceum*), glyphosate, Glyphosate plus metsulfuron, metsulfuron (Metsulfuron methyl), grazon (Triclopyre plus picloram), galrlon (Triclopyre), grazing goats and mowing.

All possible combinations of theses options are considered and illogical combinations (e.g. combining more than one chemical in a strategy) are excluded. This yielded 47 possible control strategies (Table 1). A "+" sign means that the control option is included in the list of control strategies and a "-" sign means that the control option is not included in the strategy. The efficiency multiplier $M(u_t)$ of the strategies that include a single option (strategies 2-8 and 25) are obtained from the literature which are presented in Table 1. Chalak-Haghighi (2008) has shown the additive efficacy of single control options can be used to calculate the efficacy of integrated weed control strategies. We used the same method to calculate efficacies of integrated strategies. Control costs (\$ ha $^{-1}$) include the treatment costs and transportation costs (Andrew Reeves pers. comm. 2009)

Table 1. Costs and efficacies of strategies to control blackberry. Control options are: Rust, Gly. (Glyphosate), Gly.+Met. (Glyphosate plus metsulfuron), Met. Met. (Metsulfuron methyl), grazon, galrlon, goats and Mowing.

Strategies	Control options								Efficacy multiplier ($M(u_t)$)	Costs ($ ha^{-1})	Reference
	rust	Gly.	Gly.+Met.	Met.Met.	Grazon	Garlon	Goats	Mowing			
1	-	-	-	-	-	-	-	-	1	0	
2	-	+	-	-	-	-	-	-	0.2	5100	Yeoh et al. (2006)
3	-	-	+	-	-	-	-	-	0.05	5095	Yeoh et al. (2006)
4	-	-	-	+	-	-	-	-	0.25	5040	Yeoh et al. (2006)
5	-	-	-	-	+	-	-	-	0.03	5400	Yeoh et al. (2006)
6	-	-	-	-	-	+	-	-	0.08	5200	Pritchard (1990)
7	-	-	-	-	-	-	+	-	0.55	3607	Batten (1979)
8	-	-	-	-	-	-	-	+	0.48	500	Amor and Harris (1981)
9	-	+	-	-	-	-	+	-	0.11	8707	
10	-	+	-	-	-	-	-	+	0.096	5600	
11	-	-	+	-	-	-	+	-	0.028	8702	
12	-	-	+	-	-	-	-	+	0.024	5595	
13	-	-	-	+	-	-	+	-	0.138	8647	
14	-	-	-	+	-	-	-	+	0.12	5540	
15	-	-	-	-	+	-	+	-	0.017	9007	
16	-	-	-	-	+	-	-	+	0.014	5900	
17	-	-	-	-	-	+	+	-	0.044	8807	
18	-	-	-	-	-	+	-	+	0.038	5700	
19	-	-	-	-	-	-	+	+	0.264	4170	
20	-	+	-	-	-	-	+	+	0.053	9207	
21	-	-	+	-	-	-	+	+	0.013	9202	
22	-	-	-	+	-	-	+	+	0.066	9147	
23	-	-	-	-	+	-	+	+	0.008	9507	
24	-	-	-	-	-	+	+	+	0.021	9307	

Strategies	Control options								Efficacy multiplier ($M(u_t)$)	Costs (\$ ha $^{-1}$)	Reference
	rust	Gly.	Gly.+Met.	Met.Met.	Grazon	Garlon	Goats	Mowing			
25	+	-	-	-	-	-	-	-	0.957	1	Mahr et al. (1998)
26	+	+	-	-	-	-	-	-	0.191	5101	
27	+	-	+	-	-	-	-	-	0.048	5096	
28	+	-	-	+	-	-	-	-	0.239	5041	
29	+	-	-	-	+	-	-	-	0.029	5401	
30	+	-	-	-	-	+	-	-	0.077	5201	
31	+	-	-	-	-	-	+	-	0.526	3608	
32	+	-	-	-	-	-	-	+	0.459	501	
33	+	+	-	-	-	-	+	-	0.105	8708	
34	+	+	-	-	-	-	-	+	0.092	5601	
35	+	-	+	-	-	-	+	-	0.026	8703	
36	+	-	+	-	-	-	-	+	0.023	5596	
37	+	-	-	+	-	-	+	-	0.132	8648	
38	+	-	-	+	-	-	-	+	0.115	5541	
39	+	-	-	-	+	-	+	-	0.016	9008	
40	+	-	-	-	+	-	-	+	0.014	5901	
41	+	-	-	-	-	+	+	-	0.042	8808	
42	+	-	-	-	-	+	-	+	0.037	5701	
43	+	-	-	-	-	-	+	+	0.253	4108	
44	+	+	-	-	-	-	+	+	0.051	9208	
45	+	-	+	-	-	-	+	+	0.013	9203	
46	+	-	-	+	-	-	+	+	0.063	9148	
47	+	-	-	-	+	-	+	+	0.008	9508	
48	+	-	-	-	-	+	+	+	0.020	9308	

Comparing strategies by simulation model:

Blackberry density and growth for a 100×10 metre area of the river side is simulated using Microsoft Excel. The following presents the net benefit obtained from the environment:

$$B_t = lv(1 - w_t) - c(u_t) \tag{5}$$

where *lv* is the land value, *w* is the portion of land infested by blackberry and $c(u_t)$ is the cost of control strategy adopted in year *t* (u_t).

The Net Present Value (NPV) obtained from applying each strategy follows:

$$NPV = \sum_{t=0}^{T} \frac{B_t}{(1+\partial)^t} \tag{6}$$

where B_t is the net benefit obtained from the environment and ∂ is the discount rate. NPVs of control strategies can be compared and the best of the tested control strategies can be selected.

As the number of combinations of control strategies is large finding the optimal strategy in this way can be time consuming. To solve this problem an optimisation model has been developed:

Optimisation model

The optimisation model is developed to find a sequence of control strategies (u_t) that maximises the NPV (V_t). The optimisation model follows:

$$V_t(w_t) = Max\{B_t(w_t, u_t) + \delta V_{t+1}(w_{t+1})\}$$

Subject to

$$w_{t+1} = (0.945w_t^3 - 1.46w_t^2 + 1.53w_t + 0.023) \cdot M(u_t)$$

where δ is the discount factor. The benefits in year t depend on the weed density in year t and the control strategy adopted (u_t). The future net benefits, however, are affected by the future weed density. The dynamic programming model was solved using backward induction by MATLAB for a planning horizon of 25 years.

Results

The results suggest that, for blackberry in Australia, using rust (Phra*gmidium violaceum*) as a biological control agent only marginally increases NPV and excluding rust does not affect the optimal choice of other control options. Thus we analyse strategies 1-24 that do not include rust. Strategies 25-48 are the same strategies as 1-24, except that they include rust.

Each control strategy results in a different weed density and generates different benefits. Here we first compare the weed density and net benefits for different strategies.

In Figure 2, weed densities (percentage coverage of blackberry) are presented for four strategies: no control, strategy 16 (i.e. combination of grazon and mowing), strategy 8 (i.e. mowing) and strategy 19 (i.e. goat control and mowing). These strategies are selected for illustrative purposes. They are not necessarily optimal strategies.

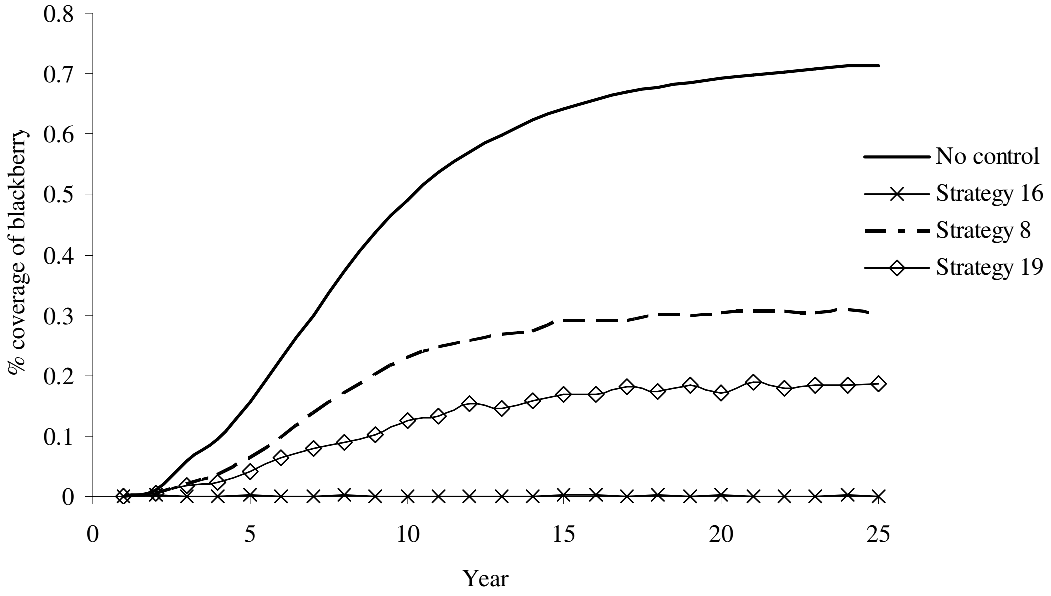

Figure 2. Percentage coverage of blackberry in year *t* for different strategies: no control, strategy 16 (i.e. combination of grazon and mowing), strategy 8 (i.e. mowing) and strategy 19 (i.e. goat control and mowing).

In the absence of control, at the beginning of time horizon, the density of weed rapidly increases. As the weed density increases, weed spread reduces due to competition of weed individuals with each other and decrease in the food sources. Strategy 16 keeps the weed density at a very low level as it has the highest efficacy (see Table 1).

Figure 2 presents the undiscounted year-by-year net benefits of the same selected strategies. These results are simply the benefits from those years; they do not factor in benefits in future years from current weed control. As this figure shows, for most years strategy 16 gives the highest net benefit. This is because strategy 16 is more cost-effective than other control options in removing weeds. Strategy 16, however, is expensive. Thus, at the beginning of the time horizon where the weed density is very low, the annual net benefit of "no control" is higher than that for strategy 16. But as the weed density increases the benefit obtained from removing the weeds exceeds the control cost and strategy 16 become more attractive.

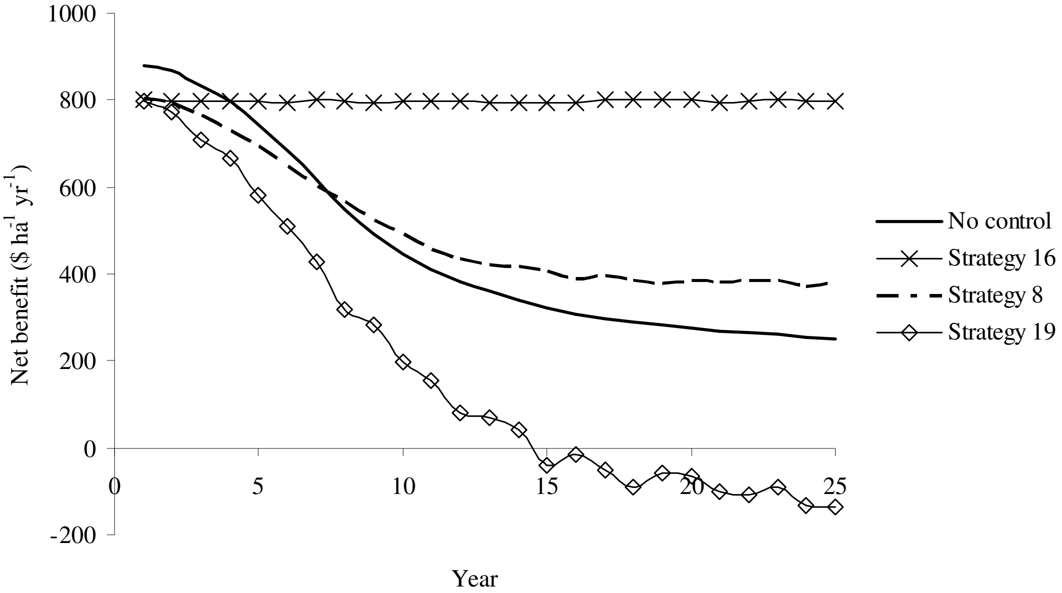

Figure 3. Net benefit obtained from the land in year *t* for different strategies: no control, strategy 16 (i.e. combination of grazon and mowing), strategy 8 (i.e. mowing) and strategy 19 (i.e. goat control and mowing).

Strategies 8 and 19 result in a lower efficacies than strategy 16 (see Table 1). Thus strategy 16 reduces weed density to a greater extent than strategies 8 and 19. Even though strategies 8 and 19 are cheaper than strategy 16, net benefit obtained from the land is higher when strategy 16 is applied. This is because strategy 16 keeps weed density to a very low level, such that the benefits exceed the control costs.

The application of strategy 19 result in a lower weed density than strategy 8 as it has a higher efficacy. However, the cost of strategy 19 is much higher than strategy 8. The control cost of 19 is so high that it outweighs the benefits of its higher efficacy (Figure 3).

The results show that, for the base-case set of assumptions, a combination of mowing and grazon (strategy 16) is the most cost effective IWM strategy for blackberry control. The sensitivity analysis shows that strategy 16 is optimal for a large range of land value (Figure 4).

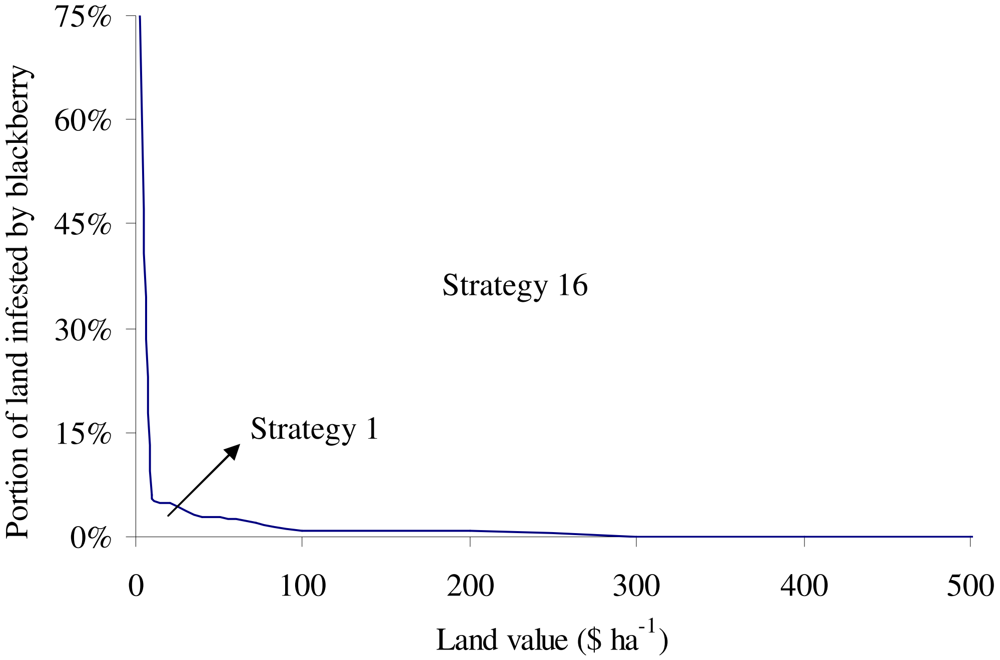

Figure 4. Optimal strategies weed control strategies depending on land value and initial weed infestation. When the land value and initial blackberry density are above the threshold line, the optimal strategy is 16, otherwise the optimal strategy is 1 (no control).

If the land value is larger than 280 $ ha^{-1} the optimal strategy is 16, irrespective of the initial weed density. When there is a combination of the low land value and low initial weed density, the optimum is strategy 1 (no control) (Figure 4).

We use sensitivity analysis to show the effect of change in the efficacy of control options on the NPV. Table 2 presents the NPV of various scenarios for a selection of strategies that are most cost-effective. For the efficacies presented in Table 1 (base case), the application of strategy 16 results in the highest NPV. As the efficacy of chemicals increases by 20 percent, strategy 3 (i.e. application of Glyphosate plus metsulfuron) gives the highest value. This is because the increase in the efficacy of chemicals enables it to reduce weed density to such a low level that including more control option will not be cost-effective. When the efficacy of chemicals decreases by 20 percent, strategy 23 (, i.e. a combination of grazon, goat control and mowing) gives a higher NPV than strategy 16. This is because, when the efficacy of chemical decreases, it becomes beneficial to at grazing by goats to the IWM strategy.

When the efficacy of goat and mowing increase or decrease by 20 percent, the NPV of the strategies that include goat and mowing (strategies 8, 16, 21 and 23) increases or decreases respectively. Results show that the strategy 16 is still the most cost-effective strategy when these changes in the efficacies of goat and mowing occur. Because these options have a much lower efficacy than chemicals, a 20 percent increase in their efficacy is not sufficient to change the optimal strategy.

Table 2. NPV (\$ ha^{-1}) of alternative control strategies in difference scenarios:

Efficacy	Strategy					
	5	8	16	21	23	3
Base case	10766	7671	10809	10764	10774	10675
Chemicals + 20%	10830	7671	10829	10796	10790	10832
Chemicals -20%	4540	7671	9089	10308	10369	4202
Goat control +20%	10766	7671	10809	10770	10784	10675
Goat Control - 20%	10766	7671	10809	10755	10771	10675
Mowing +20%	10766	7673	10812	10766	10777	10675
Mowing - 20%	10766	7668	10789	10760	10770	10675

Results show that NPV responds differently to change in treatment efficacy when the strategy includes a single control option and when it includes more than one option. For the strategies with more than one option, the change in the efficacy of one control option will be absorbed to some extent by other control options. Thus, the efficacy of a strategy with more than one treatment included is less affected by change in the efficacy of the individual options.

Previous sensitivity analysis results have been for individual changes in parameters. Table 3 shows results for combinations of parameter changes for three key parameters.

Table 3. Optimal strategies for alternative efficacies in different scenarios

Goat efficacy	Mowing efficacy	Chemicals		
		-20%	Base case	+20%
Base case	Base case	23	16	3
Base case	+20%	23	16	3
Base case	-20%	23	16	3
+20%	Base case	23	16	3
+20%	+20%	23	16	3
+20%	-20%	23	16	3
-20%	Base case	23	16	3
-20%	+20%	23	16	3
-20%	-20%	23	16	3

The results in Table 3 show that when the efficacy of chemicals is kept at base case levels (Table 1), and when the efficacies of mowing and goat either stay at base case or change by 20 percent, the optimal strategy is 16. Thus, these changes in the efficacy of mowing and grazing by goats are not large enough on their own to change the optimal strategy way from 16.

However when the efficacy of chemicals reduces by 20 percent, strategy 16 is no longer the most cost-effective option, even when efficacy of mowing increases by 20 percent. This is because the decrease in chemical efficacy increases the density of blackberry. Thus when the efficacy of chemicals decrease by 20 percent, goats need to be included in the strategy to compensate for the loss in NPV, so strategy 23 (i.e. grazon, goat and mowing) becomes the optimal strategy.

Table 4. NPV ($) for alternative efficacies in different scenarios.

Goat efficacy	Mowing efficacy	Chemicals		
		-20%	Base case	+20%
Base case	Base case	10369	10809	10832
Base case	+20%	10558	10812	10915
Base case	-20%	10093	10789	10830
+20%	Base case	10505	10812	10833
+20%	+20%	10629	10816	10921
+20%	-20%	10108	10795	10834
-20%	Base case	10130	10801	10829
-20%	+20%	10552	10811	10830
-20%	-20%	9480	10793	10828

When the efficacy of chemicals increases by 20 percent, a single chemical (Glyphosate plus metsulfuron) is the most cost-effective control option (option 3). A 20 percent increase in the efficacy of chemicals make those strategies that include chemicals highly cost-effective.

NPVs corresponding to the strategies shown in Table 3 are shown in Table 4. A decrease in the efficacy of chemicals has a larger impact on the NPV than does an increase in chemical efficacy.

Conclusions

This paper employs a stochastic dynamic simulation model and a deterministic dynamic programming model to find the most cost-effective integrated control options for blackberry in riparian areas in Australia. To do this, 48 control strategies and various case scenarios have been developed.

The results suggest that using rust has a low impact on NPV. With or without the rust option included, for a wide range of parameter values, a combination of the grazon and mowing is optimal. If chemical efficacy decreases by 20 percent it becomes optimal to combine grazing goats with other strategies. We also concluded that an increase in the efficacy of chemicals makes Glyphosate plus metsulfuron more cost-effective than other options.

References

Amor, R.L., Harris, R.V., 1981. Effects of mowing and spraying of 2,4,5-T on blackberry (Rubus fruticosus agg.) and pasture species. *Australian Journal of Experimental Agriculture and Animal Husbandry*, 21 614-617.

Anisworth, N., Mahr, F., 2006. Regrowth of blackberry two years after 2003 wildfires in Victoria. *15th Australian Weeds conference* pp. 1-4.

Batten, G.J., 1979. Controlling scrub weeds with goats. *New Zealand Journal of Agriculture* 139, 31-32.

Buckley, Y.M., Rees, M., Paynter, Q., Lonsdale, M., 2004. Modelling integrated weed management of an invasive shrub in tropical Australia. Journal of Applied Ecology 41, 547-560.

Bulte, E.H., van Kooten, C.G., 1999. Metapopulation dynamics and stochastic bioeconomic modeling. Ecological Economics 30, 293-299.

Chalak-Haghighi, M., van Ierland, E.C., Bourdôt, G.W., Leathwick, D., 2008a. Management strategies for an invasive weed: a dynamic programming approach for Californian thistle in New Zealand. New Zealand Journal of Agricultural Research. 51 (4), 409-424.

Grammie, N., 2009. Unpublished data.

Higgins, S.I., Turpie, J.K., Costanza, R., Cowling, R.M., Le Maitre, D.C., Marais, C., Midgley, G.F, 1997. An ecological economic simulation model of mountain fynbos ecosystems dynamics, valuation and management. Ecological Economics 22, 155-169.

James, R., Lockwood, M., 1998. Economics of blackberries, current data and rapid valuation techniques, *Plant Protection Quarterly* **13(4)**: 175–179.

Kennedy J.O.S., 1987. The economics of weed control. Plant Protection Quarterly 2, 118-123.

Lacey, C.A., Fay, P.K., 1989. Knapweed management: a decade of change. Proceedings of Knapweed Symposium. Bozeman Montana, pp. 1-6.

Mahr, F.A., Bruzzese, E., 1998. The effect of Phragmidium violaceum (Shultz) winter (Uredinales) on Rubus fruticosus L. agg. In southern Victoria. *Plant Protection Quarterly* 13, 182-185.

Miller I.L., Napompeth, B., Forno, I.W., Siriworakul, M., 1992. Strategies for the integrated management of Mimosa pigra. In: Herley K.L.S., (Ed.), A Guide to the management of mimosa pigra CSIRO, Canberra, Australia. pp. 86–89.

Monaco, J.T., Weller, C.S., Floyd, A.M., 2001. Weed science principals and practices. New York, Wiley.

Moore, J. 2009. Personal Communications.

Morrison, M., Bennet, J., 2004. Valuing New South Wales rivers for use in benefit transfer. *The Australian Journal of Agricultural and Resource Economics* 48, 591-611.

Odom, D.I.S., Cacho, O.J., Sinden, J.A., Griffith, G.R., 2003. Policies for the management of weeds in natural ecosystems: the case of scotch broom (*Cytisus scoparius,* L.) in an Australian national park, Ecological Economics 44, 119-135.

Pannell, D.J., Stewart, V., Bennett, A., Monjardino, M., Schmidt, C. and Powles, S.B. 2004. RIM: A Bioeconomic Model for Integrated Weed Management of Lolium rigidum in Western Australia. *Agricultural Systems* 79, 305-325.

Pritchard, G.H., 1990. Control of rust-infected blackberry with herbicides in Victoria. *Proceeding of the 9th Australian Weed Conference* 6-10.

Reeves, A, 2009. personal communication.

Reid, M., 2008. National blackberry programme, http://www.weeds.org.au/WoNS/blackberry/docs/Blackberry_Newsletter_07.pdf.

Sheppard, A.W., Hill, R., DeClerck-Floate, R.A., McClay, A., Olckers, T., Quimby Jr.P.C., Zimmermann, H.G., 2003. A global review of risk-benefit-cost analysis for the introduction of classical biological control agents against weeds: a crisis in the market? Biocontrol News and Information. 24, 91-108.

Taylor, C.R., Burt, O.R., 1984. Near-optimal management strategies for controlling wild oats in spring wheat. American Journal of Agricultural Economics 66, 50-60.

Tyser, R.W., Key, C.H., 1988. Spotted knapweed in a natural area fescue grassland: an ecological assessment. Northwest Science 62, 151-160.

Vere, D.T. and J.J. Dellow (1984) Estimating the costs of blackberry in Central Western New South Wales, *Proceedings of the 7th Australian Weeds Conference*,