Biological and ecological impact of serrated tussock (*Nassella trichotoma* (Nees) Arech.) on pastures in Australia

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Summary

Because serrated tussock is unpalatable and difficult to digest it can reduce carrying capacity by up to 97%. Animals graze associated plants with increasing severity as ground cover of the weed increases. In heavy infestations almost all native and introduced pasture species are eliminated. If control is attempted early in the invasion process it can be successful and profitable. If attempted after a substantial proportion of the property is infested heavy financial outlays are necessary and control is difficult to achieve on non-arable land with low rainfall and infertile soil.

Serrated tussock has many ecological and biological features that explain its success as a weed. The ability to produce enormous numbers of seeds that are widely distributed by wind and establish readily facilitates invasion of land unprotected by vigorous pastures. Despite relatively slow seedling growth it invades because animals graze more palatable plants. Once established individual tussocks live for long periods and withstand grazing, drought, burning, infertile soils, unfavourable aspects and competition.

Control on arable land depends on replacing the weed with a leniently grazed phalaris dominant pasture protected from reinfestation by removing invading tussocks. Where pasture improvement, fertilizer application and herbicide treatment are not undertaken, due to environmental or economic factors, the weed dominates.

Control on non-arable land under the present economic conditions is achieved by aerial application of flupropanate which, without sowing pastures, is only a short term solution and kills susceptible native grasses. Seedhead production can be stopped by applying 0.22–0.45 kg a.i. ha^{-1} glyphosate 2–8 weeks before the seedheads begin to emerge. Removal of seedlings with low rates of flupropanate offers a low-cost method of control. It requires the removal of mature tussocks initially, treatment of seedlings each time there is a major invasion and establishment of pasture species that are tolerant to the low rates. Control in native grass pastures is difficult due to their inability to compete with the weed when grazed and the susceptibility of *Danthonia* spp. and *Microlaena stipoides* to flupropanate. Control in areas where pastures are ineffective or unprofitable is being attempted by afforestation.

Impact

Serrated tussock causes greater reductions in carrying capacity than any other pasture weed in Australia (Parsons 1973). Heavy infestations carry 0.5 dry sheep equivalent (dse) ha^{-1} (Campbell 1974) compared to 7–15 dse ha^{-1} on improved pastures in similar areas (Clinton *et al.* 1968). Sheep will not graze serrated tussock by choice. If forced, they lose weight and die; a post mortem shows the rumen to be full of undigested leaves (Campbell and Irvine 1966). Attempts to enable sheep to utilize the weed by supplementing it with urea and molasses or a nutritious block lick, failed (Campbell and Barkus 1965, Campbell and Irvine 1966).

Serrated tussock has resulted in a 90% reduction in carrying capacity on some New Zealand farms and can put an end to sheep grazing. Beggs and Leonard (1959) placed seven wethers on 3 ha of serrated tussock; one died after seven weeks and the others had to be removed to prevent their death. Milne (1954) reported that 200 cattle on 49 ha in New Zealand grazed tussocks to within 11 cm of the crown but the cattle only maintained condition and 'few deaths occurred as a direct results of the enforced grazing'. Beggs and Leonard (1959) found cattle could prevent seeding, but the grazing caused dominance of serrated tussock as other useful species were killed.

The net annual loss in New South Wales (NSW) caused by serrated tussock in 1977, assessed in terms of potential wool production, was $A11.8 million, whilst the first year cost of replacing the weed with improved pasture was $A24.4 million (Vere and Campbell 1979). By 1997 the benefits of widespread control in NSW were assessed at $40.3m (Jones and Vere 1998). Because of the continuing decline in the farmers' terms of trade control in areas with low rainfall, low soil fertility and steep topography has become unprofitable (Vere *et al.* 1993). In the worst cases landholders cannot sell infested properties and have to find employment elsewhere. Because of these and a number of other factors (absentee owners, subdivision, drought, labour minimization, increasing age of producers) we are losing the fight against serrated tussock and a number of other hard-to-control weeds in NSW (Campbell and Vere 1996). To reverse this position research needs to refine present control methods and to discover new profitable methods for use in the future (Campbell 1997b).

Distribution

Serrated tussock, introduced into Australia in the early 1900s, was first identified as a weed in 1935 (Cross 1937). However no control was under taken in NSW until the 1950s by which time it had spread widely due mainly to the destruction of pastures by rabbits. By 1975 it occupied 680 000 ha (Campbell 1977b) mainly on the central and southern tablelands where 32% of all properties were infested. Between 1975 and 1985 the area infested declined to 491 400 ha due to use of flupropanate and pasture improvement (Campbell 1987a) but by 1997 the area infested had increased to 870 000 ha due mainly to low financial returns to landholders restricting the use of herbicide, seed and fertilizer. In addition, a further two million ha are at risk of infestation.

Small areas in Victoria in 1972 (Parsons 1973) increased to 100 000 ha by 1994 and to 130 000 by 1997; one million hectares are at risk of infestation.

In Tasmania an eradication campaign reduced the area infested from 3200 ha in 1959 to 800 ha in 1994 (Blacklow 1960, Harradine and Watson 1979). Between 1994 and 1997 the area infested increased to 1500 ha.

Serrated tussock is an example of a plant in equilibrium in its native country becoming aggressive in Australia because of more palatable associated pastures, less marked seasonal differences in available grazing and lower grazing pressures than in Argentina (Connor 1960).

Biology and ecology

Taxonomy

Serrated tussock is listed under the genera *Stipa* and *Nassella*, the major difference between the two resting in the shape of the lemma and the position of the awn. Taylor (1987) suggests the consensus is now with *Stipa* but in Australia *Nassella* is still used.

Climatic requirements

Serrated tussock grows in a continental climate in Argentina, oceanic in New Zealand and temperate and Mediterranean in Australia. In NSW, the distribution of serrated tussock is associated with the 21°C isotherm of mean January temperate and rainfall from 500 to 990 mm (Campbell 1977b). However, it grows well at Dalgety with a mean annual rainfall of 450 mm and a mean January temperature of 19ºC. The plant is tolerant of mean winter minimum temperatures of -5ºC, and of being covered with hoar frost and ice for varying periods (Healy 1945). Perhaps the climatic factor that most limits the spread of serrated tussock is hot summer temperatures; in NSW, seeds are dispersed by river from the central tablelands to the western plains where the resultant plants die during hot periods. As the optimum temperature for photosynthesis for serrated tussock is between 10º and 15ºC (Bate 1983) it requires relatively cool conditions for growth and survival.

Soils and aspects

Distribution of serrated tussock is not correlated with soil type nor soil fertility (Healy 1945). In New Zealand, it thrives on light textured soils of low fertility subject to moisture deficiencies, but it also occurs on fertile river flats (Dingwall 1969). In Australia, it grows on soils derived from slate, basalt, granite, sandstone and mudstone and on acid soils (pH 4.5) but is rarely found in swamps. In Argentina, serrated tussock can be found on dry northerly or shady southerly aspects and in damp and dry sites (Connor 1960).

Plant associations

The main species growing with serrated tussock in Argentina are: *Stipa gynerioides, S. dusenii, S. tenuissima, S. hyalina, S. brachychaeta* Godr., *Panicum urvilleanum* Kunth., *Eragrostis cilianensis* (All.) Link ex Vignolo and *Cenchrus pauciflorus* Benth., some of which are less attractive to grazing animals than serrated tussock (Connor 1960). Some of these grasses, e.g. *Stipa* or *Nassella hyalina*, *Stipa* or *Achnatherum brachychaetum* and *A. espartillo,* as well as other South American grasses, are becoming weeds in Australia. Serrated tussock grows in most native or introduced pastures in temperate Australia that have been disturbed by rabbits, overgrazing, drought or ploughing (Campbell 1977a). Subsequently, profuse seed production facilitates ingress into all but the most competitive pastures.

Morphology

In dense stands serrated tussock completely covers the soil surface, thereby suppressing competitors. On infertile soils mature plants grow to 15 cm in height but on fertile soils they grow to 60 cm. The tussocks have a deep root system, >1.7 m (Hely 1945), which helps explain its drought tolerance.

Perennation

The plant is long lived, though the age which individuals can attain has not been determined. Tussock centres may die during stress periods or after burning but will regrow. Seeds are produced annually.

Growth

Phalaris (*Phalaris aquatica* L.) produced six times as much foliage as serrated tussock in the six months after germination (Campbell 1965). Mature plants grow slowly producing 1100 kg dry matter ha^{-1} $year^{-1}$ on infertile soil. Most growth occurs in spring and summer, the plant being almost dormant in winter when the leaves are frosted (Campbell 1965).

Chemical composition

Mature foliage is low in crude protein (4.0%), crude fat (3.3%), total carbohydrates (29%) and minerals (Campbell 1965, 1977*a*) but high in neutral detergent (86%) and acid detergent fibre (51%) (Campbell and Irvine 1966). The major reasons for this low quality are the large amount of sclerenchyma in each leaf and the persistence of dead leaves in the tussocks. Leaf regrowth after burning or cutting has a crude protein content of 15% (Campbell 1965). Nitrogenous fertilizer raised the crude protein content of new leaves to 20% which increased palatability to cattle (Campbell and Barkus 1961). Subterranean clover (*Trifolium subterraneum* L.) grown with serrated tussock raised the crude protein content of mature foliage from 3.6 to 6.3% (Campbell 1960b).

Phenology

Seedheads first appear as thicker-than-normal tillers in mid to late spring; two weeks later the panicles begin to emerge with green translucent florets containing the anthers as a central spot; three weeks, the panicles have fully emerged and the bracts of the florets have turned purple; four weeks, the three purple anthers and two feathery stigma emerge from some florets and, presumably, fertilization takes place; five weeks, seeds reach the 'milk' stage and the panicles start to elongate; six weeks, seeds reach the dough stage; and ten weeks, the panicles are fully elongated, the seed ripe, and wind dispersal progressing (Campbell 1960a). Panicles that fail to elongate contain empty seed cases. Plants prevented from flowering in spring can sometimes flower in autumn (Healy 1945).

Breeding systems

Connor (1979) and Taylor (1987) found the majority of flowers of serrated tussock to be cleistogamic (self-fertilization of closed florets) which favours seed set in unfavourable environments. Of 100 seedheads studied 84 were entirely cleistogamous, two were chasmogamous (self or cross fertilization of open florets) and 14 were a mixture of both breeding systems. Cleistogamous florets have one fertile anther and two vestigal anthers while chasmogamous florets have three fertile anthers.

Seed production and dispersal

Under favourable conditions one plant can produce 100 seedheads in its first year and 2000 in its second (Taylor 1987). However in the field plants rarely produce seedheads in their first year and, if under stress, may not flower until they are three years old. The vast quantities of seed produced by serrated tussock, variously calculated between 900 (Campbell 1977a) to 3400 million ha^{-1} (Healy 1945), needs some explanation considering that the weed is not only a perennial, but also very hardy (Wells 1974).

Seed dispersal is mainly by wind; Healy (1945) recorded panicles being carried 16 km. Taylor (1987) suggested that seedheads could be blown >8 km day^{-1} in strong winds. Some seeds drop from the panicle before wind dispersal, but generally more than half the original number are retained during the journey (Healy 1945).

Seed is also spread by water, machinery and man. Livestock carry seeds in their coats and intestines. Sheep taken from an infested property in February passed a mean of 4634 seeds each in the four days after collection (Campbell 1962).

Seedbanks

Seed banks of 44 000 m^{-2} and 75 000 m^{-2} have been recorded in soil in, respectively, New Zealand (Healy 1945) and South Africa (Joubert 1984). Taylor (1987) showed a decline in viability of seed in the soil from 76% to 20% after one year and from 76% to 18% after six months in two separate locations in New Zealand. On the other hand Healy (1945) found seed buried 10–15 cm by cultivation at four locations for three years had a mean germination of 46%. Small quantities of seed can remain viable in the soil for at least 20 years (Taylor 1987).

Germination

Mature serrated tussock seeds germinate over a wide range of conditions (Healy 1945). However freshly collected seed from Trunkey NSW germinated more slowly than one year old seed collected from the same site (Figure 1). Joubert and Small (1982) and Taylor (1987) have shown that freshly collected seed has a low germination capacity. Healy (1945) noted that germination in autumn in the field only included a small portion of the current season's seed; most germination occurred from seed set in previous seasons.

Taylor (1987) found that dormancy of freshly harvested serrated tussock seed disappears after three month's storage. However, seed from Gallymont NSW harvested in December 1994 neither exhibited normal germination capacity nor rate until four and five months respectively after harvest (Table 1). Healy (1945) showed that germination could continue for 800 days which implied that varying permeability of the lemma controlled germination rate. Joubert and Small (1982) and

Taylor (1987) demonstrated that the removal of the palea and lemma increased germination rate. Similar results were recorded with seed collected from Trunkey in December 1995. It was stored for two months and then treated with gibberellic acid + KNO_3 and by cutting off the awn end of the seed. This resulted in dormancy being broken by cutting, gibberellic acid + KNO_3 or both (Figure 2). Taylor (1987) points out that this dormancy ensures germination and seedling growth in autumn, winter or spring when conditions are more favourable than in summer and assists establishment of the weed on steep hills with dry aspects.

Emergence
Healy (1945) found that a soil covering, 5 mm or greater, inhibited emergence of serrated tussock seedlings. However, Campbell (1965) showed that emergence was not markedly affected by soil coverings up to 18 mm. Seed buried deeper than 18 mm by ploughing would thus not establish unless the soil was reploughed.

Population dynamics
On bare soil Campbell (1958) recorded 4000 seedlings m^{-2} in the year of establishment; interplant competition, mainly during summer, reduced this population to 20 tussocks after three years. A dense mature infestation of serrated tussock generally has 5–20 tussocks m^{-2}; on fertile soil, density is low because plants are large. Most seedlings that establish in a dense stand of serrated tussock or in a vigorous improved pasture are killed by competition in their first or second spring or summer (Table 2).

Ecotypes/variation
Wells (1974) noted that the only variation in serrated tussock in Australia was in seed shape and size. However recent investigations have shown that two month-old seedlings from Melton Victoria had maroon coloured leaf sheaths whereas the leaf sheaths of seedlings from Trunkey NSW had only a few maroon streaks (Campbell unpublished data). The Victorian seedlings grew upright with heavily serrated leaves whereas the NSW seedlings had a number of twisted horizontal leaves and relatively fewer serrations. The maroon colour disappeared by five months of age on both collections.

Further evidence that there may be ecotypes in Australia comes from experiments in Victoria where glyphosate applied in July at 2.25 kg a.i. ha^{-1} gave 83% to 99% kill (Miller 1995), whereas glyphosate applied in July at 3 kg a.i. ha^{-1} in NSW, gave 52% kill (Campbell and Gilmour 1979).

Plant variation was expressed at Berridale and Tuena NSW as seedheads with lime green glumes and flowering stalks instead of the normal maroon glumes and brownish-maroon stalks. Seed collected from the Tuena 'albino' tussock was viable and plants grown from them produced 'albino' seedheads (Campbell unpublished data).

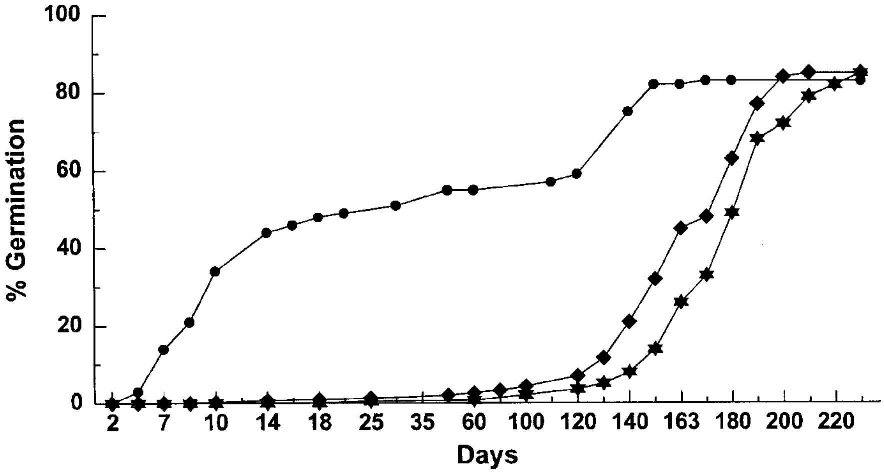

Figure 1. Effect of maturation of serrated tussock seed collected near Trunkey NSW on germination. Seed germinated in petri dishes at 17° to 25°C starting on 30 January 1997. Seed collected 12 December 1995, stored for 13 months before germination began: untreated (—●—). Seed collected 16 December 1996, stored for 1.6 months before germination began: untreated (—♦—); treated at 36°C for 20 days in an oven (— ✶ —).

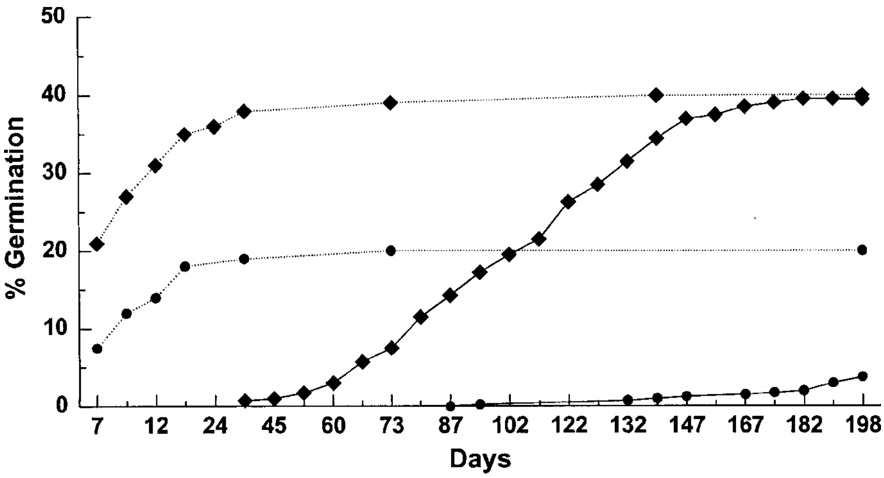

Figure 2. Effect of cutting off the awn end of serrated tussock seed and adding gibberellic acid + KNO_3 on germination: uncut - GA (—●—); uncut + GA (—♦—); cut - GA (┈●┈); cut + GA (┈♦┈). Seed collected from Trunkey NSW on 12 December 1995 and stored for two months before germination began in petri dishes at 17° to 25°C.

Table 1. Effect of time of storage on germination of serrated tussock seeds collected at Gallymont NSW on 20 December 1994.

Storage time (months)	Period of germination (days)	Final germination (%)	Rate of germination (days to 50% of final)
3	320	30 d[A]	110 a
4	320	51 c	80 b
5	280	59 bc	31 c
6	240	53 bc	19 c
7	180	73 a	31 c
8	180	61 b	28 c
14	90	52 bc	14 c

[A] Values in columns not followed by a common letter differ significantly at $P<0.05$.

Control

Prevention

Invasion of serrated tussock can be prevented by removing plants as they appear (Campbell 1977a). There are many examples of diligent landholders who have kept their properties free despite heavy adjacent infestations (Fallding 1957, Dellow 1975).

Chipping

Chipping is effective provided all roots are severed and, in wet conditions, soil is shaken from them (Dingwall 1969). New Zealand experience showed that chipping, after other control measures were imposed on heavily infested areas, resulted in a decrease in the density of tussocks in the first five years, but no corresponding decrease in chipping time until the sixth year (Dingwall 1969).

Spot spraying

Landholders in NSW prefer spot spraying to chipping because it: is faster, especially in patches and rocky areas; does not disturb the soil and provide a 'seedbed' for reinfestation; and is cheaper. In New Zealand in the late 1960s chipping gave way to spot spraying when time for chipping exceeded 15 man-hours ha^{-1} (Dingwall 1969). Although increased labour costs since then have reduced this time barrier, chipping is still the favoured method for controlling scattered plants in New Zealand (Denne 1988). A disadvantage of spot spraying is that some native grasses, e.g. *Danthonia* spp. and *Microlaena stipoides*, are killed by flupropanate (Keys and Simpson 1993, Campbell and van de Ven 1996). To minimize this, flupropanate should be applied at the recommended rate to the individual tussock and not to the surrounds.

Burning

Although serrated tussock burns readily in winter, it recovers while most associated species are killed (Healy 1945). Burning is only useful to remove foliage before ploughing, prevent seeding or to assist the effectiveness of 2,2-DPA (Campbell 1961). Burning before or after the application of flupropanate reduces its effectiveness (Campbell 1996) and results in massive seedling infestation because the physical barrier of dead leaves is removed and with it the flupropanate that is otherwise leached from the leaves to kill establishing seedlings (Campbell *et al.* in press).

Grazing

Cattle and sheep cannot control serrated tussock by grazing even when they are supplemented with urea and molasses or a nutritious block lick (Campbell and Barkus 1965, Campbell and Irvine 1966). Goats were successful in controlling the weed when it constituted 10% of an improved pasture (Campbell *et al.* 1979b) but were unsuccessful when it occupied 50% (M.H. Campbell and P.J. Holst unpublished data).

Cultivation

On arable land serrated tussock can be controlled by ploughing, sowing an improved pasture and then spelling for one year (Healy 1945). The more thorough the cultivation the better the control of the mature tussocks (Table 2) (Campbell 1960b, 1963a, 1985). If possible, one or two crops should be sown before the pasture to reduce weed seed reserves in the soil. The pasture must contain legumes, to raise soil fertility and smother serrated tussock seedlings (Table 2), a strongly perennial grass, preferably phalaris, to reduce reinfestation (Campbell 1985) and be adequately fertilized to promote growth.

Herbicides

In the late 1970s the effects of glyphosate and flupropanate were ascertained, the latter proving, despite its slow action, effective in any season of the year when applied at 1.5 kg a.i. ha^{-1} (Table 3); it was most effective from November to February (Campbell and Gilmour 1979, Campbell *et al.* 1979a). As flupropanate mixed easily with water, had low toxicity for mammals and fish, could selectively remove serrated tussock from sown pastures (Campbell 1979, Campbell *et al.* 1979a, Campbell and Ridings 1988) and was cheaper ha^{-1} than glyphosate, it became the recommended herbicide (Campbell 1980, 1985). Subsequent research showed that rates of flupropanate lower than 1.5 kg a.i. ha^{-1} were effective on mature plants (Campbell 1981) and that mixtures of 2,2-DPA + flupropanate could increase the rate of kill of the weed (Campbell and Murison 1985). It was most selective when applied in late spring, killing serrated tussock but leaving subterranean clover and sown grasses (Campbell 1987b); if applied in autumn it kills the clover seedlings. Flupropanate is effective when applied by wiping which improves its selectivity (Campbell and Nicol 1998).

A search for an alternative to flupropanate, due to the recommended retail price rising from \$A15 L^{-1} in 1978 to \$A35 L^{-1} in 1994, has shown that it was more effective than quizalofop (0.2 kg a.i. ha^{-1}), fluazifop (0.4), clethodim (0.5), sethoxydim (0.6), imazapyr (0.4), and the sulfonylurea DPX-E9636 (60 g a.i. ha^{-1}) (Campbell and Vere 1995). Glyphosate proved effective in Tasmania and Victoria (Miller 1995) but ineffective in NSW because large plants prevented the herbicide from hitting small plants and a high rate (5 kg a.i. ha^{-1}) had to be used which killed useful species (Campbell and Gilmour 1979).

Herbicide treatment alone results in reinfestation of the weed from seed in the soil. For permanent control it is essential to sow improved pastures to replace the weed (Beggs and Leonard 1959, Campbell 1964, 1974, 1977c) or to remove it selectively from an established pasture (Campbell 1979).

Seedling control

Flupropanate, residual in the soil and in dead tussock leaves, was found to kill serrated tussock seedlings that germinated soon after spraying by restricting the root, and particularly, shoot growth (Campbell and Murison 1987). Seedlings 8–18 months old infesting introduced pastures were selectively removed with 0.37–0.56 kg a.i. ha^{-1} flupropanate (Campbell 1997a), a finding which could initiate a new philosophy in control. For example, if, after treatment of a mature infestation by ploughing or spraying, serrated tussock seedlings were selectively removed after their first massive reinfestation with a low rate of flupropanate, there may be no need to spray again for some years. The advantages of this technique are that seedlings are all of a similar age and susceptible to low rates of flupropanate and, native grasses that are killed by the recommended rate of 1.5 kg a.i. ha^{-1} may tolerate

Table 2. Number of tussocks 5 m^{-2} after chisel ploughing in 1957 and 1958 and sowing an improved pasture in 1958; and their decline over time due to competition from the pasture (Campbell 1963a).

Chisel plough treatments in July 1957 and February 1958	Mature tussocks				Seedling tussock			
	1958	1959	1960	1961	1958	1959	1960	1961
July, wings twice +Feb., wings once	6 a[A]	6 a	3 a	1 a	139 a	6 a	0 a	0 a
July, chisels once +Feb., wings once	3 a	7 ab	3 a	2 a	108 ab	12 a	12 a	3 a
July, chisels once +Feb., wings once	12 a	12 ab	5 a	3 a	56 bc	8 a	7 a	2 a
Feb., chisels once +wings once	30 b	23 b	12 ab	6 a	49 c	8 a	5 a	3 a
Feb., chisels once	86 c	55 c	21 b	10 a	41 c	4 a	0 a	0 a

[A] Values in columns not followed by a common letter differ $P<0.05$.

the low rates. If reinfestation was allowed to occur for 10 years then a high rate of flupropanate would be needed to kill the mature tussocks.

Seedhead prevention

Seedhead production of serrated tussock can be prevented by applying glyphosate at 0.22 to 0.45 kg a.i. ha^{-1} from 2 to 8 weeks before seedhead emergence begins i.e. in September, October or November (Campbell *et al.* 1998).

Aerial techniques

On non-arable land serrated tussock can be controlled by aerial application of herbicide, seed and fertilizer (Beggs and Leonard 1959, Campbell 1964, 1974, 1985, Campbell *et al.* 1978) but because of the inherent difficulties, it is preferable to cultivate if possible. Control depends on replacing the weed with a strongly competitive pasture. Because aerially sown pastures establish more slowly than ground-sown pastures, spelling must be enforced for the first three spring-summer periods after sowing (Campbell 1985). The objectives are to smother seedling serrated tussock, improve soil fertility and promote dominance of phalaris; once achieved, serrated tussock can be selectively removed by aerial application of flupropanate should reinfestation occur (Campbell 1979).

Afforestation

Serrated tussock has been controlled by planting *Pinus radiata* D.Don in New Zealand and Australia. The trees, which took 10 years to kill the weed and six years to stop it seeding, were established after serrated tussock had been sprayed, cultivated, ripped or graded. Rabbits and grazing animals were excluded and firebreaks made. The cost of such treatment in 1996 was \$A1500 ha^{-1}.

Taylor (1987) showed that the growth rate of serrated tussock seedlings was reduced 96% by restricting sunlight by 90%. However growth rate at 50% and 30% of sunlight was only moderately reduced which indicates that a dense tree cover is necessary to kill the weed.

Afforestation offers an alternative method of control to pasture improvement. In country with high rainfall, fertile soils and a slope of <14º, *P. radiata* could be grown for profitable timber production. However, much of the serrated tussock that cannot be controlled profitably by pastures (Vere *et al.* 1993) occurs on country with low rainfall, infertile soils and slopes of >14º. In these situations trees could be planted to control the weed with little prospect of profit which means there needs to be publicly funded acquisition - closure of such lands (Vere and Campbell 1984, Vere *et al.* 1993). Research into low cost methods of establishing trees on this type of country (Campbell and Nicol 1996) indicates that some eucalypts, e.g. *Eucalyptus viminalis*, establish well from aerial sowing and direct drilling and *P. radiata* establishes well from direct drilling, provided weeds were controlled (Campbell and Nicol 1996). Whereas *P. radiata* provides sufficient shade to kill serrated tussock, the eucalypts may not but they could reduce seed production. In the most unfavourable environments it may not be possible to grow *P. radiata* but eucalypts will survive to compete with the weed.

Table 3. Effect of time and rate of application of flupropanate on kill (%) of serrated tussock (Campbell *et al.* 1979a).

Rate of flupropanate (kg a.i. ha^{-1})	(Lha^{-1} product)	Time of application: Feb	May	Aug	Nov
0.67	0.9	84 b[A]	42 c	41 c	99 a
1.00	1.3	98 a	76 b	77 b	99 a
1.33	1.8	100 a	99 a	94 a	100 a
1.67	2.2	100 a	100 a	97 a	100 a
2.00	2.7	100 a	100 a	99 a	100 a

[A] Means not followed by a common letter differ P<0.05.

Windbreaks

A single row of *P. radiata*, separating two paddocks, in New Zealand reduced infestation of the paddock on the windward side of a heavy infestation (Campbell 1963b). However this was in relatively flat country. In hilly country windbreaks may not be effective.

Shrubs

Kunzea ericoides controls serrated tussock in areas with infertile soils and low rainfall near Berridale NSW. Other shrubs that have some economic return could be trialed to determine whether they could control the weed at a profit.

Natural enemies

No natural enemies have been found in Australia that have inflicted more than minor damage on serrated tussock. Some subterranean caterpillars, notably *Oncopera alboguttata* in 1961 and 1964 and *O. rufobrunnea* in 1993, have killed small areas in NSW. No research has been conducted on biocontrol because it was believed that any agent that attacks serrated tussock would also attack useful grasses. However, because of advances made over the past 40 years and because it is unprofitable to control serrated tussock on infertile soil in low rainfall areas at present (Vere and Campbell 1984, Vere *et al.* 1993), there is a revived interest in biological control. The first step in this direction was taken in 1995 when two unknown agents found attacking the weed in 10 sites in Argentina were collected. Further studies of the biocontrol of this weed are essential if it is to be controlled in non-agricultural areas e.g. National Parks.

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Land management of *Nassella* areas – implications for conservation

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Summary

The spread and control of *Nassella* spp. is likely to impact mainly on open and grassy woodland communities which contain many threatened species. Some well-managed native grassland remnant areas have shown resistance to invasion by serrated tussock and Chilean needle grass, but further documentation is needed. Techniques are being developed for selective removal of these *Nassella* spp. from native grassy swards and for their replacement with native grasses. The effects of selective spraying on forb diversity are unknown. Land management practices for *Nassella* control comprises ploughing, blanket herbicide spraying and tree planting. However, surveys for native remnants should be carried out prior to commencing works, and the comparative value of keeping native remnants as weed-resistant and drought-tolerant pastures should be assessed. Chilean needle grass constitutes a high level threat because of its apparent rapid spread into a range of grassy ecosystems and detrimental effects on biodiversity. The effects on biodiversity and methods of control for the other *Nassella* spp. are unknown and need urgent attention.

Introduction

I will describe in detail the issues and requirements for control of *Nassella* spp. in the conservation context and briefly reflect on the implications for conservation of some of the current agricultural approaches to serrated tussock control. Comparisons of control methods will be made for the issues and requirements for conservation. Reasons why conservation and agricultural interests would best be served by a joint approach to the *Nassella* problem are discussed.

Setting conservation needs in the overall land management context

A clear understanding of the biology and ecology of a weed is essential for its control. However, it is not necessary to find out everything about a species before taking action. Serrated tussock is out of control and this may also apply to Chilean needle grass. Possibly other *Nassella* spp. are close to becoming problems in Victoria. Documentation of likely methods of control coupled with properly constituted field trials will add to our knowledge, particularly in the conservation context, and highlight those areas of the biology of these species most in need of investigation.

Conservationists and other land managers have the same underlying problem: how to deal with *Nassella* spp. that are actively spreading. In most cases the requirements for conservation and other land management approaches will overlap. The full effect on biodiversity by the spread of *Nassella* spp. is unknown, but likely to be major. We do know that a reduction in biodiversity reduces agricultural productivity, and that the converse applies. We must therefore be wary of simple solutions that have as a by-product the simplification of the ecosystems within which agricultural production takes place.

The need for co-ordination between conservation and agriculture

It has been argued (Hocking 1995) that a conservation focus on control of serrated tussock could make many useful contributions to the overall solution of the serrated tussock problem. In this paper I propose that:

- there will be no solution unless those with primarily agricultural or conservation perspectives resolve differences in approaches and come to common outlooks and actions; and
- threats posed by other *Nassella* spp. to both agriculture and conservation will multiply rapidly if there is not a combined effort to solve these problems.

Much of biology and ecology of *Nassella* spp. parallel those of native tussock grasses. Both groups are fire adapted, resprouting after fire and retaining dead leaf material to promote fire frequency. Both are able to survive long periods with minimal water, and are characterized by growing on soil with apparently low nutrient levels (native grasses, and probably *Nassella* spp., lower available nutrient levels in the soil by incorporating them into leaf and root biomass). Both types of grasses have seeds with relatively large awns and are adapted to ecosystems with similar climatic patterns. Despite some differences between the *Nassella* spp. and native grasses (e.g. many native grasses have C4 photosynthesis whereas all *Nassella* spp. are C3 species), comparisons between their biology, ecology and competitive relationships in conservation contexts should provide valuable information about how to counter the *Nassella* weeds in the wider land use context if the