Co-ordination requirements were a key issue identified by a number of workshop participants. Currently coordination appears to be fragmented across species, across regions and across land use types. Key issues for effective control, including enforcement, learning from best practice and targeted education and research need a level of coordination that is currently lacking. Several responses warned against the danger of adding another layer of administration and talking instead of action, but also emphasized the need to identify where coordination was required. One suggestion for coordination was to take a landscape approach, based around better information and planning delivered through catchment management authorities, and to coordinate efforts for exclusion and control of all exotic stipoids in a catchment (subject to risk analysis), not just those with current high economic impact. At the end of the workshop, who the best overall coordination body or group might be was still unidentified. The issue of how overall coordination of efforts to exclude and control exotic stipoids will be achieved is likely need follow through in the near future.

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Economics of serrated tussock and Mexican feather grass in Victoria: Why we need to act now

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Summary

The likely economic outcomes of government's pro-active and reactive-type weed control strategies to avoid the long-term 'external' cost of serrated tussock (*Nassella trichotoma* (Nees) Arechav.) and Mexican feather grass (*Nassella tenuissima* (Trin.) Barkworth) infestation in Victoria are assessed and compared from the viewpoint of the community. Partial industry-level analysis of financial costs and benefits is also explored. The potential loss avoided in agricultural production on private lands, and the savings in future control costs on both public and private lands are the long-term benefits of public investment considered and valued. Net benefits are calculated given four land-productivity and product price level scenarios.

The net economic benefits to the community of a pro-active strategy i.e., immediate eradication of Mexican feather grass within five years, would be about $41 million to $102 million depending on the scenarios tested. In present value terms, this is a potential saving to the community of about $1.2 million to $3.2 million per year over the next 30 years. On the other hand, in all scenarios tested, the cost to government of a reactive strategy i.e., suppressing serrated tussock within 20 years using chemical method alone outweighs the benefits to the community by about $260 million to $1140 million.

Introduction

In an era of increasingly scarce public funds and competing uses for limited funds, it is important that government obtains the best 'value for money' from its investments. Public investment in weed control strategies in the past has been assessed and priorities based primarily on the soundness of the control technology and other non-economic criteria. The economic impact of any pest, however, is a vital aspect in establishing priorities to direct government resources. In Victoria, government investment in weed control largely occurs through the Department of Natural Resources and Environment (DNRE) funding of Catchment Management Authorities (CMAs) Weed Action Plans. The CMAs are charged with ensuring the protection and restoration of land and water resources, the sustainable development of natural resources-based industries and the conservation of the State's natural and cultural heritage (Department of Natural Resources and Environment 1998).

Associated with the weed problem and its control are the existence of 'market failure' situations such as lack of information and externalities (Pannell 1994). In theory, externalities may be either positive or negative. If a farm worker is trained say, in weed control at the expense of farm A and after completion of the training moves to farm B where his training is of use, then farm A generates a positive externality on farm B. An example of a negative externality occurs when the failure of a private landholder to control weeds on his land causes damage to production on adjoining properties since the rate of weed spread to those properties may be increased. Acting in his/her own self-interest e.g., to maximize profit, the private landholder only has regard to the consequences of weed control on his/her own property. Thus, the weed may not be controlled or may be less intensively controlled than would be optimal from the community's viewpoint taking into account the impact of weed control on other landholders (Auld *et al.* 1987). Therefore, in the absence of public intervention in weed control, 'market failure' arising from the negative externality would lead to the best outcome for society not being provided, as insufficient effort or resources is allocated to control the weed spread by the profit-maximizing private landholder. For simplicity, the spread of weeds from farm to farm and from natural ecosystems to farm or vice versa are considered as the forms of negative externality relevant to this study.

'Market failure' is one necessary but not sufficient condition for government to intervene in weed control on private and public lands. For instance, weeds that infest public land can be important for three reasons (Eigenraam *et al.* 1997) (Table 1). First, the potential for weeds to invade and modify the natural ecosystems and to significantly alter the flora and fauna habitat; weeds diminish the value of natural capital for biodiversity purposes. Second, weeds can diminish the commercial value of public lands, for example, where these lands are used for tourism. Third, weeds can spread from public to private land imposing external costs on private landholders.

It can be inferred from Table 1 that, when one or more 'market failure' situations are present, the unregulated market will not allocate sufficient resources to weed control actions on public lands. Thus, government intervention may consider funding increased weed control where weeds on public lands cause economic damage to neighbouring private lands (only if benefits of the action exceed the cost). Government may also directly fund weed control for the purpose of conserving biodiversity on public lands, or share funding of weed control where it benefits commercial uses of public lands (Eigenraam *et al.* 1997).

Serrated tussock (*Nassella trichotoma* (Nees) Arechav.) has been reported to occupy more than 100 000 ha in Victoria and 800 000 ha in New South Wales and potentially infest more than 32 million ha of Australia (McLaren *et al.* 1998). Occurring primarily in areas with 500 mm to 950 mm annual rainfall, it is a major agricultural weed that also invades native grasslands, grassy woodlands, drier forests and rocky shrublands (McLaren *et al.* 1998). It entered Australia in the early 1900s but was not recorded until 1935 and was first reported in Victoria in 1954 (Campbell and Vere 1995). Serrated tussock is a proclaimed noxious weed in Victoria and has the potential to cause greater reductions in pasture carrying capacity than any other plant in Australia (Parsons 1973). Of the two case-study weeds, serrated tussock has been categorized as 'A Weed of National Significance' (Thorp and Lynch 2000).

Management of serrated tussock currently relies on herbicides that do not always give good long-term control. Its control is not achieved by just killing initial plants. Cultivation is commonly used to control serrated tussock on arable land, although this is an inappropriate treatment where indigenous ground-flora persists. Serrated tussock re-invades control sites with alarming speed (DNRE 2000).

Mexican feather grass (*Nassella tenuissima* (Trin.) Barkworth) however, has the potential to invade a greater range of land than serrated tussock, and if left unchecked, could spread throughout eastern Australia and as far as southern Queensland (McLaren *et al.* 1998). Due to its being closely related to serrated tussock, its control is likely to rely on the same techniques being used to treat serrated tussock infestations.

Whilst past attempts have been made to estimate the economic cost of a few stipoid grass species to Victoria at regional or industry level (Eigenraam *et al.* 1997, Lane and Mougharbel 1994, Nicholson *et al.* 1997), no statewide economic assessment has been published to date. To fill that information gap, the potential outcomes of alternative investment strategies in the statewide control of serrated tussock (*N. trichotoma*) and Mexican feather grass (*N. tenuissima*) using an economic framework are examined in this paper.

Table 1. Market characteristics and indicative government response to weeds on public land.

Issue	Market characteristics	Government response
Weeds spread from public land to private lands	External costs	To fund increased control of weeds, e.g. along borders
Biodiversity	Public good; No market place	Ensure the preservation of flora and fauna; Direct intervention to conserve biodiversity
Commercial value	Common good	Levy

Source: Eigenraam *et al.* (1997, p. 10).

Methods

Weed spread

In an *ex ante* economic evaluation of long-term weed investment strategies, information relating to the spatial and temporal nature of weed spread are critically important. To estimate the maximum potential distribution of serrated tussock and Mexican feather grass in each catchment region in Victoria, the weed distribution data from Australia and overseas, and climate modelling overlayed on geographical information system (GIS) layers of susceptible land use, vegetation classes and soil properties were utilized. In particular, a climate-matching program that uses temperature and rainfall data from a set of geographical locations to construct a climate profile was used to indicate similar climatic regions in Victoria. This was then overlayed on suitable land uses and broad vegetation classes to estimate the maximum potential geographical distribution of each weed species. Land-use types overlayed for both weed species were public lands and dryland pasture. For predicting the future distribution of serrated tussock coastal scrubs and grasslands, dry foothill forests, grasslands, plains grassy woodlands, valley grassy forests, coastal grassy woodlands, montane grassy woodlands, riverine grassy woodlands, rainshadow woodlands, and box ironbark forests were the broad vegetation classes used as overlays. To predict the future distribution of Mexican feather grass, the broad vegetation classes used as additional overlays were montane dry woodland, herb-rich woodlands, sub-alpine grassy woodland, mallee, mallee-heath, boinka-raak, mallee woodland, heathy woodland, Wimmera mallee/woodland, lowland forest, heath, inland slopes and sedge-rich woodlands.

A prediction of how quickly each weed species will spread from its present to its full potential distribution was also derived. Using Victoria's pest plant invasiveness model (Weiss 1999), the number of years to reach the maximum potential distribution of each weed species were derived for each CMA region. Victoria's pest plant invasiveness model determines the invasiveness of a pest plant by investigating its competitive ability, establishment, reproduction and dispersal properties. These characteristics are scored utilizing the analytical hierarchical process which enables particular criteria to be weighted or scored higher than others. These weightings were determined at workshop sessions in 1998 involving weed experts from around Australia. A plant's invasiveness assessment score is used to predict how quickly it will spread from its present to its full potential distribution.

For comparison purposes, the known distribution of each weed in Victoria as reported in DNRE's Integrated Pest Management System (IPMS) records was extracted and then aggregated by CMA region.

Weed control techniques and strategies

Given a particular level of weed infestation, the choice of control technique deemed suitable to apply has implication on the cost of control directly accrued by individual land managers. For simplicity, the chemical control technique (application of herbicide) was adopted in this paper. However, for each herbicide cost an adjustment was made, which is an appropriate 'discount factor' (Table 2) that allows for the fact that not all herbicides were applied to the target weed alone. Therefore, a discount factor of 0.75 was taken into account in the estimation of the average cost of chemical for both weeds e.g., (0.75 of \$85 = \$64) (Table 3). In effect, a discount factor of 0.75 reduces the original estimate of chemical cost by 25% thus reducing the average cost of control per unit area of land that is treated.

It was assumed that the heavier the farm-level infestation, the greater would be the yearly cost of spot spraying because of increased labour time. Thus, boom spraying of medium infestation (at best management practices rates), and cultivation or some alternative land management systems for heavy infestations (e.g. re-vegetation) were considered appropriate for such levels of infestation.

Table 2. Chemical discount factor applied in deriving chemical cost.

Chemical discount factor	Applied under the following circumstances
1.00	When the herbicide is applied to only control the weed in question
0.75	Broad-spectrum herbicides when the weed in question is the dominant weed targeted
0.50	Broad-spectrum and non-specific herbicides where the weed in question is one of the major weeds targeted
0.25	Broad-spectrum and non-specific herbicides when the weed in question is not the major weed targeted

Source: CRC WMS undated, Annex VI p.2.

Table 3. Herbicide used, method of application and average cost of control, 2001.

Weed	Chemical[A]	Application method	Cost of chemical (\$ ha^{-1})	Cost of application (\$ ha^{-1})	Average control cost (\$ ha^{-1})
Serrated tussock	Flupropanate	Spot spray	64	41	105
Mexican feather grass	Flupropanate	Spot spray	64	41	105

[A] Note: Chemical used was based on National Registration Authority (NRA) product lists for herbicides (2001). Cost of chemicals were supplied by DNRE Regional Weed Program Leaders and officers from the North East and North Central regions of Victoria.

Following the predominantly scattered nature of infestation reported in a survey of serrated tussock in the Geelong region of Victoria (Lane and Mougharbel 1994), the weed infestations in this study were assumed to be of generally light density level. Thus, a once-a-year spot spraying was the weed control technique built into the model for both species.

Control methods were taken from the Landcare Note Series prepared by the Keith Turnbull Research Institute. The undiscounted on-ground costs directly associated with weed control were based on the costs of herbicides and their application that were supplied by DNRE Regional Weed Program Leaders and officers from the North East, Goulburn-Broken and North Central CMA regions during a series of workshops held between May and July 2001.

Three types of weed control strategies are assessed and compared in this paper using the benefit-cost analysis (BCA) technique. First, profit-maximizing private landholders decide whether or not to control the weed on their properties in the absence of government investment (the uncoordinated control strategy). Second, government through CMAs coordinates an immediate eradication program (within five years) where the weed e.g., Mexican feather grass has not yet established (hereafter referred to as pro-active control strategy). Third, government through CMAs coordinates an area-wide suppression program (within 20 years) where the weed e.g., serrated tussock has already established over a fairly large area in a CMA region (hereafter referred to as reactive control strategy).

Many of the factors that contribute to the success of a pest eradication program investigated by Myers *et al.* (2000) were considered relevant to the case of Mexican feather grass. First, resources must be sufficient to fund the program to its conclusion. Second, the biology of the target pest must make it susceptible to control procedures. The dispersal ability and reproductive biology of the target species will determine the ease of population reduction and its potential for reinvasion. Third, reinvasion must be prevented. Finally, the pest is detectable at relatively low densities. This can lead to its early detection after introduction and before it becomes widespread. All these factors have been assumed to favour the successful implementation of the weed eradication program. Rather than attempting to totally eradicate a weed species that has already established (i.e., serrated tussock in some CMA regions), a reduction of the weed density over the entire catchment region would characterize the area-wide suppression program (Myers *et al.* 2000) referred to here as the reactive control strategy.

Economic impact

Following the guidelines for calculating the economic impact of weeds on primary industries (CRC WMS undated), the estimation of the economic impact of alternative weed control strategies in this paper have ignored two types of indirect costs. First, production losses which are a consequence of a number of factors, some controllable under management practices such as choice of pasture species, rotation, amount of fertilizer, time of sowing, overall management of the pasture. Other factors are not controllable such as climate, soil temperature and some diseases. To equate production loss (and therefore, economic impact) directly to weeds, assumes that all other factors are at an optimum. Second, product contamination (which is often a result of management decisions) which should be minimized through adequate planning and cultural practice.

Valuation and comparison of strategies

Valuation technique In assessing the economic benefits and costs of investments that occur over time, a few decision criteria have been conventionally used in formal benefit-cost analysis. Two notable examples of these are the net present value (NPV) and the benefit-cost ratio (BCR). In this paper a coordinated weed control strategy was 'approved' if the present value of net cash flows (or the NPV) over the life of the investment is positive, that is greater than zero dollars. However, for cursory comparison and ranking purposes, strategies that were assessed as having a higher BCR was preferred.

The BCR was computed by dividing the discounted dollar value of the potential stream of benefits by the discounted costs of the investment stream. The standard discounting technique was used to reduce a stream of benefits accrued or costs incurred over time to an equivalent amount of present day's dollars. This procedure is based on the fact that a dollar now is worth more than a dollar in the future. And it is when the streams of benefits and costs have been discounted that they become directly comparable with one another. Meanwhile, the NPV was calculated using Equation 1 below:

$$(1) \qquad \boldsymbol{NPV} = \sum_{t=1}^{T} \frac{B_t - C_t}{(1+r)^t}$$

Where B_t is the benefit in year t, C_t is the investment cost in year t, r is the discount rate used to find the equivalent present value of sums receivable or payable in the future and T is the duration of the evaluation period. To remain consistent with public benefit-cost analyses done in Victoria, the social rate of discount used is 4% per annum. And, as in previous economic evaluation of serrated tussock control in Victoria (Nicholson *et al.* 1997), the time horizon for the assessment of expected economic costs and benefits is 30 years.

Benefits and costs For simplicity, this study adopted a linear damage function similar to the previous economic studies of serrated tussock in New South Wales (Jones and Vere 1998) and New Zealand

(Denne 1988). Hence, given say a 30% level of weed infestation of an area, a 30% reduction in the potential farm revenue was expected. The long-term economic impact of weeds considered in this paper were quantified in terms of the value of expected loss in farm revenue on grazing lands and the future control cost on both public and private lands. The annual economic value of farm revenue at risk from weed infestation in a CMA region was expressed in terms of the gross margin (GM) of feasible grazing enterprises for that region. These grazing enterprises included self-replacing merino, merino wether, first cross ewe, dorset over merino ewe, vealer, store weaner, steer, bullock and fattening purchased steers.

Public investment costs included were administrative costs (e.g., extension, inspection, monitoring, enforcement, coordination) as well as the additional costs of on-ground works (herbicide and its application) on public lands which are over and above the current costs being incurred on current problem weeds. Community benefits considered were the potential savings in future weed control cost on public lands and that value of expected production loss on grazing lands avoided through weed reinfestation management. This latter form of community benefit was considered in this paper, as an external cost avoided that otherwise, would have been imposed on private landholders. An 80% reinfestation rate was a major assumption of the model. The management of the likely reinfestation episodes was assumed to be a key function of regionally based weed inspectors and public land managers.

Economic model

Kennedy (1987) has outlined the conditions for both single-period and multi-period optimization of benefits from weed control from the viewpoint of either an individual land manager, or the society. In this paper, the single-period, individual-interest optimization model described in Kennedy (1987) was modified to represent a group-interest (or community level) optimization model. The annual value of benefits to the community was compared with the value of public investment to determine whether the investment strategy is economically worthwhile to undertake.

The model shown as Figure 1 would describe the process of accounting for the value of control cost avoided on public and private lands in a single year as an outcome of public investment in the coordinated control of weed spread or reinfestation. To demonstrate how it works, one would start from the L axis of Quadrant 1, then move to Quadrant 2, then 3 until the G axis in Quadrant 4 is reached to complete one evaluation cycle (as indicated by the dotted line).

In Quadrant 1, L_1 would indicate the level of weed control effort by government. At this level of investment, E_1 would be the total land area that would remain at risk from weed invasion. In Quadrant 2, C_1 would indicate the total land area 'protected' from the weed by the government investment at level L_1. Multiplying C_1 by P^c or the weed control cost per unit ha of land, A_1, which is the total cost of chemical control avoided as outcome of government investment is derived. In Quadrant 4, **a** represents the weed control program administration cost, and C^g is per unit cost of on-ground weed control on public lands. Multiplying C^g by L_1, and adding this to **a**, the total cost of government investment G_1, is obtained. Therefore, NCB_c, which is the gap between A_1 less G_1, measures the net benefit (or net loss, if G_1 is greater than A_1) to the community in terms of the future control cost avoided.

On the other hand, the model shown as Figure 2 would describe the process of accounting for the value of annual production loss saved on private lands as a result of public investment. The values of L_1, E_1 and G_1 in this model are equal to that of the previous model.

At the level of investment L_1, E_1 would be the total land area that would remain at risk from weed invasion. Given this level of weed protection, Y_1 in Quadrant 2 would indicate the corresponding potential yield on private lands protected from the weed. Multiplying this amount of output by its unit price P^y, the dollar value of the expected yield saved by private landholders I_1 is obtained. NCB_y, which is the gap between I_1 less G_1, represents the net community benefits in terms of yield loss saving.

Levels of assessment In accord with the principles underpinning DNREs research and development evaluation system initiative known as 'Beneficiaries and Funders' (Agriculture Division 2000), net benefits were calculated at industry and community levels.

The future control costs avoided and the saving in expected production loss that are likely to be captured by the grazing industries net of reinfestation episodes were the net benefits to industries. The total financial outlay required to treat the weeds on grazing lands in a CMA region where farm-level control was unprofitable was assumed to represent the value of industry investment. The net difference between these benefits and costs was considered as the potential net benefit (or net loss) to the grazing industries.

Additionally, to reflect into the analysis the influence of the variability in productivity potential and economic conditions across the State, ten regional economic models (one for each CMA region) were developed.

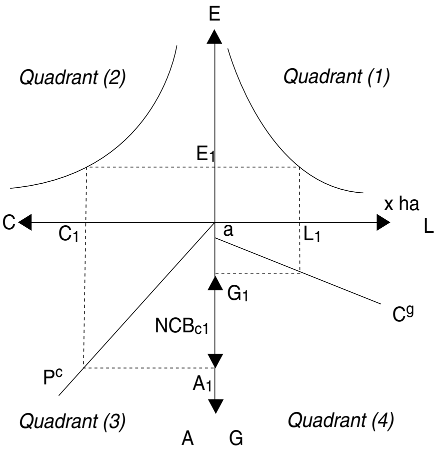

Figure 1. Economic model for assessing optimal public investment in coordinated weed control in terms of control cost avoided.

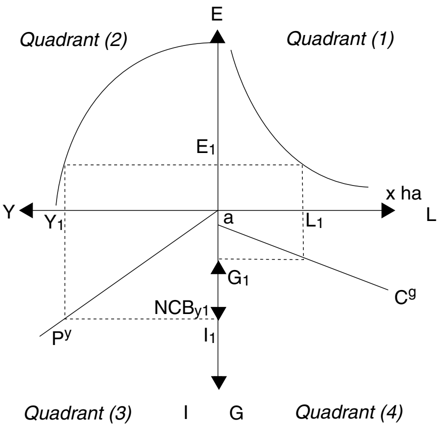

Figure 2. Economic model for assessing optimal public investment in coordinated weed control in terms of yield loss saved.

Grazing industries threatened by potential infestations in a CMA region were assessed a beneficiary from weed control (thus, a potential funder) if the aggregate value of savings (viz., avoided production loss and future control cost) from weed impact protection were greater than the required total control cost on grazing lands. Public investment in a weed control strategy was considered economically justified from the CMAs viewpoint when the long-term community-level benefits of that particular weed investment strategy outweigh public investment costs.

Model scenarios Each CMA model was run under four different scenarios viz., 'poor yield', 'high yield', 'low price' and 'high price' to generate some information on how farm-level response to variability in productivity and commodity price levels might affect future weed distribution, and consequently the economic attractiveness of alternative weed control strategies. It should be noted that these scenarios were applied to each control strategy not on a year-by-year basis but were assumed to apply throughout the entire 30-year evaluation period. For instance, the average gross margin of $48 ha^{-1} for the grazing enterprises in the North East CMA region was applied to the 'low yield' scenario over the entire 30-year evaluation period (Table 4). This procedure, while in itself less than ideal, nevertheless provides us with a means of relating likely changes in economic conditions to future weed distribution and the economic attractiveness of a control strategy in particular locations.

Results and discussion

Weed spread

The predicted maximum potential spread of each weed species (expressed as percentage of CMAs total land area) over 200 years is indicated in Figure 3. The invasiveness model prediction for serrated tussock in Glenelg, Corangamite and Port Phillip would indicate these three CMAs being the most susceptible regions to this weed. This result appears to corroborate with the indicative infestation data for these regions (Table 5). Owing perhaps to an increase in community awareness on the weed threat over time that resulted to an early identification and treatment, the actual spread of serrated tussock recorded in the Glenelg CMA region was proportionally far below the predicted maximum potential (Figure 4). Because Mexican feather grass has not yet established in Victoria, a cursory comparison of the actual and model-predicted spread was not possible.

To test how uncoordinated farm-level response to changes in economic conditions may influence the likely spread of serrated tussock and Mexican feather grass over the long term each model was run under the same four price and productivity level scenarios. In all the scenarios tested, Mexican feather grass was predicted to spread to a slightly larger area in the State than serrated tussock at the end of the 30-year simulation period (Figure 5). Because farm-level control on grazing lands for both species was found unprofitable in similar scenarios ('low yield' and 'low price') and CMA regions, the slightly higher estimates of Mexican feather grass infestation relative to serrated tussock was due to the former species being relatively more adaptable than the latter (McLaren *et al.* 1999).

In 'low yield' and 'low price' scenarios, both weeds were predicted to spread faster than the other two scenarios (Figure 5). In the base-case 'low yield' scenario, the hypothetical level of serrated tussock infestation was projected to rapidly expand from 10 ha to about 42 000 ha in 30 years. This highest level of expansion was due to the lower propensity of weed impact protection at farm level that was applied (Table 4) and the fact that the 'low yield' scenario predicted control by graziers as unprofitable in all CMA regions (Table 6). Incidentally, this particular result is in close agreement with that of a recent study on serrated tussock in south-eastern Australia where the control of serrated tussock that involved the use of herbicide was found to be unprofitable on low productivity pasturelands i.e., low rainfall-low soil fertility country (Jones *et al.* 2000).

Table 4. Gross margin values for the grazing enterprises and farm-level impact protection used for the four scenarios.

CMA Region	Scenarios Low yield	 High yield	 Low price	 High price
	Gross margin, ($ ha^{-1})^{A}			
North East	48	144	72	110
Glenelg	92	172	106	158
North Central	41	101	59	84
Corangamite	92	172	106	158
Wimmera	50	150	84	117
East Gippsland	48	144	72	110
West Gippsland	48	144	72	110
Goulburn-Broken	48	144	72	110
Port Phillip	48	144	72	110
Mallee	29	72	37	50
	Impact protection (per cent of weed-infested area)^{B}			
All CMAs	67	90	80	86

Source: ^{A}DNRE FarmSmart Gross Margin data 1998/99. ^{B}DNRE Regional Weed Program Leaders and officers from the North East and North Central regions of Victoria. The impact protection rates (or the propensity to control the weed at farm level) were assumed to be 67%, 90%, 80% and 86% for the 'low yield', 'high yield', 'low price', and 'high price' scenarios, respectively. This means that approximately 33%, 10%, 20% and 14% respectively of the total value of production would be lost.

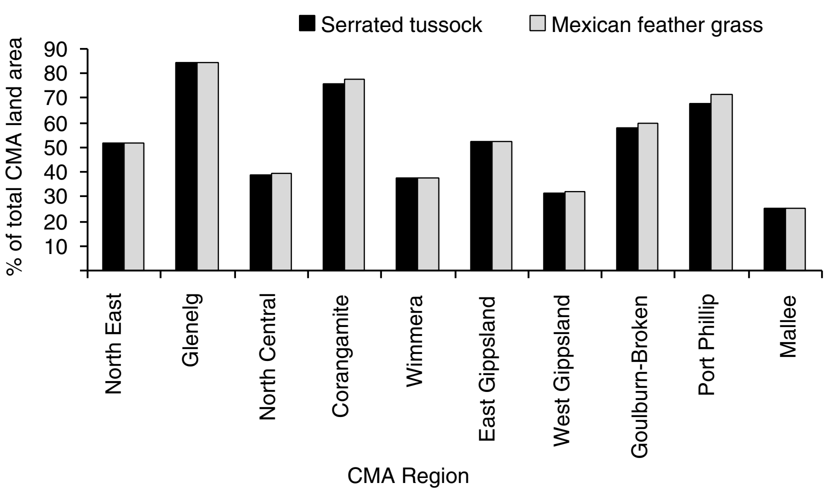

Figure 3. Maximum potential weed spread over 200 years (% of total CMA land area).

Table 5. Current infestation of serrated tussock in Catchment Management Authority (CMA) regions in Victoria.

CMA Region	Serrated tussock infestation (ha)
North East	10
Glenelg	200
North Central	10
Corangamite	75 000
Wimmera	1
East Gippsland	600
West Gippsland	100
Goulburn-Broken	40
Port Phillip	29 000
Mallee	0
TOTAL	104 961

Sources: Keith Turnbull Research Institute, Integrated Pest Management System (IPMS); BDA Group (2000).

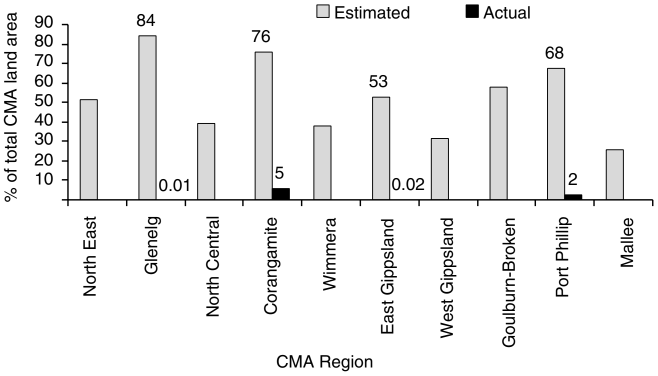

Figure 4. Predicted and actual spread (% of CMAs total land area) of serrated tussock infestation. Sources: Integrated Pest Management System (IPMS) and BDA Group (2000) for the indicative 'actual' infestation data. Note: Percentage values indicated are for the top four CMA regions with the largest current infestations (Glenelg, Corangamite, East Gippsland and Port Phillip).

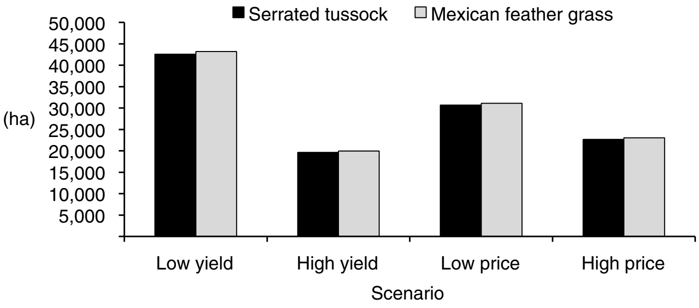

Figure 5. Predicted State-wide spread over 30 years of one-hectare hypothetical initial infestation per CMA region of each weed species, with uncoordinated farm-level response under four different scenarios.

One implication of the above result is that both weed species are likely to 'park' on marginal grazing lands for some time if their uncoordinated control would remain unprofitable at farm level. This situation demonstrates a divergence between the privately and socially optimal levels of control. This means that from the community's viewpoint, the individual private landholder under-invests in weed control. Because the best control outcome for the community was not delivered, a coordinated control strategy may be a worthwhile option.

Economic impact on grazing industries

In the absence of a coordinated weed control strategy, the combined long-term economic impact of the hypothetical infestations by these two weed species on grazing industries alone was estimated to be between $101 million and $246 million depending on the scenarios tested (Table 7). This translates to an expected annual yield loss and future weed control cost of about $3.5 million to $8.0 million for the next 30 years. In particular, the estimated value of industry loss likely to result from the entry of Mexican feather grass into Victoria was as high as $123 million ('high yield' scenario) over the next 30 years (Table 7). This result suggests that when expected yield levels on grazing lands are high, undertaking a pro-active control strategy for Mexican feather grass has the potential to deliver relatively more substantial economic benefits to grazing industries than at other times (e.g., when expected commodity prices are high). The results shown in Table 8 provide support to this particular view.

Long-term benefits to grazing industries of a coordinated control strategy

For the pro-active control of the hypothetical infestations of serrated tussock, the estimates of benefits accrued annually by grazing industries over the 30-year evaluation period were all positive in all the scenarios tested ($5.8 million to $18.0 million) (Table 9). This result suggests that grazing industries in CMA regions that

Table 6. Net loss to individual graziers in CMA regions in Victoria when controlling serrated tussock under the base-case 'low yield' scenario.

CMA Region	Loss ($ ha^{-1})
North East	61.45
Glenelg	31.25
North Central	63.05
Corangamite	31.25
Wimmera	60.55
East Gippsland	61.45
West Gippsland	61.45
Goulburn-Broken	61.45
Port Phillip	61.45
Mallee	74.65

Table 7. Economic impact on grazing industries of the hypothetical infestation of serrated tussock and Mexican feather grass in Victoria over 30 years, ($ million).

Serrated tussock	Scenarios			
CMA Region	Low yield	High yield	Low price	High price
North East	5.06	12.76	7.42	8.86
Glenelg	6.74	21.76	7.28	10.30
North Central	3.37	8.73	5.22	6.25
Corangamite	4.30	13.70	4.62	6.53
Wimmera	3.35	10.05	5.50	7.04
East Gippsland	7.28	13.24	9.18	9.90
West Gippsland	5.72	9.65	6.66	7.71
Goulburn-Broken	4.32	12.04	6.72	8.26
Port Phillip	2.49	10.10	4.29	7.01
Mallee	7.14	10.99	7.58	9.44
Expected production loss	49.77	123.02	64.47	81.30
Mexican feather grass	Scenarios			
CMA Region	Low yield	High yield	Low price	High price
North East	5.07	12.78	7.44	8.69
Glenelg	6.76	21.78	7.29	10.32
North Central	3.39	8.77	5.25	6.27
Corangamite	4.35	13.73	4.64	6.58
Wimmera	3.36	10.05	5.49	7.04
East Gippsland	7.40	13.58	9.37	10.15
West Gippsland	5.74	9.72	6.70	7.75
Goulburn-Broken	4.38	12.14	6.82	8.31
Port Phillip	2.55	10.24	4.85	7.08
Mallee	7.17	11.12	7.65	9.53
Expected production loss	50.16	123.91	65.51	81.73
Combined production loss	100.97	246.96	129.99	163.03

Table 8. Present value of net benefits (NPVs) to grazing industries associated with pro-active strategy for Mexican feather grass in Victoria, ($ million).

	Scenarios			
CMA Region	Low yield	High yield	Low price	High price
North East	0.66	2.02	1.03	1.40
Glenelg	1.45	4.35	2.06	1.27
North Central	0.57	1.57	0.90	1.13
Corangamite	0.92	2.73	1.31	0.81
Wimmera	0.53	1.79	0.91	1.26
East Gippsland	0.45	1.13	0.67	0.78
West Gippsland	0.23	0.53	0.33	0.36
Goulburn-Broken	0.69	2.11	1.10	1.45
Port Phillip	0.49	2.01	0.95	1.39
Mallee	0.05	0.08	0.07	0.06
Total NPV	6.05	18.33	9.32	9.92

Table 9. Present value of net benefits (NPVs) to grazing industry investment over 30 years for each type of control strategy for serrated tussock in Victoria, ($ million).

Uncoordinated strategy	Scenarios			
CMA Region	Low yield	High yield	Low price	High price
North East	-3.32	-10.29	-5.18	-7.13
Glenelg	-8.57	-27.67	-8.50	-12.66
North Central	-2.58	-6.73	-4.01	-4.80
Corangamite	-497.85	-2 414.90	-797.17	-899.85
Wimmera	-2.64	-8.90	-4.54	-6.24
East Gippsland	-3.69	-22.13	-7.23	-13.95
West Gippsland	-1.15	-3.25	-1.75	-2.15
Goulburn-Broken	-3.19	-9.56	-5.07	-6.50
Port Phillip	-59.39	-526.24	-222.02	-311.70
Mallee	-0.06	-0.12	-0.08	-0.08
Total NPV	-582.43	-2 856.38	-1 055.54	-1 265.07

Pro-active strategy	Scenarios			
CMA Region	Low yield	High yield	Low price	High price
North East	0.66	2.02	1.02	1.40
Glenelg	1.45	4.34	2.05	1.27
North Central	0.57	1.56	0.89	1.13
Corangamite	0.92	2.73	1.30	0.80
Wimmera	0.53	1.79	0.91	1.26
East Gippsland	0.39	1.03	0.58	0.71
West Gippsland	0.22	0.50	0.31	0.35
Goulburn-Broken	0.68	2.09	1.08	1.44
Port Phillip	0.48	1.99	0.83	1.38
Mallee	0.01	0.02	0.02	0.02
Total NPV	5.89	18.09	8.99	9.75

Reactive strategy	Scenarios			
CMA Region	Low yield	High yield	Low price	High price
North East	2.55	7.52	3.89	5.26
Glenelg	-0.06	-0.49	-0.20	-0.24
North Central	0.77	2.03	1.14	1.54
Corangamite	-197.61	-874.80	-452.80	-477.96
Wimmera	0.53	1.79	0.91	1.26
East Gippsland	-0.24	-4.32	-1.28	-1.96
West Gippsland	2.82	3.93	2.82	3.54
Goulburn-Broken	2.65	7.81	4.16	5.42
Port Phillip	-41.74	-112.71	-63.50	-92.51
Mallee	0.05	0.08	0.06	0.07
Total NPV	-252.04	-948.95	-504.80	-555.59

are likely to be at risk from the potential spread of serrated tussock would be better off investing jointly with Government in such a strategy. However, the suggestion should be treated with caution because the current estimates did not incorporate possible market and price effects of the expected increase in output due to weed control (Jones 2000, Vere *et al.* 1997). Hence, the estimates should be considered only as a possible range of values within which the true range of industry benefits is likely to fall.

In CMA regions where serrated tussock has already established viz., Corangamite (75 000 ha), Port Phillip (29 000 ha), East Gippsland (600 ha), and Glenelg (200 ha) industry investments in a reactive control strategy were found unprofitable in all the scenarios tested (Table 9). This result suggests that grazing industries are likely to become worse off investing in reactive control strategy using chemical method alone in regions where serrated tussock has already established on 200 ha or more.

Long-term benefits to the community of a coordinated control strategy

In the economic evaluation system developed for the Agriculture Division of DNRE, projects that are classified as generating community benefits have an *a priori* claim to government funding because private markets may not allocate sufficient funds to these activities (Stoneham personal communication). In the context of this evaluation system, a government-coordinated weed control strategy can only be justified if benefits to the community are greater than the costs of public investment.

The positive net value of benefits to the community in all the scenarios tested under the pro-active control strategy (Table 10) indicates that this type of public investment can be justified on economic grounds. The combined net economic benefits to the community of the pro-active control strategy would be about $82 million to $202 million depending on the scenarios tested (Table 10). In present value terms, this represents a potential saving to the community of about $2.5 million to $6.5 million per year over the next 30 years. On the other hand, the financial outlay required by government to implement a statewide reactive control strategy for serrated tussock over the same period was estimated to outweigh benefits to the community by about $260 million to $1140 million (Table 11). These results clearly indicate that in terms of economic performance, the pro-active control strategy would remain the more economically worthwhile public investment given the range of productivity and market conditions assumed to apply in the study area.

The estimates of the stream of weed control benefits to the community are likely to be understated because other values e.g., biodiversity, amenity value, etc., that are difficult to quantify but may be of equal importance to society (Bennett 1984, Gowdy 1997) were not included in the calculations. Further, because only two weed species were included in the study, the results can only partially reflect the overall economic importance to the community of a statewide coordinated pro-active strategy for pest plant management.

Overall, the results provide evidence that in the CMA regions of Victoria, a pro-active weed control strategy is likely to deliver a better 'value for money' to public investment than a reactive control strategy as shown by the benefit-cost ratios in Figure 6. The pro-active control strategy was assessed to deliver at least two-and-a-half times more return per dollar of investment than the reactive strategy. Investing in serrated tussock control where the weed has already established over a fairly large area using chemical method alone was found uneconomic. Furthermore, where individual private landholders affected by the case-study weeds under-invest in their control, the results also indicate that publicly funded actions to specifically manage the external cost of weed reinfestation would be economically worthwhile. Such actions may entail the deployment of 'weed inspectors' in every region to coordinate and perform targeted educational, monitoring and extension functions at 'ground level'. Finally, the preliminary ranking of preferred weed investment strategy at the State level i.e., pro-active over reactive control strategy was robust in the face of different yield and price level assumptions made at the start of the decision period.

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Table 10. Combined present value of net benefits (NPVs) to the community associated with pro-active control strategy for serrated tussock and Mexican feather grass in Victoria, ($ million).

Serrated tussock	Scenarios			
CMA Region	Low yield	High yield	Low price	High price
North East	4.02	10.35	6.02	7.07
Glenelg	5.44	17.03	7.86	5.09
North Central	2.42	6.78	3.94	4.73
Corangamite	3.31	10.58	4.85	3.12
Wimmera	2.44	7.87	4.20	5.39
East Gippsland	6.52	11.82	8.93	8.08
West Gippsland	5.12	8.76	7.01	5.92
Goulburn-Broken	3.26	9.56	5.25	6.43
Port Phillip	1.63	7.72	3.06	5.24
Mallee	6.74	10.58	9.04	7.17
Total NPV	40.88	101.05	60.15	58.24

Mexican feather grass	Scenarios			
CMA Region	Low yield	High yield	Low price	High price
North East	4.02	10.37	6.03	7.08
Glenelg	5.45	17.04	7.88	5.10
North Central	2.43	6.81	3.96	4.75
Corangamite	3.33	10.61	4.89	3.16
Wimmera	2.44	7.87	4.19	5.39
East Gippsland	6.56	12.05	9.10	8.19
West Gippsland	5.12	8.80	7.03	5.94
Goulburn-Broken	3.30	9.64	5.33	6.47
Port Phillip	1.67	7.84	3.52	5.30
Mallee	6.74	10.65	9.08	7.20
Total NPV	41.05	101.67	61.01	58.59
Combined total NPV	81.93	202.73	120.16	116.82

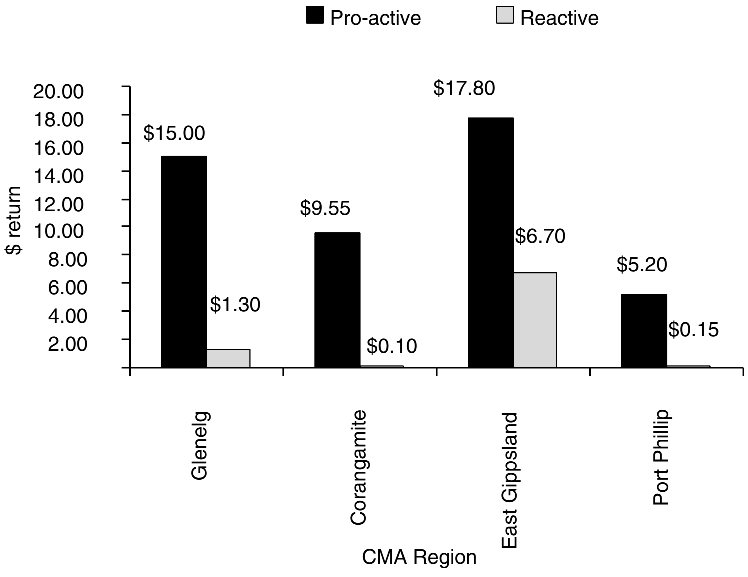

Figure 6. Benefit-Cost Ratios (BCRs) for pro-active and reactive serrated tussock control strategies in selected CMA regions (with at least 200 ha of existing infestation).

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Table 11. Comparison of present value of net benefits (NPVs) to the community associated with each control strategy for serrated tussock in Victoria, ($ million).

Uncoordinated strategy	Scenarios			
CMA Region	Low yield	High yield	Low price	High price
North East	-1.80	-2.73	-1.89	-2.35
Glenelg	-0.07	-0.17	-0.11	-0.52
North Central	-0.84	-2.21	-1.31	-1.58
Corangamite	-20.79	-60.06	-35.57	-65.57
Wimmera	-0.72	-1.15	-0.96	-0.80
East Gippsland	-5.78	-9.62	-7.76	-6.55
West Gippsland	-5.12	-9.20	-7.04	-6.22
Goulburn-Broken	-1.34	-3.58	-2.08	-2.43
Port Phillip	-40.88	-286.26	-168.85	-174.45
Mallee	-7.08	-10.87	-9.36	-7.50
Total NPV	-84.42	-385.85	-234.94	-267.96

Pro-active strategy	Scenarios			
CMA Region	Low yield	High yield	Low price	High price
North East	4.01	10.35	6.01	7.07
Glenelg	5.44	17.03	7.86	5.09
North Central	2.41	6.77	3.94	4.73
Corangamite	3.31	10.58	4.85	3.12
Wimmera	2.44	7.87	4.19	5.39
East Gippsland	6.51	11.82	8.93	8.08
West Gippsland	5.11	8.76	7.00	5.92
Goulburn-Broken	3.25	9.55	5.25	6.43
Port Phillip	1.63	7.72	3.06	5.23
Mallee	6.73	10.57	9.03	7.17
Total NPV	40.88	101.05	60.15	58.23

Reactive strategy	Scenarios			
CMA Region	Low yield	High yield	Low price	High price
North East	4.92	11.13	7.05	7.67
Glenelg	0.26	1.26	0.42	1.09
North Central	7.73	19.77	11.47	14.67
Corangamite	-217.28	-922.63	-486.78	-503.95
Wimmera	2.44	7.87	4.19	5.39
East Gippsland	7.51	4.01	6.21	35.99
West Gippsland	2.05	3.15	2.75	2.09
Goulburn-Broken	3.77	9.95	5.87	6.71
Port Phillip	-78.87	-286.49	-153.89	-152.73
Mallee	6.73	10.57	9.03	7.17
Total NPV	-260.73	-1141.39	-593.67	-575.87

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