# Economics of Controlling Serrated Tussock in the Southeastern Australian Rangelands

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**Abstract**

**Serrated tussock *(Nassella trichotoma)*, a grass native to South America, has been a major economic problem in the rangelands of southeastern Australia since 1950. It currently infests 680,000 ha in southeastern New South Wales, drastically reducing animal production. Controlling serrated tussock was profitable in most situations favourable for pasture improvement but only marginally profitable or unprofitable in areas with low to moderate soil fertility/rainfall indices. Internal rates of return ranged between 49.1% and 7.5% and the benefit-cost ratios between 1.83:1 and 0.88:1. Public intervention was considered to be necessary to expedite control in areas less favorable for pasture improvement. Public rates of return (273.1% to 132.7%) and benefit-cost ratios (32.3:1 to 11.2:1) to control were very high under a system of subsidized finance to private landholders. Various forms of potential public intervention were discussed.**

Serrated tussock *(Nassella trichotoma)*, a grass native to Peru, Chile, Uruguay, and Argentina (Parodi 1930), has become a serious weed in New Zealand, Australia, and South Africa. It is generally not a problem in its native countries where it is eaten by stock during drought (Connor 1960). Recent invasions of some overgrazed and cultivated areas have caused concern (Vervoorst 1967).

The plant is a perennial, drought-resistant, tussock-forming grass (Fig. 1). Argentinians (Itria 1961, Vervoorst 1967) name serrated tussock *Stipa trichotoma*. There appears a need to investigate its taxonomy (De Winter 1965). The grass is a weed in New Zealand, Australia, and South Africa because animals avoid it and graze more palatable associated species (Campbell 1982). In South America the associated species are quite often more unpalatable than serrated tussock (Connor 1960).

**Fig. 1.** *Individual tussocks grow to 60 cm in height with a basal diameter of 15 cm and a leaf spread of 50 cm.*

Serrated tussock is the most important perennial grass weed of pastures on the rangelands (500 to 1300 m altitude of south-eastern Australia (Parsons 1973). Because of its high neutral detergent fibre (86%) and low crude protein (4%) content, serrated tussock has little livestock grazing value (Campbell and Irvine

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1966) and is recognized as causing greater reductions in carrying capacity than any other pasture weed in Australia (Parsons 1973). Even with the availability of protein supplements, sheep are unable to gain adequate nutrition from serrated tussock to maintain good condition (Campbell and Barkus 1965, Campbell and Irvine 1966). Not only is serrated tussock unpalatable to sheep and cattle, it is difficult to identify, seeds prolifically, and is readily dispersed over large distances by wind, water, animals, and man (Campbell 1977b). Its seed has long viability in the soil (up to 13 years), it is costly and difficult to control, and readily invades improved and unimproved pastures following drought or overgrazing (Fig. 2).

Although landholders have long recognised the threat to grazing lands caused by serrated tussock and despite the successful adoption of control techniques in areas favourable for pasture improvement (Campbell 1977a), the weed remains a major economic problem in the southeastern Australian rangelands. Campbell (1977a) concluded that the total area of serrated tussock in New South Wales has declined little over the last 20 years, largely due to its invasion of new areas and to the inability of some landholders to effect control because of environmental and resource limitations.

Control of serrated tussock in New South Wales is primarily the responsibility of the landholder. Local government authorities have the power and obligation to assist cooperative landholders and to force noncooperative landholders to control the weed. In some areas (on the central tablelands in particular) there has been a significant decline in the total area infested due to the systematic control procedures used by some landholders and to the efforts of councils in enforcing the regulations of the Local Government Act (1927) (Campbell 1977a). However, it is now apparent that the control efforts of landholders and shire councils have been ineffective in preventing the weed's spread.

**Fig. 2.** *Moderate infestations develop into dense infestations due to sheep and cattle selecting associated species and leaving serrated tussock.*

## Area and Distribution of Serrated Tussock

The potential threat of serrated tussock in Australia was first recognised in 1935 (Cross 1937) in southern New South Wales, some years after its introduction from South America or New Zealand in fodder shipments imported during droughts (Campbell 1965).

By the 1950's, serrated tussock occupied large areas of southeastern Australia. Its spread was facilitated by the overgrazing of native pastures by sheep and rabbits during the droughts of the 1940's. Consequently, animal production from large areas of New South Wales was substantially reduced, some to less than one-third of their normal capacity. Serrated tussock became so abundant in nonarable country that many landholders thought that the problem was insurmountable (Fallding 1957).

Serrated tussock is now widely distributed throughout the southeastern rangelands; heaviest infestations occur on the central and southern tablelands of New South Wales (Fig. 3, Table 1). (Campbell 1977a) recorded that most infestations occurred within areas bounded by a 21°C isotherm for mean January temperature and an average annual rainfall between 500 mm and 990 mm. As only part of this area is infested, there are large areas over which the weed has further potential for spread. Serrated tussock also occurs in small areas in Victoria and Tasmania and is proclaimed noxious throughout most of southeastern Australia.

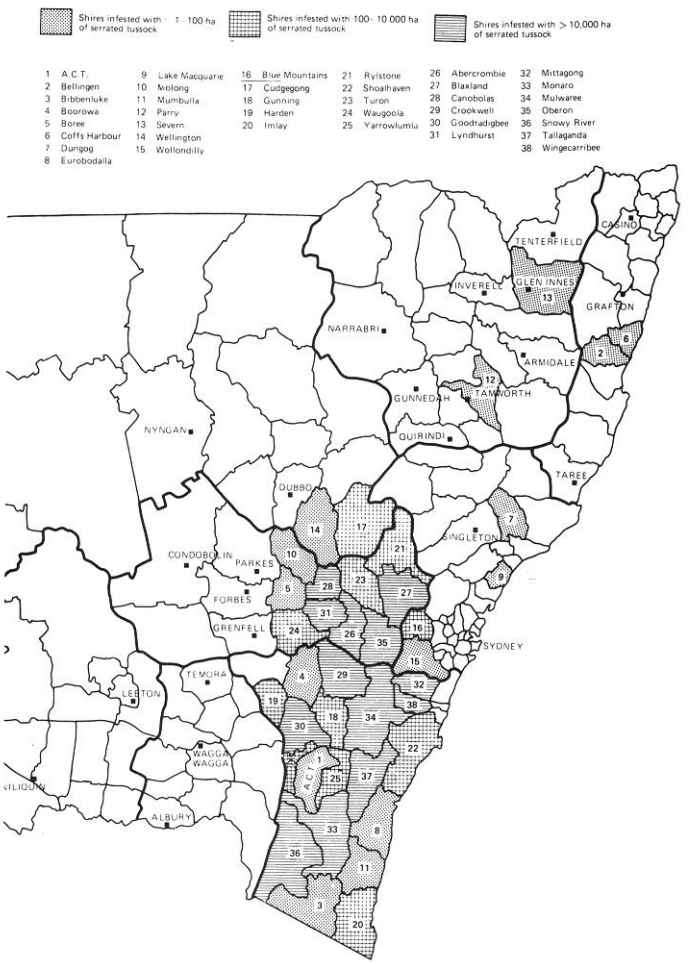


**Fig. 3.** *Distribution of serrated tussock in New South Wales on a shire classification basis.*

**Table 1. Area of serrated tussock, nature of country infested and number of properties infested in New South Wales.[1]**

| Degree of infestation | Area infested (ha) | Nature of country infested | | Properties infested (no.) |
|---|---|---|---|---|
| | | Arable (ha) | Non-arable (ha) | |
| Heavy | 71200 | 12031 | 59169 | 283 |
| Moderate | 147100 | 37213 | 109887 | 817 |
| Light | 461700 | 191452 | 270248 | 2694 |
| Totals | 680000 | 240696 | 439304 | 3794 |

[1]Source: Campbell (1977a).

The total area infested in New South Wales (680,000 ha) is much greater than the maximum area infested in New Zealand in 1945 (168,000 ha) and the present area infested in South Africa (116,000 ha) (Campbell 1982). Serrated tussock has been virtually eliminated in New Zealand due to a vigorous government campaign. However, in South Africa the infested areas have only been mod-

erately reduced despite the recent introduction of a government subsidized control programme. The total area infested with serrated tussock in New South Wales is also larger than most other serious weeds of pasture, e.g., St. John's wort *(Hypericum perforatum* var. *angustifolium)* (188,000 ha) (Campbell 1977a).

In 1976 serrated tussock occurred in 32% of all properties on the central and southern tablelands of New South Wales; in two shires over 90% of properties were infested (Campbell 1977a). Although 70% of infested properties had less than 25% of their area infested, the remaining 30% had sufficient tussock to pose serious financial problems to their owners because of enforced income reductions and the high costs of control (Vere and Campbell 1979).

## Methods of Control

The most widely used method of control is the replacement of the weed with improved pasture species (Healy 1945) comprising a perennial grass e.g. phalaris *(Phalaris aquatica)* plus legumes e.g., subterranean clover *(Trifolium subterraneum)* and white clover *(T. repens).* The legumes are necessary to crowd out tussock seedlings, mainly in the first three years after the initial ploughing and to improve soil fertility so that the perennial grasses become dominant as quickly as possible (Campbell 1963a).

On arable land one or two crops, e.g., grazing oats, are sown before the improved pasture (Table 2) to reduce tussock seed

**Table 2. Simulated pasture improvement programme for the control of serrated tussock on a five 100 ha paddock rotation.**

| | Paddocks[1] | | | | |
|---|---|---|---|---|---|
| Year | 1 | 2 | 3 | 4 | 5 |
| 1 | oats | tussock | tussock | tussock | tussock |
| 2 | oats | oats | tussock | tussock | tussock |
| 3 | pasture | oats | oats | tussock | tussock |
| 4 | pasture | pasture | oats | oats | tussock |
| 5 | pasture | pasture | pasture | oats | pasture |
| 6 | pasture | pasture | pasture | pasture | pasture |

[1]Paddocks 1 to 4 are arable and paddock 5 nonarable.

numbers in the soil. Pastures should not be grazed for one year after sowing to allow the legumes to smother tussock seedlings and to maximise seed production of subterranean clover (Campbell 1977c). Thereafter pastures are stocked lightly (Table 3) until the seeded species are sufficiently competitive to resist reinvasion.

**Table 3. Recommended grazing pressures on developing improved pastures sown to control serrated tussock in medium soil fertility and rainfall country (d.s.e. ha$^{-1}$)[1]**

| Year | Arable country | Non-arable country |
|---|---|---|
| 1 | 0 | 0 |
| 2 | 4.5 | 2.5 |
| 3 | 6.0 | 5.0 |
| 4 | 10.0 | 7.5 |
| 5 | 10.0 | 10.0 |
| 6 | 10.0 | 10.0 |

[1]Dry sheep equivalents ha$^{-1}$.

On nonarable land control is less reliable because of the difficulty of establishing pastures from aerial seeding in dry years. Herbicides (dalapon or tetrapion) are aerially applied two to six months before aerial seeding of pasture species (Fig. 4) (Campbell 1974, Campbell et al. 1979). The treated area should be rested for one year after sowing and deferred in each succeeding spring-summer period until sown species become dominant. The stocking rate is increased more slowly after control treatment on nonarable land than on arable land (Table 3). Once the introduced species become well established, a large scale reinfestation of serrated tussock can be selectively removed by the aerial application of dalapon or tetrapion (Campbell et al. 1979).

On both arable and nonarable land, pasture vigour is maintained through regular application of fertilizer (mainly superphosphate). Tussock plants remaining after treatment should be removed by digging or spot-spraying (Campbell 1977c).

Other control methods are used in areas that are not suitable for improved pastures. For example, afforestation is used to control serrated tussock on soils with low pH. Pine trees *(Pinus radiata)* planted in normal commercial densities eventually kill mature plants by shading and competition for moisture, taking from 5 to 8 years to stop tussocks seeding and from 8 to 12 years to achieve full control. Serrated tussock also occurs in areas which have minimal agricultural potential. Here control is particularly difficult and can only be achieved through the exclusion of stock to permit regeneration of the native vegetation.

## Economic Aspects of the Serrated Tussock Problem

The three main aspects of the economic problem caused by serrated tussock are: the loss of potential livestock production from infested pastures; the costs of effective control; and the externalities caused by the spread of the weed into other areas.

### Production Losses

If sheep are forced to graze a heavy infestation of serrated tussock at normal stocking rates they lose weight and will die unless removed (Campbell and Barkus 1965). Heavily infested areas can only support 0.5 dry sheep equivalents (d.s.e.) ha$^{-1}$ (Campbell 1974) compared with 7 to 15 d.s.e. ha$^{-1}$ on improved pastures on similar country (Clinton et al. 1968). Heavy infestations can reduce the carrying capacity of both improved and natural pastures by as much as 90%, while moderate infestations reduce stock numbers by 40% (Vere and Campbell 1979). Light and moderate infestations become heavy infestations over time because animals, in selecting useful associated species, give the ungrazed serrated tussock the competitive advantage (Fig. 2).

Vere and Campbell (1979) assessed in 1976-77 the annual losses of animal production caused by serrated tussock in New South Wales in terms of foregone Merino wool production, the predominant agricultural enterprise in areas infested with serrated tussock. They estimated that 7.65 million kg of greasy Merino wool valued at $11.8 million was annually lost through infestations of the weed. These estimates were based on average stocking rates and wool cuts on improved pastures and valued at an assumed gross margin per d.s.e. for individual regions (Table 4).

Production losses caused by serrated tussock are permanent and progressively increase as infestations become more dense to the point where production potential is totally foregone in the absence of effective control.

### Costs of Control

The costs of serrated tussock control include: initial pasture improvement; annual pasture maintenance with fertilizers; and removal of reinfestation until the introduced pasture has become completely dominant. Control costs vary with the degree of infestation and the topography of the country concerned (whether arable or nonarable). Similar costs are incurred with heavy and moderate infestations because the same pasture improvement techniques are used for the control of both densities of infestation. These costs are currently estimated at $112 ha$^{-1}$ and $122 ha$^{-1}$, respectively, for arable and nonarable land[1]. Light infestations (1 to 1,000 plants/ha$^{-1}$) are removed by chipping and spot-spraying at an approximate cost of $7 ha$^{-1}$.

Successful control of serrated tussock on a large area of heavily infested land therefore requires a high capital outlay and necessarily long periods (11 to 22 years) before revenues exceed pasture establishment costs (Vere and Campbell 1977a, 1977b). Apart from finance, other resource requirements include: above average

[1] These estimates are the undiscounted costs of pasture improvement which include cultivation, herbicide, fertilizer, seed, and the removal of reinfesting tussock plants.

**Fig. 4.** *The most widely used method of control on nonarable land is the aerial application of herbicide, seeding and fertilization.*

management ability of the landholder concerned; a predominance of fertile soil; and relatively high rainfall (600 mm). Additionally, an absence of serious droughts during the control period is necessary. If any of these factors are lacking there is a risk of failure.

**Table 4. Estimates of annual economic loss from serrated tussock infestations in New South Wales, assessed in terms of greasy wool production.**

| Shire | Area infested[1] Heavy (ha) | Medium (ha) | Light (ha) | Average stocking[2] (d.s.e. ha$^{-1}$) | Forced reduction in stocking potential Heavy (d.s.e. ha$^{-1}$) | Medium (d.s.e. ha$^{-1}$) | Estimated[3] economic loss ($10$^6$) |
|---|---|---|---|---|---|---|---|
| Cabonne | 5000 | 4000 | 20000 | 12.5 | 12.0 | 5.0 | 0.760 |
| Crookwell | 3200 | 30000 | 51000 | 12.5 | 12.0 | 5.0 | 1.790 |
| Evans | 17260 | 28380 | 41400 | 10.0 | 9.5 | 4.0 | 2.643 |
| Gunning | 1600 | 800 | 2100 | 10.0 | 9.5 | 4.0 | 0.138 |
| Lithgow | 3600 | 4000 | 73000 | 10.0 | 9.5 | 4.0 | 0.477 |
| Lyndhurst | 1200 | 2000 | 12200 | 15.0 | 14.5 | 6.0 | 0.279 |
| Mittagong | 20000 | 28000 | 40000 | 10.0 | 9.5 | 4.0 | 2.265 |
| Monaro | 2400 | 4800 | 20000 | 10.0 | 9.5 | 4.0 | 0.273 |
| Mulwaree | 8500 | 8100 | 60000 | 12.5 | 12.0 | 5.0 | 1.354 |
| Oberon | 4100 | 10100 | 40500 | 15.0 | 14.5 | 6.0 | 1.141 |
| Snowy River | 3200 | 23000 | 40000 | 7.5 | 7.0 | 3.0 | 0.503 |
| Tallaganda | 1000 | 3300 | 8000 | 10.0 | 9.5 | 4.0 | 0.170 |
| Waugoola | — | 200 | 200 | 12.5 | — | 5.0 | 0.009 |
| Yarrowlumla | — | 80 | 200 | 10.0 | — | 4.0 | 0.003 |
| Totals | 71060 | 146760 | 408600 | | | | 11.805 |

[1]Source: Campbell 1977a.
[2]Stocking potential on improved pastures.
[3]Based on assumed gross margin per d.s.e for each Shire.

Many landholders have been unable to meet the management requirements and as a result control has either been unsuccessful or not attempted (Fallding 1957, Campbell 1977a). Others have had difficulty in raising the large amounts of capital needed for control particularly if they are already in debt. For example, in 1976, as a direct result of serrated tussock infestations, 34 landholders in Crookwell shire were forced to obtain off-farm work to attempt to raise the necessary control capital (Campbell 1977a).

### Externalities

The threat of continued spread of serrated tussock generates externalities in terms of the additional costs incurred by landholders in their efforts to keep their pasture free the of weed. Efficient landholders in infested areas have this problem imposed upon them by neighbours who have done little to effect control. Dellow (1975) cites the opinions of a group of progressive graziers who expressed their concern at the "great cost and inconvenience that negligent graziers were inflicting on them by failing to control tussock". They believe that a "strong public effort should be mounted to force lax graziers to consider the welfare of the community which was being jeopardized by their carelessness". Methods used to prevent infestation of an otherwise uninfested property include regular digging and spot-spraying and/or a reduced stocking rate to allow pastures to remain competitive. The former method was estimated to cost an average size central tableland property three man months labour per year while the latter method entailed a sacrifice of 2.5 d.s.e. $ha^{-1}$ per year.

While the size of this external cost cannot be accurately measured because its impact will vary according to the proximity of tussock infestations, the topography, the ability of the farm manager, and the level of pasture improvement, it is clear that the presence of the weed imposes costs on landholders that would otherwise not be necessary. The minimum external cost would be that of digging or spot-spraying regenerating tussock seedlings while the maximum cost would be that of the pasture improvement required to replace the weed.

### Economic Analysis of Private Control by Landholders

Discounted cash flow analysis was used to establish the profitability of investment in serrated tussock control under pasture improvement. Twenty-year cash flow budgets were prepared for nine soil-rainfall combinations which cover most of the situations in which serrated tussock occurs (Table 5). Regional differences due to soil and rainfall variation were reflected in the ease of pasture establishment, subsequent pasture vigour, stocking rates, and per capita wool cuts. Profitability was assessed using the net present value (NPV), internal rate of return (IRR), and benefit-cost ratio investment criteria. This procedure is similar to that used to assess the economics of weed control in the rangelands in western United States (Nielsen and Hinckley 1975, Nielsen and Cronin 1977, and Whitson and Scifres 1981). Costs and returns were based on 1982 values; returns were assessed in terms of the value of increased greasy wool production that would result from replacing serrated tussock with improved pastures.

Under most circumstances, investment in serrated tussock control by landholders was profitable but strongly influenced by prevailing climatic and edaphic conditions. With the exception of those areas of low soil fertility and low rainfall, all estimated private investment criteria (IRR, NPV, and benefit-cost ratios) were favourable, and in some instances, were particularly high. In areas where conditions favoured growth of improved pastures, control was most profitable with returns exceeding control costs in six years or less. Control remained profitable in moderately favourable areas although profits took longer to accrue due to reduced pasture growth and stocking potential. Investment profitability became uneconomic in low fertility/low rainfall situations because of the problem of establishing and maintaining a competitive pasture.

If the nine soil fertility/rainfall situations in Table 5 are subdivided into four categories based on stocking potential (Table 6), most of the serrated tussock in New South Wales is seen to occur in the medium/medium, medium/low, low/medium, and high/low categories. In these situations, average stocking potential is 10 d.s.e $ha^{-1}$ and investment profitability varies from moderate to marginal (Table 5). Constraints to pasture establishment such as drought, further reduce the returns to investment in control.

**Table 6. Estimates of the area of serrated tussock in New South Wales according to four soil fertility/rainfall categories and average stocking potential.**

| Soil fertility/rainfall index | Averate stocking potential (d.s.e. $ha^{-1}$) | Area infested (ha) |
|---|---|---|
| High/high | 15 | 70100 |
| High/medium; medium/high; low/high | 12.5 | 190200 |
| Medium/medium; medium/low; low/medium; high/low | 10 | 299920 |
| Low/low | 7.5 | 66200 |

### Public Control

The rationale for public intervention in the control of serrated tussock is based on the grounds that the weed represents a special problem which is beyond the ability of the private agricultural sector to overcome on an extensive basis. Private landholders may not be able to obtain the large amounts of finance or lack the management skills necessary to control extensive infestations and that control is likely to be unprofitable in low rainfall/soil fertility

**Table 5. Estimates of investment profitability in the control of serrated tussock by private landholders using pasture improvement[1] in New South Wales rangelands.**

| Soil fertility rainfall index[2] | Investment criteria: Internal rate of return (%) | | Investment criteria: Net present value @ 11% ($'000) | | Investment criteria: Benefit-cost ratio @ 11% | | Financial criteria: Peak debt ($'000) | | Financial criteria: Years of debt | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Arable | Nonarable | Arable | Nonarable | Arable | Nonarable | Arable | Nonarable | Arable | Nonarable |
| High/high | 49.1 | 43.2 | 82.6 | 83.1 | 1.83:1 | 1.86:1 | 18.50 | 18.11 | 4 | 5 |
| High/medium | 34.7 | 36.0 | 69.0 | 62.8 | 1.82:1 | 1.76:1 | 17.71 | 18.24 | 4 | 5 |
| High/low | 26.1 | 24.1 | 28.7 | 27.9 | 1.44:1 | 1.44:1 | 19.55 | 19.66 | 5 | 7 |
| Medium/high | 37.0 | 32.4 | 57.8 | 52.4 | 1.68:1 | 1.62:1 | 18.91 | 19.76 | 5 | 6 |
| Medium/medium | 33.0 | 17.3 | 44.9 | 16.7 | 1.60:1 | 1.19:1 | 18.10 | 25.90 | 5 | 11 |
| Medium/low | 21.2 | 15.0 | 21.2 | 9.7 | 1.32:1 | 1.15:1 | 20.01 | 25.42 | 8 | 12 |
| Low/high | 24.1 | 20.1 | 27.2 | 22.1 | 1.35:1 | 1.30:1 | 19.63 | 22.31 | 7 | 8 |
| Low/medium | 14.3 | 12.3 | 6.6 | 3.4 | 1.09:1 | 1.05:1 | 23.58 | 28.32 | 12 | 18 |
| Low/low | 8.4 | 7.5 | -4.9 | -6.0 | 0.89:1 | 0.88:1 | 56.06 | 65.02 | ∞ | ∞ |

[1]Unit area = 100 ha.
[2]High/high relates to high soil fertility, high rainfall, and so on.

situations. Under these circumstances some form of public intervention utilizing public finance, similar to that used in New Zealand (Campbell 1963b), may be necessary. To justify public funding it would be necessary to establish that such action would yield net public benefits.

The economics of extensive control of serrated tussock using public funds was assessed using benefit-cost analysis. To facilitate the analysis, it was assumed that a public authority took responsibility for a coordinated control programme. The main data requirements involved estimates of: the area of serrated tussock in individual shires; the production increases post control for each shire; the areas infested according to their agricultural potential for pasture improvement, pine afforestation, or acquisition-closure (Table 7).

The benefits from the control of serrated tussock were assessed in terms of greasy wool production from Merino wethers estimated according to the stock that might be carried if serrated tussock was replaced by improved pastures, at an assumed gross margin per d.s.e. (gross returns from wool sales less the variable costs of production) for each shire. Stocking rates on improved pastures for each shire were based on rainfall and soil fertility indices and a stocking rate survey conducted by Clinton et al. (1968). No monetary benefits were assumed from using afforestation or acquisition-closure because of the long control periods involved and the low agricultural potential of the country[2].

The costs of a public control programme included pasture improvement, afforestation, acquisition-closure, administration and supervison, and subsidized interest rates on funds advanced to landholders for control purposes. Control was assumed to be effected under pasture improvement utilising the low interest loan finance which is currently available to landholders (for serrated tussock control) from the New South Wales Government. Because these costs are eventually recovered through repayment, they are regarded as transfer items and not true public costs[3]. Both benefits and costs were projected over 20 years and into perpetuity at a 10% rate of discount, and public benefit-cost ratios and rates of return from expenditure on control were estimated[4].

The potential benefits, costs, net benefits, costs, serrated benefit-cost ratios and rates of return from a public programme of tussock control in New South Wales are presented in Table 8. Under all public control options, the total and net public benefit estimates were positive with public benefit-cost ratios and rates of return between 11.2:1 to 32.3:1 and 132.7% to 273.7%, respectively.

Net social benefits were highest from the programme based on the greatest input of pasture improvement; less pasture improvement meant more afforestation and acquisition-closure were necessary from which no monetary benefits were assumed to result. Estimates of the public benefit-cost ratios and rates of return from expenditure on extensive serrated tussock control were high, indicating that such expenditure would be a profitable public undertaking (Table 8).

## Discussion

Although serrated tussock can be profitably controlled in most situations in which it occurs, the high costs of effective control, the prevalence of the weed in moderate to low soil fertility/rainfall situations, the occurrence of drought, and the resource requirements for effective control have prevented many landholders from overcoming the problem. As a result, control procedures have been confined mainly to those areas most suited to pasture improvement. Such efforts have been insufficient to substantially reduce the total area infested in New South Wales.

It is therefore apparent that public intervention is necessary to expedite extensive control of the weed, the principal justification being that noncontrol generates external costs to landholders in their efforts to keep their land free of the weed. The methods of control, pasture improvement, afforestation, and acquisition-closure, are not considered to be alternatives for public investment, but rather the basic components of a coordinated control programme. Pasture improvement is considered to be the most desirable as it generates substantial long run benefits in terms of increased livestock production. Thus, it is believed that the most effective form of public intervention is to encourage landholders to undertake pasture improvement through a combination of monetary inducements and enforced regulation.

Monetary incentives have been insufficient to expedite extensive control; for example, although the New South Wales Government has provided subsidized loan finance at interest rates between 4½ and 6% to landholders for serrated tussock control, only 60 applications were made between 1967 and 1977, and 133 subsequently lodged to June 1982; low usage considering there were approximately 1100 properties carrying moderate or heavy infestations in 1977 (Table 1). The major reason for this is that many landholders are not aware of the availability of the loans, while others regard the 13-year term of the loan to be too short and the amount advanced (an average $20,000) too restricted to permit the control of large areas of serrated tussock.

An effective programme of public intervention in serrated tussock control using pasture improvement should therefore comprise landholder education regarding the benefits of improving pastures to control the weed; increased publicity to increase landholder awareness of the availability of loan finance for control; promotion by state and local government bodies of loan utilization; improvement of the terms of the loan to cater for low to moderate soil fertility/rainfall areas and drought years; and enforcement of control legislation where lax landholders are concerned.

A public authority may be needed to manage control procedures in areas where the economics of private control is marginal. The authority will need to make special administrative decisions such as the designation of those areas in the low to moderate soil fertility/rainfall areas that need acquisition-closure, afforestation, or pasture improvement for control of the weed. It will also be needed, *inter alia*, to supervise landholders incapable of success-

[2] While there would be some long-term timber benefits from afforestation, we have assumed that the trees are allowed to stand indefinitely to prevent tussock reestablishment.

[3] We recognise that these costs might be regarded as social costs since individual landholders are members of society. They have not been included here as we regard the true public cost in this instance to be the cost of subsidized loan finance—the difference between the cost of loan funds and the general market interest rate for on-farm development.

[4] This analysis has not considered the important market and resource allocation effects that may result from the widespread adoption of serrated tussock control technology as they have been previously discussed by the authors (Vere et al. 1980).

**Table 7. Estimated distribution of three methods for the control of heavy and moderate infestations of serrated tussock in New South Wales rangelands.**

| Recommended method of control | Assumed area distributions | | | | | |
|---|---|---|---|---|---|---|
| | Percentages | | | Hectares | | |
| Pasture improvement | 80 | 85 | 90 | 174640 | 185555 | 196470 |
| Pine afforestation | 15 | 10 | 5 | 32745 | 21830 | 10915 |
| Acquisition-closure | 5 | 5 | 5 | 10915 | 10915 | 10915 |
| Totals | 100 | 100 | 100 | 218300 | 218300 | 218300 |

**Table 8. Estimated benefits, costs, benefit-cost ratios, and rates of return from public expenditure in serrated tussock control on the New South Wales rangelands.**

| Level of pasture improvement | Benefits[1] ($m) | Costs[1] ($m) | Net benefits ($m) | Benefit-cost ratios[1] 20 years | Benefit-cost ratios[1] Perpetuity[2] | Rates of return 20 years | Rates of return Perpetuity[2] |
|---|---|---|---|---|---|---|---|
| 90% | 227.4 | 7.4 | 220.0 | 30.9:1 | 32.3:1 | 261.1 | 273.1 |
| 85% | 220.9 | 13.5 | 207.4 | 16.3:1 | 17.3:1 | 184.0 | 191.1 |
| 80% | 217.4 | 19.7 | 197.7 | 11.2:1 | 11.9:1 | 132.7 | 140.3 |

[1]Discounted at 10%.
[2]A perpetuity represents a perpetual annuity.

fully implementing control by pasture improvement but could manage the pastures, under supervision, once they have been successfully improved. Difficult country, once effectively improved by the authority, could be returned to the landholder and the costs recovered under pre-determined finance conditions. This strategy has been used successfully in New Zealand (Campbell 1963b). The authority would need to purchase and manage land designated for afforestation and acquisition-closure. For the purposes of this analysis, it was assumed that afforestation and acquisition-closure would not yield monetary benefits. Control using these methods will therefore represent a direct public cost, the returns to which will result from the removal of the threat of infestation to more productive areas.

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