The native grasslands of the Monaro region: Southern Tablelands of NSW

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Benson, J.S., (National Herbarium of New South Wales, Royal Botanic Gardens, Sydney, Australia 2000) 1994. The native grasslands of the Monaro region: Southern Tablelands of NSW. Cunninghamia *3(3): 609–650.* Eight grassland plant communities were defined from a cluster analysis of vascular plant species recorded in 62 quadrats surveyed between the Australian Capital Territory (35° 11' S) and the Victorian border (36° 53' S) (148° 35'–149° 25' E). 265 taxa were recorded, 189 native and 76 (29%) exotic. Five of the native species are registered as rare or threatened in Australia. Cluster analyses using cover data were deemed superior to presence/absence data. Hybrid, non-metric multi-dimensional scaling revealed that altitude is the main determinant for the distribution of native grassland species and communities.

The native grasslands on the tableland tract of the study area (none of which are protected in conservation reserves) contain a high number (> 35%) of exotic species due to more than a century of grazing and decades of pasture improvement in the surrounding countryside. A number of sites are recommended for protection based on their species diversity, presence of threatened species, or because they are representative of a particular plant community. Many of these are dominated by *Themeda australis*, indicating a lack of continuous grazing. Most of these are located in fenced-off areas such as cemeteries, roadsides or travelling stock reserves (TSRs). Until more research is done on native grassland management it is recommended that practices such as intermittent grazing or occasional burning in autumn should continue. Significant remnants on public land should be managed for grassland conservation.

Introduction

It is remarkable that such an extensive tract of country as that known as the Monaro Plains, should naturally be almost destitute of trees and shrubs ... the country is made up of clear undulating plains, with only a few isolated tree-clad localities. (Cambage 1909)

Recent studies of native grasslands and native grass species in south-eastern Australia have investigated their benefit to grazing or uses in revegetation (Leigh 1991, Roberts 1991, Lodge et al. 1991, Jefferson et al. 1991). Other studies have highlighted the rarity of native grasslands and proposed areas for their conservation (Stuwe 1986, Frawley 1991, McDougall & Kirkpatrick 1993).

In 1991 the World Wide Fund for Nature (WWF) funded surveys of temperate grasslands remnants in four states of south-eastern Australia: New South Wales (including the Australian Capital Territory ACT), Victoria, South Australia and Tasmania. The results of this study are presented in McDougall and Kirkpatrick (1993). As part of that report, Benson and Wyse Jackson (1993) derived a floristic classification of the Monaro native grasslands using TWINSPAN (Hill 1979). Through a combination of iterative (Kirkpatrick 1983) and score-based evaluation methods (Wright 1977), Benson and Wyse Jackson (1993) identified 17 grassland sites of significance for nature conservation.

This paper reclassifies the Monaro data using the flexible UPGMA cluster strategy (PATN package, Belbin 1993) and incorporates additional quadrat data mainly from

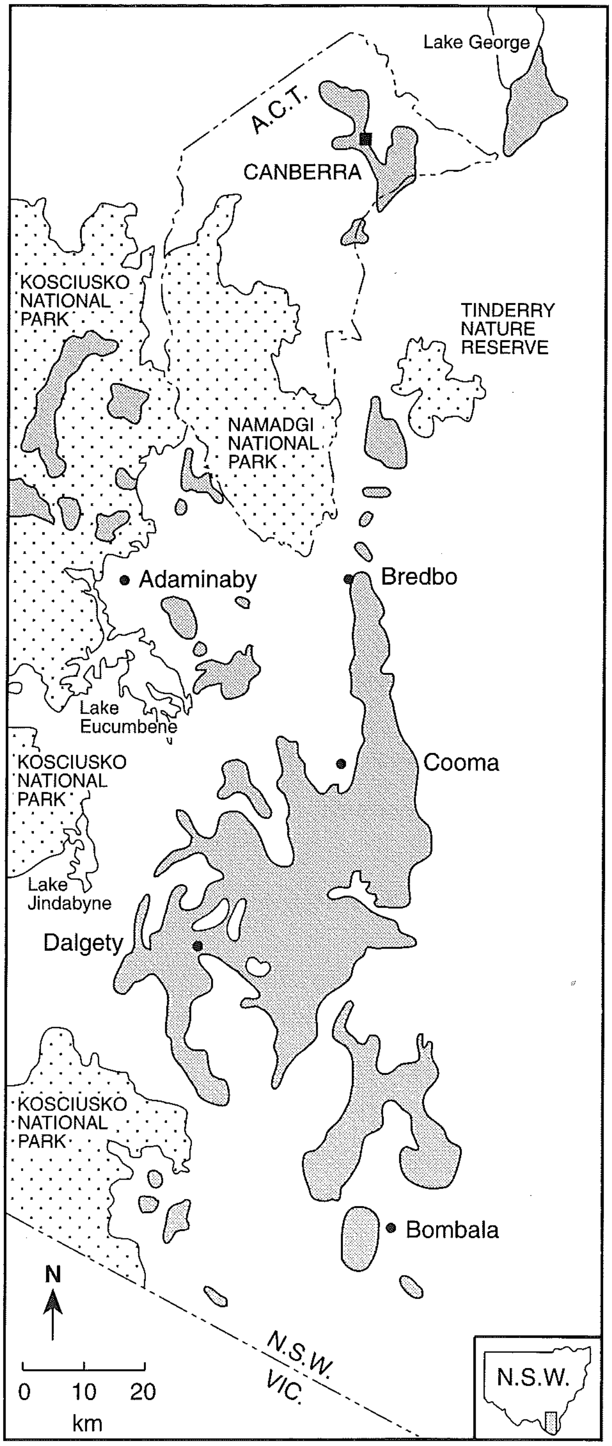

Figure 1. Estimated original extent of native grasslands at the time of European settlement (grey-toned area), excluding subalpine and alpine grasslands above 1500 m. Only a small proportion remains today. Dotted areas are onservation reserves. From Costin (1954) and author's knowledge.

the Montane tract (Costin 1954) on the eastern fringe of Kosciusko National Park. Analysis of the importance of some environmental attributes in determining community distribution was also undertaken. Discussion is provided on the floristic composition, environmental determinants, condition and conservation status of native grasslands and rare grassland species on the Monaro. UPGMA and TWINSPAN are compared regarding their effectiveness in classifying the grassland communities.

For the purposes of this study, the term 'native grassland' refers to areas that contain predominantly native grass and forb plants and are largely devoid of trees and shrubs. In some circumstances a residual understorey of native grass and forb species may exist after the clearing of trees and this may resemble an original native grassland. This survey concentrated on areas that were considered to have been treeless and dominated by herbaceous plants at the time of European settlement.

The study area

The study area is located on the Southern Tablelands of NSW between 35° 11' S and 36° 53' S and 148° 35' and 149° 25' E. It includes most of the tableland (600–950 m a.s.l.) and montane (950–1500 m a.s.l.) climatic provinces of the Monaro region defined by Costin (1954). This region extends from Canberra and Queanbeyan in the north to the Victoria border in the south, bounded in the east by the Kybean Range and in the west by the Snowy Mountains (Figure 1).

Based on the area of grassland mapped in Costin (1954), notes in the early annals of European explorers and the author's field inspections, the pre-European extent of grassland on the Monaro is estimated to have been approximately 250 000 ha.

The elevation of the sites sampled range from 579 m at Queanbeyan to 1380 m at Boggy Plain in Kosciusko National Park. The survey excluded approximately 50 000 ha of grasslands in the alpine and subalpine communities above 1500 m in Kosciusko National Park (McRae 1989) in NSW and subalpine and montane grasslands located in Namadgi National Park in the Australian Capital Territory.

Most of the undulating tableland tract of the region, where the largest area of native grassland once existed, is privately owned and grazed by stock; minor cropping takes place on alluvial flats. Most of the higher altitude or more rugged terrain in the region is located in national parks and state forests.

Climate

On the Monaro, rain falls predominantly in winter. In the south, Dalgety receives only 459 mm annual precipitation. This increases eastwards to Nimmitabel (688 mm) and north-westwards to Adaminaby (701 mm) (Table 1). At the northern end of the study area, Queanbeyan receives an average of 573 mm. Rainfall increases markedly in the mountain ranges to the east and the west. The relative aridity of the tableland section of the Monaro is due to a rainshadow effect which has existed since at least the Miocene (Ride et al. 1989).

Temperatures are cold in winter and mild in summer. The mean temperature of the coldest month ranges from 1.1° C at Adaminaby to 6.1° C at Queanbeyan (Table 1). In summer the mean temperature of the warmest month ranges from 21.1° C at Queanbeyan to 15.6° C at Adaminaby. The coldest temperatures in the study area are experienced in the montane frost hollow valleys in Kosciusko National Park.

Table 1. Climatic attributes of locations on the Monaro (from Costin 1954, Flood 1980)

Location	Latitude	Longitude	Alt (m)	M.C. (°C)	M.H. (°C)	M+9	R (mm)
Queanbeyan	35° 21' S	149° 28' E	579	6.1	21.1	9	573
Cooma	36° 14' S	149° 07' E	811	4.4	18.9	8	476
Nimmitabel	36° 30' S	149° 17' E	1068	2.8	15.8	7	688
Bombala	36° 55' S	149° 14' E	705	5.0	17.8	8	625
Jindabyne	36° 24' S	147° 40' E	945	1.7	16.1	6	547
Dalgety	36° 36' S	148° 50' E	896	3.9	18.3	7	459
Adaminaby	36° 03' S	148° 42' E	1067	1.1	15.6	7	701
Kiandra	35° 52' S	148° 32' E	1395	-0.6	13.3	5	1602

M.C. = mean temperature of coldest month (Celsius)
M.H. = mean temperature of hottest month (Celsius)
M+9 = months with mean temperature > 9^0 Celsius
R (mm) = mean annual rainfall in mm

Geology

The underlying rocks are mainly Palaeozoic sediments which have been folded, faulted and metamorphosed during the formation of the Lachlan Fold Belt which covers a large section of south-eastern Australia (Ollier& Wyborn 1989). Granite intrusions, including the Kosciusko Batholith intruded in the Silurian period. The land surface eroded to a palaeoplain by the Jurassic. This was uplifted, due to undetermined causes, in the Miocene by way of large fault blocks (Ollier & Wyborn 1989). Between 45 and 34 m yrs B.P., during the Eocene, a shield-like volcano erupted causing basalt flows over the southern half of the Monaro. This volcano is thought to have been centered on Brown Mountain (Ollier & Taylor 1988) which is located on the south-eastern fringe of the present Monaro tableland.

The rocks outcropping today vary greatly from the north to the south. Between Canberra and Cooma the main substrates are Silurian and Ordovician volcanics, mudstones, shales and limestones. Some of the larger valleys in the Canberra area, where native grassland was known to exist, are composed of Cainozoic sediments. The elevated region between Cooma and Bombala in the south is mainly composed of Eocene basalt. The western part of the study area in Kosciusko National Park and between Adaminaby and Dalgety is composed of granite and sediments. In the east, the Kybean Range is composed of granite.

The large number of geological types mapped by the Australian Geological Survey in the region have been amalgamated into 12 major groups by Spate (1993) based on their similarity of mineral composition. Soils in the study area are documented in Costin (1954). They include peat and humus podsols in the montane tract; chocolate soils or chernozems on the high basalt plateau between Cooma and Bombala; and red, grey and brown clayey soils (podsols and laterites) derived from volcanic and sedimentary substrates occurring elsewhere on the tableland.

While the drainage in the region tends to follow the north-south orientated bedrock, some rivers have been captured and diverted to the coast with the westwards retreat of the great escarpment (Ollier 1982). Today most drainage is dendritic, except in the south where remnant landforms associated with the Monaro Volcano cause the drainage to be radial.

Some of the higher ground within the study area may have been affected by periglacial activity at the height of the last ice age (18–23 000 yrs B.P.) (A. Costin pers. comm.). The numerous lakes set among the grasslands on the basalt and granite plateau on the southern Monaro are an interesting geomorphological feature (see Benson and Jacobs 1994).

Land-use history and previous botanical studies

A detailed history of Aboriginal occupation in the Monaro is provided by Flood (1980). Due to cold temperatures, and possibly lack of game, it is likely that Aborigines did not favour year-round occupation of the higher parts of the Monaro compared to lower elevations. In autumn, the Aborigines may have gathered and baked seeds of grasses such as *Themeda australis*. However, it seems that seed grinding was not a major part of the economy of the tribes occupying the Monaro. The first European botanist to visit the region, Allan Cunningham, observed Aborigines burning grasslands in Autumn (Havard 1936).

The first European to explore the northern part of the Monaro was Throsby in 1821. Settlement had advanced as far south as Berridale by 1827 (Costin 1954). Both Cunningham and Lhotsky mention the existence of extensive open grasslands in the Goulburn, Lake George and Limestone Plains (Canberra) areas. Lhotsky (1835) estimated that there were 10 000 hectares of grassland on the Limestone Plains. South of the Limestone Plains he describes *Poa* tussock grasslands and gives one of the first descriptions of the Monaro grasslands in the vicinity of Cooma:

> *The scene all around was composed of undulating downs, long projected hills among them, covered with a very few trees.*

The reasons for this absence of trees on the Monaro have long held the interest of botanists. Cambage (1909) suggested the lack of trees could be explained through a combination of low rainfall, cold temperatures, drying summer winds and the structure of the soil. From 1830 onwards the squatters moved in and carved up the country into grazing runs and only a small fraction of the region remained in government ownership. As early as 1840, only 15 years after the first Europeans settled on the Monaro, the explorer Strezlecki expressed concern about the effects that drought, cropping and overgrazing were having on soil erosion (Hancock 1972). Small-scale pasture improvement began in the 1860s. Rabbits proliferated after 1900. Clovers were first sown in the 1920s but pasture improvement accelerated after the second world war, along with the application of superphosphate fertiliser (Hancock 1972).

Cambage (1909 and 1918) provided lists of plant species occurring in the area. A detailed botanical study of the region was undertaken by Costin (1954). This work intuitively classified vegetation to an alliance level and a small scale vegetation map was produced. Costin (1954) recognised two main grassland subformations in the study area; dry tussock grassland dominated by *Stipa scabra* and *Stipa bigeniculata* and wet tussock grassland typified by the presence of *Themeda australis*, *Poa*, *Juncus* and *Carex* species. Pryor (1954) described and mapped the major plant communities occurring in the ACT. A quadrat-based phytosociological study of pastures was carried out by Doing (1972).

Several detailed grassland studies have concentrated on the ACT section of the study area where about 40 grassland remnants have been surveyed (Chan 1980, Hogg 1990, Frawley 1991). The waterplants growing in the lakes on the southern Monaro have been sampled by Benson and Jacobs (1994).

Methods

Compared to their usefulness in vegetation surveys of forest and shrubland, aerial photographs or LANDSAT images proved to be of limited assistance in distinguishing native from modified grasslands on the Monaro. It was therefore decided to select grassland sites through expert advice and by undertaking ground traverses of the countryside. Many sites were selected on the recommendations of the NSW Department of Agriculture, Rural Lands Protection Board, CSIRO and University of Canberra. Additional sites were selected during road traverses on the basis of their apparent natural condition compared to surrounding paddocks. Most of these were located within smaller fenced-off paddocks postulated to have been subject to less continuous grazing. Sampling also aimed to cover the region's main rock and soil types, a range of altitudes and various landform positions (flat, slope, ridge). This meant that some poorer quality sites were recorded to fulfill this aim (for example, drainage lines or flats dominated by *Poa labillardieri* and exotic species).

Sixty-two grassland sites were sampled by way of 100^2 m quadrats placed within them. Sixty quadrats were sampled between October 1991 and January 1992 — a period that coincided with favourable rainfall and abundant flowering. A further two sites were sampled in February 1993. All plant species within a quadrat were recorded and assigned a cover rating based on a six point cover scale (< 1%, 1–5%, 6–25%, 26–50%, 51–75%, 76–100%). Physiographic attributes (slope, aspect, altitude, soil texture, geology and drainage), vegetation structure, land tenure and an estimation of degree of disturbance (including percentage of exotic species) were recorded at each site (Table 2). On the advice of Spate (pers. comm.), his 10 geological categories (Spate 1993) present in the study area were reduced to five by amalgamating three volcanic and sediment categories which have similar compositions (the limestone and Cainozoic sediment categories were maintained).

Soil categorisation at each site was based on observations of texture and colour and reference to Costin (1954). The Australian Map Grid (AMG) coordinate was derived by a geographical positioning system device and topographic maps. Plant species nomenclature follows the *Flora of New South Wales* (Harden 1990–1993).

Data analysis

Quadrats and species were classified into groups by way of an agglomerative hierarchical classification using the Kulczynski coefficient dissimilarity measure and applying the flexible unweighted paired group arithmetic averaging (UPGMA) sorting strategy (PATN, Belbin 1993). The benefits of using the Kulczynski coefficient compared to other measures are discussed in Faith, Minchin and Belbin (1987).

Several UPGMA analyses were performed. One analysis incorporated all species including cover ratings in a matrix of 62 sites (objects) and 265 taxa (attributes). Another analysis excluded exotic species but still included cover ratings, resulting in a reduced matrix of 62 x 189 (it was considered that this analysis may assist with the interpretation of any underlying native floristic patterns not clouded by exotic taxa, many of which have been imposed on the landscape through direct pasture seeding, for example *Trifolium* spp). Further analyses, using all species and native species only, excluded cover ratings and included presence/absence data only. The aim was to assess the importance or otherwise of cover rating in the sorting of sites into groups.

A check on sites suspected to be misplaced in the groupings derived by the favoured UPGMA analysis (this excluded exotic species and included cover ratings of native species) was undertaken by examining the five nearest neighbours of those sites that were generated from the ASO file in PATN using the Kulczyski dissimilarity measure.

Two-way tables for the 'all species' and 'native species only' matrices were generated using the 2-Step association measure on species and Kulczynski coefficient on sites (Belbin 1993). These helped to identify common and indicator plants for each UPGMA defined community and enabled a plant list to be compiled showing the frequency of taxa occurring in each plant community.

Hybrid nonmetric multidimensional scaling (NMDS) (Kruskal 1964) was undertaken to ordinate the quadrat data along three vectors (using PATN, Belbin 1993). NMDS is a robust technique to examine compositional dimensions associated with environmental gradients (Minchin 1987).

To help understand the nature of the environmental space being described by these vectors, a number of analyses were carried out. Scatter plots of sites in the ordination space transcribed by the three vectors were made to look for simple relationships. The GSTA (Group Statistics) module of PATN (Belbin 1993) was performed on the environmental attributes geographic position (easting and northing) and altitude, grouped according to the community analysis. The results of these analyses suggested that vector 2 may describe an altitudinal surrogate. Scatter plots were then constructed for sites which were numbered as per their UPGMA classified community (1–8).

Results

Floristic composition

Two hundred and sixty-five vascular plant species (Appendix 1) were recorded from the 62 quadrats. Of these, 189 are native species and 76 (29%) exotic. The most frequent native species recorded were *Poa sieberiana* (58%), *Acaena ovina* (52%), *Themeda australis* (50%), *Leptorhynchos squamatus* (42%), *Asperula conferta* (39%), *Carex inversa* (37%) and *Elymus scaber* (37%). The most frequent exotic species were *Hypochaeris radicata* (69%), *Vulpia myuros* (58%), *Trifolium campestre* (47%), *Trifolium arvense* (44%), *Bromus hordeaceus* (42%) and *Acetosella vulgaris* (39%).

Large numbers of exotic species were found in most communities but the ratio of native to exotic species varied (Table 2). Sites dominated by *Poa labillardieri* (Community 8) on average contained 52% exotic species. In contrast, only 6% of species recorded in the montane sod-tussock grassland (Community 6) were exotic. Community 3, dominated by *Themeda australis*, contained a lower percentage of exotic species (33%) than the other communities located below 1200 m altitude.

Sites with the highest number of native species were located in lightly grazed areas such as Kosciusko National Park, site 336 at Mount Jerrabomberra, Site 411 on the Snowy Plain, site 354 in the Yaouk Valley and the two sites near Adaminaby (352, 357).

Plant community analysis

Eight communities were defined by the favoured UPGMA cluster analysis selected at the 0.8 level of dissimilarity (Figure 2). This analysis excluded exotic species and included cover data for the native species in the matrix. If taken at the 0.74 dissimilarity level the 17 sites in Community 3 would separate into two groups. It was decided that their overall similarities outweigh their differences, although two sub-

Table 2. Attributes of sample sites

Site	East	North	Location	Geol	Soil	Landf.	Alt	Sl	Asp	Tsp	Nsp	Esp (%)	Tenure
336	6996	60832	Mt Jerrabomberra	S/V	Red clay	LS	610	4	280	39	32	7 (18)	Private
348	6902	60997	Navigation Centre	S/V	Red clay	LS	580	8	0	31	16	15 (49)	Navy
350	6981	60822	Poplars	S/V	Red clay	LS	590	2	320	21	12	9 (43)	Private
349	6973	60930	Campbell	S/V	Red clay	LS	600	3	110	29	18	11 (38)	Open space
351	6882	60996	Lake Ginninderra	S/V	Red clay	LS	580	8	280	25	14	11 (44)	Open space
337	6930	60145	Gungarlin	S/V	Loam clay	MS	600	5	120	20	10	10 (50)	ACT Govt.
338	6832	60737	Paddys River	G	Loam clay	MS	690	11	40	22	12	10 (45)	Private
364	6928	60007	2CY Tower	S/V	Loam clay	F	600	0	–	23	13	10 (43)	Private
366	6827	60741	Paddys Road	G	Loam clay	US	710	3	30	30	19	11 (37)	Roadside
368	6893	60927	Aust. Museum	S/V	Loam clay	LS	570	5	160	23	10	13 (56)	Open space
367	6994	60932	Airport Beacon	CS	Loam clay	F	590	1	240	24	17	7 (29)	Airport
345	6819	59867	Slacks Plain	S/V	Red clay	LS	900	2	330	29	16	13 (45)	Roadside
363	7099	59955	Numeralla Cemetery	S/V	Red clay	LS	610	4	280	16	9	7 (44)	Cemetery
355	6962	60063	Bredbo	S/V	Red clay	LS	720	3	90	39	30	9 (23)	Private
358	6958	60094	Bredbo	S/V	Red clay	R	810	3	30	30	20	10 (33)	Private
356	6557	59551	Beloka Cemetery	S/V	Red clay	US	860	4	315	33	20	13 (39)	Cemetery
352	6617	60150	Adaminaby Hill	S/V	Red clay	US	1040	5	120	35	23	12 (34)	Private
354	6640	60356	Yaouk	CS	Red clay	F	1110	0	–	41	32	9 (22)	Private
357	6612	60144	Adaminaby Saleyards	S/V	Red clay	R	1020	3	80	34	22	12 (35)	TSR
361	6533	59872	Round Plain Church	CS	Grey clay	F	1080	2	160	32	18	14(44)	Church
408	7100	59575	Kydra	G	Grey clay	R	1100	5	160	24	16	8 (33)	TSR
353	6946	60717	Royalla	S/V	Rey clay	LS	890	1	280	32	21	11 (34)	Railway
360	6947	60574	Williamsdale	S/V	Grey clay	LS	750	1	90	31	20	11 (35)	Railway
365	6956	60555	Waterholes	S/V	Red clay	MS	770	1	90	21	16	5 (24)	Railway
359	6537	59869	Round Plain	CS	Grey clay	F	1100	1	180	24	15	9 (37)	TSR
420	7064	59207	Black Lake	B	Choc/cher	R	960	3	270	23	17	6 (26)	TSR
362	6828	60812	Kambah	S/V	Grey clay	US	550	10	330	33	24	9 (27)	Cons. Res.
419	6793	59385	Bungarby	B	Choc/cher	R	960	3	270	21	15	6 (29)	Private
339	6846	59476	Avonlake	B	Choc/cher	US	880	4	120	28	19	9 (32)	TSR
340	6920	59746	Bondo	B	Choc/cher	LS	930	4	90	22	14	8 (36)	TSR
342	6861	59768	North Brother	B	Choc/cher	LS	940	3	240	31	16	15 (48)	TSR
343	6986	59750	Rock Flat	B	Choc/cher	LS	890	5	210	29	14	15 (52)	TSR
341	6828	59677	Ravensworth	B	Choc/cher	MS	1010	4	300	23	16	7 (30)	TSR
344	7013	59300	Home Dale	B	Choc/cher	US	900	5	50	23	14	9 (39)	TSR
346	6964	59779	Manaroo	B	Choc/cher	MS	920	8	290	22	14	8 (36)	Private
347	6899	59710	South Brother	B	Choc/cher	MS	1100	7	90	9	3	6 (66)	Private
369	6604	59670	Birkenhead	G	Sandy clay	R	940	3	320	23	16	7 (30)	Private
372	6791	59169	Quidong	L	Loamy clay	F	630	3	250	24	15	9 (37)	Private
370	6801	59156	Quidong	L	Loamy clay	US	700	9	220	31	21	10 (32)	Private
374	6636	59583	Dalgety	g	Sandy clay	US	760	6	210	18	11	7 (39)	TSR
376	6669	59621	Wyreela	G	Sandy clay	US	800	4	100	20	12	8 (40)	Private
377	6965	60853	Symonston	S/V	Grey clay	F	580	0	–	22	8	14 (63)	Private
371	6964	59252	Bukalong	S/V	Sandy Clay	R	820	2	50	23	14	9 (39)	Roadside
375	6714	59582	Black Range	S	Sandy clay	R	820	0	–	22	12	10 (45)	Roadside
378	6821	59503	Timbury Range	G	Sandy clay	R	940	4	290	13	5	8 (62)	Private
373	6823	59533	Maffra Church	G	Sandy clay	R	930	0	–	18	11	7 (39)	Church

409	6496	60584	Coolamine	L	Humus podsol	F	1260	4	90	26	26	0 (0)	NP
410	6452	60601	Long Plain	S/V	Humus podsol	F	1360	1	150	32	30	2 (6)	NP
418	6489	60290	Nungar Plain	S/V	Humus podsol	F	1340	3	180	26	24	2 (8)	NP
413	6399	60485	Long Plain	S/V	Humus podsol	F	1320	1	30	29	27	2 (7)	NP
411	6403	59933	Snowy Plain	G	Humus podsol	F	1340	2	150	34	32	2 (6)	Private
417	6391	59947	Davies Hut	G	Humus podsol	F	1320	0	–	22	21	1 (5)	NP
416	6398	59862	Botheram Plain	G	Humus podsol	F	1300	0	–	30	26	4 (13)	NP
412	6435	60294	Boggy Plain	G	Humus podsol	F	1380	2	340	32	28	4 (12)	NP
415	6392	59947	Snowy Plain	G	Humus podsol	F	1370	1	0	31	27	4 (13)	Private
414	6521	60364	Gulf Plain	S/V	Humus podsol	F	1240	3	70	28	25	3 (11)	NP
402	6987	59699	Rock Flat Creek	B	Black cher	C	930	2	330	13	6	7 (54)	Private
405	6670	59621	Wyreela	G	Humus loam	C	800	6	120	20	9	11 (55)	Private
403	6998	59975	Spring Bush	S/V	Loamy clay	C	740	2	80	7	4	3 (43)	Private
407	6681	60057	Caddigat Creek	S/V	Humus loam	C	1160	0	–	16	8	8 (50)	Private
404	7172	59727	Kybean River	G	Humus loam	C	1020	0	–	13	5	8 (62)	Private
406	6840	60168	Joes Swamp	G	Humus loam	C	1300	2	90	21	11	10 (48)	Private

Notes.

Full Australian Map Grid (AMG) references are given. **Alt** = altitude; **Sl** = slope in degrees from horizontal; **Asp** = aspect; **Tsp** = total no. species; **Nsp** = no. native species; **Esp** (%) = no. exotic species (percentage of total). **Geol** = Geology (from Spate (1993): S/V = Palaeozoic sediments or volcanics; CS = Cainozoic sediments; G = granites; L = limestone; B = basalt). **Soils** are classified from field observations and from Costin 1954. Choc/cher = chocolate or chernozem soils derived from basalt. **Landf. (LF)** = LS: lower slope; MS: mid-slope; US: upper slope; R: ridge; F: flat; C: creek or drainage line.

Site 367 has been transferred from Community 3b (where it was placed in the UPGMA analysis) to Community 2 (see text).

groups (3a and 3b) are recognised based on a number of species exclusive to one or the other (for example *Dodonaea procumbens* only occurs in 3a).

One site, 367, which is dominated by *Themeda australis* and *Poa sieberiana*, was manually transferred from Community 3 to Community 2 in the classification based on an examination of the location of its five nearest neighbours in the analysis, its species composition and its geographical position in the ACT. Two sites in Community 2 (sites 368 and 337) listed site 367 as one of their closely allied sites, yet the two nearest neighbours to site 367, grouped into Community 3, did not have 367 as their nearest neighbour. Site 367 also contains *Eryngium rostratum* with *Juncus filicaulis* recorded as being adjacent to the quadrat. Both of these species are more typical of sites grouped under Community 2 than Community 3.

Relationships of site groupings to site attributes can be seen by examining Table 2, Figure 3 (altitude versus vector 2) and Figure 4 (geographic position map). Table 2 reveals the fidelity that some communities have for geology and soil type and therefore the value of these attributes as predictors of the vegetation. Community 4, for example, is restricted to basalt substrate weathering to deep chocolate or chernozem soils. Alternatively, Community 3 is less predictable by way of these attributes as it is present on a range of substrates and soil types.

Altitude was revealed as a possible explanatory variable by examination of Table 2 along with the GSTA analysis. A significant correlation ($p < 0.001$) was found between altitude and vector 2 using all communities (Figure 3; $r = -0.73$). thus, vector 2 may describe a surrogate for an altitudinal gradient, or at least one in which altitude plays a part (for example moisture).

Some communities also display high geographical fidelity. Figure 4 shows how in both eastings and northings Community 1 is tightly clustered and is geographically discrete (ACT region). Community 2 occupies an equally narrow longitudinal band but extends latitudinally much further. Community 4 also occupies a discrete space (south of Cooma). Community 3 is the most widespread of the communities occupying sites from near Queanbeyan to Bombala. There is significant overlap between communities 6 and 7, however they have been separated by the UPGMA classification, and probably reflect local environmental variation.

UPGMA: all species versus native species only

Including the exotic species in the analysis resulted in three of the 62 sites (sites 347, 357 and 367) changing communities. These site changes were judged to have weakened the classification based on site floristics and geographical position. For example it resulted in a poorer relationship of the two subsections of Community 3 (3a and 3b).

UPGMA: cover rating versus presence/absence

When cover rating for each species were replaced with presence/absence in the UPGMA analysis of native species only, changes occurred in the groupings of sites. Group definition became less defined and the dendrogram generated more groups at the 0.8 level of dissimilarity. Communities 6 and 7 did not change, but eight sites (338, 339, 371, 345, 367, 375, 377 and 402) moved between the other groups. Some of these changes contradicted the classification which used cover data. For example, site 402, which is a species-poor site dominated by *Poa labillardieri*, was placed distant from Community 8 where it clearly belongs and into a group resembling Community 2. Likewise, site 375, which is dominated by *Stipa* grasses, changed from its previous logical grouping with other *Stipa* grass sites and was placed among the *Poa sieberiana* dominated sites that occur on basalt.

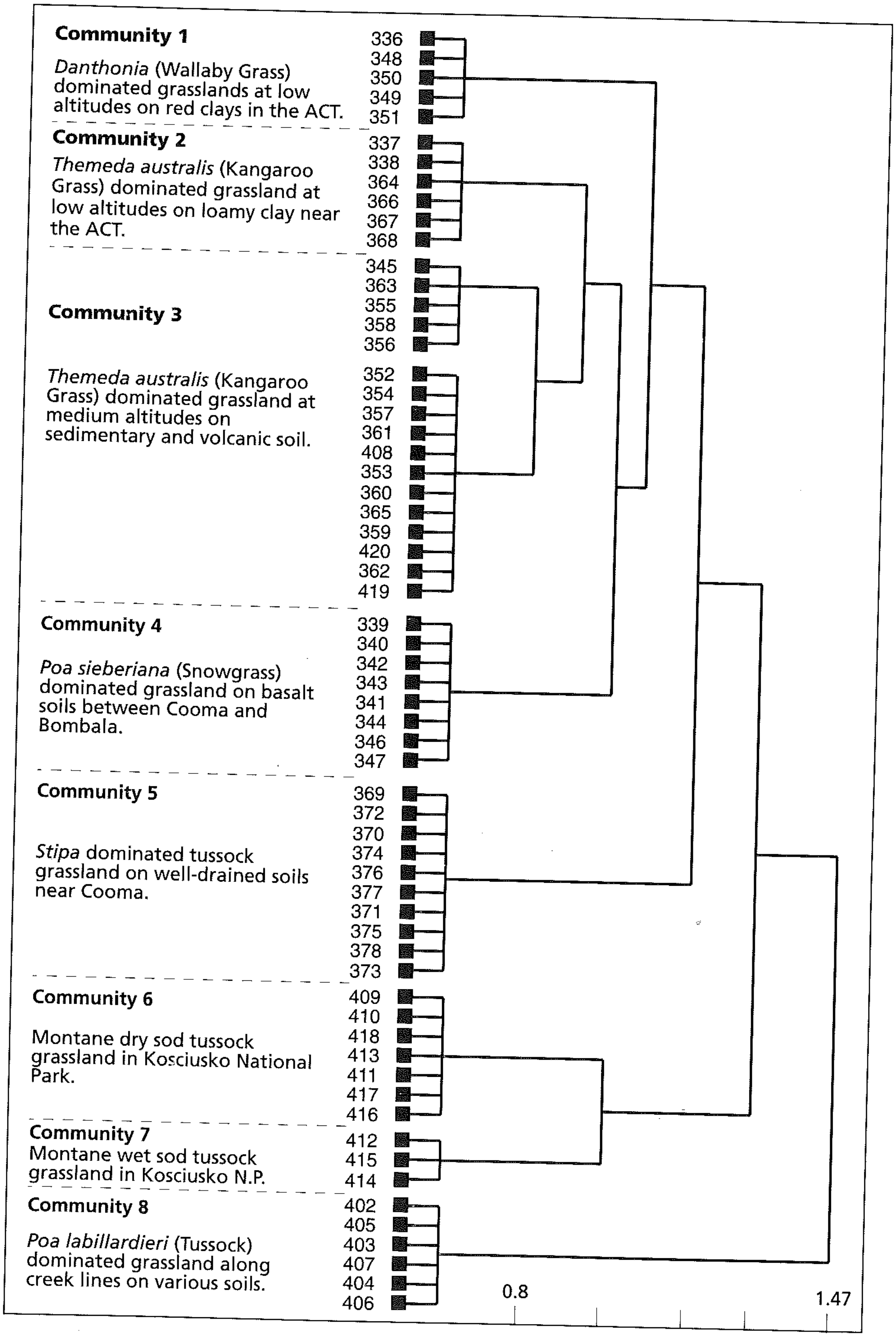

Figure 2. Agglomerative classification of sites by their similarity of vascular plant composition selected at the 0.8 disassociation value. This analysis is based on cover ratings for native species in each quadrat and excludes exotic species.

It is possible that the use of cover ratings in the UPGMA analysis may have clouded more subtle species relationships between sites due to their sharing of less abundant species. In most sites, however, only a few species per quadrat were assigned high cover ratings and it was assumed that the combined association values generated between all species and sites in the analysis would do more to dictate the groupings than a few species with high cover ratings. Ratings were used to help with the classification and perennial dominant species are important in this regard. This hypothesis, however, needs more testing.

UPGMA versus TWINSPAN

The classification of the plant communities generated by the agglomerative hierarchical classification UPGMA sorting strategy (Belbin 1993) was considered to be superi-

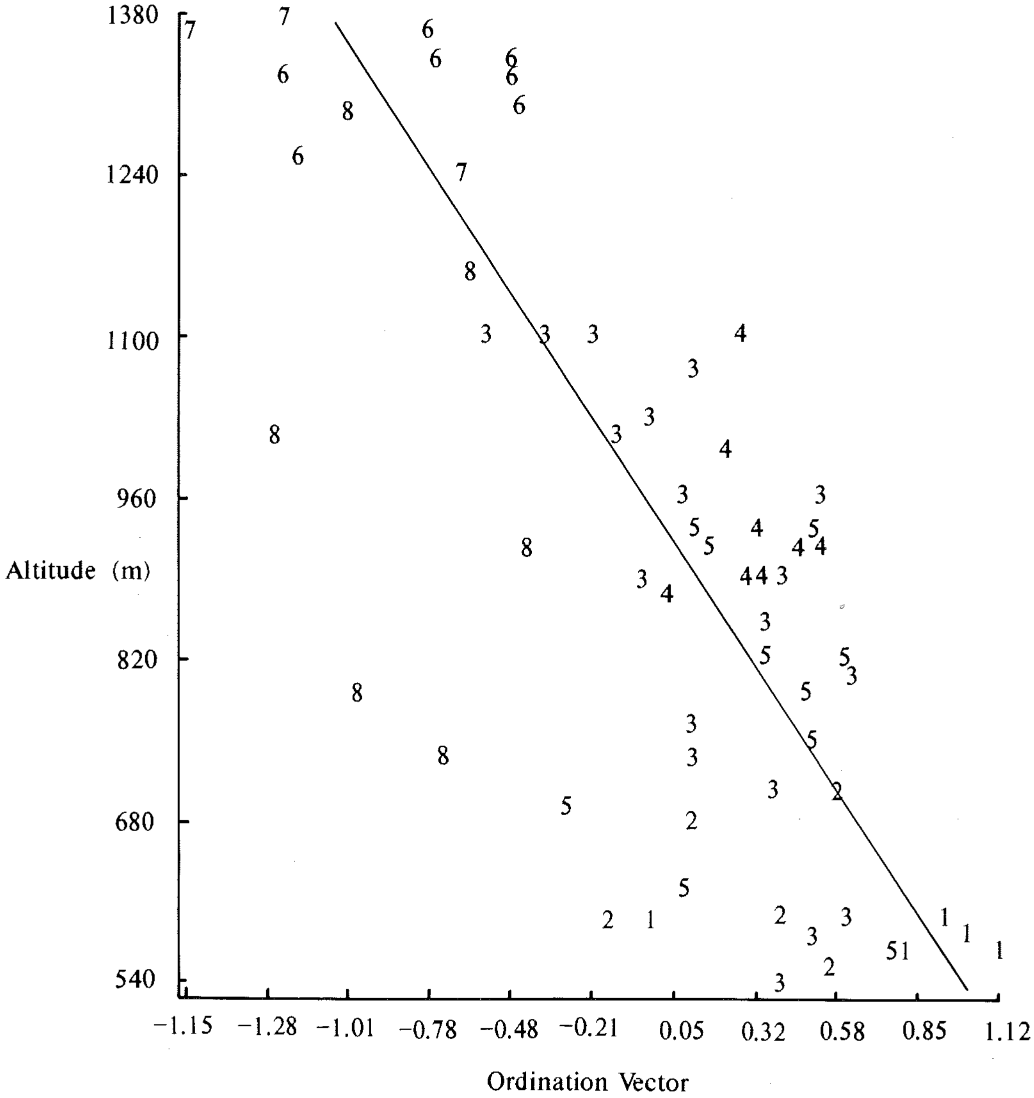

Figure 3. Scatter plot of the altitude and ordination vector 2 values of sites. The site numbers (1–8) reflect their community groupings as defined in the cluster analysis.

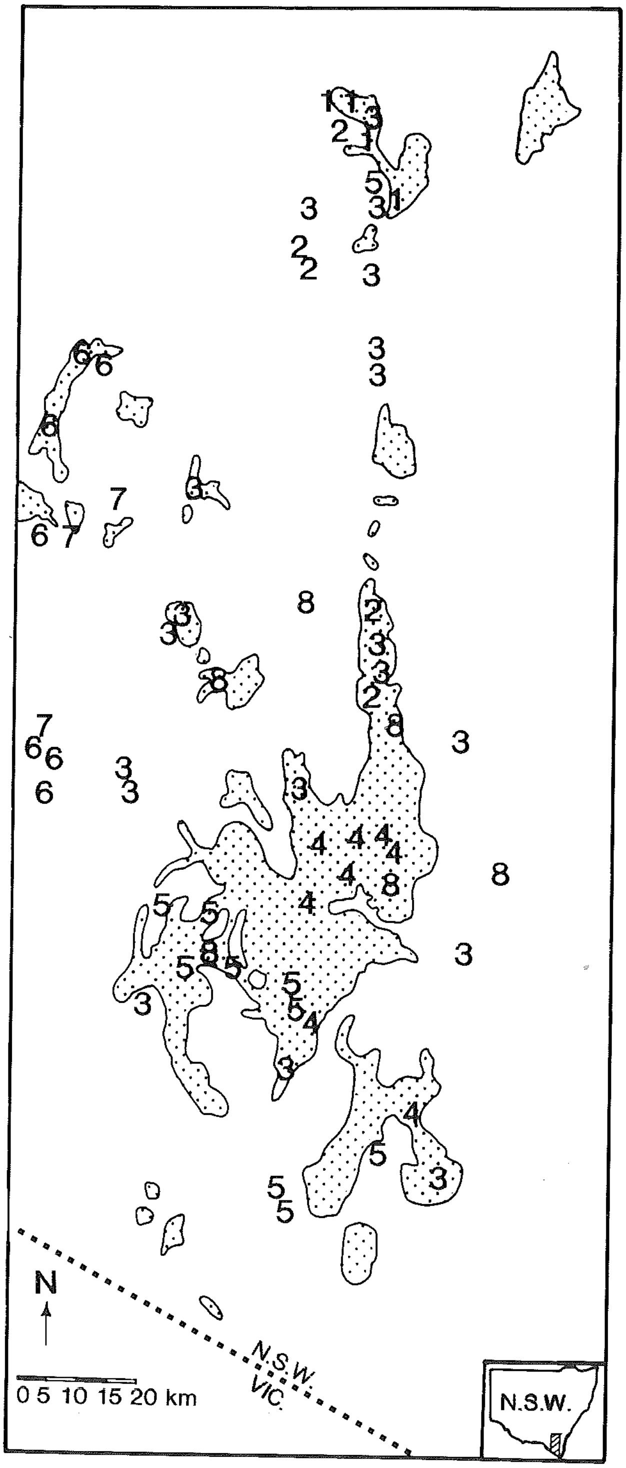

Figure 4. Scatter plot showing the Australian Map Grid locations of the sample sites in the study area. Sites are classified into communities 1–8.

or to that generated by the polythetic hierarchical divisive classification TWINSPAN (Hill 1979) presented in Benson and Wyse Jackson (1993). The UPGMA sorting strategy yielded groups with improved correlation with substrate and geographical location than the TWINSPAN sorting strategy. For example, the two sites within 1 km of each other on the same soils and altitude at Adaminaby (sites 357 and 352) were split into different groups by TWINSPAN but lumped into the same group by all of the UPGMA analyses (native species only, all species, cover ratings, presence/absence). TWINSPAN separated these two sites at an early level in its sorting, principally because site 352 was dominated by *Themeda australis* and site 357 lacked this species because it had been recently grazed.

Grassland communities

The structure and floristics of the eight plant communities selected from the favoured UPGMA analysis are detailed below. The structural classification is based on Walker and Hopkins (1990). Dominant native and common weed species have been selected by examining a two way table generated using cover ratings and all species. Indicator species were also selected from this two way table on the basis of their frequency of occurrence in a community or because they were largely confined to a single community.

• Community 1. *Danthonia* spp.–*Asperula conferta*–*Bothriochloa macra* low grassland on the northern Monaro

No. sample sites: 5

Structure: Mid-dense, low tussock grassland.

Mean no. native spp. per site: 18

Mean no. exotic spp. per site: 11 (38%)

Dominant native species: *Danthonia carphoides, Danthonia auriculata, Asperula conferta, Bothriochloa macra, Vittadinia muelleri, Chrysocephalum apiculatum, Goodenia pinnatifida.*

Indicator native species: *Danthonia carphoides, Danthonia auriculata, Aristida ramosa, Triptilodiscus pygmaeus, Goodenia pinnatifida, Pterostylis mutica.*

Common exotic species: *Vulpia myuros, Bromus hordeaceus, Plantago lanceolata, Parentucellia latifolia, Moenchia erecta, Hypochaeris radicata, Trifolium campestre, Aira elegantissima.*

Landform, geology and soils: Occupies the lower slopes on the margins of valleys composed of paleaozoic sediments and volcanics which weather to form red clay soil.

Distribution: Confined to the ACT and Queanbeyan districts on the northern Monaro. This area contains the lowest elevations and warmest temperatures in the study area; altitude range 580–610 m.

Condition: With the exception of site 336 at Mount Jerrabomberra, this community has a high number of weeds but areas subject to mowing at a height of 10 cm or higher appear to contain healthy stands of *Danthonia* and other native species.

Threats and conservation status: The main threat is urban expansion and the small size of the remnants. No sites are currently protected in reserves.

Key sites for conservation: Site 336, Mount Jerrabomberra, contains one of the largest remaining populations of the endangered plant, *Rutidosis leptorhynchoides*. Site 348, Navy Navigation Centre Belconnen, contains the largest *Danthonia carphoides* dominated remnant sampled in the survey. The site is important as a habitat for a large population of an endangered moth, *Synemon plana*, which feeds on the roots of *Danthonia carphoides* (Edwards 1989).

• Community 2. *Themeda australis*–*Juncus filiformis* grassland of the ACT

No. sample sites: 6 (including site 367)

Structure: Mid–dense, mid–high tussock grassland.

Mean no. native spp. per site 13

Mean no. exotic spp. per site 11 (46%)

Dominant native species: *Themeda australis, Juncus filiformis, Rumex brownii, Eryngium rostratum, Carex inversa.*

Indicator native species: *Themeda australis, Juncus filiformis, Drosera peltata.*

Exotic species: *Acetosella vulgaris, Hypochaeris radicata, Bromus hordeaceus, Vulpia myuros, Cirsium vulgare, Aira elegantissma, Briza minor, Moenchia erecta, Plantago lanceolata.*

Landform, geology and soils: Occurs on gentle slopes or flats on either granite or sediments/ volcanics substrate forming loamy clay soils. Sites are often moist indicated by the prevalence of *Juncus filiformis.*

Distribution: Low elevation section of the tableland in the ACT.

Condition: High weed content, low native species diversity.

Threats and conservation status: Most sites are threatened by urban development and further weed invasion. Sites 337 and 368 are in ACT urban parkland.

Key sites for conservation: Site 364, 2CY Tower ACT; site 367, Airport Beacon which contains three threatened fauna species (S. Sharp pers. comm.).

• **Community 3. *Themeda australis–Poa sieberiana–Chrysocephalum apiculatum–Acaena ovina* tall grassland** (Figures 5, 6 and 7)

No. sample sites: 17 (excluding site 367).

Structure: Dense, tall tussock grassland.

Mean no. native spp. per site 20

Mean no. exotic spp. per site 9 (33%)

Dominant native species: *Themeda australis, Poa sieberiana, Chrysocephalum apiculatum, Acaena ovina, Leptorhynchos squamatus, Plantago varia, Asperula conferta, Danthonia laevis, Elymus scaber, Carex inversa.*

Indicator native species: This relatively heterogeneous community falls into two subgroups (3a and 3b). Subgroup 3a is distinguished by containing *Dodonaea procumbens, Swainsona sericea, Pimelea curviflora, Vittadinia muelleri, Stipa scabra* subsp. *falcata* and *Stipa nodosa*. Subgroup 3b is distinguished by the presence of *Ranunculus lappaceus, Geranium retrorsum, Lomandra multiflora, Senecio quadridentatus, Carex inversa, Geranium solanderi* and *Leptorhynchos squamatus.*

Figure 5. A travelling stock reserve near Black Lake east of Bombala dominated by a summer growth of *Themeda australis*. This species and other palatable plants were found to be most abundant in fenced off and lightly grazed areas such as churches, cemeteries, TSRs and rail easements.

These floristic differences indicate that Community 3a contains species more adapted to well drained sites than Community 3b.

Exotic species: *Trifolium glomeratum*, *Trifolium arvense*, *Trifolium campestre*, *Vulpia myuros*, *Tragopogon dubius*, *Hypochaeris glabra*, *Hypochaeris radicata*, *Cerastium glomeratum*, *Bromus hordeaceous*.

Landform, geology and soils: Community 3a occurs on well drained slopes or ridges on sediments or volcanic substrates forming red clay soils. The two Bredbo sites (355 and 358) are situated on tilted shales with shallow soils. Community 3b occurs in a variety of positions in the landscape, on mixed substrates and different soil types, although grey clay was recorded as the most common soil.

Distribution: Low to high altitudes mainly on the tableland tract. This is the most widespread of the eight communities, ranging from Kambah near Canberra in the north to near Bombala in the south and Adaminaby in the west. It occurs at a range of altitudes (550–1100 m).

Condition: Excluding the montane communities 6 and 7, the sites in this community were deemed to be in good condition. They contained a relatively low percentage of exotic species and a high diversity of native plants. It would appear that sites dominated by *Themeda australis* have been less intensively grazed, at least over recent times.

Threats and conservation status: Most of these sites are fenced off from stock for one reason or another. Some such as TSRs are subject to intermittent grazing, others such as the Beloka and Round Plain cemeteries are subjected to occasional mowing. The main threats are increased grazing pressure and further weed invasion. Site 354 in the Yaouk Valley is threatened by cultivation. None of the grassland areas of this community are protected in conservation reserves. Previously forested grassland containing a similar species composition to this community is located in the Naas and Grassy Creek sections of Namadgi National Park in the ACT (unpublished site data F. Ingwersen pers. comm.).

Key sites for conservation: With the exception of site 345, Slacks Plain, all of these sites are worthy of protection. The most important sites are: sites 355 and 358 at Bredbo that contain populations of the rare *Dodonaea procumbens*; sites 352, 357 and other areas at Adaminaby which contain populations of the rare *Discaria pubescens*; site 354 at Yaouk which contains a high species diversity; sites 353 and 360 along the abandoned Queanbeyan railway line which contain the largest known populations of the endangered *Swainsona recta*.

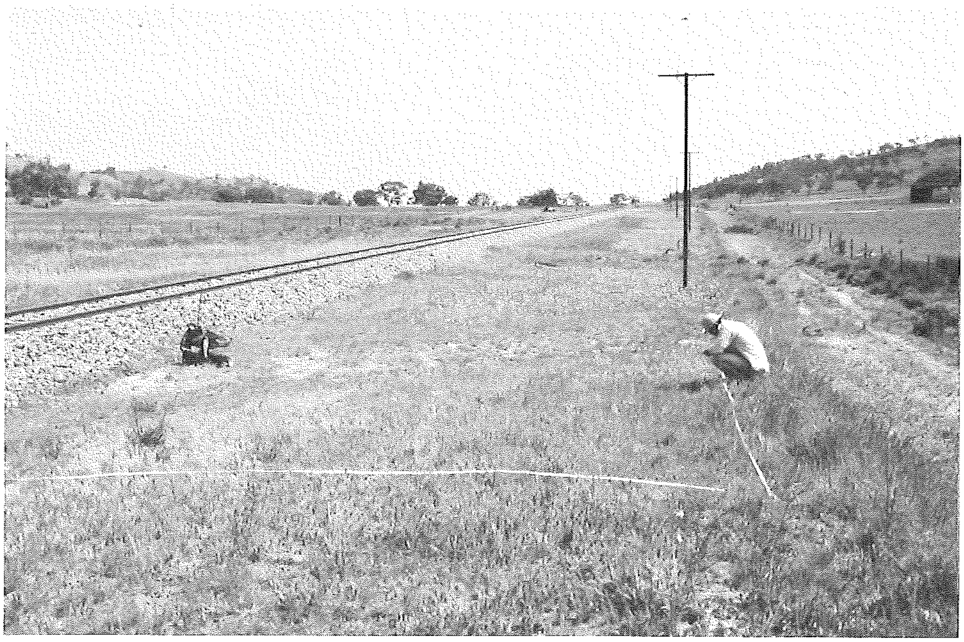

Figure 6. The Queanbeyan–Cooma abandoned railway easement contains patches of *Themeda australis* grassland and the largest known population of the endangered forb *Swainsona recta* (site 353).

Figure 7. *Themeda australis* growing on private land east of Adaminaby (site 352). Several adjacent TSRs also contain grassland in relatively natural condition.

• **Community 4. *Poa sieberiana–Acaena ovina* grassland on basalt, southern Monaro** (Figure 8)

No. sample sites: 7

Structure: Dense, mid–high tussock grassland.

Mean no. native spp. per site 14

Mean no. exotic spp. per site 10 (42%)

Dominant native species: *Poa sieberiana, Acaena ovina, Asperula conferta, Bothriochloa macra, Danthonia caespitosa, Scleranthus diander, Psoralea tenax, Stipa bigeniculata, Wahlenbergia communis.*

Indicator native species: *Poa sieberiana, Psoralea tenax, Scleranthus diander.*

Exotic species: *Poa bulbosa, Vulpia myuros, Trifolium striatum, Trifolium campestre, Salva verbenacea, Petrorhagia nanteulii, Hypochaeris radicata.*

Landform, geology and soils: Occurs on an undulating plateau composed of basalt which has weathered to form deep, chocolate/chernozem soils.

Distribution: This is the dominant vegetation community on the extensive basalt plateau situated on the high tableland section of the study area between Cooma and Bombala. Maximum elevations extend to 1100 m (montane). Approximately 80 000 hectares of this area is covered with this semi-natural tussock grassland.

Condition: Moderate numbers of native species; all sites with a mixed native/exotic species cover occupying the inter-tussock space.

Threats and conservation status: The region where this community occurs is grazed by sheep and cattle and there has been some improvement of pasture — particularly by sowing clover species. The quadrat data suggest that TSRs have a higher native species richness than private land. Overgrazing of TSRs remains the major threat. No sites are protected in conservation reserves.

Key sites for conservation: Based on floristic composition it is difficult to single out any of the sites for special conservation action. All sites are valuable for conserving representive samples of this community. A number of the TSRs could be protected by reservation or conservation agreement (see Table 3).

• **Community 5. *Stipa scabra* subsp. *falcata*–*Stipa bigeniculata* grassland** (Figure 9)

No. sample sites: 10

Structure: Mid–dense, tall tussock grassland.

Mean no. native spp. per site: 13

Mean no. exotic spp. per site: 9 (43%)

Dominant native species: *Stipa scabra* subsp. *falcata, Stipa bigeniculata, Elymus scaber, Danthonia caespitosa, Enneapogon nigricans, Wahlenbergia communis.*

Indicator native species: *Stipa scabra* subsp. *falcata, Stipa bigeniculata, Stipa blackii, Danthonia linkii* subsp. *linkii.*

Exotic species: *Trifolium arvense, Vulpia myuros, Hypochaeris glabra, Hypochaeris radicata, Carthamnus lanatus, Paronychia brasiliana, Aira caryophyllea.*

Landform, geology and soils: Mainly on upper slopes and ridges with well drained, sandy or loamy clay soils derived from granite, limestone and sediments.

Distribution: Occurs on rolling downs below the basalt plateau on the tableland tract in the Dalgety–Berridale region. Outlying sites occur on limestone at Quidong near Dalgety and on the southern outskirts of Canberra.

Condition: Most sites have been heavily grazed and contain moderate numbers of native plants and high numbers of exotics. *Themeda australis* may have been more common before European settlement but is now largely absent.

Threats and conservation status: Pasture improvement and overgrazing threatens the remaining remnants. Site 377 (Symonston) in the ACT is threatened by urban development and is large in area and worthy of protection.

• Community 6. *Poa* spp–*Geranium antrorsum*–*Scleranthus biflorus*–*Leptorhynchos squamatus*–*Ranunculus graniticola* montane, sod tussock grassland (Figure 10)

No. sample sites: 7

Structure: Dense, mid–high, sod-tussock grassland.

Mean no. native spp. per site: 27

Mean no. exotic spp. per site: 2 (6%)

Dominant native species: *Poa sieberiana, Poa costiniana, Geranium antrorsum, Scleranthus biflorus, Leptorhynchos squamatus, Ranunculus graniticola, Acaena ovina, Oreomyrrhis argentea, Craspedia coolaminica, Podolepis robusta.*

Indicator native species: All of the above excluding *Poa sieberiana, Leptorhynchos squamatus,*

Figure 8. North Brother TSR (site 342). *Poa sieberiana* dominated grassland (Community 4) is confined to the high basalt plateau between Cooma and Bombala.

Figure 9. Bukalong roadside (site 371). The *Stipa scabra* subsp *falcata–Stipa bigeniculata* community (Community 5) occurs on better drained and less fertile soils than Community 4. It is likely that *Themeda australis* would have been common in this community before European settlement.

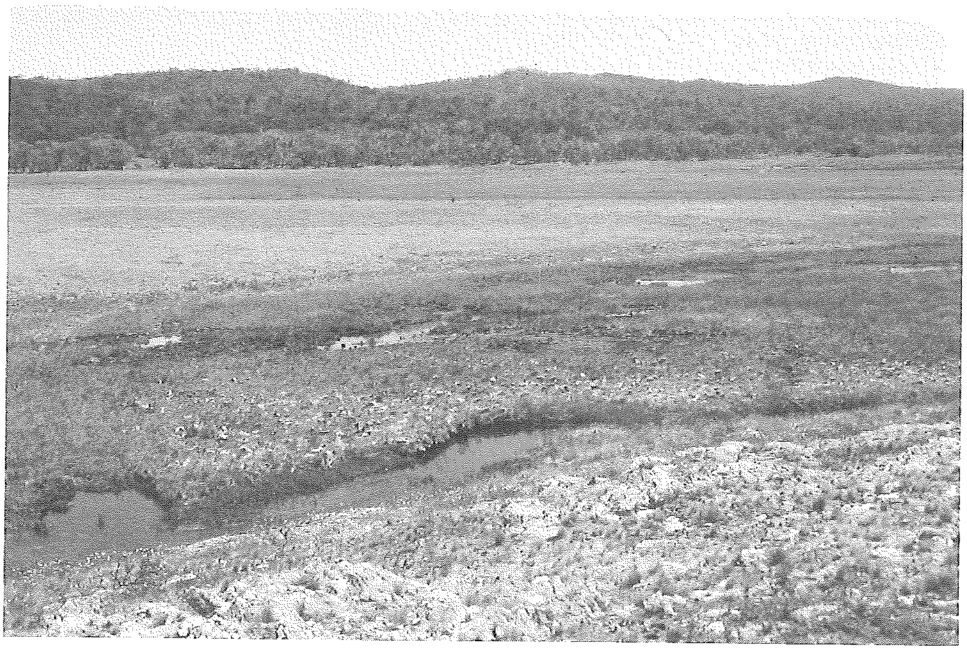

Figure 10. Long Plain (Site 413). The montane/subalpine grasslands (communities 6 and 7) growing in humus soil in frost hollows on the eastern side of Kosciusko National Park contain flora distinct from that present in the grasslands on the tableland tract (see Figure 2).

Acaena ovina. Also, *Microseris lanceolata*, *Wahlenbergia densifolia*, *Danthonia nudiflora*.

Exotic species: Few exotic species were recorded from this community: the most common were *Acetosella vulgaris*, *Hypochaeris radicata*, *Cerastium fontanum* subsp. *trivale*.

Landform, geology and soils: Occurs on valley flats or adjoining gentle slopes affected by cold air drainage; on granite or sedimentary substrates; soils are humus podsolic or peaty, formed under a high rainfall, cold temperature climatic regime.

Distribution: Between 1300–1400 m in the montane, south-western section of the study area.

Condition: Although these valleys were grazed over the last century, there was little pasture improvement and the grasslands are in excellent condition with few exotic species present.

Threats and conservation status: Large areas of this community are represented in Kosciusko National Park.

Key sites for conservation: Site 411 situated on Snowy Plain is outside the Park. In terms of its condition, the whole of the Snowy Plain is worthy of addition to the Park.

• Community 7. *Poa costiniana–Epilobium billardierianum* subsp. *cinereum–Brachycome scapigera–Asperula gunnii* montane, sod-tussock grassland

Sample sites: 3

Structure: Dense, mid–high sod-tussock grassland.

Mean no. native spp. per site: 27

Mean no. exotic spp. per site: 4 (12%)

Dominant native species: *Poa costiniana*, *Epilobium billardierianum* subsp. *cinereum*, *Brachycome scapigera*, *Asperula gunnii*, *Geranium retrorsum*, *Stylidium graminifolium*, *Wahlenbergia multiflora*.

Indicator native species: The above listed species and *Craspedia jamesii*, *Restio australis*, *Cardamine paucijuga*.

Exotic species: *Hypochaeris radicata*, *Acetosella vulgaris*, *Trifolium repens*, *Cerastium fontanum* subsp. *trivale*.

Landform, geology and soils: In wetter areas than Community 6, on valley flats affected by cold air drainage; on humus or peaty soils.

Distribution: Occurs in the same regions as Community 6.

Condition: Contains more weeds than Community 6 but is also in excellent condition.

Threats and conservation status: Well conserved in Kosciusko National Park.

• Community 8. *Poa labillardieri* tall tussock grassland (Figure 11)

No. sample sites: 6

Structure: Dense, very tall tussock grassland.

Mean no. native spp. per site: 7

Mean no. exotic spp. per site: 8 (52%)

Dominant native species: *Poa labillardieri*, *Carex appressa*, *Carex inversa*.

Indicator native species: Species listed above and *Juncus filiformis*, *Haloragis heterophylla*, *Hydrocotyle peduncularis*.

Exotic species: *Poa pratensis*, *Rumex crispus*, *Trifolium repens*, *Trifolium dubium*, *Cirsium vulgare*, *Holcus lanatus*.

Landform, geology and soils: Restricted to drainage lines or river flats on a range of substrates; soils generally loamy.

Distribution: Tableland and montane sections of the study area at a range of altitudes (740–1300 m). Widespread but restricted in extent where it occurs.

Condition: Poor condition; exotic species out number native species.

Threats and conservation status: Nutrient increases due to the application of agricultural fertilisers probably encourages weed invasion. No sites sampled are considered worthy of protection. All are on private land.

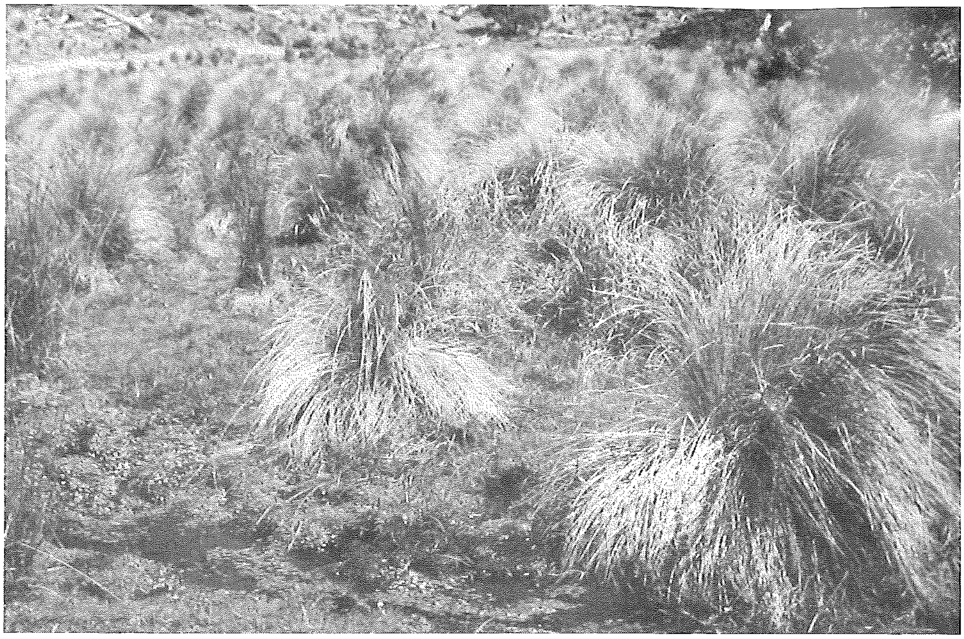

Figure 11. Joes Swamp (site 406). All sites sampled in Community 8 dominated by tall tussocks of *Poa labillarderi* contained a high proportion of exotic plants and low native plant diversity. This community is confined to drainage lines and river flats in the study area.

Figure 12. A healthy population of the rare plant *Discaria pubescens* occurs in the lightly grazed Round Plain Uniting Church (site 361) and near Adaminaby (site 352 and adjacent TSRs).

Nationally rare or threatened species

The following five species recorded in the survey are currently listed on ROTAP (Briggs and Leigh in prep.).

- *Swainsona recta* (3ECi): Approximately 1000 plants (J. Briggs pers. comm.) of this species have been counted in *Themeda australis* grassland (Community 3b) along a 22.5 km section of the abandoned Queanbeyan to Cooma railway easement between Tuggeranong in the north and south of Williamsdale in the south (including areas sampled in sites 353 and 360). This represents the largest known population of *Swainsona recta*, which is apparently restricted to grey loamy clay in the study area, as it has not been recorded in similar grassland on red clay further south. A small population also occurs in Canberra and several hundred plants grow near Wellington on the Central Western Slopes of NSW. In October 1993 less than 100 plants were observed in the vicinity of site 353 (J. Briggs pers. comm.). The rail easement population is threatened by grazing by stock, herbivorous invertebrates and by weed invasion. Fire may also play a role in its survival by removing the rank growth of grasses, stimulating resprouting from rootstock or the germination of seed. The railway easement is no longer regularly burnt as it was prior to its closure in 1987 (Zich 1993a). A rare grasshopper, *Keyacris scurra* is also present at this site.
- *Rutidosis leptorhynchoides* (3ECa): This species was once widespread in Victoria (Department of Conservation and Environment 1993a) and in the ACT–Queanbeyan region of NSW. Many populations, have recently been destroyed by urban expansion (Zich 1993b). Over 1000 plants are known from the two hectare Queanbeyan Nature Reserve but a larger population exists at site 336, in Community 1, at the north-western foot of Mount Jerrabomberra. This site is also threatened by urban development.
- *Dodonaea procumbens* (3V): This species was added to the national list due, in part, to the findings of this survey. It is distributed (West 1984) from the Lofty Ranges of South Australia, where small roadside populations remain, to the Penola and Grampians areas of Victoria where it is considered rare (J. Briggs pers. comm.) and to the Monaro in NSW where it has only been collected on the tilted shale bands running north from Bredbo. Here it grows in *Themeda australis–Poa sieberiana* grassland (Community 3a, Sites 355, 358).
- *Calotis glandulosa* (3VC-): The seven collections of this species in the NSW National Herbarium reveal that this species is mainly restricted to grasslands on the Monaro, with outlying collections at Oberon on the Central Tablelands and Mount Imlay on the South Coast. The accuracy of J.C. Boorman's 1916 record on Mount Imlay requires confirmation given that recent surveys have not located it in its vicinity (Keith and Sanders 1990). *Calotis glandulosa* was located once during this survey at site 356, Beloka Cemetery, in a *Themeda australis* dominated grassland protected from grazing (Community 3a). *Calotis glandulosa* has also been recently recorded from Bibbenluke Cemetery between Nimmitabel and Bombala (I. Lunt pers. comm.) and along the Dalgety–Jindabyne Road easement (G. Harden pers. comm.). These latest recordings suggest this species may be more common than previously thought, although it is notable that it tends to be restricted to areas where grazing is largely excluded. It therefore appears that grazing by stock may have led to a decline in abundance of *Calotis glandulosa* throughout its range.
- *Discaria pubescens* (3RCa): This species has a widespread distribution from Queensland to Victoria. It appears to decline with grazing pressure and seed-

lings are rarely found (Department of Conservation and Natural Resources 1993b). It was recorded in two quadrats, 352 Adaminaby Hill (Figure 12) and 361 Round Plain Church. It is also known to occur in the TSRs at Adaminaby adjoining site 352. All sites where *Discaria pubescens* is recorded were fenced off from stock and are likely to have had a history of less intense or less frequent grazing. Herbarium records reveal this species is conserved in Kosciusko and Namadgi National Parks.

Wahlenbergia densifolia, previously listed as a rare species on the national list, was in five of the eight sites in Kosciusko National Park where it is under no threat and well conserved. It has therefore been removed from the ROTAP list (Briggs and Leigh in prep.).

Regionally rare species

Since the grassland ecosystems on the Monaro have been subject to major alteration since European settlement and little remains in good condition, it is logical that many grassland plant species would have declined in abundance during the same period. This particularly applies to inter-tussock, palatable forb species that have an upright habit (McIntyre 1993).

While 53 native species were recorded only once in the survey (Appendix 1) the vast majority of these are known to be common over their recorded range or common in other habitats. These include *Centrolepis strigosa, Podolepis hieracoides, Leptorhynchos elongatus, Swainsona behriana, Poa petrophila, Dichanthium sericeum, Dichelachne rara, Stipa blackii* and *Stipa densifolia.*

Species deemed to be regionally rare on the Tableland tract of the Monaro are *Diuris punctata, Swainsona monticola, Swainsona behriana, Stipa blackii, Senecio velleioides, Ranunculus sessiliflorus* var. *sessiliflorus, Podolepis hieracioides, Leptorhynchos elongatus* and *Solenogyne dominii.* Further surveys would refine this list.

This listing excludes species recorded in communities 6 and 7 that are located at higher elevations mainly in Kosciusko National Park. It is based on the frequency of each species recorded in this survey, herbarium records for the area and the author's knowledge of other habitats on the Southern Tablelands.

Discussion

The hypothesis of Cambage (1909) to explain the geographical distribution of natural grassland on the Monaro is largely supported by Ripley (1992) who states that grasslands throughout the world occur on a variety of substrates and landscapes but share the climatic characteristics of being subject to periodic drought and occurring in regions with a precipitation of between 350–800 mm. Titlyanova et al. (1990) add that the distribution of grassland is largely determined by the amount of available moisture in the soil. The lower altitude grasslands on the rainshadow-affected tableland tract of the Monaro fit with these findings.

The great prairie grasslands of North America and Russia grow on heavy chernozem soils, in low rainfall zones subject to drought (Moore 1964). Moisture availability in these heavy soils for the growth of trees is critical during dry times. Similar conditions prevail on the basalt plateau on the southern Monaro where *Poa sieberiana* is dominant (Community 4). A thick carbonate horizon is often present in these chernozem soils at less than 1 m depth (Costin 1954 and pers. comm.). This suggests that water does not percolate to a great depth. Given the low rainfall for this area, it is likely that the available moisture in the top layer of soil is exhausted by the dense herbaceous vegetation and tree seedlings may be outcompeted by a dense sward of grasses and forbs. When trees do grow they tend to occupy rocky ridges where ground vegetation is more sparse and where their roots can penetrate through cracks in rocks to the water table.

Some wetter parts of the Monaro grasslands may be subject to gradual recolonisation by shrub and tree species that survived the dry conditions of the last ice age in refuge areas, such as the coastal plain and escarpment (A. Costin pers. comm.). The montane and subalpine sod-tussock grasslands of Kosciusko National Park receive high precipitation and are less prone to drought. Tree growth is restricted in this area by frequent frosts and competition of tree seedlings with forbs and grasses (Harwood 1976).

Of the eight grassland groups described, communities 1, 2 and 3 (mostly occurring below 1000 m) appear to be most similar in species composition to the grasslands on the basaltic western plains of southern Victoria (based on comparisons in McDougall and Kirkpatrick 1993 and the discussion in Willis 1964).

The Monaro grasslands today

With the exception of the montane, sod-tussock grasslands (Communities 6 and 7) the grassland communities on the Monaro have been substantially modified since European settlement. Exotic species comprise over 35% of the flora in most places. It appears that many native plants have been eliminated or reduced in abundance through a history of intense grazing, competition with weeds and perhaps altered fire regimes. Although at most sites the bulk of the vegetation is composed of a small number of dominant native species, there is now an abundance of introduced annual species such as *Vulpia* occupying the inter-tussock space. Similar trends have been documented for other regions — Moore (1953) for inland NSW, and Barr and Cary (1992) for Victoria.

It is estimated that only a small fraction of the original extent of communities 1,2,3 and 5 remain in reasonable condition, that is, have a range of native species providing most of the biomass. The best remnants occur on roadsides, in church yards, cemeteries and in Travelling Stock Reserves. A shared feature of these places is that they have been fenced off from continual grazing and have not been subject to intensive pasture improvement or cropping. Similar findings have been documented for grasslands in Victoria (Stuwe 1986, McDougall et al. 1993).

Environmental determinants of communities

While altitude is the major determinant in the distribution of most species and the vegetation communities, the tall tussock *Poa labillardieri* grassland (Community 8) occurs at a range of altitudes and on a number of substrates. The main factor determining its distribution is landform position, since it is confined to drainage lines or river flats. These locations are moister than the surrounding slopes and probably act as nutrient drains and therefore provide a suitable habitat for many introduced plants which favour moist, higher nutrient sites (Doing 1972).

Most of the Monaro grasslands occur on heavy textured soils derived from fine grained sediments or volcanics, basalt or limestone. The sites grouped under Community 3 cover the greatest variation in substrate, soils and altitude. Their grouping is largely due to a shared dominance of *Themeda australis* and *Poa sieberiana*, and the common presence of other grass and forb species such as *Geranium solanderi* and

Stackhousia monogyna. The presence of a high diversity of inter-tussock forbs, many with an upright habit, may indicate a history of light (or at least intermittent) grazing at these sites. *Themeda australis* can quickly respond to summer rainfall and proliferates when grazing is excluded but does not withstand continued heavy grazing (Vickery 1961). Moore (1959) considers *Themeda australis* was dominant on much of the Tablelands in New South Wales, including the Monaro, prior to European settlement. It is also postulated to have been more widespread in the lowland grasslands of southern Victoria (McTaggart 1936, Barr & Cary 1992). During the initial stages of settlement on the Monaro, Lhotsky (1835) noted *Themeda* as abundant. It may have been a codominant with species of *Stipa* in Community 5 which is restricted to sandier soils derived from granite and sediments. This supposition is supported in Hancock (1972), quoting from the landholder Crisp, who refers to the changes in condition of grassland in the late 19th century at Jimenbuan, a settlement 25 km south of Dalgety situated on granite:

> *Free selection and the introduction of sheep put an end to extensive raising of cattle because of the loss of water in the main creek and because the best grasses for cattle disappeared and made way for a finer and, in my opinion, less nourishing grass. I have seen kangaroo grass, when in seed, like a field of wheat three feet high. This disappeared.*

The results of the extensive trials of the water requirements of agricultural plants undertaken by Shantz and Piemeisal (1927) showed that plants with the C3 photosynthetic system are better adapted in terms of water use efficiency, to cold temperatures and winter rainfall, while the malate-transporting C4 plants are more efficient with summer rainfall and warmer temperatures. *Themeda australis*, which is a C4 species, is probably not as well adapted photosynthetically to growing on the high basalt plateau south of Cooma (Community 4) as are the *Poa* species. *Themeda australis* does, however, exhibit a range of tolerances and other adaptations to the environment; indeed some ecotypes can grow in winter (Waterhouse 1993) and Groves (1975) found that separate populations contain varying flowering responses in relation to adaptions to different temperature regimes. *Themeda australis* may have existed in Community 4 as an inter-tussock subdominant before European settlement, if so it is now uncommon and must have been grazed out or outcompeted by *Poa* due to some unsubstantiated cause. *Poa sieberiana*, which is a C3 plant, is likely to have been a dominant in Community 4 at the time of European settlement as it is now. Conversely, *Themeda australis* may have adaptive advantages over *Poa sieberiana* at lower altitudes, such as in the vicinity of Dalgety or Bredbo, where the temperatures are warmer, soils are more permeable and drought more intense. *Themeda australis* may outcompete other species in these warmer climes in the absence of continuous grazing by its ability to respond quickly to summer rainstorms. The classification of Chan (1980) which lists eight grassland associations in the ACT would appear to fit as subdivisions under Community 1 (*Danthonia* dominated) and Community 2 (dominated by *Themeda australis* and *Bothriochloa macra*) derived in the present survey.

The results of the present survey suggest that the *Stipa scabra–Stipa bigeniculata* alliance mapped by Costin (1954) contains several distinct communities: Community 3, dominated by *Themeda australis* occurs mostly on sedimentary substrates in places such as Beloka, Bredbo and Adaminaby. Community 5, which is dominated by *Stipa scabra* subsp. *falcata* and *Stipa bigeniculata* occurs on sediments or granite near Cooma, Berridale and Dalgety, while the most distinctive and easily mappable unit, Community 4 (*Poa sieberiana*), covers the vast majority of the high basalt terrain. All of these communities contain *Stipa* species, which may explain their lumping by Costin (1954) at the alliance level. It may be better to redefine Costin's alliance as a *Poa sieberiana–Stipa scabra* subsp. *falcata–Stipa bigeniculata–Themeda australis* alliance.

Impact of grazing on plant communities

Differing grazing regimes may explain some of the differences between communities 3 and 5 on one hand, and communities 1 and 3 on the other. *Themeda australis* may have been largely eliminated from communities 1 and 5 leaving a dominance of hardier *Danthonia* and *Stipa* spp. respectively. It is possible, however, that *Danthonia* was always a major component of Community 1 (Edwards 1993). Therefore, it may be simplistic to describe the communities dominated by *Stipa* and *Danthonia* as 'disclimax' as suggested by Costin (1954), as these genera may have always have been abundant.

Because of the palatability of *Themeda australis*, sites where it is recorded as abundant are deemed to have a history of light grazing and therefore assessed as being in good condition. This includes most of the sites in Community 3 located in TSRs, railway easements, churchyards and cemeteries. Groves et al (1973) found that *Poa labillardieri* outcompeted *Themeda australis* in uptaking phosphorous and nitrogen when both species were grown together in pots. *Poa labillardieri* was found to contain more surface roots than *Themeda* which gave it an advantage in absorbing fertiliser nutrients from the topsoil. If it is assumed the same findings would apply to *Poa sieberiana*, then the widespread use of superphosphate on the Monaro may have advantaged *Poa sieberiana* over *Themeda australis* in communities 2–5. However, the previous discussion about the physiological advantage of the C3 *Poa* over the C4 *Themeda* under certain climatic regimes may provide a better explanation for the dominance of the former over the latter in Community 4, which occupies a region with low temperatures and naturally high nutrient soils. It is possible, however, that Community 3 represents something similar to the 'original' grassland of the lower altitudes in the study area. This is supported by its wide distribution on various substrates with the main common factor being that most sites have been protected from continuous heavy grazing. This may explain why communities 1,2,3 and 5 share many forb species but community 3 contains a greater proportion of upright forbs such as *Microseris lanceolata*, *Podolepis hieracioides* and *Bulbine bulbosa*.

The montane grasslands (communities 6 and 7) were grazed for over 100 years (Hancock 1972) (Snowy Plain is still grazed by sheep) but they have not been subject to pasture improvement or cultivation, although some areas may have been top-dressed with superphosphate. This would explain their relatively natural condition compared to the other grasslands in the study area.

Other types of grassland are present in the understorey of woodlands but these were not sampled in this survey. A distinctive example is the very tall, tussock grassland dominated by *Chionochloa pallida*. This was rarely observed and seemed to be restricted to poorer soils on quartz-rich ridges dominated by *Eucalyptus pauciflora* south of Cooma.

Rare grassland species

In a study of grassy vegetation on the Northern Tablelands of NSW McIntyre et al. (1993) suggest that inconspicuous, widespread, sparsely distributed species may have been overlooked in rare species listings. For many forbs in grassland, sparseness appears to be a common feature. This is supported by the floristic site data in Appendix 1 where a large proportion of grassland species was recorded in less than 5% of all quadrats. However, some of these species are common in adjoining woodlands and forests. The rarity of species recorded in this Monaro grasslands survey, as presented in the results section, was judged by a combination of measures including herbarium records, survey records and expert opinion. Herbaceous species of the

Monaro are not considered to be under-represented on the national rare plant list (Briggs and Leigh in prep.). Rather, the grassland ecosystems in the region are threatened and this has longer term implications for the continual survival of widespread herbaceous species in one region of south-eastern Australia.

Cover ratings and exotic species in classification

Many exotic species have been dispersed across the Monaro landscape through pasture-improvement programs (Wilson 1968, Douglas n.d.), and do not necessarily reflect complete naturalisation patterns. Therefore, it is not surprising that the UPGMA classification in which they were excluded was considered superior to those analyses that included them. It also appears that cover rating data gave a better result than using presence/absence data only. Others disagree (Kirkpatrick 1993 and pers. comm.) and consider that because the extent of cover of many grassland species varies considerably over time and with the seasons, presence/absence data is more meaningful. As far as the Monaro grasslands are concerned, most of the dominant native species are perennial, not annual or ephemeral. Cover ratings provide more information on this aspect of the floristics of the grasslands. This may explain why using cover ratings appeared to improve floristic classification. One danger of relying only on analyses using cover ratings may be that they overemphasise the importance of frequency variation in a few dominant species at the expense of less common species.

The UPGMA analysis may have been superior to the TWINSPAN analysis for the reasons outlined in Minchin (1987). Divisive classifications such as TWINSPAN classify deductively, and errors may accumulate as divisions are made in the sorting strategy. UPGMA makes no such assumptions, and calculates directly a hierarchical classification from the association measure matrix.

Management of remnants

Most research on native grasslands has concentrated on the use of native grasses as feed for stock (Roberts 1990, Munnich et al. 1991). Comparatively little is known about how to manage native grasslands for their intrinsic value, although there has been some research on the impact of mowing (Chan 1980) and fire (Lunt 1990). A review of lowland grassland management in Victoria is provided by Lunt (1991) and Kirkpatrick (1991) comments on managing Tasmanian natural grassland remnants.

Disturbance in grasslands would have occurred prior to European settlement through grazing and digging by native animals and by way of fire. Disturbance results in inter-tussock space which provides space for recruitment or resprouting of forbs. The survival of some forbs depends on light availability at ground level (Lunt 1993). Leaf arrangement (rosette versus erect) may explain differential survival rates of species grazed by stock (McIntyre 1993).

One of the main challenges to native grassland management is to understand how to impose disturbance that succeeds in stimulating seed germination (or resprouting) of native forbs in the inter-tussock gaps, without increasing invasion by weeds.

Fire

Given the early accounts of burning of the grassland vegetation on the Monaro by Aboriginal people (see Flood 1980, p. 285), grasslands are likely to have adapted to these fire regimes. These may have consisted of occasional patchy, low intensity fires, although it is presumed wildfires would have occasionally swept through landscape.

In 1824 the botanist Allan Cunningham observed Aborigines burning the 'Isabella' grassy plain in Autumn (Havard 1936), the present-day site of Tuggeronong, south of Canberra. Little is recorded about changes in frequency or intensity of fire after European settlement. A recent dendrochronological study of old *Callitris glaucophylla* trees in the nearby lower Snowy River valley (Pulsford 1991) has pointed to an increase in frequency and intensity of fires since then.

If burning regimes did change after Europeans arrived, there could have been detrimental impacts on some native plant species. However, data is lacking to even allow generalisations to be drawn about appropriate fire regimes in grasslands, although Lunt (1991) suggests *Themeda australis* grasslands should be burnt every five years. There is evidence, however, that different fire regimes may be required to maintain the native species diversity at different sites (Lunt 1993). Also, the benefits of fire to native plant diversity may be overwhelmed by post-fire weed invasion if a site has already been invaded by introduced species (Lunt 1990). Fire, however, appears to be necessary for the survival of *Swainsona recta* in the remnant grassland beside the Queanbeyan–Cooma railway easement (J. Briggs pers. comm.). As stated above, this species may require regular burning to keep competing grass species in check and stimulate seed germination or resprouting. The current lack of burning along the easement may be adversely affecting its population.

Site 361 Round Plain TSR has been burnt regularly by local landholders (B. Jardine pers. comm.) and it was recorded in this survey as being in good condition and worthy of nature reserve status.

Grazing

In 1862, one of the principal graziers in the Cooma district, James Litchfield, warned of the need for owners of large holdings to avoid overstocking and argued against tilling the soil in the region (Hancock 1972). This advice is just as relevant today.

Implementing appropriate grazing regimes is likely to be just as complicated as working out fire management. Only very general recommendations can be made. Some grazing may be beneficial for some sites, particularly if it is intermittent and carried out in autumn when most flowering and fruiting have finished. Year round, intense grazing (high stock numbers) is likely to eliminate some native species based on the findings that some species (including rare species) only survive in fenced off, non-grazed areas. At some sites the elimination of grazing altogether may, over time, lead to a simpler flora. Observations during a 1993 visit to site 364 (2CY Tower) in the ACT, two years after it was surveyed and two years after light grazing was removed, suggest that *Themeda* has increased its dominance and inter-tussock species have decreased in abundance.

The need to control the noxious weed *Hypericum perforatum* (St. Johns Wort) further complicates grazing management of grasslands. Currently, the Rural Lands Protection Board manages this weed on TSRs by spraying it with a herbicide or subjecting it to heavy grazing in spring before it can set seed (W. Phillips pers. comm.). This management, if carried out over important grassland sites, could conflict with protecting conservation values. It is therefore suggested that if *Hypericum perforatum* occurs in an important grassland site it should be treated by careful spraying or by a biological control agent (one demonstrated not to adversely affect native *Hypericum* species), but not by intensive spring grazing. Also, spelling an area from grazing for several years appears to reduce the population of this weed (R. Good pers. comm.).

Conservation

Concern for the loss of native pastures has long been expressed. Maiden (1898) was alarmed at the loss of native grasses and the increased dominance of introduced non-palatable weeds. He advised that efforts should be made to preserve native grasses as they are adapted to the conditions that prevail in the region.

Until recent times little attention has been paid to protecting and managing grasslands in reserves. They have not held the same appeal as forests or wetlands. This may be one reason why the grasslands of south-eastern Australia are poorly represented in reserves (McDougall and Kirkpatrick 1993).

No reserves have specifically been established to protect temperate grasslands on the tableland tract of the Southern Tablelands of NSW. Only one 150 ha nature reserve (Derrimut) has been permanently reserved for the protection of a lowland grassland ecosystem in Victoria, a State that has carried out extensive surveys of its grasslands, and this reserve is threatened by surrounding industrial development (Criagie 1993). Tunbridge Nature Reserve is the only place that samples natural grassland in the midlands of Tasmania.

The only grasslands protected on the Monaro are the montane, subalpine and alpine grasslands in Kosciusko and Namadgi National Parks. These are very different from the grasslands on the tableland tract (Figure 2).

More intensive surveys of grasslands in the ACT (Hogg 1990) have resulted in a large number of conservation proposals for that area. Also, research on the distribution of several rare fauna species (Edwards 1989, Osborne et al. 1991, S. Sharp pers. comm.) has resulted in conservation priorities that do not necessarily correspond to the priorities set by analysing floristics. For example, the Airport Beacon site (site 367) in the ACT contains three threatened species of animals (S. Sharp pers. comm.) but on the basis of its flora was not considered to be as important as other *Themeda*-dominated sites in the study area. Furthermore, Yen (1993) has shown, from work in Victoria, that the priorities for conserving grassland invertebrates do not necessarily match priorities set for protecting grasslands based on vascular plant data. More research is needed to examine the relationships between flora and fauna in grasslands to assist with grassland conservation.

Few options remain for the conservation of the tableland tract grasslands on the Monaro, but conservation efforts will be made easier because of the public ownership of most of the better remnants. A total of 23 sites of scientific significance have been identified (Table 3). This list includes 16 of the 17 sites documented in Benson and Wyse Jackson (1993). Given their scarcity, there is a valid argument that the remaining native grassland patches in good condition should be protected in reserves or by caveats attached to the title of the land (Table 3).

Public land, including travelling stock routes, containing native grassland should not be sold off to private landholders or leased for continual grazing. TSRs contain some of the best examples of native grassland and should be managed for conservation as well as catering for the needs of travelling stock. Some TSRs warrant stronger protection, either through dedication as nature reserves, or by way of management agreements drawn up under conservation agreements between the Rural Lands Protection Board and the NSW National Parks and Wildlife Service (Table 3). Maffra Lake TSR contains a stand of Community 4 grassland (not sampled in this survey) and contains one of the most important wetlands on the Monaro (Benson and Jacobs 1994). Reserving this TSR as a nature reserve would therefore result in achieving two nature conservation objectives.

Table 3. Grassland sites of the Monaro of scientific significance (excluding sites in Kosciusko National Park)

Site	Location	Community	Prot.	Justification	Management
336	Foot of Mt Jerrabomberra	1	NR	T1,C,D,R	LG,
348	Navy Navigational Centre ACT	1	NR	T2,M,R	LG,M,W
364	2CY Tower, ACT	2	NR	T2,C,M,R	LG,W
367	Airport Beacon, ACT	2	NR	T2,M	LG,W
363	Numeralla Cemetery	3a	CA	C,M,D	M,W
355	Haere Mai, Bredbo	3a	NR	T,C,M,D,R	LG,R
358	Nianna, Bredbo	3a	NR	T,C,M,D,R	LG,R
356	Beloka Cemetery	3a	CA	T,C,M	M,W,R
352	Adaminaby Hill*	3b	NR	T,C,M,D,R	LG,W,R
354	Yaouk	3b	CA	C,M,D,R	LG
357	Adaminaby Saleyards TSR	3b	CA	C,M	LG,W
361	Round Plain Uniting Church	3b	CA	T,C,M	M,W,R
353	Rail easement, Royalla	3b	NR	T,D	F,W,R
359	Round Plain TSR	3b	NR	C,M,R	F
420	Black Lake TSR	3b	NR	C,M,R	LG,W
339	Avon Lake TSR	4	CA	C,M,R	LG
340	Bondo TSR	4	CA	C,M,R	LG
342	North Brother TSR	4	CA	C,M,R	LG
343	Rock Flat TSR	4	CA	C,M,R	LG
341	Ravensworth TSR	4	CA	C,M,R	LG
377	Symonston	5	CA	R	LG
411	Snowy Plain	6	NP	C	LG
NA	Maffra Lake TSR**	4	NR	C,M	LG

Notes.

* Reservation of site 352 should be extended to include TSR No. 12. Alternatively, the private land portion of this area could be protected by a Conservation Agreement.

** Maffra Lake provides an opportunity to protect both a grassland and an important wetland in a reserve.

Prot. = Protection mechanism: NR = nature reserve, CA = conservation agreement

NP = add to existing national park

Justification:

T1 = contains rare or threatened plant species

T2 = contains rare or threatened animal species

C = is in relatively good condition

M = is well fenced or easy to manage in other ways

D = contains a high diversity of native plant species

R = outstanding example of a plant community

Management:

LG = light intermittent grazing based on past land use

M = irregular mowing of site

F = fire may be required based on past land use

W = weed control of major concern

R = monitoring and research of populations of rare species

The preparation of a conservation program for the native grassland remnants of the Monaro, similar to that produced for grassy vegetation in Victoria by the Victorian Department of Conservation and Environment (1993c), would be a worthy objective.

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Appendix 1. Frequency (%) of plant species recorded in native grassland communities and overall (* denotes introduced species;)

Species	Plant communities								Total
	1	2	3	4	5	6	7	8	
Acaena novae-zelandiae (Rosaceae)	–	–	–	–	–	–	–	33	3
Acaena ovina (Rosaceae)	40	17	88	87	10	86	–	–	52
*Acetosella vulgaris** (Polygonaceae)	–	50	47	–	50	57	67	33	39
Aciphylla simplicifolia (Apiaceae)	–	–	–	–	–	–	33	–	2
Acrotriche serrulata (Epacridaceae)	–	17	6	–	–	–	–	–	3
Agrostis aemula (Poaceae)	–	–	6	–	–	–	–	–	2
Agrostis avenacea var. *avenacea* (Poaceae)	–	–	–	–	–	–	–	17	2
Agrostis parviflora (Poaceae)	–	–	–	–	–	–	33	–	2
Agrostis venusta (Poaceae)	–	–	6	–	–	28	33	–	6
*Aira caryophyllea** (Poaceae)	–	–	41	12	30	14	33	17	23
*Aira elegantissima** (Poaceae)	80	83	41	12	10	–	–	–	29
*Arctotheca calendula** (Asteraceae)	20	–	–	–	–	–	–	–	2
*Arenaria serpyllifolia** (Caryophyllaceae)	–	–	–	12	–	–	–	–	2
Aristida ramosa var. *scaberula* (Poaceae)	40	–	6	–	–	–	–	–	5
Arthropodium milleflorum (Anthericaceae)	–	–	–	–	–	29	67	–	6
Asperula conferta (Rubiaceae)	60	50	35	87	20	43	–	–	39
Asperula gunnii (Rubiaceae)	–	–	–	–	–	14	100	–	6
Asperula scoparia (Rubiaceae)	–	–	–	–	–	29	–	17	5
*Avena barbata** (Poaceae)	–	33	12	–	–	–	–	–	6
Baeckea virgata (Myrtaceae)	–	17	–	–	–	–	–	–	2
Bothriochloa macra (Poaceae)	100	17	18	75	10	–	–	–	26
Brachycome aculeata (Asteraceae)	–	–	6	–	–	43	34	–	8
Brachycome heterodonta (Asteraceae)	–	–	12	–	10	–	–	–	5
Brachycome scapigera (Asteraceae)	–	–	–	–	–	43	100	–	10
Brachyloma daphnoides (Epacridaceae)	–	–	6	–	–	–	–	–	2
*Briza maxima** (Poaceae)	–	17	–	–	–	–	–	–	2
*Briza minor** (Poaceae)	40	50	12	–	–	–	–	–	11
*Bromus diandrus** (Poaceae)	–	17	–	–	10	–	–	–	3
*Bromus hordeaceus** (Poaceae)	80	100	23	37	60	–	–	50	42
*Bromus molliformis** (Poaceae)	–	–	–	25	–	–	–	–	3
Bulbine bulbosa (Asphodelaceae)	20	33	12	–	–	43	67	–	16
Calotis glandulosa (Asteraceae)	–	–	6	–	–	–	–	–	2
*Capsella bursa-pastoris** (Brassicaceae)	–	–	–	–	10	–	–	–	2
Cardamine paucijuga (Brassicaceae)	–	–	–	–	–	14	35	–	5
Carex appressa (Cyperaceae)	–	–	–	–	–	–	–	67	6

Appendix 1. (cont.)

Species	Plant communities 1	2	3	4	5	6	7	8	Total
Carex breviculmis (Cyperaceae)	–	–	–	–	–	14	–	–	2
Carex canescens (Cyperaceae)	–	–	–	–	–	14	–	–	2
Carex inversa (Cyperaceae)	20	67	47	37	40	–	–	50	37
Carex longebrachiata (Cyperaceae)	–	–	–	–	–	–	–	17	2
*Carthamus lanatus** (Asteraceae)	–	–	–	25	30	–	–	–	8
Celmisia asteliifolia (Asteraceae)	–	–	–	–	–	14	–		2
*Centaurium erythraea** (Gentianaceae)	–	50	35	–	–	–	–	–	14
Centrolepis strigosa (Centrolepidaceae) subsp. *strigosa**	–	17	–	–	–	–	–	–	2
Cerastium fontanum (Caryophyllaceae) subsp. *triviale**	–	–	6	–	–	14	67	17	8
*Cerastium glomeratum** (Caryophyllaceae)	–	33	17	12	–	–	–	17	11
Chamaesyce drummondii (Euphorbaceae)	20	17	6	–	40	–	–	–	8
Cheilanthes sieberi (Sinopteridaceae) subsp. *sieberi*	20	–	6	–	–	–	–	–	3
Chloris truncata (Poaceae)	–	–	–	–	10	–	–	–	2
Chrysocephalum apiculatum (Asteraceae)	80	33	82	75	30	–	–	–	47
Chrysocephalum semipapposum (Asteraceae)	20	–	12	–	–	–	–	–	5
*Cicendia quadrangularis** (Gentianaceae)	–	17	–	–	–	–	–	–	2
*Cirsium vulgare** (Asteraceae)	–	17	6	25	10	–	–	100	18
Convolvulus erubescens (Convolvulaceae)	60	17	47	75	40	–	–	–	35
Coprosma nivalis (Rubiaceae)	–	–	–	–	–	14	–	–	2
Craspedia coolaminica (Asteraceae)	–	–	–	–	–	86	–	–	10
Craspedia jamesii (Asteraceae)	–	–	–	–	–	–	67	–	4
Crassula sieberiana (Crassulaceae)	–	–	12	12	–	–	–	–	5
Cryptandra amara (Rhamnaceae)	–	–	6	–	–	–	–	–	2
Cymbonotus lawsonianus (Asteraceae)	40	17	12	–	10	–	–	–	10
Cymbonotus preissianus (Asteraceae)	–	–	–	–	–	14	67	–	5
Cynoglossum suaveolens (Boraginaceae)	20	17	6	–	–	–	–	–	5
*Dactylis glomerata** (Poaceae)	–	–	–	–	10	–	–	–	2
Danthonia auriculata (Poaceae)	40	–	–	–	–	–	–	–	3
Danthonia caespitosa (Poaceae)	–	17	35	75	70	–	–	–	32
Danthonia carphoides (Poaceae)	80	17	6	–	–	–	–	–	10
Danthonia laevis (Poaceae)	–	–	29	12	30	14	–	–	16
Danthonia linkii var. *linkii* (Poaceae)	–	–	6	–	30	–	–	–	6

Appendix 1. (cont.)

Species	Plant communities 1	2	3	4	5	6	7	8	Total
Danthonia monticola (Poaceae)	–	–	6	–	–	–	–	–	2
Danthonia nudiflora (Poaceae)	–	–	–	–	–	71	33	–	10
Danthonia pilosa var. *pilosa* (Poaceae)	–	–	6	–	–	–	–	–	2
Danthonia racemosa (Poaceae) var. *racemosa*	–	–	18	–	50	–	–	–	13
Daucus glochidiatus form F (Apiaceae)	–	–	–	12	–	–	–	–	2
Daviesia mimosoides (Fabaceae)	–	–	6	–	–	–	–	–	2
Daviesia ulicifolia (Fabaceae)	–	–	6	–	–	14	–	–	3
Desmodium varians (Fabaceae)	60	–	29	25	30	–	–	–	21
Dichanthium sericeum (Poaceae) subsp. *sericeum*	–	–	–	12	–	–	–	–	2
Dichelachne micrantha (Poaceae)	–	–	12	–	–	14	–	–	5
Dichelachne rara (Poaceae)	–	–	6	–	–	14	–	–	3
Dichondra sp. *A* (Convolvulaceae)	–	–	–	12	10	–	–	–	3
Dichondra repens (Convolvulaceae)	20	17	6	–	10	–	–	–	6
Dichopogon fimbriatus (Antheriaceae)	40	33	–	–	–	–	–	–	6
Discaria pubescens (Rhamnaceae)	–	–	12	–	–	–	–	–	3
Diuris punctata (Orchidaceae)	–	–	12	–	–	–	–	–	3
Dodonaea procumbens (Sapindaceae)	–	–	12	–	–	–	–	–	3
Drosera peltata (Droseraceae)	20	33	–	–	–	–	–	–	5
*Echium vulgare** (Boraginaceae)	–	–	–	12	–	–	–	–	2
Einadia nutans subsp. *nutans* (Chenopodiaceae)	–	–	–	–	10	–	–	–	2
Elymus scaber (Poaceae)	20	–	47	25	60	71	33	–	37
Enneapogon nigricans (Poaceae)	20	–	6	50	70	–	–	–	21
Epacris petrophila (Epacridaceae)	–	–	–	–	–	14	–	–	2
Epilobium billardierianum (Onagraceae) subsp. *cinereum*	–	–	41	25	–	57	100	33	29
Eragrostis brownii (Poaceae)	20	17	–	–	–	–	–	–	3
*Erodium cicutarium** (Geraniaceae)	–	–	–	–	10	–	–	–	2
*Erophila verna** (Brassicaceae)	–	–	6	50	10	–	–	–	10
Eryngium rostratum (Apiaceae)	40	50	–	12	10	–	–	–	11
Eucalyptus blakelyi (Myrtaceae)	–	–	6	–	–	–	–	–	2
Eucalyptus bridgesiana (Myrtaceae)	20	–	6	–	–	–	–	–	3
Eucalyptus melliodora (Myrtaceae)	–	–	12	–	–	–	–	–	3
Euphrasia collina (Scrophulariaceae) subsp. *paludosa*	–	–	–	–	–	14	–	–	2

Appendix 1. (cont.)

Species	Plant communities 1	2	3	4	5	6	7	8	Total
Festuca asperula (Poaceae)	–	–	6	–	–	29	67	–	8
*Galium divaricatum** (Rubiaceae)	20	–	6	–	–	–	–	–	3
Geranium antrorsum (Geraniaceae)	–	–	12	–	–	100	100	17	21
Geranium retrorsum (Geraniaceae)	–	–	29	–	–	–	–	33	11
Geranium solanderi (Geraniaceae)	–	–	35	12	–	–	–	–	11
Glyceria australis (Poaceae)	–	–	–	–	–	–	–	17	2
Glycine clandestina (Fabaceae)	–	–	23	–	–	–	–	–	6
Glycine tabacina (Fabaceae)	–	–	6	–	–	–	–	–	2
*Gnaphalium americanum** (Asteraceae)	–	–	6	–	–	–	–	–	2
Gnaphalium gymnocephalum (Asteraceae)	–	–	–	–	10	29	33	–	6
Gonocarpus tetragynus (Haloragaceae)	–	17	6	–	–	–	–	–	3
Goodenia pinnatifida (Goodeniaceae)	100	33	18	37	–	–	–	–	21
Hakea microcarpa (Proteaceae)	–	–	12	–	–	–	33	–	5
Haloragis heterophylla (Haloragaceae)	–	–	–	–	–	–	33	33	5
Hedypnois rhagadioloides (Asteraceae) subsp. *cretica**	20	–	–	–	–	–	–	–	2
Helichrysum scorpioides (Asteraceae)	–	–	6	–	–	–	33	–	3
Hemarthria uncinata (Poaceae) var. *uncinata*	–	–	–	–	–	–	–	17	2
*Hirschfeldia incana** (Brassicaceae)	–	–	–	–	10	–	–	–	2
*Holcus lanatus** (Poaceae)	–	17	–	–	–	–	–	50	6
*Hordeum leporinum** (Poaceae)	–	–	–	–	10	–	–	–	2
Hovea purpurea (Fabaceae)	–	–	–	–	–	14	–	–	2
Hydrocotyle laxiflora (Apiaceae)	20	–	6	–	–	–	–	–	3
Hydrocotyle peduncularis (Apiaceae)	–	–	–	–	–	–	33	33	5
Hydrocotyle gramineum (Clusiaceae)	20	33	23	12	–	–	–	–	13
Hydrocotyle japonicum (Clusiaceae)	–	–	–	–	–	–	33	–	2
*Hydrocotyle perforatum** (Clusiaceae)	–	17	–	–	–	–	–	–	2
*Hypochaeris glabra** (Asteraceae)	60	–	23	–	40	–	–	–	18
*Hypochaeris radicata** (Asteraceae)	60	100	82	50	60	71	67	50	69
Hypoxis hygrometrica (Hypoxidaceae) var. *hygrometrica*	–	–	–	–	–	–	33	–	2
Isolepis cernua (Cyperaceae)	–	–	–	–	–	–	–	17	2
Juncus australis (Juncaceae)	–	17	–	–	10	–	–	50	8
*Juncus bufonius** (Juncaceae)	20	33	–	–	–	–	–	17	6
*Juncus capitatus** (Juncaceae)	–	33	–	–	–	–	–	–	3

Appendix 1. (cont.)

Species	Plant communities 1	2	3	4	5	6	7	8	Total
Juncus filicaulis (Juncaceae)	–	83	–	12	–	–	33	50	16
*Lepidium africanum** (Brassicaceae)	–	–	6	–	10	–	–	–	3
Leptorhynchos elongatus (Asteraceae)	–	–	–	12	–	–	–	–	2
Leptorhynchos squamatus (Asteraceae)	40	33	71	12	–	100	67	–	42
Leptospermum lanigerum (Myrtaceae)	–	–	–	–	–	–	33	–	2
Leucopogon hookeri (Epacridaceae)	–	–	–	–	–	43	33	–	6
Limosella australis (Scrophulariaceae)	–	–	–	–	–	–	–	17	2
*Linaria arvensis** (Scrophulariaceae)	–	–	12	25	–	–	–	–	6
*Linaria pelisseriana** (Scrophulariaceae)	20	–	6	–	–	–	–	–	3
Linum marginale (Linaceae)	–	–	–	–	–	–	67	–	3
Lissanthe strigosa (Epacridaceae)	20	–	–	–	–	–	–	–	2
*Lolium perenne** (Poaceae)	20	–	–	–	10	–	–	17	5
Lomandra filiformis (Lomandraceae) subsp. *filiformis*	40	17	–	–	–	–	–	–	5
Lomandra multiflora (Lomandraceae)	20	33	18	–	–	–	–	–	10
Luzula densiflora (Juncaceae)	–	17	23	–	–	–	–	–	8
Luzula modesta (Juncaceae)	–	17	–	–	–	–	–	–	2
Luzula ovata (Juncaceae)	–	–	6	–	–	71	33	–	11
*Medicago lupulina** (Fabaceae)	–	–	6	25	–	–	–	–	5
*Medicago minima** (Fabaceae)	–	–	6	25	–	–	–	–	5
*Medicago sativa** (Fabaceae)	–	–	–	–	10	–	–	–	2
Melichrus urceolatus (Epacridaceae)	–	–	6	–	–	–	–	–	2
Microseris lanceolata (Asteraceae)	20	–	12	–	–	57	33	–	13
Microtis unifolia (Orchidaceae)	–	–	6	–	–	–	–	–	2
Mirbelia oxylobioides (Fabaceae)	–	–	12	–	–	–	–	–	3
*Moenchia erecta** (Caryophyllaceae)	80	17	12	–	20	–	–	–	14
Muehlenbeckia axillaris (Polygonaceae)	–	–	–	–	–	14	–	–	2
*Myosotis caespitosa** (Boraginaceae)	–	–	–	–	10	–	–	–	2
*Myosotis discolor** (Boraginaceae)	–	50	6	–	–	–	–	–	6
*Nassella trichotoma** (Poaceae)	20	17	–	–	–	–	–	17	5
Oenothera stricta (Onagraceae) subsp. *stricta**	–	–	6	–	–	–	–	–	2
Oreomyrrhis argentea (Apiaceae)	–	–	–	–	–	57	–	–	6
Oreomyrrhis eriopoda (Apiaceae)	–	–	18	12	20	29	33	–	14
Oxalis exilis (Oxalidaceae)	–	17	12	–	30	14	33	–	13
Oxalis perennans (Oxalidaceae)	20	17	18	12	20	14	33	–	16

Appendix 1. (cont.)

Species	Plant Communities 1	2	3	4	5	6	7	8	Total
*Parentucellia latifolia** (Scrophaceae)	80	–	–	–	–	–	–	–	6
*Paronychia brasiliana** (Caryophyllaceae)	–	–	–	–	40	–	–	–	6
Pentapogon quadrifidus (Poaceae)	–	–	–	–	–	29	33	–	5
Persoonia chamaepeuce (Proteaceae)	–	–	6	–	–	–	–	–	2
*Petrorhagia nanteuilii** (Caryophyllaceae)	–	–	59	75	30	–	–	–	31
Pimelea alpina (Thymelaeaceae)	–	–	–	–	–	27	–	–	3
Pimelea biflora (Thymelaeaceae)	–	–	–	–	–	14	–	–	2
Pimelea curviflora (Thymelaeaceae)	–	–	41	–	–	–	–	–	11
Pimelea glauca (Thymelaeaceae)	–	–	18	–	–	–	–	–	5
Plantago antarctica (Plantaginaceae)	–	–	–	–	–	86	–	–	10
*Plantago lanceolata** (Plantaginaceae)	60	50	23	37	10	–	–	17	24
Plantago varia (Plantaginaceae)	40	33	41	25	10	–	67	–	26
*Poa bulbosa** (Poaceae)	–	–	–	25	10	–	–	–	5
Poa costiniana (Poaceae)	–	–	–	–	–	29	100	–	8
Poa labillardieri (Poaceae)	20	33	–	–	–	14	–	100	16
Poa meionectes (Poaceae)	–	–	18	–	–	14	–	–	6
Poa petrophila (Poaceae)	–	–	6	–	–	14	–	–	3
Poa phillipsiana (Poaceae)	–	–	–	–	–	14	–	–	2
*Poa pratensis** (Poaceae)	–	17	6	25	–	–	–	83	14
Poa sieberiana (Poaceae)	20	33	88	100	40	85	–	–	58
Podolepis hieracioides (Asteraceae)	–	–	12	–	–	–	–	–	3
Podolepis robusta (Asteraceae)	–	–	–	–	–	71	–	–	8
Poranthera microphylla (Euphorbiaceae)	–	–	6	–	–	57	–	–	8
Prasophyllum alpinum (Orchidaceae)	–	–	–	–	–	14	67	–	5
Prasophyllum suttonii (Orchidaceae)	–	–	–	–	–	29	–	–	3
Pratia pedunculata (Lobeliaceae)	–	–	–	–	–	–	–	17	2
*Psilurus incurvus** (Poaceae)	20	–	–	–	–	–	–	–	2
Psoralea tenax (Fabaceae)	–	–	12	62	–	–	–	–	11
Pterostylis mutica (Orchidaceae)	60	–	–	–	–	–	–	–	5
Pultenaea fasciculata(Fabaceae)	–	–	6	–	–	29	–	–	5
Pultenaea polifolia (Fabaceae)	–	–	–	–	–	29	–	–	3
Ranunculus graniticola (Ranunculaceae)	–	–	–	–	–	85	67	–	13
Ranunculus lappaceus (Ranunculaceae)	–	–	23	–	–	–	–	–	6
Ranunculus pimpinellifolius (Ranuncaceae)	–	–	–	–	–	–	–	17	2

Appendix 1. (cont.)

Species	Plant Communities 1	2	3	4	5	6	7	8	Total
Ranunculus pumilio (Ranunculaceae) var. pumilio	–	–	–	–	–	–	–	17	2
Ranunculus sessiliflorus (Ranunculaceae) var. sessiliflorus	–	–	6	–	–	–	–	–	2
Restio australis (Restionaceae)	–	–	–	–	–	–	33	–	2
Rhodanthe anthemoides (Asteraceae)	–	–	–	–	–	29	–	–	3
Rhytidosporum alpinum (Pittosporaceae)	–	–	6	–	–	29	–	–	5
*Rosa rubiginosa** (Rosaceae)	–	17	18	12	–	–	–	17	10
Rumex brownii (Polygonaceae)	20	83	47	25	50	–	–	–	34
*Rumex crispus** (Polygonaceae)	–	–	–	–	–	–	–	33	3
Rutidosis leptorhynchoides (Asteraceae)	20	–	–	–	–	–	–	–	2
*Salvia verbenaca** (Lamiaceae)	–	–	18	62	40	–	–	–	19
Schoenusapogon (Cyperaceae)	20	50	23	–	–	–	33	–	14
Scleranthus biflorus (Caryophyllaceae)	–	–	18	–	10	100	67	–	21
Scleranthus diander (Caryophyllaceae)	–	–	18	62	20	–	–	–	16
Senecio lautus subsp. *alpinus* (Asteraceae)	–	–	–	–	–	57	–	–	6
Senecio quadridentatus (Asteraceae)	–	17	12	–	–	–	–	–	5
Senecio velleioides (Asteraceae)	–	–	–	–	–	19	–	–	2
Solenogyne dominii (Asteraceae)	–	–	–	–	30	–	–	–	5
Solenogyne gunnii (Asteraceae)	–	–	12	–	–	43	–	17	10
Sonchus asper (Asteraceae) subsp. *glaucescens**	–	–	6	–	–	–	–	–	2
*Spergularia rubra** (Caryophyllaceae)	–	–	–	–	10	–	–	–	2
Sphaerolobium vimineum (Fabaceae)	–	–	–	–	–	–	33	–	2
Stackhousia monogyna (Stackhousiaceae)	–	–	28	–	–	–	–	–	8
Stellaria angustifolia (Caryophyllaceae)	–	–	–	–	–	–	33	17	3
Stellaria multiflora (Caryophyllaceae)	–	–	–	–	–	–	33	–	2
Stipa bigeniculata (Poaceae)	60	17	18	62	90	–	–	–	34
Stipa blackii (Poaceae)	–	–	–	–	20	–	–	–	3
Stipa nodosa (Poaceae)	–	–	18	25	10	–	–	–	10
Stipa scabra subsp. *falcata* (Poaceae)	20	–	23	12	90	–	–	–	24
Stylidium graminifolium (Stylidiaceae)	–	–	12	–	–	14	100	–	35
Swainsona behriana (Fabaceae)	–	–	12	12	–	–	–	–	5
Swainsona monticola (Fabaceae)	–	–	6	12	–	29	–	–	6
Swainsona recta (Fabaceae)	–	–	12	–	–	–	–	–	3

Appendix 1. (cont.)

Species	Plant Communities 1	2	3	4	5	6	7		Total
Swainsona sericea (Fabaceae)	–	–	12	–	20	–	–	–	6
*Taraxacum officinale** (Asteraceae)	–	–	6	–	–	14	–	50	8
Themeda australis (Poaceae)	20	100	100	37	20	14	33	–	50
Trachymene humilis (Apiaceae) subsp. *humilis*	–	–	–	–	–	14	–	–	2
*Tragopogon dubius** (Asteraceae)	–	–	12	25	10	–	–	–	8
*Tragopogon porrifolius** (Asteraceae)	–	–	6	–	10	–	–	–	3
Tricoryne elatior (Anthericaceae)	20	–	–	–	–	–	–	–	2
*Trifolium angustifolium** (Fabaceae)	–	–	6	–	–	–	–	–	2
*Trifolium arvense** (Fabaceae)	40	–	76	62	57	–	–	–	44
*Trifolium campestre** (Fabaceae)	80	33	88	50	30	–	–	17	47
*Trifolium dubium** (Fabaceae)	80	67	12	–	20	–	33	67	27
*Trifolium glomeratum** (Fabaceae)	–	–	35	25	30	–	–	–	18
*Trifolium pratense** (Fabaceae)	–	–	6	–	–	–	–	–	2
*Trifolium repens** (Fabaceae)	–	–	23	12	–	29	67	33	18
*Trifolium striatum** (Fabaceae)	–	–	29	87	20	–	–	–	23
*Trifolium subterraneum** (Fabaceae)	80	50	12	–	40	–	–	17	23
Triptilodicus pygmaeus (Asteraceae)	60	33	18	–	10	–	–	–	14
Velleia paradoxa (Goodeniaceae)	–	–	–	–	–	29	–	–	3
Verbascum thapsus (Scrophulariaceae) subsp. *thapsus**	–	–	6	12	10	–	–	–	5
*Vaerbascum virgatum** (Scrophulariaceae)	–	17	18	–	–	–	–	–	6
*Veronica arvensis** (Scrophulariaceae)	–	–	6	–	–	–	–	17	3
Vaeronica calycina (Scrophulariaceae)	–	–	6	–	–	–	–	–	2
Viola betonicifolia (Violaceae)	–	–	6	–	–	29	33	–	6
Vittadinia cuneata (Asteraceae) var. *cuneata*	–	–	17	25	10	–	–	–	10
Vittadinia muelleri (Asteraceae)	80	17	23	12	50	–	–	–	24
*Vulpia bromoides** (Poaceae)	20	33	12	–	–	–	–	33	11
*Vulpia muralis** (Poaceae)	20	–	–	–	–	–	–	–	2
*Vulpia myuros** (Poaceae)	100	33	64	87	100	–	–	17	58
Wahlenbergia communis (Campanulaceae)	60	–	41	62	60	–	–	–	34
Wahlenbergia densifolia (Campanulaceae)	–	–	–	–	–	71	–	–	8
Wahlenbergia gracilis (Campanulaceae)	–	–	–	–	20	–	–	–	3
Wahlenbergia multicaulis (Campanulaceae)	20	–	23	–	–	–	100	–	13
Wurmbea dioica (Colchicaceae)	20	16	6	–	–	–	–	–	5