Distribution and diversity of exotic plant species in montane to alpine areas of Kosciuszko National Park

*Roxana Bear, Wendy Hill and Catherine M. Pickering**

School of Environmental and Applied Sciences, Griffith University, PMB 50 Gold Coast Mail Centre, Queensland 9726, AUSTRALIA.
*Corresponding author email c.pickering@griffith.edu.au

Abstract: Diversity and distribution of exotic plant taxa in Kosciuszko National Park in south-eastern Australia were reviewed based on 1103 records of exotics from 18 vegetation surveys conducted between 1986 and 2004. 154 taxa from 23 families were recorded in the alpine to montane zones, with eleven taxa in the alpine, 128 taxa in the subalpine and 69 taxa in the montane zone. Nearly all taxa were associated with anthropogenic disturbance with only four taxa exclusively recorded in natural areas. 62 taxa were recorded from subalpine ski resort gardens, and although not recorded as naturalised in the vegetation surveys, their presence in the Park is a concern.

Road verges provided habitat for numerous exotics (65 taxa). 44 taxa were recorded in both disturbed and natural locations but most were uncommon (33 taxa < 2% frequency). Nine common taxa *Acetosella vulgaris, Achillea millefolium, Agrostis capillaris, Anthoxanthum odoratum, Cerastium* spp., *Dactylis glomerata, Hypochaeris radicata, Taraxacum officinale* and *Trifolium repens* comprised 68% of records. These species are common to disturbed areas in other areas of Kosciuszko National Park, NSW and worldwide. The forb *Acetosella vulgaris* was the most ubiquitous species particularly in natural areas where it was recorded at 36% frequency. Based on the data presented here and a recent review of other data sets, there are at least 231 exotic taxa in the Park (including exotics in gardens). The increasing diversity and abundance of exotics is a threat to the natural values of this Park.

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Introduction

Mountain regions are biodiversity hot spots, with alpine regions worldwide estimated to have 8 000–10 000 plant species, around 4% of identified higher plants (Körner 1999). A high proportion of native taxa in mountain regions is endemic (Körner 1999). For example in the alpine area around Australia's highest mountain (Mt Kosciuszko, 2228 m elevation) in south-eastern Australia, 10% of the 212 native ferns and flowering plants are endemic to that alpine area (Costin et al. 2000).

There is widespread agreement that exotic plants pose a threat to natural areas, by competing with natives for light, space and nutrients, and modifying the natural functioning of the ecosystem (Blossey 1999, Prieur-Richard & Lavorel 2000, Williams & West 2000). Community composition and structure may change, affecting availability of food and shelter for native fauna (Adair 1995). Exotic plants may pose a serious threat to the biodiversity and values of native vegetation (Adair 1995), and their increasing diversity and abundance in mountain conservation reserves is of concern.

The diversity and abundance of exotic plant taxa in mountain regions is increasing principally as a result of human activities (Mallen-Cooper 1990, McDougall & Appleby 2000, Johnston & Pickering 2001, McDougall 2001, Godfree et al. 2004, McDougall et al. 2005), and increases in diversity and abundance of exotics in the Australian Alps including Kosciuszko National Park in the last 150 years highlight this pattern. Deliberate and accidental introduction of many species occurred during the exploitation of the high country during the grazing era from the 1830s to 1944 in the alpine zone, and for some 15–20 years longer (i.e. up to the 1960's) in the subalpine and montane area (Helms 1893, Costin 1954, Mallen-Cooper 1990, Good 1992a,b). Rehabilitation of damaged soils and vegetation following cessation of grazing has been another major source of exotic species introductions (Mallen-Cooper 1990, McDougall et al. 2005). Construction and maintenance of the large Snowy Mountains Hydro-Electric Scheme, including some 2000 km of access roads and tracks, buildings, dams and soil piles have resulted in introduction and spread of exotics (Mallen-Cooper 1990). More recently, increased use of Kosciuszko National Park for tourism, including the construction of tourism infrastructure, has contributed to increased diversity of exotic species, including around ski resorts (Mallen-Cooper 1990, Johnston & Pickering 2001, Pickering et al. 2002).

Diversity of exotic plants in Kosciuszko National Park decreases with increasing altitude, due in part to increasing severity of climatic conditions at higher altitudes (Mallen-

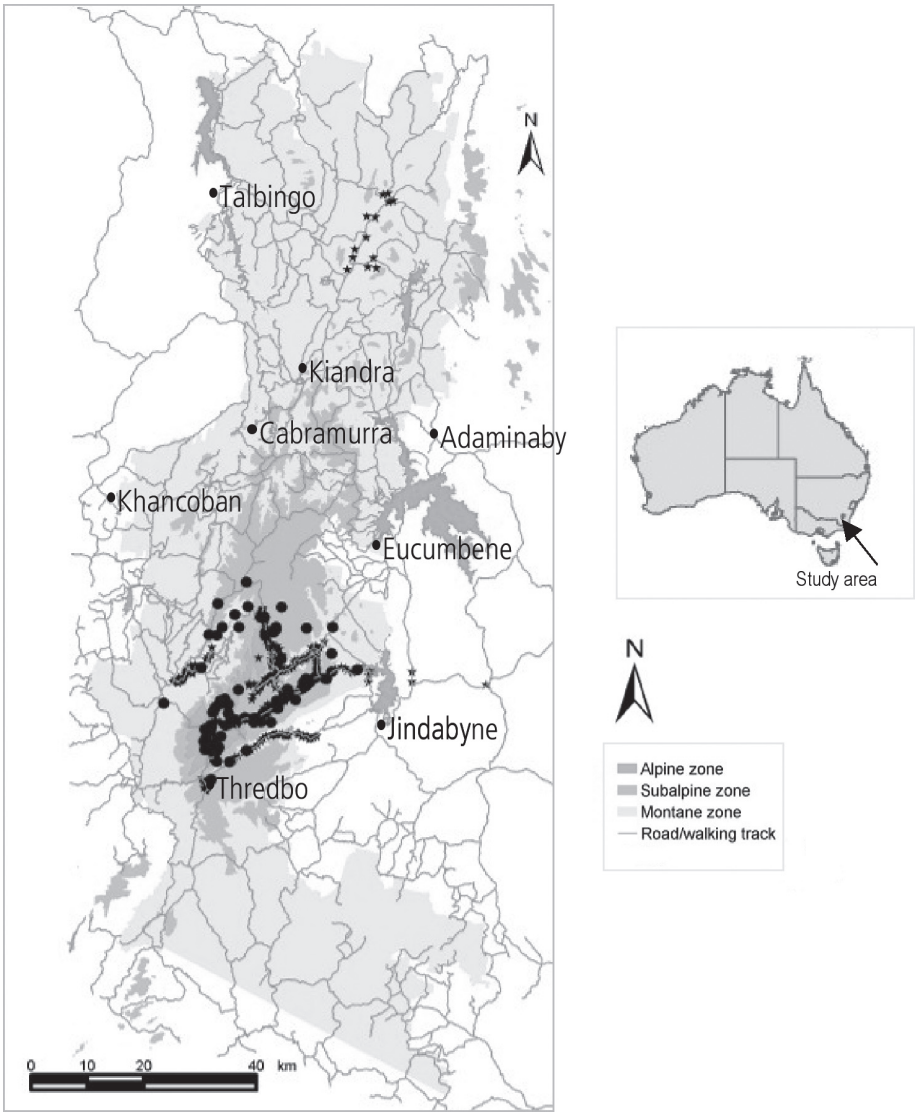

Fig. 1. Location of the 499 sites surveyed in 18 vegetation surveys (1986 to 2004) in alpine to montane zones of Kosciuszko National Park. Sites with exotic taxa and those with only native species are marked.

Cooper 1990, Costin et al. 2000, Johnston & Pickering 2001, McDougall et al. 2005). Many exotics are unable to survive the effects of frost and snow (Mallen-Cooper 1990), while the shorter growing season in alpine areas may prevent exotic seedlings from establishing and growing to reproductive maturity. The structure of native vegetation may also influence invasion by exotic plants, with the discontinuous canopy and patchy understorey of some *Eucalyptus* forests in the montane zone being more susceptible to colonisation than the almost complete vegetative cover that occurs in many alpine and subalpine communities (Mallen-Cooper 1990).

The high conservation values of the Australian Alps, including Kosciuszko National Park, are acknowledged both nationally and internationally (Good 1992a,b, ISC 2004), and the increasing threat posed by exotic plants is recognised (ISC 2004). To obtain a more comprehensive measure of the diversity and distribution of exotic species in the montane to alpine zones of Kosciuszko National Park, existing records from 18 published and unpublished vegetation surveys were collated and analysed. This included comparing diversity and frequency of exotics between areas affected by human disturbance and areas with natural vegetation.

Methods

Kosciuszko National Park Covering approximately 690 000 ha is located in the Snowy Mountains region of the Great Dividing Range between latitudes 33° and 35° south. It is the largest national park in the Australian Alps and one of the largest conservation reserves in Australia (NPWS 2004), with a diverse assemblage of plant communities including many endemic species (Costin et al. 2004). Within the Park there are three main floristic zones — montane, subalpine

and alpine - strongly correlated with altitudinal/climatic gradients (Costin 1954, Good 1992b), though some vegetation communities may occur outside 'defined' altitudinal ranges under specific micro-climatic conditions.

The montane zone occurs from approximately 500 m to 1500 m (Good 1992b) and is dominated by *Eucalyptus pauciflora* alliance woodlands in association with other *Eucalyptus* species (*E. delegatensis, E. bicostata, E. glaucescens* and *E. fastigata*) (Good 1992a,b). Dams, powerlines, buildings and the maintenance of sealed and gravel access roads associated with the hydroelectric scheme are the primary sources of anthropogenic disturbance in the montane zone (ISC 2004).

The subalpine zone occurs from the lower winter snow line at approximately 1500 m to the climatic limit of tree growth at 1850 m (Costin 1954). Winter temperatures average 0°C with a diurnal range of approximately -5°C to 2°C (Happold 1998) and snow cover is continuous for at least one month per year (Green & Osborne 1994). The dominant vegetation is *Eucalyptus niphophila* woodland interspersed with areas of bog, fen, heath and grasslands (Good 1992a,b, Costin et al. 2000). Visitor traffic (vehicular, skiing and walking), ski resort infrastructure and maintenance of roads and ski slopes are major sources of disturbance (ISC 2004).

The alpine zone occurs from the climatic treeline at approximately 1850 m to the top of Australia's highest mountain, Mt Kosciuszko at 2228 m and covers an area of approximately 250 sq. km (Costin et al. 2000). Australia's largest contiguous alpine area is in the park, around Mt Kosciuszko and covers about 100 sq. km (Costin et al. 2000). Annual precipitation ranges from 1800 mm to 3100 mm in the alpine zone, about 60% of which falls as snow, and persists for more than four months in some areas (Green & Osborne 1994). Low-growing shrubs, grasses and forbs characterise the alpine zone and occur in a number of different communities according to the biotic and abiotic characteristics of a site. The primary areas of current disturbance in the alpine zone are gravel access roads and gravel, paved and informal walking tracks (Worboys & Pickering 2002).

Database of exotic plants in Kosciuszko National Park

Exotic taxa recorded in 18 general vegetation surveys undertaken between 1986 and 2004 in the alpine to montane zones of Kosciuszko National Park were collated. Data sources include published research papers, PhD and Honours theses, NSW National Parks and Wildlife Service reports, and unpublished research by the authors, and other members of the School of Environmental and Applied Sciences Griffith University (Table 1). Each exotic species record was classed as either from a natural or a disturbed area; natural locations showed no obvious evidence of human disturbance. Some surveys were specifically undertaken to examine anthropogenic disturbance on vegetation and are more likely to record exotic species. Taxa identified to genus level only were included in these results only when there were no other records of that genus. Species native to NSW but not naturally occurring in Kosciuszko National Park were identified using Duncan (1994). Species names are those currently used in PlantNet (2005). Taxa recorded exclusively in ski resort gardens are listed separately and are not used in comparison with species recorded in other disturbed areas or with species occurring in both natural and disturbed areas. Species recorded in both natural and disturbed areas are considered here to be naturalised species.

Results

Diversity and distribution of exotic taxa (excluding ski resort gardens)

A total of 92 taxa from 23 families were recorded in the 18 vegetation surveys (1986–2004) in the alpine to montane zones of Kosciuszko National Park (1103 records; Tables 3–4). Poaceae had the greatest species richness with 25 taxa, followed by Asteraceae (14), Fabaceae (10), Rosaceae (8), and Caryophyllaceae (4). Over half the families were represented by only one species (Table 2).

Over half the exotic species were forbs (51 taxa); these were also recorded most frequently (71% of records). Graminoids comprised 29 taxa; 27% frequency. Correspondingly, few taxa were shrubs or trees (6 taxa each) (Table 4) possibly an effect of biased sampling as most surveys were conducted in grassland vegetation with few sites in heath or woodland areas (Table 1).

Only three taxa were very common (defined as having an overall frequency ≥ 8% (Table 2). These were the forbs *Acetosella vulgaris* (Sheep Sorrel, 19.7%), *Hypochaeris radicata* (Cat's-ear, Flatweed, 12.6%), and *Trifolium repens* (White Clover, 8%). Six taxa were fairly common; *Agrostis capillaris* (Browntop Bent, 5.3%), *Taraxacum officinale* (Dandelion, 5.3%), *Dactylis glomerata* (Cocksfoot, 4.7%), *Cerastium* spp. (Chickweed, 4.4%), *Anthoxanthum odoratum* (Sweet Vernal Grass, 4.2%) and *Achillea millefolium* (Yarrow, 4%). Together these nine taxa comprised 68% of records. All other species were recorded at low frequency, 2% or less of total records (Table 2).

Disturbed environments

Nearly all exotic taxa (88 out of 92) were associated with anthropogenic disturbance (Table 2). 65 taxa were recorded from road verges. Poaceae, Asteraceae and Fabaceae were the most species rich families in disturbed areas (25, 14 and 10 taxa respectively; Table 2). Correspondingly, forbs and graminoids were the most common lifeform (48 and 29 taxa respectively; Table 4). The most frequent taxa in disturbed areas were *Acetosella vulgaris* (13% of disturbed records e.g. 100 records out of 782 in disturbed sites)

Table 1. Details of 18 general vegetation surveys (1986 to 2004) in montane to alpine zones of Kosciuszko National Park.

Data source	Floristic zone, vegetation type & disturbance type	Details of site, sampling unit & sampling method	Survey year
1. Bear R (2004)	1. Subalpine zone	**Number of sites**: 12	2004
	2. Natural tall alpine herbfield burnt in 2003 bushfires & adjacent unburnt tall alpine herbfield.	**Number of sites with exotics:** 10 **Area of each site**: 6 x 20 m with five 20 m line transects 1.5m apart, sampled **Survey method**: 40 point quadrats every 0.5 m along transects	
2. Bear R & Pickering (unpublished data) CM Impacts of fire on road verge vegetation & adjacent natural areas [1]	1. Subalpine zone 2. Disturbed road verge vegetation & adjacent natural grassland.	**Number of sites**: 22 **Length of site:** 3 x 20 m transects at each site **Number of sites with exotics:** 21 **Survey method**: 40 point quadrats per transect (every 50 cm)	2004
3. Campbell M (2004)	1. Alpine zone 2. Natural short alpine herbfield & tall alpine herbfield	**Number of sites**: 15 **Number of sites with exotics:** 1 **Area of each site** 0.3 x 05 m **Survey method** 40 point quadrats for each photoquadrat	2004
4. GLORIA Global (unpublished data) Research Initiative in Alpine Environments (2004 sampling)	1. Alpine zone 2. Natural tall alpine herbfield & heath.	**Number of sites sampled**: 5 **Number of sites with exotics:** 5 **Area of each site**: at least 50 x 50 m **Survey method**: visual estimation	2004
5. Growcock A (2005)	1. Alpine & subalpine zone 2. Natural tall alpine herbfield & subalpine grassland	**Number of sites**: 10 **Area of site:** 2.16 m^2 **Number of sites with exotics:** 1 **Survey method**: visual estimation	2003
6. Hill W & Pickering CM (unpublished data) Effect of drought & fire on alpine & subalpine vegetation in Kosciuszko National Park: severity of initial impact & predictions for recovery.	1. Alpine & subalpine zone 2. Natural tall alpine herbfield, windswept feldmark, heath & subalpine grassland burnt in 2003 bushfires & nearby natural unburnt vegetation.	**Number of sites**: 31 **Number of sites with exotics**: 22 **Size of sites**: 30 x 20 m quadrat. **Survey method**: 200 points sampled by step pointing systematically over site. Rare/uncommon species not detected by step pointing were also recorded and attributed a small default cover value.	2003
7. Johnston F & Johnston SW (2004) [1]	1. Subalpine zone 2. Disturbed road verge vegetation & adjacent natural subalpine grassland vegetation.	**Number of sites:** 18 **Area of site:** 1 x 1 m quadrat **Number of sites with exotics:** 18 **Survey method**: visual estimation	2001
8. Johnston F (2005) [1]	1. Subalpine zone 2. Disturbed road verge vegetation & nearby natural subalpine grassland.	**Number of sites**: 4 **Area of site:** 0 .5 x 0.5 m quadrats **Number of sites with exotics:** 2 **Survey method**: visual estimation	2001

9. Mallen-Cooper J (1990)[1]	1. Alpine, subalpine, montane & tableland zones 2. Disturbed road verge vegetation & nearby natural vegetation	**Number of sites**: 61 **Number of sites with exotics:** 53 **Area of each site**: 20 x 6 m **Survey method**: visual estimation	1986-89
10. Pickering C Appleby M Good R Hill W McDougall K Wimbush D & Woods D (2002)[1]	1. Alpine & subalpine zone 2. Natural tall alpine herbfield, heath, subalpine grassland & subalpine woodland. Disturbed areas in & around ski resorts including ski slopes.	**Number of sites:** 45 **Number of sites with exotics:** 45 **Number of sites in ski resort gardens:** 3 **Area of each site**: at least 50 x 50 m **Survey method**: visual estimation	2002
11. Pickering CM & Hill W (2006)[1]	1. Alpine zone 2. Disturbed vegetation on verges of walking tracks & adjacent natural tall alpine herbfield.	**Number of sites**: 76 **Number of sites with exotics:** 41 **Area of each site**: 1.5 m x 0.5 cm quadrat. **Survey method**: visual estimation	2002
12. Pickering CM Growcock A Hill W Banks J & Field J (unpublished data) Long Plain, Kosciuszko National Park disturbed through prior grazing[1]	1. Montane zone 2. Woodland & grassland disturbed by livestock grazing practices (>40 years previously)	**Number of sites**: 14 (7 woodland & 7 grassland) **Number of sites with exotics:** 14 **Area of each site**: 6 x 1 m quadrat **Survey method**: visual estimation	2003
13. Pickering CM Growcock A Hill W Banks J & Field J (unpublished data) Long Plain Kosciuszko National Park natural areas	1. Montane zone 2. Natural woodland & grassland	**Number of sites**: 14 **Number of sites with exotics:** 14 **Area of each site**: 6 x 1 m quadrat **Survey method**: visual estimation	2003
14. Pickering CM Growcock A Hill W Banks J & Field J (unpublished data) Long Plain Transgrid power lines[1]	1. Montane zone 2. Disturbed heath & grassland under powerlines	**Number of sites**: 7 **Number of sites with exotics:** 7 **Area of each site**: 6 x 1 m quadrat **Survey method**: visual estimation	2003
15. Scherrer P Wimbush D & Wright G (2004)	1. Subalpine zone 2. Natural subalpine grassland and heath	**Number of sites**: 2 **Length of each transect**: 320 m **Number of transects with exotics**: 2 **Survey method**: 3300 point quadrats along each transect	2003-2004
16. Scherrer P (2003) Chapter 4	1. Alpine zone 2. Natural tall alpine herbfield	**Number of sites**: 6 long transects (assessed as 12 sections per transect) **Number of transect sections with exotics:** 5 **Length of each transect section:** ~15.25 m **Survey method**: 99 evenly spaced point quadrats per transect section	2002
17. Scherrer P (2003) Chapter 5	1. Alpine zone 2. Natural tall alpine herbfield	**Number of sites**: 30 photoquadrats **Area of photoquadrat:** 0.7 x 0.9 m **Number of photoquadrats with exotics:** 4 **Survey method**: 130 point quadrats per photoquadrat	2001
18. Scherrer P (2003) Chapter 6	1. Alpine zone 2. Disturbed tall alpine herbfield on rehabilitated walking track 15 years ago & adjacent natural tall alpine herbfield.	**Number of sites**: 42 **Area of site:** 1 x 1 m **Number of sites with exotics:** 18 **Survey method**: visual estimation	2001

[1] Survey examined effect of anthropogenic disturbance on vegetation, therefore more likely to record exotic species.

Table 2. Number of records for each exotic taxon recorded in 18 vegetation surveys (1986 - 2004) in alpine to montane zones of Kosciuszko National Park excluding only taxa recorded in ski resort gardens. (n = 1103 records). Taxa in bold occur in both natural and disturbed areas and hence could be considered naturalized.

			Natural			Disturbed				
Family	**Taxon (source)**	**Lifeform**	**Alpine**	**Sub alpine**	**Montane**	**Alpine**	**Sub alpine**	**Montane**	**Total**	**Source**
Asteraceae	***Achillea millefolium***	Forb		10	2	1	26	5	44	1,2,7,8,9,10,11
Asteraceae	*Cardus tenuiflorus*	Forb			1				1	9
Asteraceae	*Chondrilla juncea*	Forb						3	3	9
Asteraceae	***Cirsium vulgare***	Forb		2	2		9	11	24	2,9
Asteraceae	***Conyza sumatrensis***	Forb			1			1	2	9
Asteraceae	***Crepis capillaris***	Forb		1	2			13	16	9,10
Asteraceae	***Hypochaeris radicata***	Forb	5	15	30	8	44	37	139	1,2,6,7,9,10, 11,12,13,14,15 16,17
Asteraceae	***Lactuca serriola***	Forb			2			1	3	9
Asteraceae	***Leontodon taraxacoides***	Forb			1		1		2	10
Asteraceae	***Sonchus asper***	Forb			1			1	2	9
Asteraceae	*Sonchus oleraceus*	Forb					2		2	10
Asteraceae	***Taraxacum officinale* complex**	Forb	2	15	5	9	19	8	58	1,2,6,9, 10,11, 12,15,16
Asteraceae	***Tragopogon dubius***	Forb			2		1	1	4	9,13
Asteraceae	*Tragopogon porrifolius*	Forb					1		1	10
Boraginaceae	*Echium plantagineum*	Forb					4	1	5	7
Boraginaceae	*Echium vulgare*	Forb					3	1	4	9,10
Boraginaceae	***Myosotis discolor***	Forb		1	2		1	3	7	9
Boraginaceae	***Myosotis laxa* subsp. *caespitosa***	Forb			1		1		2	10
Brassicaceae	*Hirschfeldia incana*	Forb					1	1	2	9,10
Brassicaceae	*Erophila verna*	Forb						3	3	9
Caryophyllaceae	*Cerastium* spp.	Forb	1	8	2		17	20	48	2,9,10,11,15
Caryophyllaceae	***Petrorhagia nanteuilii***	Forb			1			2	3	9
Caryophyllaceae	*Sagina apetala*	Forb						1	1	9
Caryophyllaceae	*Spergularia rubra*	Forb				1	5	1	7	9,10
Chenopodiaceae	*Chenopodium album*	Forb						1	1	9
Clusiaceae	*Hypericum calycinum*	Shrub					1		1	10
Fabaceae	*Lotus uliginosus*	Forb			1				1	10
Fabaceae	*Medicago lupulina*	Forb					1		1	9
Fabaceae	*Melilotus alba*	Forb					1		1	9
Fabaceae	*Trifolium ambiguum*	Forb					3	1	4	9,10
Fabaceae	***Trifolium arvense***	Forb			2		2	3	7	9,10
Fabaceae	***Trifolium campestre***	Forb			2			2	4	9
Fabaceae	*Trifolium dubium*	Forb					1	2	3	9,10
Fabaceae	***Trifolium glomeratum***	Forb			2		1	1	4	9,10
Fabaceae	*Trifolium pratense*	Forb					6	1	7	8,9,10
Fabaceae	***Trifolium repens***	Forb		7	4	7	33	37	88	2,6,7,8,9,10, 11,12,14
Gentianaceae	***Centaurium erythraea***	Forb			1			3	4	9
Geraniaceae	*Erodium cicutarium*	Forb						3	3	9
Juncaceae	*Juncus acutiflorus*	Graminoid						1	1	9
Juncaceae	*Juncus articulatus*	Graminoid					1		1	9
Juncaceae	*Juncus bufonius*	Graminoid					1		1	10
Juncaceae	***Juncus effusus***	Graminoid			1		4		5	10
Lamiaceae	*Prunella vulgaris*	Forb						1	1	9
Lamiaceae	*Salvia verbenaca*	Forb						1	1	9
Malvaceae	*Malva parviflora*	Shrub					1		1	10

			Natural			Disturbed				
Family	**Taxon (source)**	**Lifeform**	**Alpine**	**Sub alpine**	**Montane**	**Alpine**	**Sub alpine**	**Montane**	**Total**	**Source**
Onagraceae	***Epilobium ciliatum***	Forb			2		5		7	10
Pinaceae	*Pinus mugo*	Tree		1					1	16
Plantaginaceae	***Plantago lanceolata***	Forb			1		11	5	17	2,9,10,13,14
Poaceae	***Agrostis capillaris***	Graminoid	1	5		2	29	21	58	1,2,9,10,11,15
Poaceae	*Agrostis stolonifera*	Graminoid					1		1	10
Poaceae	***Aira caryophyllea***	Graminoid		1	2		2	4	9	9,10,15
Poaceae	***Anthoxanthum odoratum***	Graminoid		16	2		23	5	46	1,2,7,8,9,10,15
Poaceae	*Bromus cartharticus*	Graminoid					1		1	10
Poaceae	*Bromus diandrus*	Graminoid					1		1	10
Poaceae	***Bromus hordeaceus***	Graminoid			1		3	3	7	9
Poaceae	*Bromus racemosus*	Graminoid					1		1	10
Poaceae	***Bromus sterilis***	Graminoid		1			1		2	9
Poaceae	*Bromus tectorum*	Graminoid					2	2	4	9
Poaceae	***Dactylis glomerata***	Graminoid		3	4		24	21	52	2,9,10,12,13
Poaceae	*Festuca arundinacea*	Graminoid					1		1	10
Poaceae	***Festuca rubra***	Graminoid	1	3	1	1	15	2	23	2,9,10,11
Poaceae	***Holcus lanatus***	Graminoid		1	2		11	2	16	2,9,10
Poaceae	*Hordeum leporinum*	Graminoid						1	1	10
Poaceae	*Hordeum vulgare*	Graminoid					1		1	10
Poaceae	***Lolium perenne***	Graminoid			1		2	2	5	9
Poaceae	*Panicum gilvum*	Graminoid					1	1	2	9
Poaceae	*Paspalum dilatatum*	Graminoid						1	1	9
Poaceae	***Phleum pratense***	Graminoid		2	2		14	1	19	2,9,10
Poaceae	***Poa annua***	Graminoid			2	1	10	2	15	9,10
Poaceae	*Poa bulbosa*	Graminoid						1	1	9
Poaceae	***Poa pratensis***	Graminoid		3	1	1	13	1	19	2,9,10,11
Poaceae	***Vulpia bromoides***	Graminoid			1			1	2	9
Poaceae	***Vulpia myuros***	Graminoid			1			3	4	9
Polygonaceae	***Acetosella vulgaris***	Forb	52	41	25	26	39	34	217	1,2,4,5,6,7,8, 9,10,11,12,13, 14,15,16,17,18
Polygonaceae	*Polygonum* spp.	Forb					4	3	7	9
Polygonaceae	*Rumex crispus*	Forb					2		2	9,10
Primulaceae	*Anagallis arvensis*	Forb						1	1	9
Rosaceae	***Aphanes arvensis***	Forb			1			2	3	9
Rosaceae	***Malus x domestica***	Tree		1	1		2	1	5	9,10
Rosaceae	*Potentilla recta*	Shrub					1		1	10
Rosaceae	*Prunus armeniaca*	Tree					1		1	10
Rosaceae	*Prunus lusitanica*	Tree					1		1	10
Rosaceae	*Prunus persica*	Tree					1		1	10
Rosaceae	***Rosa rubiginosa***	Shrub			1		1		2	9,10
Rosaceae	*Rubus fruticosus* spp.agg.	Shrub						1	1	9
Salicaceae	***Salix* sp.**	Tree			1		1		2	10
Scrophulariaceae	*Linaria arvensis*	Forb			1				1	9
Scrophulariaceae	*Mimulus moschatus*	Shrub					1		1	10
Scrophulariaceae	***Verbascum thapsus***	Forb			1		1	3	5	9,10
Scrophulariaceae	***Verbascum virgatum***	Forb		1	1		3	3	8	9,10
Scrophulariaceae	***Veronica arvensis***	Forb			1			2	3	9
Violaceae	*Viola arvensis*	Forb					1		1	9
Total records			**62**	**138**	**124**	**57**	**422**	**300**	**1103**	
Number of species			**6**	**21**	**45**	**10**	**63**	**60**	**92**	

1 Disturbed areas were defined as those with obvious evidence of anthropogenic disturbance.
2 Taxa/taxon identified to genus level only.
Sources (see Table 1 and References for details)

Hypochaeris radicata (11%, 89 records), *Trifolium repens* (10%, 77 records) *Agrostis capillaris* (7%, 52 records) and *Dactylis glomerata* (6%, 45 records).

The gardens of ski resorts with 81 taxa were a major potential source of exotic species, 62 of which were only recorded from the gardens. Some of these species are naturalised outside our Kosciuszko National Park survey areas and others may naturalise in the future (See Appendix).

Natural environments

Fewer exotic taxa were recorded in natural areas (48 taxa, Table 2). Of these, 44 taxa were also found in disturbed areas (Table 2). Poaceae, Asteraceae and Fabaceae were again the most species-rich families (14, 11, and 5 taxa respectively; Table 2). Correspondingly, forbs and graminoids were the most common lifeform (29 and 15 taxa respectively; Table 4). The small ubiquitous herb *Acetosella vulgaris* accounted for 36% (117) of all records in natural areas (322 records; Table 2). The only other common species in natural areas were *Hypochaeris radicata* (16%, 50 records) *Taraxacum officinale* (6%, 21 records) and *Anthoxanthum odoratum* (6%, 18 records, Table 2). Four exotic taxa were recorded exclusively in natural areas although with very low frequency *Carduus tenuiflorus* (Winged Thistle), *Linaria arvensis* (Corn Toadflax), *Lotus uliginosus* (Greater Birdsfoot Trefoil), and *Pinus mugo* (only one record each).

Floristic zone

Of the 11 exotics in the alpine zone, *Acetosella vulgaris* was by far the most frequent (66%, 78 of the total of 119 alpine records; Table 2). Other frequent species were *Taraxacum officinale* (10%, 11 records in alpine) and *Hypochaeris radicata* (11%, 13 records). *Trifolium repens* was relatively common (6%, 7 records) but was only found on the verge of walking tracks. Six of the eleven taxa (*Acetosella vulgaris*, *Achillea millefolium*, *Agrostis capillaris, Epilobium ciliatum*, *Hypochaeris radicata*, *Taraxacum officinale*) were found in natural areas (Table 2).

The subalpine and montane zones both had numerous exotic taxa. Of the 66 exotic taxa in the subalpine zone, only 36% were recorded in natural areas, whereas, 69% of the 69 exotic taxa in the montane zone taxa were recorded in natural areas (Table 2). *Acetosella vulgaris* was again the most common species in the subalpine zone and was equally frequent in natural and disturbed areas (14%, 80 of the 561 records in the subalpine). *Hypochaeris radicata* was also common in the subalpine zone (11%, 59 subalpine records) but was more frequent in disturbed areas (8%, 44 records) than in natural areas. *Hypochaeris radicata* (14%, 59 records) and *Acetosella vulgaris* (16%, 67 records) were the most frequent exotic taxa in the montane zone and equally common in natural and disturbed areas. The frequency of most taxa in both montane and subalpine zones was very low, with around 65% of taxa having < 1% of records (Table 2).

Table 3. Number (%) of exotic plant taxa from 18 vegetation surveys (1986 - 2004) in alpine to montane zones of Kosciuszko National Park, excluding taxa only recorded in ski resort gardens. n = 1103 records of exotic taxa.

[1]Disturbed areas were defined as those with obvious evidence of anthropogenic disturbance.

	Alpine	**Subalpine**	**Montane**	**Total**
Natural vegetation	6 (5%)	21 (34%)	45 (48%)	48 (51%)
Disturbed vegetation[1]	10 (11%)	64 (70%)	60 (64%)	88 (95%)
Total	11 (12%)	66 (72%)	69 (74%)	92

Table 4. Number of exotic taxa in each lifeform recorded in 18 vegetation surveys (1986 to 2004) in alpine to montane zones of Kosciuszko National Park, excluding taxa only recorded in ski resort gardens, n = 1103 records of exotic taxa.

[1]Disturbed areas were defined as those with obvious evidence of anthropogenic disturbance.

	Natural			**Disturbed**			**Total**	
Lifeform	**Alpine**	**Subalpine**	**Montane**	**Alpine**	**Subalpine**	**Montane**	**Number**	**(%)**
Forb	4	10	29	6	31	39	51	71
Graminoid	2	9	13	4	23	19	29	27
Shrub			1		5	1	6	0.6
Tree		2	2		5	1	6	1
Total	6	21	45	10	64	60	92	100

Crepis capillaris is a species that may need to be monitored as it is relatively common along road verges in the montane zone and has been recorded in montane woodland, but so far appears to be infrequent in the subalpine zone.

The most common taxa

Nine taxa are common in all zones in both natural and disturbed areas and together accounted for 68% of all records (Table 5). The most common species were *Acetosella vulgaris* and *Hypochaeris radicata* which together comprise 32% of all records). Some of the taxa were formerly used in vegetation rehabilitation programs (*Dactylis glomerata* and *Agrostis capillaris*); however, other rehabilitation species (*Lolium perenne, Holcus lanatus, Festuca rubra, Phleum pratense*) while present in subalpine end montane zones, are uncommon. All nine common weeds are perennial forbs or graminoids native to Europe and are naturalized in Australia (Table 5). Most of them can reproduce vegetatively, by rhizomes or stolons, and can be found in mountains in other regions of the world. They are well established in the Australian Alps and are commonly found in other recent vegetation surveys, particularly along roads (McDougall 2001; Godfree et al. 2004). Several were recorded in the earliest plant surveys in the Australian Alps, and all date back to the grazing period (Johnston & Pickering 2001).

Discussion

Increased diversity and abundance of exotics

European landuse in Kosciuszko National Park has resulted in the introduction and spread of exotic taxa over the last 150 years. On Mount Kosciuszko in the 1890's Joseph Maiden (1898, 1899) recorded four exotic taxa in the montane zone, and three in the subalpine zone, but none in the alpine zone. Costin's (1954) extensive survey of the Monaro region, done in the mid-1950s following 100 years of livestock grazing, recorded 67 exotic species in the montane zone, 44 in the subalpine zone, and six in the alpine zone.

Using data from 18 general surveys undertaken between 1986 and 2004 we have recorded 69 taxa in the montane, 66 taxa in the subalpine and 11 taxa in the alpine zones, with a total of 92 exotic taxa overall. An additional 62 exotic taxa were

Table 5. Characteristics of the nine most common taxa recorded in 18 vegetation surveys in Kosciuszko National Park (1986 - 2004) excluding taxa only recorded in ski resort gardens, n = 1103 records. (sources for characteristics are Harden 1993, Lamp and Collet 1996, Blood 2001, PlantNet 2005). Recorded in 1899 = Maiden (1899), Recorded in 1954 = Costin (1954).

Species (family)	Lifeform	Life history strategy	Origin (native to)	Naturalized/invasive in Australia	Recorded in
Acetosella vulgaris (Polygonaceae)	Forb	Perennial	Europe, North Africa, Temperate Asia	Yes	1899
Achillea millefolium (Asteraceae)	Forb	Perennial	Europe, Temperate Asia, North America	Yes	1954
Agrostis capillaris (Poaceae)	Graminoid	Perennial	Europe, North Africa, Temperate Asia	Yes	1954
Anthoxanthum odoratum Poaceae)	Graminoid	Perennial	Europe, Temperate Asia, North Africa	Yes	1954
Cerastium spp. (Caryophyllaceae)	Forb	Perennial	Europe, North Africa, Temperate Asia	Yes	1954
Dactylis glomerata Poaceae)	Graminoid	Perennial	Europe, North Africa, Temperate Asia	Yes	1954
Hypochaeris radicata (Asteraceae)	Forb	Perennial	Europe, North Africa, Temperate Asia	Yes	1899
Taraxacum officinale (Asteraceae)	Forb	Perennial	Europe, Asia	Yes	1899
Trifolium repens (Fabaceae)	Forb	Perennial	Europe, North Africa, Temperate Asia	Yes	1954

recorded in the subalpine zone from ski resort gardens only, although 12 of these are reported to be naturalised elsewhere (Johnston & Pickering 2001).

Most recently McDougall et al. (2005) have recorded 128 invasive species, based on 1400 floristic quadrats in just the treeless vegetation in the Australian Alps above 1200 m.

Rehabilitation species and common forbs

Some exotics recorded in this study were intentionally introduced as part of rehabilitation projects. Grasses such as *Agrostis capillaris, Festuca rubra*, *Lolium perenne*, *Dactylis glomerata* and *Phleum pratense* were used in the 1950s in rehabilitation work carried out to counteract erosion caused by livestock grazing in the higher altitude areas of Kosciuszko National Park (Costin 1954, Mallen 1984). These species were inexpensive, available in commercial quantities and known to rapidly establish protective ground cover (Mallen 1984). It was expected that native species would replace exotic species when soil conditions returned to 'normal', but recent studies suggest that this may not be occurring as quickly as once thought, especially in areas experiencing continued disturbance (McDougall 2001, Scherrer 2003). In some high altitude sites, rehabilitated sites have started to re-erode (Johnston et al. 2002). These species are still present in disturbed sites along road verges in the subalpine zone, with *Agrostis capillaris* and *Festuca rubra* also associated with tracks in the alpine zone. They have been recorded from natural areas in the montane zone. *Agrostis capillaris* is of concern as it is considered to be particularly persistent, even in the absence of continued disturbance (McDougall 2001).

Future

This study, like those in the past, highlights the increasing abundance and diversity of exotics in the Australian Alps, and the need for effective management. The recent extensive bushfires in Kosciusko National Park in January-February 2003 burnt over 486 000 ha, including more than 70% of the subalpine zone (NPWS 2004, ISC 2004). Immediately after the fire there was a dramatic loss of native vegetative cover, including areas near roads and tracks (Bear 2004, Scherrer et al. 2004). However few road verges, or areas around ski resorts and other infrastructure were burnt, leaving exotic taxa there unaffected and able to disperse seed into recently burnt areas. As a result, there is the potential for the spread of exotics from anthropogenically-disturbed sites into areas previously covered by intact native vegetation (Johnston & Johnston 2003, Costin et al. 2004).

Climatic change is also likely to increase the spread of exotics (Scherrer & Pickering 2001; Pickering & Armstrong 2003, Pickering et al. 2004). An increase in temperature between +0.6, and +2.9°C, as predicted for the Australian Alps, would result in between 38–96% decrease in the area receiving at least 60 days of snow cover by 2050 (Henessey et al. 2003). As the distribution and abundance of some exotic taxa is thought to be limited by current climatic conditions (Mallen-Cooper 1990, Pickering & Armstrong 2003, Pickering et al. 2004, McDougall et al. 2005) it is likely that there could be even greater invasion and distribution of exotic taxa as conditions change (Pickering et al. 2004, McDougall et al. 2005). For example, in a study of treeless vegetation in the Australian Alps, approximately 22 invasive species were recorded above 1800m, and 41 invasive species between 1600m and 1800m. If, as predicted, climatic conditions above 1800m became more similar to those currently at lower elevations, it is likely that there will be a dramatic increase in the number of exotic species including in natural treeless vegetation in the Park (McDougall et al. 2005). This highlights the importance of managing the current threat from exotics before they have an even greater impact.

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Appendix. Exotic taxa found in ski resort gardens (Pickering et al. 2002) and not recorded in Table 2.

Family	Taxon	Lifeform
Aceraceae	*Acer negundo*	Tree
Aceraceae	*Acer pseudoplatanus*	Tree
Apocynaceae	*Vinca major*[1]	Forb
Apocynaceae	*Vinca minor*	Forb
Aquifoliaceae	*Ilex aquifolium*	Tree
Aquifoliaceae	*Ilex cornuta*	Shrub
Araliaceae	*Hedera helix*	Shrub
Asteraceae	*Anthemis tinctoria*	Forb
Asteraceae	*Artemisia absinthium*	Shrub
Asteraceae	*Aster alpinus*	Forb
Asteraceae	*Leucanthemum* x *superbum*	Forb
Baueraceae	*Bauera rubioides*	Forb
Betulaceae	*Alnus incana*	Tree
Betulaceae	*Betula pendula*	Tree
Boraginaceae	*Myosotis sylvatica*	Forb
Brassicaceae	*Aurinia saxatilis*	Forb
Caprifoliaceae	*Lonicera japonica*	Shrub
Caprifoliaceae	*Lonicera nitida*	Shrub
Caryophyllaceae	*Dianthus barbatus*	Forb
Caryophyllaceae	*Dianthus subacaulis*	Forb
Commelinaceae	*Tradescantia* Andersoniana Group	Forb
Crassulaceae	*Echeveria secunda*	Forb
Crassulaceae	*Sedum* spp.[2]	Forb or shrub
Crassulaceae	*Sempervivum montanum*	Forb
Dipsacaceae	*Scabiosa columbaria*	Forb
Ericaceae	*Erica* sp.[2]	Forb
Ericaceae	*Rhododendron* sp.[2]	Tree
Fabaceae	*Cytisus scoparius*[1]	Shrub
Fabaceae	*Lotus corniculatus*	Shrub
Fabaceae	*Lupinus polyphyllus*[1]	Forb
Fabaceae	*Wisteria* sp. [2]	Shrub
Iridaceae	*Iris* spp.[2]	Forb
Juncaceae	*Juncus tenuis*	Graminoid
Lamiaceae	*Lavandula angustifolia*	Forb
Lamiaceae	*Origanum vulgare*	Forb
Lamiaceae	*Stachys byzantina*	Forb
Lamiaceae	*Thymus* sp.[2]	Forb
Lamiaceae	*Westringia fruticosa*	Shrub
Liliaceae	*Agapanthus* sp.[1]	Forb
Liliaceae	*Muscari armeniacum*	Shrub
Linaceae	*Linum perenne*	Forb
Myrtaceae	*Eucalyptus cordata*	Tree
Oleaceae	*Syringa vulgaris*	Shrub
Onagraceae	*Oenothera rosea*	Forb
Poaceae	*Avena barbata*	Graminoid
Proteaceae	*Grevillea juniperina*	Shrub
Proteaceae	*Grevillea rosmarinifolia*	Shrub
Rosaceae	*Duchesnea indica*	Forb
Rosaceae	*Fragaria* sp.[2]	Forb
Rosaceae	*Photinia glabra* 'Rubens'	Shrub
Rosaceae	*Prunus avium*	Tree
Rosaceae	*Prunus cerasifera*	Tree
Rosaceae	*Pyracantha crenulata*	Tree
Rosaceae	*Rosa multiflora*	Shrub
Rosaceae	*Spiraea thunbergii*	Shrub
Salicaceae	*Populus alba*	Tree
Salicaceae	*Populus nigra*	Tree
Salicaceae	*Salix cinerea*[1]	Tree
Scrophulariaceae	*Misopates orontium*	Forb
Tiliaceae	*Tilia cordata*	Tree
Ulmaceae	*Ulmus parvifolia*	Tree
Ulmaceae	*Ulmus procera*'Louis van Houtte'	Tree

Total number of families	39
Total number of taxa	62
Total number of forb taxa	28
Total number of shrub taxa	16
Total number of tree taxa	16
Total number of graminoid taxa	2

[1]Taxon has been recorded in Kosciuszko National Park previously but not recorded in 18 surveys (Table 3).

[2] Taxon/taxa identified to genus level only.