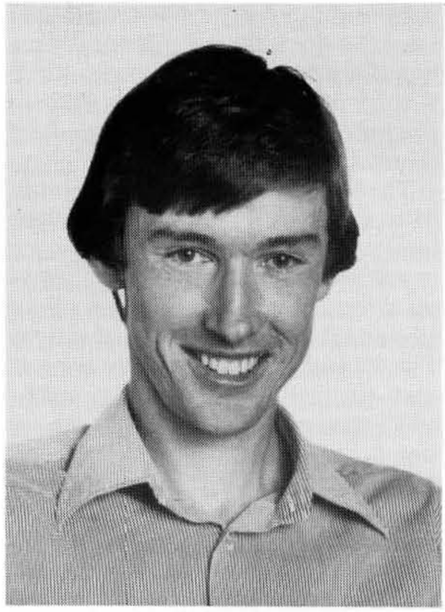
REVIEWS



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Using simulation for economic assessment of the skeleton weed eradication programme in Western Australia

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Summary

Skeleton weed (*Chondrilla juncea* L.) is a serious pest to cereal farmers in eastern Australia and is established in scattered locations in Western Australia, where it is controlled by an eradication programme. Dynamic simulation modelling is used to estimate Net Present Values of the eradication programme for many combinations of assumptions. The most likely assumptions are identified; Net Present Values associated with them are close to zero or slightly positive. Under some assumptions net benefits of eradication would be large, while at worst net losses would be relatively small. Consequently, continuation of the programme is recommended despite the likelihood that net present benefits will be small. The use of simulation in economic evaluations of weed control programme is discussed.

Introduction

Government administered weed control programmes are seldom subjected to a thorough evaluation of likely benefits and costs (Chiarrappa *et al.*, 1972; Vere *et al.*, 1980; Vere and Auld, 1982; Swarbrick, 1983). As observed by Swarbrick (1983); 'Such a procedure should surely be part of the background research before long-term projects are developed, providing a sound basis for decision making.' This paper describes an economic evaluation of the skeleton weed eradication programme which is conducted in Western Australia by the Agriculture Protection Board (APB).

In south-eastern Australia skeleton weed (*Chondrilla juncea* L.) is widespread and a considerable financial burden on cereal farmers (Marsden *et al.*, 1980; Sheldon, 1980). In Western Australia it occurs in only isolated outbreaks (Panetta and Dodd, 1984) and its further spread is hindered by a comprehensive eradication programme, which is funded through an annual levy of $30 on cereal farmers and supported by volunteer farm labour. It is not known how widely distributed or how dense the infestations of the weed would become if the eradication programme were to be terminated, and this lack of information makes it difficult to estimate the Net Present Value (NPV) of the programme. This study uses simulation modelling to calculate NPVs for different combinations of possible outcomes regarding the weed's ecology and control in Western Australia. Since almost all benefits and costs of the programme accrue to farmers and the decision to fund the programme was made by farmers, the investment problem is considered purely from the farmers' point of view. Will future farmer investment in the programme yield positive net benefits?

A subsidiary aim of this paper is to discuss the use of simulation in economic evaluations of weed control programmes.

Skeleton weed

Skeleton weed's ecology and control in south-eastern Australia have been described by McVean (1966) and Wells (1971). It is difficult to control by chemical and ecological means (Moore and Robertson, 1963; 1964). Greatest success has been through biological control (Cullen *et al.*, 1973; Groves and Williams, 1975; Cullen, 1979; Marsden *et al.*, 1980; Sheldon, 1980; Burdon *et al.*, 1981; Davidson, 1983).

There have been regular outbreaks of skeleton weed in Western Australia since 1963, with well over a hundred now recorded (Meadly, 1966; APB Annual Reports, 1974 to 1983; Panetta and Dodd, 1984).

Methods

The appropriate technique for economic evaluation of a publicly funded project is the use of economic surplus concepts in a Cost Benefit Analysis framework. Vere *et al.* (1980) have reviewed this technique with specific reference to weed control programmes.

This study is a private Cost Benefit Analysis, so only benefits to the investors (farmers) are estimated and the concept of economic surplus is not used for the estimation, although the same procedure could have been used if the programme had been publicly funded. This is because produce affected by the programme (i.e. cereal grain) is sold on world markets to which Australia is a relatively small contributor. The demand curve in such a situation is very highly elastic with the consequences that both consumer surplus and price will be little affected by supply shifts. These consequences simplify the estimation of social benefits and allow a simple enumeration and summation of benefits to suppliers.

A dynamic simulation model is used to calculate the benefits of skeleton weed eradication by estimating changes in crop yields and skeleton weed level with and without the eradication programme. Menz and Auld (1977) observed that '... it is difficult to translate the physical consequence of control into a measure of economic benefit since weed control is only part of the overall production process.' Simulation is a convenient and widely understood framework for dealing with the complex interactions of the 'overall production process' (Ferrari, 1978; Jeffers, 1978; Brockington, 1979).

Continuation of the eradication programme will not cause an increase in net receipts, but rather will avoid a decrease. Benefits of skeleton weed eradication calculated in this study include avoidance of decreased cereal yields and avoidance of herbicide costs. Yield loss parameters used are based on estimates made by Marsden *et al.* (1980) for New South Wales. Marsden and his colleagues made allowance for the fact that in the absence of other control methods, legume rotations allow some degree of control.

For the purposes of the dynamic simulation model an index of skeleton weed density in each shire is used. In the model this index varies over time (according to the parameters of the model) and has a crucial effect on the level of net receipts from cereal cropping. Table 1 shows the underlying assumptions regarding weed density and distribution within a shire associated with a particular skeleton weed index.

Benefits not calculated include savings on damage to harvesting machinery (assumed to be precluded by herbicide applications), avoidance of grain contamination (assumed seed set after harvesting), avoidance of land use restrictions (inclusion would be double counting) and avoidance of decreased stock carrying capacity (assumed insignificant). Another possible benefit not included in calculations is the cost of introducing biological control agents if the programme were ceased. It is assumed that no further research than has already been conducted by the CSIRO would be necessary and that farmers would not be required to pay directly for the introduction. The cost of introduction would have been included if this evaluation had been of a public programme, although it would not be large.

Costs of the eradication programme included in calculations are the annual levy of $30 per grain farmer ($262 700 in 1982–83 [APB, 1983]), interest on accumulated levy ($87 900 in 1982–83) and the opportunity cost of volunteer farm labour employed in the the search (1712 man-days @ $60=$100 000 in 1981–82). Not included is the loss of skeleton weed as an animal feed. Four streams of costs are calculated and discounted to their present values. Four streams are necessary to allow for two assumptions regarding success of the programme and two time periods. A discount rate of 12% is used, based on 7% inflation, 4% opportunity cost of capital and 1% risk premium. It is assumed that expenditure on the programme will increase by 10% per year (in actual terms) from the present $300 000 over the next 20 years. If complete success of the programme is assumed, labour costs increase at 10% per year from the present $100 000. If temporary (10 year) success is assumed, labour costs increase at 10% for 10 years and 14% thereafter. Table 2 gives the present values of costs calculated under these assumptions.

The model

There are five materials or state variables in the model. These are the potential yields of wheat, of oats and of barley, the level of skeleton weed and the level of biological control agent. The potential yields are those which would be obtained if there were no skeleton weed present. The maximum or goal level of skeleton weed is set by assumption, while the goal fungus level is dependent on the skeleton weed level.

Table 1 Skeleton weed indices for simulation model

Skeleton weed index in whole shire	Yield loss for whole shire (%)	Distribution of weed over shire (plants m^{-2})
100	25	20%@>100 20%@10-100 20%@1-10 40%@0
64	16	20%@10-100 20%@1-10 60%@0
16	4	20%@1-10 80%@0

Actual cereal yields (the crucial variables in the model) are not treated as state variables. They are calculated by reference to potential cereal yields and the skeleton weed level. Actual yields are used to calculate gross margins from cropping, and subsequently benefits of the eradication programme.

Testing the sensitivity of results to changes in uncertain variables was an important part of this study. Variables for which sensitivity analyses were conducted include the following. Two assumptions regarding ultimate success of the eradication programme examined are: a) that the programme will be only partially successful, having the effect of delaying skeleton weed spread from existing infestations for 10 years, after which the weed will spread as if there were no programme, and b) the programme will be completely successful in eradicating the weed, and will continue to be so for the next 20 years.

Four skeleton weed goal indices are input for each shire based on assumptions ranging from a confined distribution and low density to a very wide distribution and high density.

As with skeleton weed, the level of biological control agent is represented by an index in the range 0 to 100. The goal index is dependent on the present level of skeleton weed. The parameter which determines the effect of weed on fungus (and ultimately of fungus on weed) is varied over four values corresponding to nil, low, medium and high biological control agent levels. Further details of the model's structure and the estimation of parameters have been lodged with the editor and are available on request.

The model is run separately for each possible set of assumptions (for two programme success levels, four biocontrol levels and four weed levels) for each of the 68 shires which make up the Western Australian wheatbelt and the results aggregated giving 32 streams of benefits. Each of these streams is then discounted using two time periods (10 and 20 years) to give 64 possible present values of benefits. From each of these one of four present values of costs (from Table 2) is subtracted to give 64 possible net present values of the eradication programme.

Assumptions of the model

Implicit in the higher biocontrol success assumptions is that an agent will soon be discovered for the broad-leafed form of skeleton weed. The CSIRO is currently attempting to find such an agent.

Table 2 Present values of costs of eradication programme

Programme success	10 years ($ million)	20 years ($ million)
Low (delay spread)	3.88	7.28
High	3.88	7.11

Table 3 Net present values of eradication programme

Weed distribution density	Project success	Time period (years)	Biocontrol success ($ million) 4	3	2	1
Confined	partial	10	−2.7	−2.5	−2.4	−2.4
		20	−4.9	−2.4	−0.1	5.2
	complete	10	−2.7	−2.5	−2.4	−2.4
		20	−3.6	−0.8	1.7	7.0
Medium	partial	10	−1.8	−1.6	−1.5	−1.4
		20	−3.5	−0.3	2.4	7.9
	complete	10	−1.8	−1.6	−1.5	−1.5
		20	−1.4	2.2	5.1	10.6
Wide	partial	10	0.1	0.6	0.8	1.0
		20	1.4	10.4	19.2	36.5
	complete	10	0.1	0.6	0.8	1.0
		20	5.6	15.8	25.2	43.9
Very wide	partial	10	5.1	8.6	10.7	13.2
		20	9.2	28.2	54.8	90.0
	complete	10	5.1	8.6	10.7	13.2
		20	18.4	42.4	73.5	112.9

The level of success of biological control is assumed to be uniform across the wheatbelt for all forms of the weed. In reality there would be regional variations. However, the general level of biocontrol success is more important than its likely distribution of success and failure.

It is assumed that skeleton weed would spread at a constant rate of 12 km per year regardless of the suitability of the region over which it is spreading.

Gross margins on sheep are assumed to be the same in every shire. The relatively minor increase in accuracy from estimating gross margins from different shires would not warrant the considerable effort involved.

Marginal cropping costs are assumed in a similar way to sheep gross margins to be identical throughout the wheatbelt, and for the same reasons. The same is true of wheat, oats and barley prices.

It is assumed that the area of each crop will remain constant within a shire unless the gross margin for that crop falls below the gross margin for a sheep enterprise.

Assumptions have been made in the estimation of all parameters in the model. Most estimates have a theoretical basis for their choice. However four, in particular, are speculative. These are the rates of increase of fungus level, skeleton weed level, sheep gross margins and cereal prices. The first two could be clarified by ecological research in Western Australia, but the latter two are unknowable in advance.

Results

Net Present Values of the eradication programme are presented in Table 3. Under the most restricted distribution/density assumption skeleton weed would not spread outside the seven shires already infested in 1981–82 (in fact it already has). Within these shires it would have a goal index of 30. In this case, unless there would be little or no effect of biological control agents and a long-term view is taken, benefits to farmers as a group would not outweigh costs. Officers of CSIRO Division of Entomology believe that there is a high probability of biological control agents establishing successfully in Western Australia (M. J. Whitten, personal communication). In that case this most limited distribution/density would not be enough to warrant eradication.

Under the second distribution/density assumption the 18 shires which share borders with already infested shires would have goal skeleton weed indices of 10 rather than zero. This change does not have a great effect on the number of sets of assumptions which yield positive net present values. Again the eradication programme would probably not be warranted.

In the third distribution/density assumption the weed would infest seven shires with a goal index of 50, 18 shires at 30 and 12 shires at 10. NPVs under this assumption are all positive, so continuation of the programme would seem justified if such a wide distribution of the weed were to be expected.

The break up of shires with particular skeleton weed goal indices under the widest distribution/density assumption is as follows.

Number of shires	Goal skeleton weed index
7	100
18	50
12	30
10	10
21	0
Total 68	

Under this scenario over two-thirds of the Western Australian wheatbelt would be infested with skeleton weed to some degree. Again there is no set of assumptions under which costs of the programme are not outweighed by benefits. If a long-term view is taken, there is the potential for substantial benefits to be made (i.e. substantial costs to be avoided), particularly if biological control would be less than highly successful.

Discussion

Which of the NPVs presented in Table 3 are mostly likely to be correct? The present distribution of outbreaks over the state and the suitability of light soils for skeleton weed suggest that a fairly wide distribution of skeleton weed would be likely if the eradication programme were to be discontinued. Consideration of the unfavourable climatic factors common in Western Australia leads to the conclusion that the most widespread distribution assumption is not as likely as the second most extensive assumption.

As has already been mentioned, it is possible (some would argue likely) that biological control would be successful in Western Australia.

A comparison of the number of infestations found between 1963 and 1983 (116) with the number of infestations eradicated (14) (APB Annual Report, 1982; 1983) makes partial success of the programme appear more likely than complete success.

This process of elimination of assumptions identifies four most likely

NPVs, ranging from 0.1 to 10.4 million, depending on time period and bio-control success. These are small values compared with the several thousand million dollars present value which will be made by Western Australian farmers from cropping over the same period, and would be overshadowed by seasonal variations. Nevertheless farmers could support the eradication programme confident that they would at least not lose much.

An additional factor in favour of the programme is risk avoidance. Under certain scenarios examined in this study, net benefits of eradication would be considerable. While these scenarios may be considered to be unlikely, they are still possible. On the other hand it appears that net losses, if they did occur, would be small. On this basis farmers would probably be wise to continue with the scheme despite the likelihood that net benefits will be small. The results of ecological research now under way (Panetta, 1984; Panetta and Dodd, 1984) will refine these conclusions further.

Apart from evaluating the skeleton weed programme, this study has demonstrated the usefulness of simulation in Cost Benefit Analyses of weed control programmes. Simulation has been found to be a convenient way of integrating and identifying necessary assumptions. In addition it eases the chore of mathematical calculation, speeding the task of sensitivity analysis. The technique has limitations, being dependent on accuracy of data and assumptions, but most of the same data and assumptions would have to be used in a Cost Benefit Analysis even if simulation were not utilized. In addition the problem is overcome to some extent by conducting a wide ranging sensitivity analysis. The application of simulation modelling would be slightly more complicated but quite plausible in a public Cost Benefit Analysis with a downward sloping demand curve.

In summary, then, although likely net benefits from the skeleton weed eradication programme are not great it would seem prudent to continue with the campaign since potential benefits are large relative to potential losses.

Where it is feasible and appropriate, simulation is recommended to economic researchers as a productive aid to weed programme evaluation.

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References

Agriculture Protection Board, *Annual Reports*, 1974 to 1983. Agriculture Protection Board of Western Australia, Perth.

Brockington, N. R. (1979). *Computer Modelling in Agriculture.* Oxford University Press.

Burdon, J. J., Groves, R. H. and Cullen, J. M. (1981). The impact of biological control on the distribution and abundance of *Chondrilla juncea* in south-eastern Australia. *Journal of Applied Ecology* **19**:957–66.

Chiarrappa, L., Chiang, H. C. and Smith, R. F. (1972). Plant pests and diseases: assessment of crop losses. *Science* **176**:769–73.

Cullen, J. M. (1979). Biological control of weeds in cereals. *Invited Reviews and Situation Papers, Australian Applied Entomological Research Conference, Queensland Agricultural College, Lawes, June 1979.* CSIRO, Canberra.

Cullen, J. M., Kable. P. F. and Catt. M. (1973). Epidemic spread of a rust imported for biological control. *Nature* **244**:462–4.

Davidson, S. (1983). Weed problem changes form. *Rural Research in CSIRO* **120**: 28–30.

Ferrari, Th. J. (1978). *Elements of Systems-Dynamics Simulation.* Pudoc, Wageningen.

Groves, R. H. and Williams, J. D. (1975). Growth of skeleton weed (*Chondrilla juncea* L.) as affected by growth of subterranean clover (*Trifolium subterraneum* L.) and infection by *Puccinia chondrillina* Bubak and Syd. *Australian Journal of Agricultural Research* **26**: 975–83.

Jeffers, J. N. R. (1978). *An Introduction to Systems Analysis: with Ecological Applications.* Edward Arnold, London.

Marsden, J. S., Martin, G. E., Parham, D. J., Ridsdill Smith, T. J. and Johnston, B. G. (1980). *Returns on Australian Agricultural Research.* CSIRO, Canberra.

McVean, D. N. (1966). The recent story of skeleton weed–a menace to our wheat industry. *Western Australian Journal of Agriculture* **7**:125–30.

Meadly, G. R. W. (1966). The recent story of skeleton weed – a menace to our wheat industry. *Western Australian Journal of Agriculture* **7**:125–30.

Menz, K. M. and Auld, B. A. (1977). Galvanised burr, control, and public policy towards weeds. *Search* **8**:281–7.

Moore, R. M. and Robertson, J. A. (1963). Studies on skeleton weed – chemical control. *Field Station Record*, Division of Plant Industry, CSIRO, Canberra, **2**:1–8.

Moore, R. M. and Robertson, J. A. (1964). Studies on skeleton weed–competition from pasture plants. *Field Station Record*, Division of Plant Industry, CSIRO, Canberra. **3**:69–72.

Panetta, F. D. (1984). Forms of skeleton weed (*Chondrilla juncea* L.) in Western Australia. *Australian Weeds* **3**:50.

Panetta, F. D. and Dodd, J. (1984). Skeleton weed: how serious a threat in Western Australia? *Western Australian Journal of Agriculture* **25**:37–41.

Sheldon, B. (1980). Biological control of skeleton weed, *Rural Research in CSIRO*, **107**:16–20.

Swarbrick, J. T. (1983). Economic justification of weed research and control at government level. *Australian Weeds* **2**:86.

Vere, D. T. and Auld, B. A. (1982). The cost of weeds, *Protection Ecology* **4**:29–42.

Vere, D. T., Sinden, J. A. and Campbell, M. H. (1980). Social benefits of serrated tussock control in New South Wales, *Review of Marketing and Agricultural Economics* **48**:123–38.

Wells, G. J. (1971). The ecology and control of skeleton weed (*Chondrilla juncea* L.) in Australia. *Journal of the Australian Institute of Agricultural Science* **37**: 122–37.