But through the greater part of Victoria these conditions do not apply, and dense growths of plants formerly unknown or uncommon in an area are cause for concern.

While there are several introduced grass species that form extensive single-species swards, most of these are rhizomatous, such as *Pennisetum clandestinum* (kikuyu) and *Cynodon dactylon* (couch), or annuals such as *Briza* species (blowfly grasses), *Vulpia* species (squirrel-tail fescues or silver grasses), *Avena* species (oat-grasses) and *Schismus barbatus* (Arabian grass).

Tussock-forming perennials that occur in dense, uniform stands, readily displacing the 'resident' species or communities, include *Phalaris aquatica* (canary grass) and *Lophopyrum elongatum* (tall wheat-grass). Both of these deep-rooted species have been extensively grown in areas prone to salination. They are both now proving to be a severe threat to native grassland communities. Both have flattish leaf-blades, the former to 20 mm wide, the latter to approximately 6 mm wide. Both are readily distinguished from stipoid grasses by the absence of awns on the lemmas, and by the narrow, more or less cylindrical inflorescences.

Should Table 1 not provide a satisfactory identification of a grass believed to be a member of the Stipeae, or if other grasses, unknown to local agriculture officers, are proving cause for concern, a flowering or seeding specimen should be forwarded to an appropriate agency for expert identification (usually the State Herbarium, situated in each of the Australian capital cities). The specimen may represent the first wave of the invasion of a potentially troublesome or devastating weed and its early detection and eradication could save untold expense and hours of labour.

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The distribution and impact of South/North American stipoid grasses (Poaceae: Stipeae) in Australia

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Abstract

The current and potential distribution of ten introduced South/North American stipoid grass weeds is documented. The known ecology and the impacts on agriculture and the indigenous vegetation are presented. *Nassella trichotoma* has significant impacts on both agriculture and the environment. *N. neesiana* is among the most serious environmental weeds of grassland and grassy-woodland communities in southeast Australia. *N. leucotricha* and especially *N. hyalina* are serious environmental weeds of grassland communities, particularly on the Victorian Volcanic Plains. *Achnatherum caudatum* and *A. brachychaetum* have the potential to become very serious agricultural and environmental weeds, as they possess abundant cleistogenes that promote dispersal and survival under cultivation. *A. brachychaetum* remains poorly known due to its similarity and confusion with *A. caudatum*. *N. charruana* poses a significant weed threat due to its invasiveness and unpalatibilty. *N. megapotamia* and *Piptochaetium montevidense* are poorly known species with little to no information available on their ecology and weed status in Australia. Attempts to eradicate *Jarava plumosa* in South Australia have proved difficult. Ten recommendations are made.

Introduction

Many potential weeds are regarded as 'sleepers' whose populations may slowly increase (lag phase) but not be noticed for many years, before they increase dramatically making eradication almost impossible. Groves (1986) divided this weed invasion process into three phases. An introduction phase (the process of invading a previously unoccupied region), a colonization phase (the process of being able to survive and reproduce, producing a self-perpetuating population) and a naturalization phase (the weed disperses widely and creates further self-perpetuating populations which become incorporated into the resident flora). The introduction of several South and North American stipoid species into Australia has raised concerns about the impacts these grasses could have on both agriculture and the environment.

The Stipeae (Family: Poaceae) is a cosmopolitan tribe of approximately 450 species in 14 genera (Barkworth 1993, Reyna and Barkworth 1994, Jacobs and Everett 1996). Including the indigenous genus *Austrostipa*, there are six stipoid genera in Australia, five of which are of exotic origin. These are *Achnatherum*, *Jarava*, *Nassella*, *Piptochaetium* and *Piptatherum*. *Achnatherum* is the largest and most widespread genus. It occurs in Africa, Eurasia, New Zealand and North and South America (Barkworth 1993) but is primarily of Eurasian / North American origin. *Jarava*, a recently resurrected genus (Jacobs and Everett 1997), is endemic to South American. *Nassella* is essentially from South America while *Piptochaetium* is from both North and (mainly) South American. *Piptatherum* is (mainly) Eurasian but is also represented in North America and is represented by only one species in Australia, *P. miliaceum* (L.) Coss. As this species appears to be confined to urban settlements (Walsh and Entwisle 1994) it will not be considered. Species of the other genera are cause for serious alarm from both an environmental and agricultural perspective.

In Australia 11 species of exotic stipoid species are naturalized. They are: *Achnatherum brachychaetum* (Godron) Barkworth, *A. caudatum* (Trin.) S.W.L. Jacobs & J. Everett, *Jarava plumosa* (Sprengel) S.W.L. Jacobs & J. Everett, *Nassella charruana* (Arech.) Barkworth, *N. hyalina* (Nees) Barkworth, *N. leucotricha* (Trin. & Rupr.) Pohl., *N. megapotamia* (Spreng. ex Trin.) Barkworth, *N. neesiana* (Trin. & Rupr.) Barkworth, *N. trichotoma* (Nees) Hack. ex Arechav., *Piptatherum miliaceum* and *Piptochaetium montevidense* (Spreng.) Parodi. Due to the resemblance of these South / North American stipoid species with indigenous *Austrostipa* species, they can be easily overlooked as weeds, increasing their likelihood of successful naturalization.

The ability of a weed to invade, reproduce and increase is largely dependent upon habitat and its adaptive characteristics (i.e. dispersal adaptations, seed production etc.). Habitat has been defined as 'the sum of the factors at a point in space that may affect a plant's ability to survive and to contribute to the next generation' (Cousens and Mortimer 1995). These may include abiotic factors such as climate (temperature, rainfall, humidity), soil type, day length, and biotic factors such as competition from neighbouring plants, predators and diseases.

Since the factors defining the suitability of a habitat to a particular weed may be unknown, computer models which create an empirical set of parameters based on current distribution can be used to describe areas for weed survival. These parameters can then be used to predict the potential spread of weed species by analysing the climatic variables where the species is naturalized (Pheloung and Scott 1996, Cousens and Pheloung 1996). A climate matching system called CLIMATE has been developed by Agriculture Western Australia from the concepts contained in the BIOCLIM (Busby 1991) and CLIMEX (Sutherist and Maywald 1985) prediction systems. The CLIMATE system generates a prediction of a species' distribution based on the climate of its known distributions and is used particularly where detailed biological data on a species are lacking. It does not take into consideration soil type, day length or biotic factors and as such may represent an overestimate of the plant's potential distribution.

Predictions of a species' distribution based on its climatic potential are useful when making management decisions as they allow land managers to identify land at risk of infestation. This may provide a focus on a species, which may have otherwise escaped attention. It can act as a useful aid for making decisions on:

i. Declaration of a species as a noxious weed.
ii. Assessing possible environmental and agricultural impacts.
iii. Assessing and developing guidelines for importation of plants into Australia.
iv. The future direction of weed research and weed control resources.

Materials and methods

Thirty-five herbaria across Australia were contacted for collection records for all species of *Achnatherum*, *Jarava*, *Nassella* and *Piptochaetium* recorded in Australia. Departments of Agriculture and Natural Resources and Environment were also contacted for species' distribution data. Further data were obtained from the observations, fieldwork and collections by Stajsic and Gardener. These data were then mapped in ARCVIEW (ESRI 1996).

The maps for *N. trichotoma*, were compared with past surveys from New South Wales (Campbell 1977) and Victoria (Lane *et al.* 1980) to determine the increase in spread over the last 20 years.

A climate analysis was used to determine the potential distributions of each species. Latitude, longitude and altitude data were obtained from a representative sample of sites for each species in Australia. They were analysed by the BIOCLIM program (Nix 1986) using the CLIMATE system to predict areas in Australia that possess similar climatic profiles.

Results and discussion

Serrated tussock, *Nassella trichotoma*

Nassella trichotoma is a perennial, drought resistant species that is native to the pampas grasslands of Argentina, Uruguay, Chile and Peru (Parodi 1930, Rosengurtt *et al.* 1970) and has been reported from Bolivia (Walsh and Entwisle 1994).

Nassella trichotoma is a proclaimed noxious weed in the Australian Capital Territory, New South Wales, Victoria, South Australia and Tasmania and has been described as potentially causing greater reductions in carrying capacity than any other plant in Australia (Parsons and Cuthbertson 1992). It has also naturalized in New Zealand and South Africa while small infestations also occur in England, France, Italy, Scotland (Campbell 1982, Stace 1997) and in the United States (Westbrooks 1991, Westbrooks and Cross 1993).

Nassella trichotoma was probably introduced into Australia in the early 1900s but was not recorded in Australia until 1935 when a collection was made at Yass (55 km N.E. of Canberra) (Campbell and Vere 1995, Figure 1). However, the earliest lodged collection is based on a specimen collected at Yass on 7 February 1936 (NSW Herbarium, specimen No 115759) and a further two collections were made later that year, also at Yass. In 1977 it occupied 680 000 ha (Campbell 1977) and now occupies more than 870 000 ha in New South Wales with an estimated 2 000 000 ha at risk of infestation (McGowan personal communication, Figure 1). In Victoria *N. trichotoma* was first collected on 19 December 1954 at Broadmeadows (15 km N.N.W. of Melbourne). By 1979 it had spread to occupy approximately 30 000 ha (Lane *et al.* 1980) and by 1998 it occupied in excess of 130 000 ha (Pest Management Information System, Keith Turnbull Research Institute, Figure 1). *N. trichotoma* is also found in Tasmania where it was is was first recorded in 1956 (Parsons and Cuthbertson 1992) and is currently spread in scattered populations over an area of approximately 1000 ha (C. Goninon personal communication).

By using CLIMATE, the potential distribution of *N. trichotoma* in Australia has been estimated at 32 million ha (best prediction only, Figure 2) with substantial areas of New South Wales, Victoria and Tasmania at risk of invasion.

In 1988, *N. trichotoma* was estimated to cost the Australian Wool Industry approximately $12.9 million annually (Sloane *et al.* 1988). A recent report produced (Aberdeen 1995) stated that Victoria could save approximately $35 million per year if it restricted the distribution of *N. trichotoma* to 200 000 ha. A conservative figure for the cost of *N. trichotoma* in Victoria is $5 million per year (Nicholson *et al.* 1997) and for New South Wales $40 million per year (Jones and Vere 1998).

In contrast to the vast literature on the impacts of *N. trichotoma* on agricultural productivity, there is little on its environmental impacts. Carr *et al.* (1992) classified *N. trichotoma* as a very serious environmental weed that invades dry coastal vegetation, lowland grassland, grassy woodland, sclerophyll forest and woodland and rocky outcrop vegetation (Table 1).

Chilean needle grass, *Nassella neesiana* (Syn. *Stipa neesiana* Trin. & Rupr.)

Nassella neesiana is a tufted perennial that is becoming a serious pasture and environmental weed in south eastern Australia. It is indigenous to Argentina, Bolivia, Chile, Ecuador, Southern Brazil and Uruguay (Rosengurrt *et al.* 1970). This species is a serious weed in New Zealand (Bourdôt and Hurrell 1989). It has also been recorded in south east England (Stace 1997) and has been found on ballast dumps such as in Mobile, Alabama (US Department of Agriculture 1953) in the United States but there have been no recent records according to Barkworth (1993).

The earliest known collection of *N. neesiana* in Australia was made in October 1934 in Northcote, an inner northern suburb of Melbourne (MELU specimen) but was 'originally identified as *Stipa elatior* (*S. scabra* var. *elatior*)' i.e. *Austrostipa flavescens* (Figure 3). In New South Wales, the earliest known collection was made in 1944 at Glen Innes on the New England Tablelands (284 km S.W. of Brisbane) (Figure 3). *N. neesiana* is also naturalized in South Australia where it was first recorded from Lucindale (265 km S.E. of Adelaide) on 18 November 1988 and 'it does not seem at this stage that it is causing any trouble' (J.P. Jessop, AD Herbarium, personal communication). In New South Wales the species is declared as a category W3 noxious weed in the New England tablelands, Severn Shire County and the Glen Innes municipality, while it has yet to be declared in Victoria and South Australia (J. Fisher personal communication).

Currently there are no published estimates of the area infested with *N. neesiana* from any of the three states where it occurs. By using CLIMATE, the potential distribution of *N. neesiana* has been estimated at 41 million ha (best prediction

Table 1. Vegetation impacts of exotic stipoid species.

Species/Vegetation formations invaded	Locations	Species associated/Invaded/Reference
Serrated tussock, *Nassella trichotoma*		
Dry coastal vegetation	• Torquay (81 km S.W. of Melbourne)	*Leptospermum laevigatum, Melaleuca lanceolata, Leucopogun parviflorus, Poa poiformis, Poa labillardieri* (P. Wlodarczyk personal observation)
Lowland grassland and grassy woodland	• Bacchus Marsh, Melton, Exford, Parwan, Melbourne Airport (20–50 km W. of Melb.)	Grey box, *Eucalyptus microcarpa* – understorey species being seriously threatened. (V. Stajsic, D. McLaren personal observation)
	• St. Albans, Rockbank, Mt. Cotterell, Melton, Bailliang E. (20–50 km W. of Melb.)	*Austrostipa / Austrodanthonia* dominated grasslands, *Themeda triandra* (V. Stajsic, D. McLaren, G. Carr, C. Hocking personal observation)
Roadside reserves	• Geelong area (70 km W. of Melbourne)	*Themeda triandra* (M. Trengrove personal observation)
Dry sclerophyll forest	• Plenty Gorge Park (20 km N.W. of Melb.)	*Eucalyptus melliodora, E. leucoxylon* ssp. *connata, E. goniocalyx* (V. Stajsic personal observation)
	• Studley Park (8 km N.W. of Melbourne)	*Eucalyptus leucoxylon* ssp. *connata* (G. Carr personal observation)
	• St. Andrews (35 km N.E. of Melbourne)	*Eucalyptus goniocalyx, E. macrorhycha* (P. Wlodarczyk personal comm.)
Rocky outcrop vegetation	• Werribee River (33 km W. of Melbourne), Deep Creek (35 km N.W. of Melbourne)	*Themeda triandra, Austrostipa* sp., *Austrodanthonia* sp., *Poa sieberiana, Echinopogon ovatuss, Bothriochloa macra* (V. Stajsic, D. McLaren personal observation)
Chilean needle grass, *Nassella neesiana*		
Lowland grassland	• Derrimut and Laverton North grassland reserves (18 km W. of Melbourne)	*Themeda triandra* (M. Bartley personal communication)
Grassy woodland	• Tarnagulla and Tooleen(123 km N. of Melbourne) flora reserves	Grey box, *Eucalyptus microcarpa* (Liebert, 1996)
	• Melbourne Airport (20 km N.W. of Melb.)	*Eucalyptus microcarpa* (V. Stajsic personal observation)
	• Long Forest Flora Reserve area at Coimadai (49 km N.W. of Melbourne)	*Eucalyptus microcarpa* (P. Wlodarczyk personal communication)
Riparian vegetation	• Lollypop Creek, Little River (You Yangs), Coimadai Creek (Long Forest Reserve 49 km N.W. Melbourne), Tullaroop Creek (N.E. of Clunes)	(V. Stajsic personal observation)
	• Tarnagulla (160 km NW Melb).	(Liebert 1996)
Cane needle grass, *Nassella hyalina*		
Grasslands	• Ravenhall, Tarneit, Rockbank, Organ Pipes National Park (20–30 km W.N.W. of Melb.), Turpin's Falls (85 km N.W. of Melb.), Sutherland Creek (70 km S.W. of Melbourne)	*Themeda triandra, Austrostipa* and *Austrodanthonia* species
	• Epping (20 km N. of Melbourne)	*N. charruana, Rosa rubiginosa, Plantago lanceolata, Bromus hordeaceus, Avena barbata, Cynosurus echinatus, Erodium botrys* (V. Stajsic personal observation)
Riparian vegetation	• Ravenhall, Barfold Gorge (90 km N.N.W. of Melbourne)	*Eucalyptus camaldulensis, Callistemon sieberi, Hymenanthera dentata* var. *angustifolia* and *Poa labillardieri* (V. Stajsic personal observation)
Texas needle grass, *Nassella leucotricha*		
Native grasslands	• Taradale (90 km N.W. of Melbourne), Tullaroop Creek (40 km N. of Ballarat), Mt. Ridley (30 km N. of Melbourne)	*Austrostipa/Austrodanthonia, Themeda triandra*
Lobed needle grass, *Nassella charruana*		
Native grasslands	• Thomastown (15 km N.N.E. of Melbourne)	*N. neesiana, N. hyalina, N. trichotoma, N. leucotricha, Phalaris aquatica* (V. Stajsic personal observation)
	• Janefield Reserve in Plenty Gorge Metropolitan Park (18 km N.E. of Melbourne)	*Kunzea phylicoides, Acacia pycnantha, A. mearnsii* and scattered *Eucalyptus melliodora, Poa labillardieri, Themeda triandra, Austrostipa rudis* and *Astroloma humifusum* (V. Stajsic personal observation)
	• Epping (20 km N.E. of Melbourne)	*N. hyalina* (abundant), *Rosa rubiginosa, Plantago lanceolata, Bromus hordeaceus, Avena barbata, Cynosurus echinatus, Erodium botrys* (V. Stajsic personal observation)
Uruguayan ricegrass, *Piptochaetium montevidense*		
Grassland	• Cherry Lake Altona (15 km S.W. of Melbourne)	*Themeda triandra* (G. Carr personal communication)
Short-spined needle grass, *Nassella megapotamia*		
Grassy woodland	• Black Mountain Canberra	Dry sclerophyll forest
Broad kernal espartillo, *Achnatherum caudatum*		
Riparian vegetation	• Dunnolly (150 N.W. of Melbourne) Tullaroop, Birch and Creswick creeks (120–130 km N.W. of Melbourne)	Threatening the vulnerable hairy anchor plant (*Discaria pubescens*) at Creswick Creek (McPhee and May 1992, V. Stajsic and E. Bruzzese personal observation)
	• Edgars Creek (8 km N. of Melbourne)	Melbourne (R. Hore, D. McLaren, V. Stajsic personal observation)
Narrow kernal espartillo, *Achnatherum brachychaetum*		
Grassland	• Merriwa (225 km N.W. of Sydney)	No data
Plumerillo, *Jarava plumosa*		
Grassland	• Waite Agricultural Inst. (South Australia)	*Austrodanthonia* spp. (dominant), *Convulvulus erubescens, Einadia nutans, Enchylaena tomentosa, Maireana enchylaenoides* (J.P. Gardner personal communication).

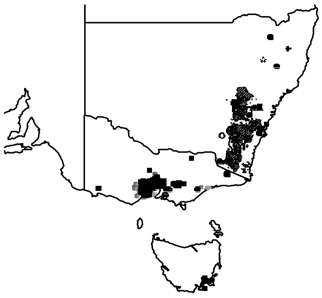

Figure 1. *Nassella trichotoma* 1935.

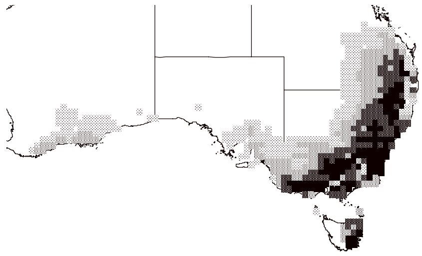

Figure 2. *Nassella trichotoma*.

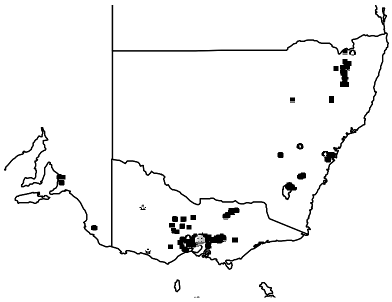

Figure 3. *Nassella neesiana* 1934.

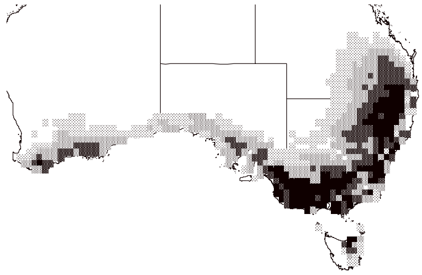

Figure 4. *Nassella neesiana*.

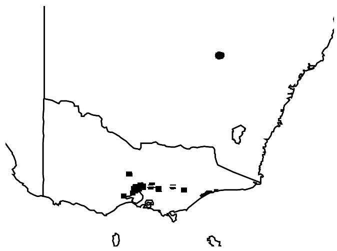

Figure 5. *Nassella hyalina* 1951.

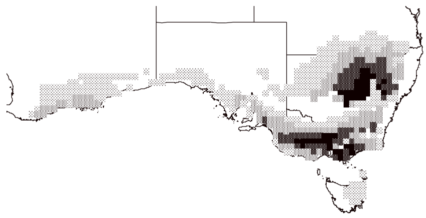

Figure 6. *Nassella hyalina*.

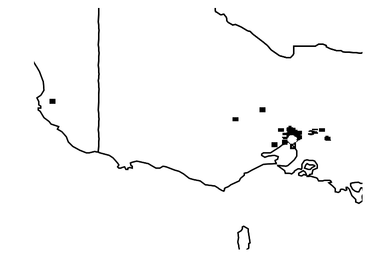

Figure 7. *Nassella leucotricha* 1934.

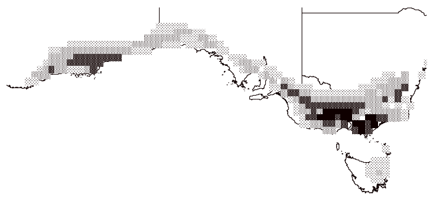

Figure 8. *Nassella leucotricha*.

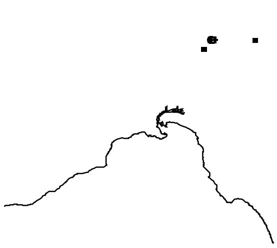

Figure 9. *Nassella charruana* 1995.

Figure 10. *Nassella charruana*.

Figures 1, 3, 5, 7 and 9: The first recorded actual distributions in Australia.

Figures 2, 4, 6, 8 and 10:

■ **Best prediction (10% of mean)**
▩ **(20% of mean)**
▩ **(30% of mean)**
□ **Worst prediction (40% of mean)**

only, Figure 4) with substantial areas of Victoria and New South Wales at risk. Likewise there have been no estimates or reports of the economic losses incurred by *N. neesiana.*

The competitive ability and efficient reproductive mechanisms of *N. neesiana* have enabled it to dominate large areas of highly productive pastures on the Northern Tablelands of New South Wales and on the Volcanic Plain of Victoria (Gardener and Sindel 1998). During warmer months it produces large numbers of unpalatable flower stalks and very little leaf material, resulting in a severe reduction in summer stock carrying capacity. Conversely, a reasonable quantity of good feed is produced during the winter months on the New England Tablelands (Gardener and Sindel 1998).

Nassella neesiana has been described as being potentially the worst environmental weed of indigenous grasslands in Victoria (C. Hocking personal communication). Carr *et al.* (1992) classified *N. neesiana* as a very serious environmental weed that invades lowland grassland, grassy woodland and rocky outcrop vegetation (Table 1).

It tolerates drought and heavy grazing and, at least in Victoria, it also tolerates soils or sites that are subject to seasonal water-logging such as at Derrimut and the Laverton North grassland reserves (V. Stajsic personal observation) and the Tarnagulla (160 km N.W. of Melbourne) flora reserve (Liebert, 1996). It has also been found on the alluvial flats that are subject to seasonal waterlogging at the Wattle Park (12 km E. of Melbourne) (G. Carr personal communication). Liebert (1996) comments that *N. neesiana* often establishes in damp depressions such as drainage lines and roadsides and then radiates out into the drier grassland. Its apparent drought tolerance and ability to tolerate seasonal waterlogging gives this species a wide ecological amplitude and potential to spread and overrun existing indigenous vegetation.

The presence of cleistogenes hidden at the base of the tillers (Gardener and Sindel 1998) allows this species to reproduce after most of the plant has been destroyed in a fire. The cleistogenes represent approximately 50% of the total annual seed production (R. Parsons personal communication) and in New Zealand it has been observed that frequent burning of sites promotes *N. neesiana* and assists it in forming a monoculture (Bourdôt personal communication).

Nassella neesiana is much more invasive in *Themeda triandra* dominated grasslands than is *N. trichotoma* (M. Trengove personal communication). In trial plots, *N. neesiana* has not only invaded areas of *T. triandra* but has also choked out *N. trichotoma* (Hunt 1996).

Nassella neesiana is frequently associated with watercourses, growing along the banks of streams or even on islands that are subject to temporary flooding. Floodwaters play a significant role in the dispersal of seeds (Liebert 1996).

Cane needle grass, *Nassella hyalina* (Syn. *Stipa hyalina* Nees)

Nassella hyalina is a tufted, perennial grass indigenous to Argentina, southern Brazil and Uruguay (Caro 1966, Rosengurrt *et al.* 1970). In Argentina it is a common species but is quite sparse and is of only intermediate feed value. It occurs predominantly on fertile soils in variable situations and is also found in woodlands (Rosengurrt *et al.* 1970, M. Gardener personal observation). It is reportedly palatable to stock (Rosengurrt *et al.* 1970) and is regarded as producing reasonable fodder. Currently it is reported as being naturalized in both Victoria (Walsh and Entwisle 1994) and New South Wales (Harden 1993). It was first recorded between Glen Innes and Inverell in central New South Wales in 1951.

In Victoria it was first recorded from a collection made at Woodstock on 24 January 1964. Major infestations are presently centred around the outer western suburbs of Melbourne and central Victoria (Figure 5, Table 1).

At Ravenhall, in the outer western suburbs of Melbourne, it has been observed that when the existing pasture is of low quality, *N. hyalina* is grazed. It is preferentially avoided when more palatable pasture species such as *Themeda triandra* and various *Austrostipa* and *Austrodanthonia* species are present (V. Stajsic personal observation).

Recently, an unusual mechanism of seed dispersal was observed. After seed drop, the penultimate stem node becomes fragile and can be broken by passing animals, wind or water. The apical section of the stem which contain the hidden stem seeds are thus dispersed (i.e. typical awned seed, not cleistogenes) (V. Stajsic and E. Bruzzese personal observation).

Carr *et al.* (1992) considered *N. hyalina* a serious risk as an environmental weed. It is primarily a weed of indigenous grasslands (Table 1) but has also been observed growing in areas subject to seasonal waterlogging and riparian vegetation

Walsh and Entwistle (1994) comments that *N. hyalina* commonly produces cleistogenes in its native countries, but the Australian material examined lacks these structures. However, it is unclear from the South American literature whether *N. hyalina* actually produces cleistogenes. This states that *N. hyalina* is predominantly cleistogamous (Rosergurrt *et al.* 1970). The terms cleistogamous and cleistogenous/cleistogene are confused. The term cleistogamous can be used to refer to the presence of cleistogenes. A cleistogamous flower is one that remains closed, is self-pollinating and sets fertile seed. A cleistogene is a hard awnless nut-like structure hidden at the base of the tiller within the leaf sheaths. They are different in appearance and structure from the inflorescence seeds. A cleistagomous floret does not necessarily produce a cleistogene, it either produces a 'seed' like that produced by the inflorescence or it can produce a cleistogene which is usually awnless, hard and nut-like.

By using CLIMATE, the potential distribution of *N. hyalina* in Australia has been estimated at 0.9 million ha (best prediction only, Figure 6) with substantial areas of Victoria and New South Wales at risk.

Texas needle grass, *Nassella leucotricha* (Syn. *Stipa leucotricha* Trin. & Rupr.)

Nassella leucotricha is a tufted perennial grass indigenous to Oklahoma, Texas and central Mexico (Leithead *et al.* 1971, Reyna and Barkworth 1994). Thus far, it has only naturalized in Victoria where it was first collected in October 1934 in Northcote, an inner northern suburb of Melbourne. By 1948, it was found approximately 14 km away in the suburb of North Brighton. It has since been collected from various northern and western suburbs of Melbourne, as well as from Taradale in central Victoria and near Mt. Beckworth (Figure 7). By using CLIMATE, the potential distribution of *N. leucotricha* in Australia has been estimated at 4.8 million ha (best prediction only, Figure 8) with substantial areas of Victoria at risk.

In Texas the species is known as either Texas needle grass or Texas wintergrass, it is readily grazed by livestock and is apparently of significant value for early spring or winter grazing (Leithead *et al.* 1971, Gould 1978). In its indigenous habitat, *N. leucotricha* thrives under conditions of moderate disturbance and is frequently abundant on roadsides, in open grassland sites and heavily grazed pastures (Leithead *et al.* 1971). To date no information is available about its fodder value in Australia.

In Victoria, *N. leucotricha* invades native pasture and native grasslands (Table 1).

Cleistogenes are produced in its native habitat but have not been observed in Australia (Walsh and Entwisle 1994). Unlike *N. hyalina*, the literature appears to be clearer concerning their presence (Dysterhuis 1945, Leithead *et al.* 1971, Barkworth *et al.* 1989). Their potential importance is indicated by studies of *N. leucotricha* that increased its density in response to grazing. This is partially attributable to the cleistogenes which provide a source of new plants even if the exposed panicles are grazed (Barkworth *et al.* 1989). Seeds are similar to *N. neesiana* and becomes readily attached to the hair and wool of grazing animals and can cause injury to stock (Leithead *et al.* 1971).

Lobed needle grass, *Nassella charruana* (Syn. *Stipa charruana* Arech.)

Nassella charruana is indigenous to Uruguay, Argentina and south east Brazil (Rosengurrt *et al.* 1970). It is a perennial that has a very distinctive seed with large apical lemma lobes (Rosengurrt *et al.* 1970). It forms dense competitive infestations in Australia (D. McLaren, V. Stajsic personal observation) and Argentina (M. Gardener personal observation). It provides productive winter fodder but its seeds can penetrate the fur and skin of stock (Rosengurrt *et al.* 1970). In Argentina *N. charruana* was regarded as very poor fodder. Unlike *N. trichotoma* and *N. neesiana* it was considered an extremely damaging noxious weed due to its invasiveness, competitiveness, unpalatability and very sharp and clinging seeds (M. Gardener personal observation).

It is naturalized only in Victoria and it was first collected and determined in 1995 at Thomastown (G. Carr personal communication). It has also been recorded at Janefield Reserve (C. Beardsal personal communication, V. Stajsic personal observation) and near Cooper St. Epping where it has been reportedly growing for more than 40 years (P. Haberfield personal communication) (Figure 9, Table 1). It was growing primarily in direct sunlight or light shade and appears to prefer wet depressions, but also grows on stoney rises. It was discovered on clay (grey/black cracking) which Rosengurrt *et al.* (1970) comments is the preferred soil type in South America.

The Department of Natural Resources and Environment has recently begun a program to eradicate this weed. At the Thomastown site, the infestation occurs in line with road works for the Western ring road. The infestation was sprayed prior to commencement of road works and contaminated soil was stockpiled at a known location to enable control of re-growth. The road works contractor was instructed to implement a vehicle hygiene program to reduce spread of the weed. At Janefield Reserve, a population of 105 *N. charruana* plants ranging from seedlings to adult plants were sprayed with glyphosate on 24 December 1997 (V. Stajsic personal observation). A large infestation (10–15 ha) at Cooper Street is currently being assessed for an extermination program over the next few months. A detailed survey and community awareness campaign will be implemented next spring when it is in flower and is easily identified. Young cattle will not eat it.

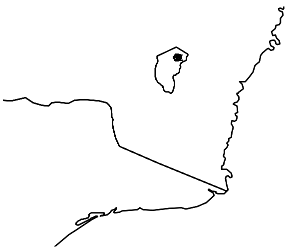

Figure 11. *Nassella megapotamia* 1961.

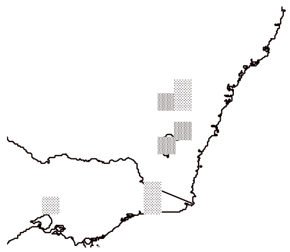

Figure 12. *Nassella megapotamia*.

Figure 13. *Piptochaetium montevidense* 1988.

Figure 14. *Piptochaetium montevidense*.

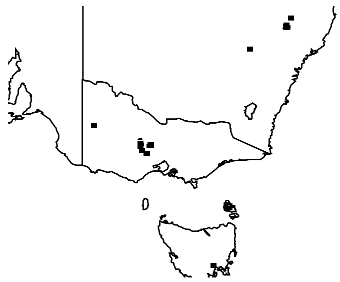

Figure 15. *Achnatherum caudatum* 1959.

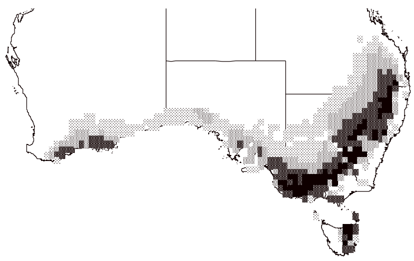

Figure 16. *Achnatherum caudatum*.

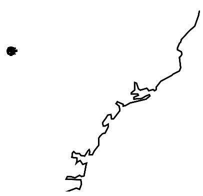

Figure 17. *Achnatherum brachychaetum* 1955.

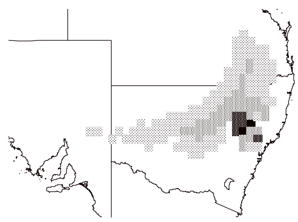

Figure 18. *Achnatherum brachychaetum*.

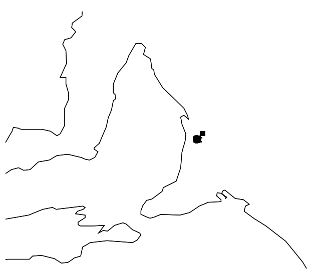

Figure 19. *Jarava plumosa* 1968.

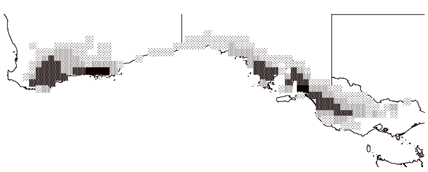

Figure 20. *Jarava plumosa*.

Figures 11, 13, 15, 17 and 19: The first recorded actual distributions in Australia.

Figures 12, 14, 16, 18 and 20:

■	**Best prediction**	**(10% of mean)**
▩		**(20% of mean)**
▦		**(30% of mean)**
□	**Worst prediction**	**(40% of mean)**

By using CLIMATE, the potential distribution of *N. charruana* in Australia has been estimated at 0.6 million ha (best prediction only) with a substantial area of Victoria at risk (Figure 10).

Short-spined needle grass, *Nassella megapotamia* (Syn. *Stipa megapotamia* Spr. ex Trin.)

Nassella megapotamia is indigenous to Argentina and Southern Brazil (Rosengurtt *et al.* 1970) where it inhabits undisturbed areas and is rarely found on grazed land. It is considered rare, palatable and of low to medium productivity potential. The seeds of *N. megapotamia* are considered innocuous (Rosengurtt *et al.* 1970). The first collection was made in 1961 at the CSIRO site at Black Mountain, Canberra (Figure 11) and it appears to be confined to this area. No collections have been lodged at the New South Wales and Canberra herbaria since the 1960s but it was still thought to be surviving at Black Mountain during the 1980s (S. Jacobs personal communication). It is apparently an escapee from the CSIRO plant introduction plots (R. Pullen personal communication). The environmental weed status of this species is unknown in Australia and an urgent survey of Black Mountain is required to determine the status of this species. However, *N. megapotamia* could be considered a potential environmental weed (M. Lazarides personal communication) with a potential distribution as indicated in Figure 12.

Uruguayan ricegrass, *Piptochaetium montevidense*

This grass is uncommon in Argentina and is a small perennial that produces many seeds. Its stock food value is unknown, its seeds cause no problems to stock and have low weed potential (M. Gardener personal communication). It is indigenous to Argentina, Bolivia, southern Brazil, Paraguay, Uruguay and Chile (Roig 1978).

It was first recorded in 1988 from Cherry Lake, Altona (G. Carr personal communication, Figure 13) and it is uncertain whether it is still extant. Its impact as an agricultural or environmental weed is unknown.

By using CLIMATE, the potential distribution of *P. montevidense* in Australia has been estimated at 0.6 million ha (20% prediction only) with only a relatively small area of Victoria at risk (Figure 14).

Broad-kernel espartillo, *Achnatherum caudatum* (Syn. *Stipa caudata* Trin.)

Achnatherum caudatum is a perennial densely tufted grass indigenous to Chile and Argentina (Rosengurtt *et al.* 1970, Caro and Sanchez 1971). *A. caudatum*, like the very closely related species *A. brachychaetum*, has been identified as a problem weeds in lucerne crops in both Argentina and California (Parsons and Cuthbertson 1992). In Chile and Argentina *A. caudatum* is regarded of being of little to no fodder value, inhabits fertile areas but its seeds are not harmful to stock. It is considered an aggressive plant on fallow lands of calcareous soils (Rosengurrt *et al.* 1970).

The earliest known collection in Australia was made in the Cootamundra district of New South Wales on 5 November 1959 and has since spread to the Deniliquin area (Parsons and Cuthbertson 1992) (Figure 15). In Victoria it was first observed near Dunnolly on 30 November 1984. It has also been collected from Cambells Creek near Castlemaine. According to McPhee and May (1992), *A. caudatum* was first introduced to Clunes in gravel, possibly during the 1970s. It has recently been found invading riparian vegetation along Edgars Creek, Coburg (Table 1).

This species also occurs in Tasmania. It was recorded on Flinders Island in 1979 (Parsons and Cuthbertson 1992) and on mainland Tasmania at Bridgewater and is declared as a noxious prohibited species. It has yet to be declared in New South Wales and Victoria.

In New South Wales, *A. caudatum* is becoming a serious weed, invading pasture particularly after cultivation. It invades resown pasture and becomes prominent by the third year. In native pasture it is limited to areas of disturbance and along fence lines. Near Clunes in Victoria, *A. caudatum* poses a serious threat to grazing production and an unknown threat to cropping and horticulture. It is a poor fodder plant but starving animals will feed on young plants that were still vigorous under heavy grazing pressure (McPhee and May 1992). At Maryborough, cattle were observed to feed on it where little or no other pasture species remained (V. Stajsic, E. Bruzzese personal observation).

Achnatherum caudatum is reportedly spread by water, particularly after flooding and by stock along stock routes (J. Cherry personal communication, McPhee and May 1992). It is also spread by slashing, mowing and soil disturbance by machinery along roadsides in the Maryborough, Talbot and Clunes areas (V. Stajsic personal observation, McPhee and May 1992). In Victoria, *A. caudatum* was observed invading riparian vegetation in central Victoria and Melbourne (Table 1).

The species produces abundant hard awnless 'nut-like' cleistogenes at the base of the leaf sheaths. The tussocks are spiny at the crown which may serve to protect the basal sheaths containing the cleistogenes (McPhee and May 1992).

By using CLIMATE, the potential distribution of *A. caudatum* in Australia has been estimated at 12.9 million ha (best prediction only) with a substantial area of Victoria, New South Wales and Tasmania at risk (Figure 16).

Narrow-kernel espartillo, *Achnatherum brachychaetum* (Syn. *Stipa brachychaeta* Godron)

Native to Uruguay, Chile and Central Argentina (Rosengurrt *et al.* 1970). In Chile and Argentina *A. brachychaetum* is regarded of being of little to no fodder value, inhabits fertile areas but its seeds are not harmful to stock. It is considered an aggressive plant on fallow lands with calcareous soils (Rosengurrt *et al.* 1970).

The earliest Australian record comes from Merriwa, New South Wales on 15 November 1955 (Figure 17). It has been difficult to obtain reliable data on this species in New South Wales due its close resemblance to *A. caudatum*. Like *A. caudatum*, *A. brachychaetum* produces cleistogenes in the lower leaf sheaths.

Achnatherum brachychaetum is listed by the Federal Government of the United States as a noxious weed and was collected from ballast near Portland Oregon and occurs in California (USA Department of Agriculture 1953, Barkworth 1993).

By using CLIMATE, the potential distribution of *A. brachychaetum* has been estimated at 0.6 million ha (best prediction only) with a large area of New South Wales at risk (Figure 18).

Plumerillo, *Jarava plumosa* (Syn. *Stipa papposa* Nees)

Jarava plumosa is indigenous to southern Brazil, Uruguay, Argentina and Chile (Roig 1978). Its seed has an apical pappus and is the only exotic stipoid species in Australia that has seed adapted for wind dispersal (Jacobs and Everett 1997). This is not to be confused with wind dispersed inflorescences of *N. trichotoma.* It is reportedly of little fodder value and its seed is irritable to stock (Rosengurrt *et al.* 1970). This species has been recorded in Catalonia in Spain (Fornell and De Blas 1985) and also at Berkley, California in 1983 but has not persisted (Barkworth 1993).

Jarava plumosa was first introduced as a potential pasture plant by the Waite Agricultural Research Institute, probably in the early 1940s and the first herbarium record came from a cultivated glasshouse specimen on 10 January 1941 (Gardner *et al.* 1996, Figure 19). The species has established itself periodically between 1968 and 1995 but it was not recorded as naturalized as it was confined to the Arboretum where infestations were grubbed out. However, in 1994 a population was discovered at South Parklands, bordering Adelaide which has also been grubbed out (Gardner *et al.* 1996). At the Waite Arboretum it grows on Urrbrae fine sandy loam (Gardner 1990).

By using CLIMATE, the potential distribution of *J. plumosa* has been estimated at 1.8 million ha (best prediction only, Figure 20) with a substantial area of South Australia and Western Australia at risk.

Conclusions and recommendations

The introduction and proliferation of exotic stipoid grasses over the past 100 years is seriously threatening agricultural productivity and the integrity of Australia's indigenous flora and fauna, particularly its grasslands. How these weeds have entered Australia is unclear. However, *N. trichotoma* was introduced into the United States in 1988 as a contaminant of eight shipments of tall fescue (*Festuca arundinacea* Schreb.) seed from Argentina. A recall of contaminated material was made in early 1989 but by then over 24 000 kg of contaminated seed had already been sold to retail customers in over 49 counties in Illinois, Kentucky, Missouri, North Carolina and South Carolina (Westbrooks and Cross 1993). It would be interesting to establish whether Australia has also received shipments of tall fescue or other seed from Argentina. Several exotic stipoid species appear to have originated from the northern suburbs of Melbourne. A former trotting stud located on Darebin Creek Epping, owned by a Mr. Tatlo, is rumoured to have been a source of 'needle grass' in the area. These were often referred to as 'Tatlo needle grass' (P. Haberfield personal communication). Other potential sources of introduction could be via cropping (oats and barley were planted in the locality during the 1930s) or from contaminated stock/fodder (dairying, sheep and pigs were common in this area) (P. Haberfield personal communication).

Nassella trichotoma is regarded as one of the worst agricultural weeds in Australia (Campbell and Vere 1995) and is also recognized as a serious environmental weed (Carr *et al.* 1992). It sets a precedent against which the impacts of other exotic stipoid species can be measured. The lesson we should learn is that prompt control action should be undertaken to eradicate these weed species before their populations get beyond extirpation.

Recommendations

1. A ban is placed on introduction of exotic stipoid grass species into Australia. The increased interest in grasses in landscaping will make it very tempting for the horticulture industry to import attractive exotic stipoid grasses.
2. That a weed alert system be put in place that links herbariums, weed experts, the horticultural industry and the community so that new weeds can be quickly identified and eradicated.
3. That a weed extermination contingency plan is formulated that will lay down a

framework to ensure that new, potentially disastrous weeds are destroyed before populations get out of control.

4. That research is conducted on the biology, ecology, digestibility, competitiveness and control techniques for these stipoid species.
5. That *N. charruana*, *N. megapotamia*, *A. brachychaetum*, *P. montevidense* and *J. plumosa* be exterminated.
6. That a biological control program is initiated against *N. trichotoma* and *N. neesiana* that could be extended to include *N. leucotricha*, *N. hyalina* and *A. caudatum*.
7. That an Australia wide 'exotic stipoid' awareness campaign is initiated that provides clear information on how to identify these weed species.
8. That where environmental impact studies are conducted with regard to physical works (i.e. roadworks), weeds as well as endangered species are considered so that vehicle/equipment hygiene procedures can be put in place to reduce weed spread.
9. That a program is initiated to investigate the impact of these weeds on flora and fauna biodiversity.
10. That research is undertaken into rehabilitation of infested lands, particularly with native species.

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The economics of serrated tussock in New South Wales

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Summary

Serrated tussock (*Nassella trichotoma*) is a grass native to South America which has become a serious weed in Australia, New Zealand and South Africa because firstly, it results in significant losses in livestock production due to heavy reductions in carrying capacity in infested pastures. Secondly, control by pasture improvement requires a large capital investment which hinders the adoption of control recommendations for many landholders. Thirdly, significant external costs can be attributed to this weed. Spread is generally by wind with seeds from uncontrolled areas travelling up to 20 km a day.

The distribution and density of serrated tussock has been surveyed for 19 local government areas in central and southern New South Wales. These data have been incorporated into a GIS which has been combined with data on soil fertility and rainfall to provide the necessary constraints for a regional linear programming model to estimate the production losses due to this weed. Econometric models of the wool and livestock industries were used to estimate the economic impact of serrated tussock on the New South Wales central and southern tablelands.

Introduction

Serrated tussock (*Nassella trichotoma*) is a grass native to South America and is a serious weed in Australia, New Zealand and South Africa. The threat posed by this weed was first recognized in 1935 in southern New South Wales after its introduction in fodder shipments imported during droughts. By the 1950s serrated tussock had occupied large areas of south-eastern Australia with most infestations occurring within areas bounded by a 21°C isotherm for mean January temperature and an average rainfall between 500 and 990 mm. This area covers most of the central and southern tablelands of New South Wales.

Serrated tussock has no grazing value because of its high fibre (86%) and low protein content (4%). Consequently infestations of this weed result in a significant loss in livestock production. Heavy infestations of serrated tussock can reduce the carrying capacity of both improved and natural pastures by as much as 90% while moderate infestations can reduce stock numbers by 40%.

The first survey of the area and distribution of serrated tussock was by Campbell (1977) who determined that the total area of infestations in New South Wales was 680 000 ha (Table 1). Campbell classified infestations into three densities:

i. dense infestations in which animal production was seriously diminished (Class 1),
ii. scattered patches with isolated plants interspersed which would soon increase to (i) in the absence of control (Class 2), and
iii. scattered plants with no heavy concentrations (Class 3).

Subsequent serrated tussock surveys by Campbell (1987) and Gorham (unpublished) in 1994 (Table 1) indicated that the area of serrated tussock had declined by about 30% between 1977 and 1987, but by 1994 the infested area of 740 716 ha had increased above the 1977 level of 680 000 ha. Campbell (1987) attributed the release of the chemical tetrapion as one of the significant reasons for the decline in serrated tussock by 1987. Gorham gave no reasons for the subsequent increase by 1994.

Serrated tussock has been the principal noxious weed in New South Wales for the past 15 years despite the development and extension of proven control technologies and the demonstration of the economic benefits of these methods in areas favourable to pasture improvement, as well as continued enforcement of control legislation by local government. The information derived from both the Campbell and Gorham surveys was collected using mail questionnaires to all New South Wales local government area (LGA) weed

Table 1. Estimated areas (ha) infested with serrated tussock in New South Wales by various surveys.

	Campbell (1977)	Campbell (1987)	Gorham (1994)
Class 1	71 200	47 000	55 268
Class 2	147 100	61 800	86 253
Class 3	461 700	382 600	599 195
Total	680 000	491 400	740 716