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Long-term Vegetation Change in Relation to Cattle Grazing in Subalpine Grassland and Heathland on the Bogong High Plains: An Analysis of Vegetation Records from 1945 to 1994

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Abstract

Changes in vegetation composition and structure are described for grassland and heathland communities on the Bogong High Plains, in the Victorian Alpine National Park. The data are based on long-term records collected from permanent reference plots over the period 1945 to 1994 from plots established in 1945, 1946 and 1979. In the Pretty Valley grassland plots, established in 1946, cattle grazing has prevented the large-scale regeneration of a number of tall, palatable forbs and short, palatable shrubs, while in the absence of grazing, the cover of these life forms increased substantially. The amount of bare ground and loose litter was significantly greater on the grazed compared with the ungrazed plot. Between 1979 and 1994, there was little or no identifiable trend in the cover of vegetation or bare ground at either the Pretty Valley grazed site, or two additional grazed grassland sites established nearby in 1979. The current condition of grazed grassland on the Bogong High Plains is interpreted as stable, yet degraded. Improvement in condition will occur in the absence of grazing. In the Rocky Valley open heathland plots, established in 1945, increases in shrub cover over the study period were due to growth of shrubs following the 1939 bushfires that burnt much of the Bogong High Plains. From 1945–1979 shorter-lived shrubs increased in cover; since 1979, these shrubs have senesced, and are being replaced mainly by grasses. On the grazed plot longer lived, taller shrubs have continued to increase in cover and are not senescing. Between 1979 and 1989, total shrub cover declined on the ungrazed plot, but increased on the grazed plot. There was no evidence that grazing has reduced shrub cover, and therefore potential fire risk, in open heathland. These findings have significant management implications for the Alpine National Park and are consistent with those from other regions in the Australian alps.

Introduction

Long term studies of the ecology of native plant communities in Australia have been relatively uncommon, but they are a feature of the scientific studies in the Australian alps. Permanent plots established in the 1940s constitute some of the oldest reference areas in the country (Costin 1954; Carr and Turner 1959*a*, 1959*b*). In addition, these studies are some of the earliest attempts to assess land degradation scientifically. Thus, along with long-term studies of vegetation at sites such as Koonamore, in semi-arid South Australia (Wood 1936; Noble and Crisp 1980), studies initiated in the alps half a century ago have provided a firm basis on which to assess ecological processes in native plant communities, and the impacts of human activities, especially the impacts of domestic stock, on those processes.

With increased public interest in the alps, and land use questions in general throughout the 1960s and 1970s, issues and hypotheses raised by these early studies formed the basis of the experimental and monitoring studies in the alpine region during the 1980s. With the declaration of an extensive Alpine National Park in Victoria in 1980, and the controversy surrounding the decision to allow grazing by cattle to continue within the Park, it is appropriate that the most recent data from these long-term studies be presented. The aim of this paper is to assess the trends in, and impacts of cattle grazing on, both vegetation

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composition and ground cover in two major subalpine plant communities—grassland and open heathland—within the permanent plots established in the 1940s on the Bogong High Plains, the most extensive of the alpine and subalpine areas in Victoria.

Historical and Scientific Background

The alpine grazing issue must be seen in the context of the history of science and land use in the Australian high country. Grazing by domestic livestock commenced in the 1830s in the Kosciusko region in New South Wales, and in the 1850s on the Bogong High Plains (Hancock 1972; Cabena 1980). Along with their stock, graziers also introduced regular burning-off to the alpine vegetation. Scientific investigations of the alpine environment commenced in the 1850s, with visits to the Australian high country by botanists such as von Mueller. Subsequent visits in the 1890s by Helms, von Lendenfeld, Maiden and Wragge represented pioneering studies (Hancock 1972; Good 1992). Such scientific activity in the Australian alps was primarily concerned with biological and geographical inventory, rather than the effects of land use, although concern about the effects of burning-off was raised by Helms (1896). By the 1860s, Hancock (1972) describes graziers as 'looking to the high country to save them from disaster in years of drought', and stock numbers increased progressively from the latter decades of the 19th century up to the 1930s. In the early 1900s, large numbers of stock were brought to the high country for drought relief. For example, in the summer of the severe 1902 and 1903 drought, an estimated 40 000 sheep, in addition to large mobs of cattle and horses, were on the Bogong High Plains. Many of the sheep came from as far away as the Riverina. This practice was repeated during other severe droughts, when stocking pressure was intense.

Such over-grazing, associated with regular burning-off and the occasional severe bushfire, caused extensive damage to parts of the alpine environment. In many places, the soils and vegetation were severely affected by selective grazing and trampling of fragile soils and plant communities. By the 1940s the condition of the Bogong High Plains and other high country catchments was cause for concern following degradation in previous decades and the disastrous bushfires of 1939, which burnt much of the high country in south-eastern Australia. Miss Maisie Fawcett (later Mrs Carr), an ecologist, was appointed by the newly formed Soil Conservation Board and Melbourne University in 1941 to assess the effects of cattle grazing on the soils and vegetation of the Bogong High Plains. In 1946, concern about soil erosion and the effects of siltation on the hydro-electricity scheme led government departments and graziers to modify the land management practices on the Bogong High Plains. Sheep, horses and burning-off were banned, the length of the grazing season limited and numbers held at the then current levels of some 8000 adult cattle plus calves. It was within this context that experimental plots were established on the Bogong high Plains in the mid-1940s by Miss Fawcett and Professor John Turner.

During the 1950s and 1960s, grazing was progressively withdrawn from the highest ridges and peaks, which were invariably the most degraded. Areas were also withdrawn from grazing to allow development of a hydro-electric scheme and ski resorts. Likewise, in NSW, grazing was removed progressively between 1946 and 1968 from what is now the Kosciusko National Park. Work by Costin (1954; Costin *et al.* 1959, 1960) and the campaign by the Australian Academy of Science (1957) was instrumental in achieving this.

Since the 1950s, on the Bogong High Plains, there has been an overall decline of about 60% in stock numbers and the area grazed. Over this period, the area occupied by shrubs has increased, especially in the montane forests and snowgum woodland (Carr and Turner 1959*a*; Williams and Ashton 1987*b*), further reducing the areas of grassland available for grazing. The reference plots have been maintained and regularly assessed. Investigations of ecological processes that were commenced by Carr and Turner (1959*a*, 1959*b*) subsequently formed the basis of experimental studies (Williams and Ashton 1987*b*) and studies of cattle behaviour (van Rees and Hutson 1983). The declaration of the Alpine National Park in 1980 was accompanied by an expansion of ecological studies to include the major ecosystems and geographical units on the Bogong High Plains and surrounding summits. The area grazed and the number of cattle were reduced further in 1991 so that, at present, a total of approximately 3100 head graze on the licence areas between December and April each year.

Methods

Site Selection

In 1944, a site of approximately 7 ha, which was part of a small first-order catchment containing representative areas of most subalpine plant communities on the Bogong High Plains, was selected by Maisie Fawcett and fenced. Within the exclosure, one plot, approximately 500 m^2 in area, was set up in each of three vegetation types: open heathland, closed heathland and a sedge and herbfield snow patch community. Similar plots were established outside the exclosure on similar slopes and aspects, thus providing one grazed and one ungrazed plot within each community (Turner and Fawcett 1948, 1951; Carr and Turner 1959*a*, 1959*b*). These became known as the 'Rocky Valley plots' (Fig. 1) and were first sampled in the summer of 1945. In 1946, another site of about 0.2 ha was selected in exposed grassland not adequately represented within the Rocky Valley exclosure. This was an important grassland to monitor because of its extensive distribution on the Bogong High Plains and the occurrence, within this community, of numerous plant species thought to be favoured by cattle. Two adjacent plots were established, 5 m apart, one fenced and one unfenced, and each approximately 400 m^2 (Figs 2 and 3). These became known as the 'Pretty Valley plots' and were sampled initially in January 1947 (Fig. 1).

In 1979, two additional grassland sites were selected in a region about 1 km from the Pretty Valley site, in the vicinity of Cope Hut and Cope Creek (Fig. 1). The Cope Hut and Cope Creek sites have been subject to grazing by cattle, and will continue to be so for the foreseeable future. The sites were originally selected with the aim of monitoring vegetation change at a number of grazed grassland sites within the fledgling Alpine National Park (van Rees *et al.* 1984). In this study, these reference sites serve as replicates of the grazed treatment at the Pretty Valley site for the period 1979–1994. A summary of the general geographic information pertaining to each site is given in Table 1.

Vegetation Sampling

Botanical composition of the vegetation at all sites was determined using point quadrats (Levy and Madden 1933; Kent and Coker 1992). Pins were 4 mm in diameter and at every point each species and the number of contacts each species made with the pin were recorded. From 1945–1951 at the Rocky Valley and Pretty Valley plots, the vegetation was sampled annually and then once or twice per decade until 1994. In 1989, structural data from the shrubs—height, canopy diameter and stem diameter—were collected from both within and adjacent to the reference plots. In 1990, estimates of the age of individual shrubs at the Rocky Valley Plots were made from ring counts of the dominant species, *Phebalium squamulosum* and *Prostanthera cuneata*. Approximately 30 shrubs of each species were collected from areas immediately adjacent to both the grazed and ungrazed plots at Rocky Valley.

Point quadrats were sampled initially (from 1945–1950) using a steel frame containing ten pins. The frame was positioned randomly within each plot, and in this way data were collected from 1000 and, when time permitted, 2000 point quadrats. Subsequent analyses by Goodall (1952) demonstrated that a uniform distribution of single point quadrats was a more efficient method of collecting cover data than was the random placement of groups of ten pins. Furthermore, a more accurate estimate of trends in vegetation cover could be obtained by sampling the same set of points along permanent transects (Goodall 1952). Thus, permanently marked transects located approximately 3 feet (0.9 m) apart, with points within transects also 0.9 m apart, were established at each experimental plot in 1951. Since then, point quadrat data have been collected from point quadrats distributed uniformly along these permanent transects. Depending on the length of each transect, the number of points per transect ranged from 18–30 at the Pretty Valley plots and from 19–38 at the Rocky Valley plots.

In this paper, we present the vegetation and soil cover data from the Pretty Valley grassland plots for the years 1947, 1951, 1957, 1958, 1966, 1979, 1982, 1989 and 1994, and from the Rocky Valley open heathland plots for the years 1945, 1947, 1951, 1958, 1960, 1966, 1979 and 1989. At the Cope Hut and Cope Creek grassland sites, cover data have been collected annually since 1979, using 10 m long permanent transects and sampling 50 point quadrats per transect. Details of the locations of these transects are given by van Rees *et al.* (1984); analyses of these data from 1979–1994 are included in this paper.

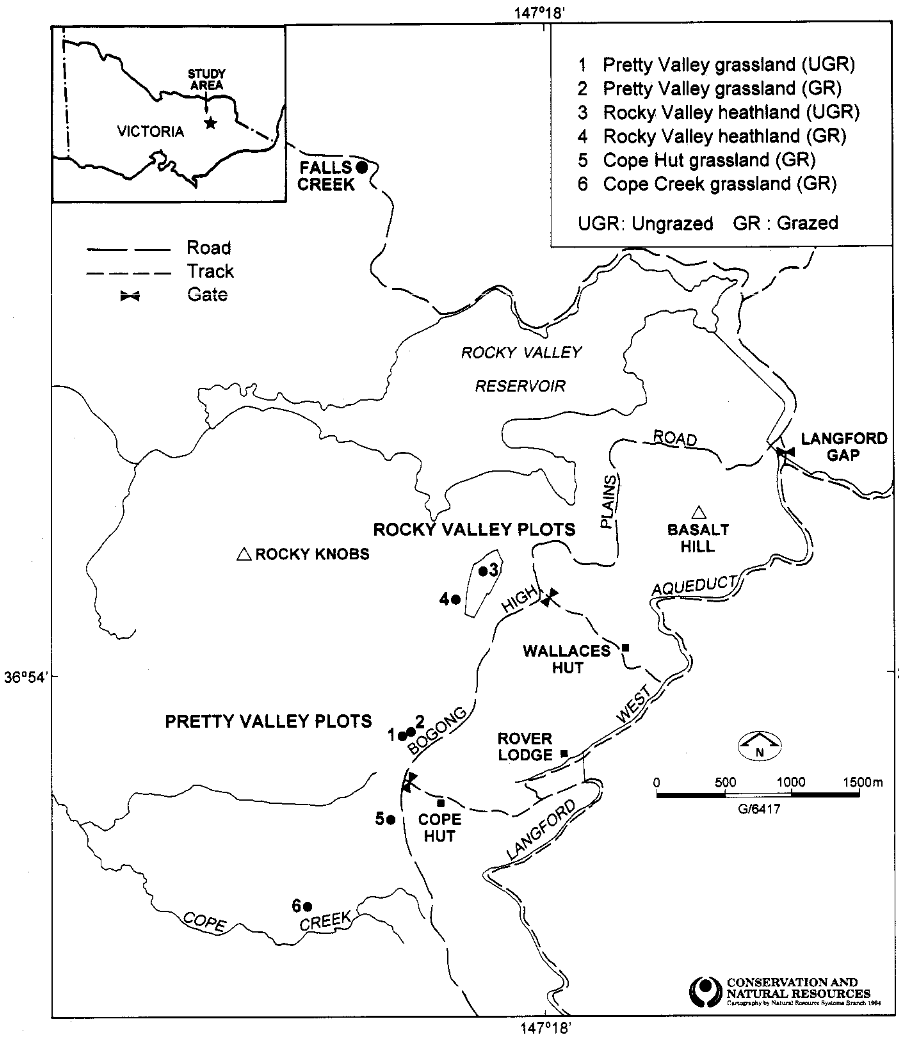

Fig. 1. Location map of plots.

Table 1. Summary of geographical information for reference plots on the Bogong High Plains

G: grassland, OH: open heathland; UGR: ungrazed, GR: grazed; number of transects in 1989 for the Rocky Valley plots and 1994 for all other sites. See Fig. 1 for site locations

Site	Pretty Valley		Cope Creek	Cope Hut	Rocky Valley	
Community	G	G	G	G	OH	OH
Grazing status	UGR	GR	GR	GR	UGR	GR
No. of transects	44.00	44.00	12.00	10.00	26.00	31.00
Altitude (m a.s.l.)	1700.00	1700.00	1690.00	1690.00	1680.00	1680.00
Approximate area (m^2)	900.00	900.00	1500.00	1500.00	450.00	570.00
Aspect	S	S	S	S	NW	NW
Slope (%)	< 1	< 1	< 1	< 1	5.00	5.00

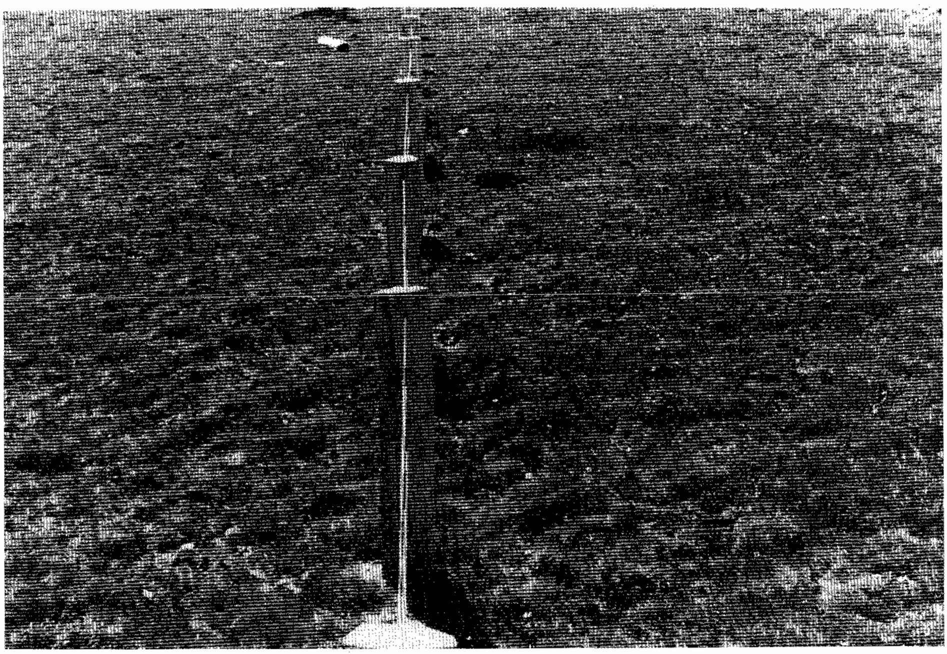

Fig. 2. The Pretty Valley plots in 1948. The grazed plot is on the left.

Fig. 3. The Pretty Valley plots in c. 1950. *(a)* View of the ungrazed plot.

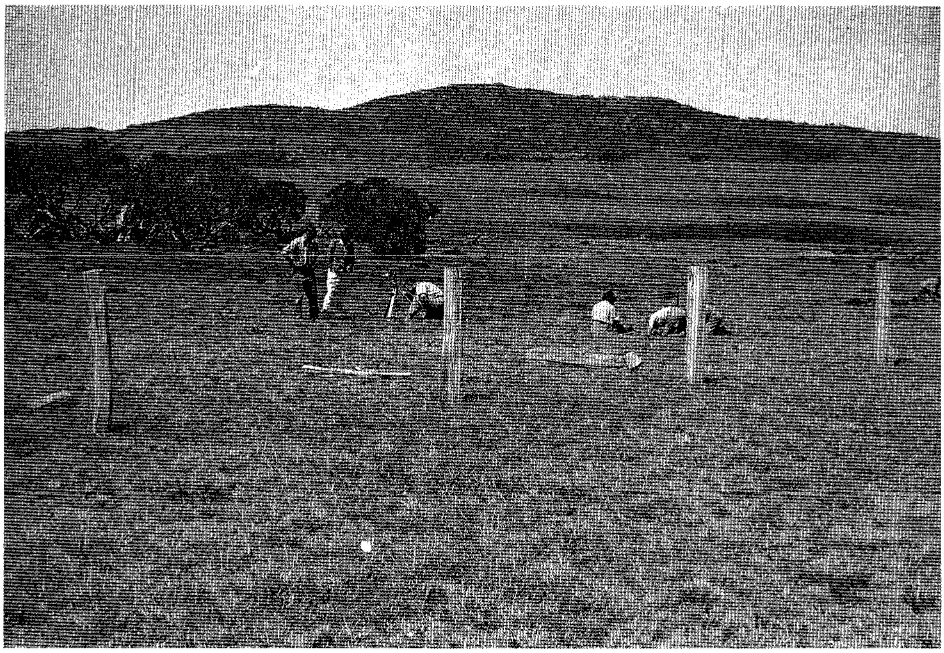

Fig. 3. cont
(*b*) Looking from the ungrazed plot to the grazed plot.

Data Manipulation

The percentage overlapping cover (% OC) of each species or cover class (e.g. shrub, grass, forb, litter, bare ground) was calculated by transect as follows:

% OC of species A = (No. points with species A/Total No. Points in transect) x 100.

In 1979, a more precise method of recording cover at the soil surface was developed because criteria used prior to this were considered too general. The new scheme was first used in 1979 at the Cope Creek and Cope Hut sites and from 1982 at the Pretty Valley and Rocky Valley plots.

The new criteria distinguished whether cover at a point was bare ground or litter. Where it was litter, this was divided into fixed (dead plant material still attached to the plant) and loose (easily dispersed by wind). The loose litter layer was further divided into thick (> 5 mm) and thin (< 5 mm). Finally, any vegetation covering the point was assessed as dense (> ten hits per point), medium (3–9 hits per point) or sparse (< three hits per point). In this way, cover at a point was placed in one of the three following cover classes (CC), the potential for soil erosion increasing from Cover Class 1 (CC1) to Cover Class 3 (CC3):

(*1*) CC1: point covered by fixed litter or thick, loose litter with a dense cover of live vegetation;
(*2*) CC2: point covered by thick, loose litter with a sparse to medium cover, or thin, loose litter with a medium to dense cover, or bare ground with medium to dense cover;
(*3*) CC3: point covered by thin, loose litter with a sparse cover or point consisting of bare ground with sparse or no cover.

Before statistical analyses were undertaken, the percentage overlapping cover data were transformed using the arcsine or angular transformation (Winer 1971; Underwood 1981). Probability plots and the Kolmogorov-Smirnov test (Sokal and Rohlf 1981) indicated that following transformations, the assumption of normality was satisfied in all cases.

Data Analysis

The initial design of this exclusion experiment resulted in two statistical difficulties: (1) the vegetation sampling comprised two methods; and (2) the grazing treatment was not replicated. The former problem resulted from point quadrats being distributed in random groups of ten until 1951 and then uniformly in a fixed grid. This affected tests for changes through time using repeated measures of analysis of variance (Winer 1971; Keppel 1982). The analysis requires the same replicates for each time (Tabachnick and Fidell 1989) and, because transect numbers were not always recorded, only data from the years when points along transects were recorded could be used in the analysis. These years were 1951, 1979, 1982, 1989 and 1994 for the Pretty Valley plots, and 1951, 1979 and 1989 for the Rocky Valley plots.

The original experimental design was pseudoreplicated (Hurlbert 1984), an inherent difficulty accompanying the data set that could not be corrected. Within grassland, it has been offset by using the two additional grassland sites established in 1979 (Cope Hut and Cope Creek), which serve as replicates for the grazing-present treatment between 1979 and 1994. No such data exist for grazed heathland sites that are comparable in site and disturbance history to the Rocky Valley plots, hence an analysis similar to that undertaken for the grasslands could not be done. Restrictions on statistical inferences do not necessarily prevent ecological interpretations; experiments involving unreplicated treatments can yield valuable ecological knowledge, especially where patterns and processes have been well documented (Hurlbert 1984; Collins and Barber 1985; Belsky 1986*a*, 1986*b*, 1992).

Single factor analysis of variance (ANOVA) was used to compare the mean percentage cover of individual species or ground classes between plots (Appendix 1). The effects of plot (grazed vs ungrazed) and time were analysed using both univariate and multivariate repeated measures analysis of variance (URANOVA and MRANOVA; Tabachnick and Fidell 1989). The Geisser-Greenhouse correction (Winer 1971) was used to adjust degrees of freedom prior to calculating F-ratios in URANOVA (Appendix 2). To test significance of main effects and interactions in MRANOVA, Pillai's criterion was used because of its robustness (Olson 1979). As analyses involved multiple dependent variables (e.g. taxa), the Bonferroni multiple comparison procedure was used to guard against type I errors (Keppel 1982; Kirk 1982). Subsequent to URANOVA and MRANOVA, linear and quadratic orthogonal polynomial functions were fitted to the temporal data. Regression analysis was used on the percentage cover versus time data for all major species and ground cover classes (Appendix 3). This tested the null hypothesis, that there was no trend in cover of a particular species or ground cover over time, and determined the proportion of the variation in cover over time explained by the regression line.

Results

Pretty Valley and Cope Grassland Sites

In 1947, when the Pretty Valley plots were first measured, there were few differences between plots in the cover provided by major life forms and species (Figs 2 and 3). Tussock snowgrass (mainly *Poa hiemata*) predominated on both the grazed and ungrazed plot, providing approximately 60% overlapping cover (OC), while forbs and shrubs contributed about 35 and 4% OC respectively. In 1994, however, the plots were quite distinct (Figs 4*a* –*d*), with respect to the cover of forbs and shrubs, and the quality of the ground cover (Figs 5–7; Table 2). Despite increases in the cover of these forbs and shrubs on both plots over the study period, the cover they provided was significantly greater on the ungrazed plot. In addition to differences between the Pretty Valley plots, vegetation structure and composition within the ungrazed plot at Pretty Valley was manifestly different from that of the vegetation at the other two grassland sites (Cope Hut and Cope Creek) for the period 1979–1994.

Changes in Major Life Forms and Species at Pretty Valley, 1947–1994

(*i*) *Graminoids*. The cover of *Poa* fluctuated on both plots between 1947 and 1994 (Fig. 5). The degree of fluctuation in the cover of *Poa*, however, was greater on the ungrazed plot than on the grazed plot, mainly as a consequence of the drop in 1982 and recovery in 1989. This contributed to a difference in trends for the two plots (Appendix 3).

Fig. 4. The Pretty Valley plots. (*a*) The Pretty Valley plots in January 1993; the ungrazed plot is on the left. (*b*) Aerial photograph of the Pretty Valley plots in January 1992; the ungrazed plot is clearly distinguishable from both the grazed plot and surrounding vegetation. (*c*) The ungrazed Pretty Valley plot from inside the exclusion plot in February 1993; the grazed plot can be seen in the upper right hand corner of the picture; some of the taller forbs (*Craspedia*, *Celmisia*) are shown in flower in the foreground. (*d*) The grazed Pretty Valley plot in February 1993; the ungrazed plot can be seen in the upper right hand corner of the picture.

The cover provided by *Carex* spp. (*C. hebes* and *C. breviculmis*) decreased on both plots between 1947 and 1994, although by a greater amount on the ungrazed plot (about 16% compared with 5%; Fig. 5). In 1947, the cover of *Carex* spp. was significantly higher on the ungrazed plot. Between 1947 and 1966, however, the % OC of *Carex* spp. was similar on both plots, despite an overall decrease of approximately 3% on the ungrazed plot, a trend that continued from 1966–1994 (Fig. 5). Consequently, the cover of *Carex* spp. was significantly greater on the grazed plot between 1966 and 1994 (Appendix 1).

(*ii*) *Forbs*. Over the study period, there were major differences between plots in the amount and composition of the forb component (Fig. 6). In 1947, there were some differences between plots in the abundance of common species. The cover of *Celmisia* spp. was initially 3% higher on the ungrazed plot, the cover of *Leptorhynchos squamatus* was 10% higher on the grazed plot, and the cover of *Craspedia* spp. was negligible on both plots. Since 1947, however, the cover of these major forbs has differed considerably between plots. The cover of *Celmisia* increased substantially on the ungrazed plot, from 5% in 1947 to 44% in 1994. By contrast, there was no increase in the cover of *Celmisia* on the grazed plot. Similarly, *Craspedia* increased on the ungrazed plot, from < 1% to 9%, but remained inconspicuous on the grazed plot (Fig. 6). *Podolepis robusta* did not occur on either plot in 1947; in 1994 there were no plants of this species on the grazed plot, but 55 plants were recorded on the ungrazed plot. *Leptorhynchos* increased in cover on both plots,

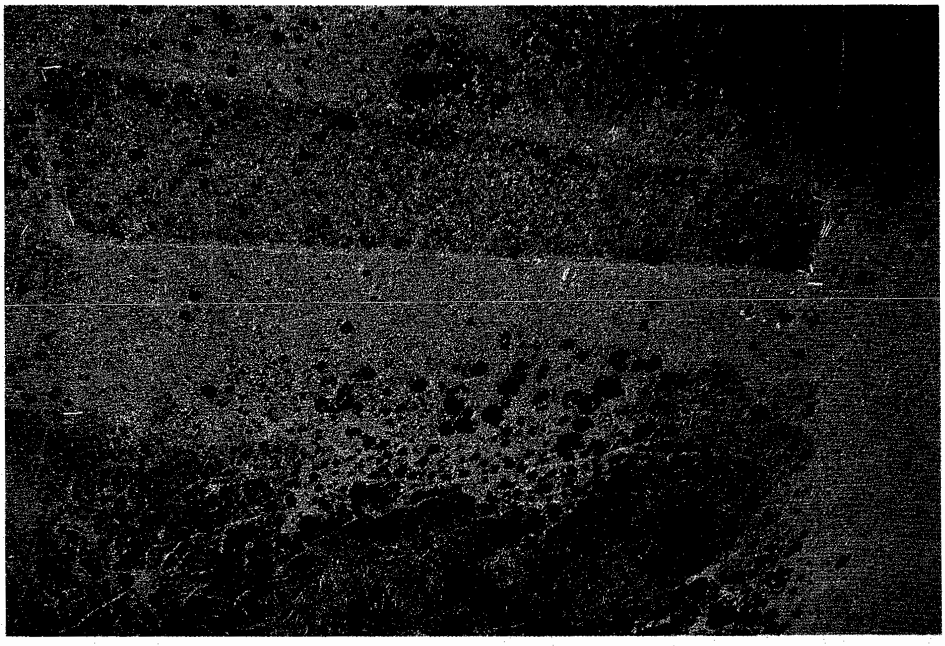

Fig. 4 *b*

Fig. 4 *c*

Fig. 4 *d*

and by 1994 was the only common forb on the grazed plot. Trends in the cover of this species differed between plots, however (Fig. 6). On the ungrazed plot, its cover rose markedly between 1947 and 1958, then fell sharply. By comparison, *Leptorhynchos* on the grazed plot did not increase in cover between 1947 and 1966, then increased substantially in cover, from 24 to 37%. As a consequence, between 1979 and 1994 the cover of *Leptorhynchos* was significantly higher on the grazed plot than on the ungrazed plot (Appendix 1).

(*iii*) *Shrubs*. The % OC of shrubs differed markedly on the two plots for all years after 1951 (Fig. 7, Appendix 1). Cover increased on both plots, but at a greater rate on the ungrazed plot. On the ungrazed plot, shrub cover reached a maximum of 47% in 1982, then decreased to 43% by 1994. On the grazed plot, shrubs increased in cover from 4% in 1947 to 13% in 1994. The most common shrubs on both plots were *Asterolasia trymalioides* and *Grevillea australis*; minor species included *Leucopogon hookeri, Kunzea ericifolia, Pimelea alpina* and *Hovea montana*. *Asterolasia* was by far the most common shrub on the ungrazed plot, increasing steadily in cover to a maximum of 38% in 1982 (Fig. 7). From 1982 to 1994, *Asterolasia* decreased significantly in cover on the ungrazed plot, but continued to provide considerably more cover than any other shrub on this plot. Moreover, in 1994, *Asterolasia* was more evenly distributed on the ungrazed plot, by contrast to its patchy distribution on the grazed plot (Fig. 8). The cover of *Asterolasia* on the grazed plot remained at about 1% over the entire study period. *Grevillea* increased in cover by 4 or 5% on both plots, showing little fluctuation between sampling periods. In 1994, there was no difference in the cover of *Grevillea* between plots (Appendix 1), but there were differences in both the size, vigour and distribution of individual shrubs (Fig. 8).

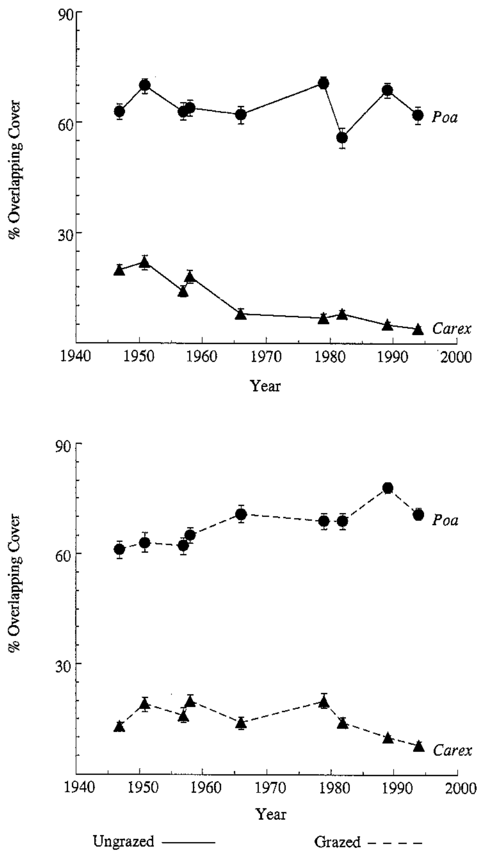

Fig. 5. Changes in percentage overlapping cover of *Poa* and *Carex* (± SE), 1947–1994, at the Pretty Valley grassland plots. Error bars that are within the dimensions of the symbols are not shown.

On the ungrazed plot, shrubs were taller than those on the grazed plot (mean height of 47 cm vs 30 cm). However, there was a greater number of smaller, more vigorously growing *Grevillea* shrubs on the grazed plot than on the ungrazed plot. Thus, the cover of *Grevillea* was very patchy on the ungrazed plot and more evenly distributed on the grazed plot (Fig. 8). Most *Grevillea* shrubs on the two plots (93% and 76% on the grazed and ungrazed plot respectively) contained canopy gaps, indicating senescence. These gaps were mostly occupied by snowgrass and other herbs.

Table 2. Mean percentage cover of each cover class (± SE) on the Pretty Valley grassland plots: 1982, 1989 and 1994

UGR: ungrazed plot, GR: grazed plot. Cover class 1: point covered by fixed litter or thick, loose litter (> 5 mm) with a dense cover of live vegetation (> ten hits per point); cover class 2: point covered by thick, loose litter with a sparse to medium cover (3–10 hits per point), or thin, loose litter (< 5 mm) with a sparse to dense cover, or bare ground with medium to dense cover; cover class 3: point covered by thin, loose litter with a sparse cover or point consisting of bare ground with sparse or no cover

Year	1982		1989		1994	
Cover Class	UGR	GR	UGR	GR	UGR	GR
1	76 ± 2.6	53 ± 2.2	71 ± 2.4	61 ± 2.3	66 ± 2.1	72 ± 1.8
2	21 ± 2.0	31 ± 2.7	24 ± 1.9	20 ± 2.1	31 ± 2.1	17 ± 1.5
3	3 ± 1.1	16 ± 1.3	5 ± 0.8	19 ± 1.5	3 ± 0.7	10 ± 1.1

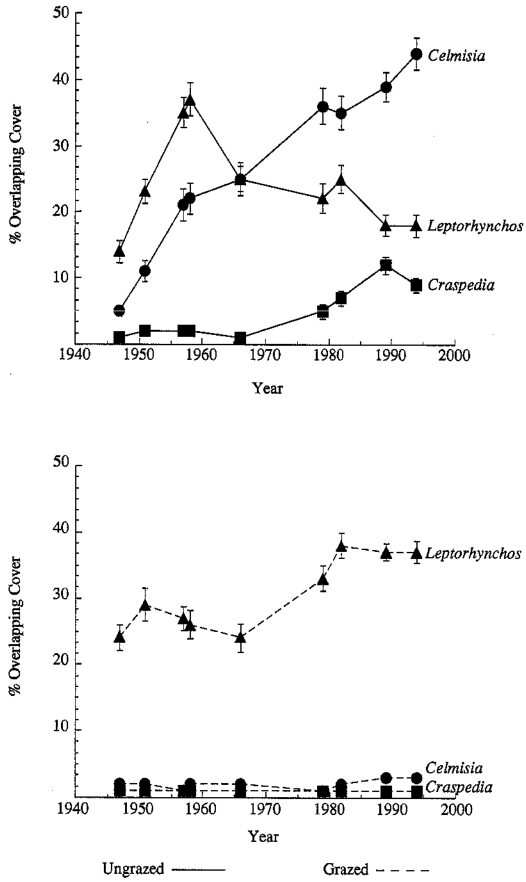

Fig. 6. Changes in percentage overlapping cover of the main forb species (± SE) —*Celmisia, Craspedia* and *Leptorhynchos* —from 1947 to 1994, at the Pretty Valley grassland plots.

Changes in Ground Condition at Pretty Valley, 1947-1994

The quality of ground cover over the study period was higher on the ungrazed plot than on the grazed plot. In 1947, the amount of poor quality cover (bare ground and loose litter, analogous to CC3) was 16% on the grazed plot; from then until 1958 this cover varied between 5 and 17%, depending on season (Fig. 9). On the ungrazed plot, this cover type declined from 10% in 1947 to between 2 and 6% in subsequent years. Between 1982 and 1994 the amount of CC3 (thin, loose litter with sparse or no cover, or bare ground with sparse or no cover) was 10–19% on the grazed plot, compared with 3–5% on the ungrazed plot (Table 2). Trends in ground cover between 1979 and 1994 were therefore similar to those described by Carr and Turner for the period 1947–1958 (Carr and Turner 1959*b*). The amount of high quality cover (CC1, fixed litter or thick, loose litter with a dense cover of live vegetation) fluctuated substantially over time, but was generally 10–15% higher on the ungrazed plot. Only in 1994 was the amount of CC1 higher on the grazed plot. The decline in CC1 on the ungrazed plot since 1982 was concomitant with an increase in CC2, rather than an increase in CC3.

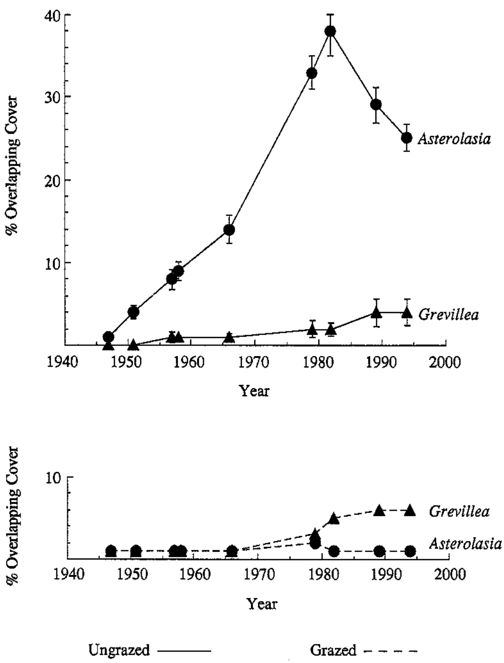

Fig. 7. Changes in percentage overlapping cover of the main shrub species (± SE) —*Asterolasia* and *Grevillea* —from 1947 to 1994, at the Pretty Valley grassland plots.

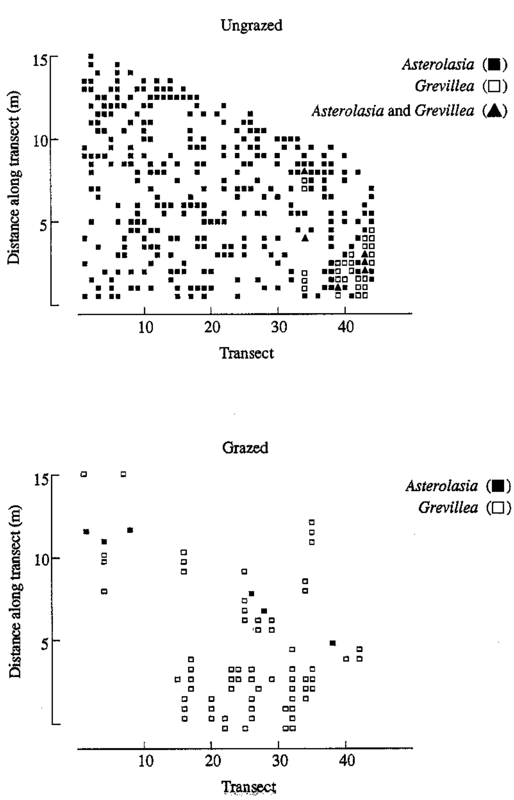

Fig. 8. Distribution of points with *Asterolasia, Grevillea* or points touching both species, at the Pretty Valley grassland plots, 1994.

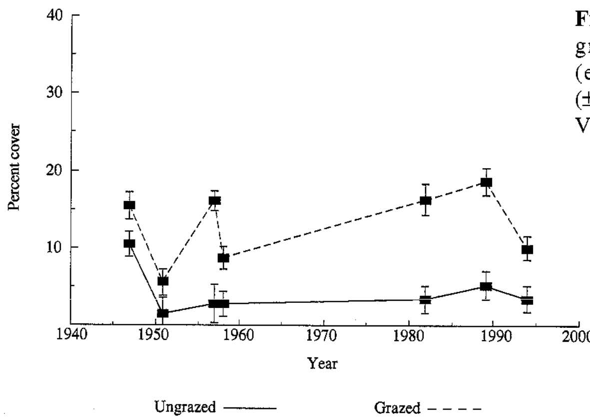

Fig. 9. Percentage cover of bare ground and/or loose litter (equivalent to cover class 3) (± SE), 1947–1994, at the Pretty Valley grassland plots.

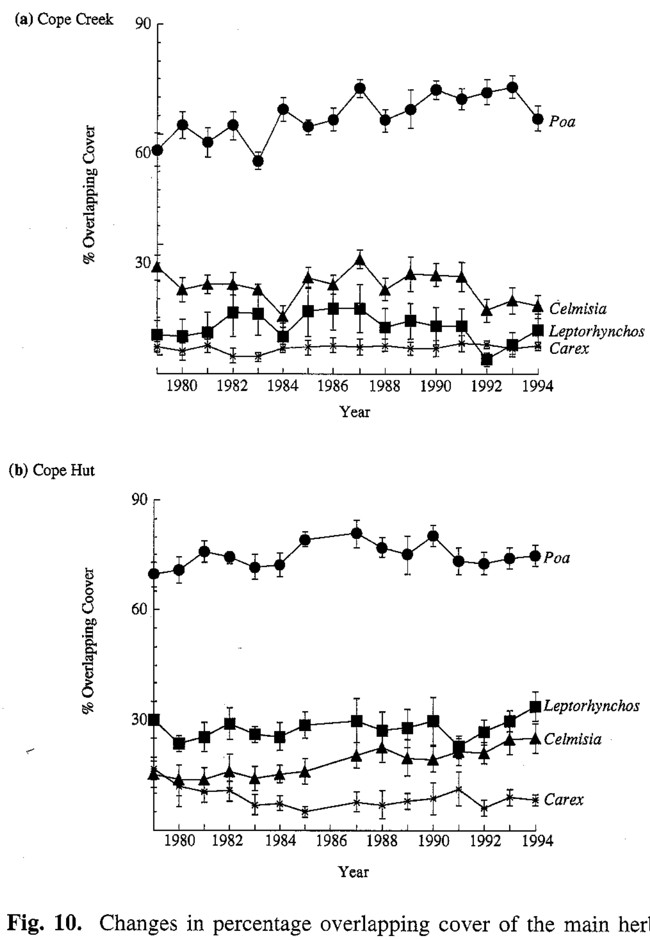

Fig. 10. Changes in percentage overlapping cover of the main herb species (± SE) —*Poa, Carex, Celmisia* and *Leptorhynchos*—from 1979 to 1994, at (*a*) the Cope Creek, and (*b*) Cope Hut transects.

Cope Hut and Cope Creek Grassland Sites, 1979–1994

The changes in cover of major species at the Cope Hut and Cope Creek grassland sites for 1979–1994 are given in Fig. 10. These two Cope sites served as replicates for the grazing treatment, permitting comparisons of cover data between the single ungrazed Pretty Valley plot and the three grazed sites (Pretty Valley plot, Cope Creek, and Cope Hut). The results of the MANOVA and regressions contrasting trends in the major species at these four sites are given in Tables 3 and 4. The data from the three grazed sites illustrate the spatial and temporal variability in cover of the constituent species within grassland. Spatial variability in the cover of *Celmisia* was especially evident, ranging from 3% at the Pretty Valley grazed site, to 25% at Cope Hut (Table 3). Most of the major grassland species at the two Cope sites—*Carex*, *Leptorhynchos*, *Craspedia* and *Asterolasia* —showed little trend in cover between 1979 and 1994, as shown by regression analysis (Table 4). The exceptions were *Poa*, which increased from 61% to 70% at the Cope Creek site, and *Celmisia*, which increased by 10% at Cope Hut. Over the sampling period there was little or no change in cover classes, CC1 and CC3, at the two sites (Tables 3 and 4). This lack of trend at Cope Hut and Cope Creek from 1979 to 1994 was similar to that observed at the grazed Pretty Valley plot from 1947–1994, indicating that all three grazed sites changed little in species composition during the study period. By comparison, on the ungrazed Pretty Valley plot there were substantial changes during the same period. For the years 1979, 1982, 1989 and 1994, the ungrazed plot at Pretty Valley was significantly different from all three grazed sites, both in the abundance of major species such as *Celmisia* and *Craspedia*, and the quality of the ground cover (Table 3).

Rocky Valley Open Heathland Plots

In 1945, the two open heathland plots at Rocky Valley were similar in structure and composition, and typical of this community (Figs 11–13). *Poa* (*P. hiemata*) predominated, with 43% and 53% cover on the grazed and ungrazed plots respectively; shrubs provided 14% and 21% cover respectively, and forb cover was generally less than 10%. In 1989, the cover of *Poa*, forbs and shrubs was similar on the two plots, although there was a considerable difference in species composition and structure between plots. On the ungrazed plot, *Grevillea australis* and *Phebalium squamulosum* predominated (Figs 11*a* and 13); on the grazed plot, *Grevillea* was uncommon, with *Phebalium* and *Prostanthera cuneata*, in association with *Bossiaea foliosa* and *Orites lancifolia* providing most of the cover (Figs 11*b* and 13).

Changes in Major Life Forms and Species, 1945–1989

The cover of *Poa* increased on both heathland plots from approximately 50% in 1947 to 80% in 1989. However, the cover fluctuated considerably between sampling periods on both plots (Fig. 12). Between 1947 and 1960 the magnitude of the fluctuations was greater on the grazed plot than on the ungrazed plot. From 1960 to 1989, however, trends in the cover of *Poa* were similar on both plots, with a decrease in cover between 1960 and 1979, followed by an increase between 1979 and 1989. Despite these contrasting trends in the cover of *Poa*, no significant difference in cover between plots was detected using univariate repeated measures analysis (Fig. 12, Appendices 2 and 3).

Forbs were a minor component of these plots over the entire sampling period, providing 6–8% cover on both plots. In 1979, however, there was a sharp increase in the cover of two minor forbs, *Asperula gunnii* and *Rumex acetosella,* on the ungrazed plot, which declined sharply after this time. At all other times, the cover of these and other forbs was less than 10% on both plots.

Total shrub cover did not differ significantly between ungrazed and grazed plots over the sampling period. Cover increased on both plots, from about 15–20% in 1945 to 70% in 1989.

Table 3. Mean cover values (%) for the main species and cover classes (1 and 3) at the four grassland sites in 1979, 1982, 1989 and 1994

Repeated measures analysis of variance, contrasting ungrazed and grazed sites; analysis of cover classes used data from 1982, 1989 and 1994. * = 0.01 < *P* < 0.05, ** = 0.001 < *P* < 0.01, *** = *P* < 0.001; NS: not significant; UGR: ungrazed plot, GR: grazed plot; NA: not available. *Poa* (*P. hiemata*), *Carex* (*C. breviculmis, C. hebes*), *Cel* (*Celmisia* spp.), *Lep* (*Letorhynchos squamatus*), *Cras* (*Craspedia* spp.), *Ast* (*Asterolasia trymalioides*)

Year	Site	Treatment	CC1	CC3	*Poa*	*Carex*	*Cel*	*Lep*	*Cras*	*Ast*
1979	Cope Creek	GR	62.00	25.00	61.00	7.00	29.00	10.00	2.00	13.00
	Cope Hut	GR	85.00	6.00	70.00	17.00	15.00	30.00	< 1	2.00
	Pretty Valley	GR	NA	NA	69.00	20.00	1.00	33.00	1.00	2.00
	Pretty Valley	UGR	NA	NA	71.00	7.00	36.00	22.00	5.00	33.00
1982	Cope Creek	GR	45.00	21.00	67.00	5.00	24.00	17.00	2.00	12.00
	Cope Hut	GR	71.00	7.00	74.00	11.00	16.00	29.00	< 1	3.00
	Pretty Valley	GR	53.00	16.00	69.00	14.00	2.00	38.00	< 1	1.00
	Pretty Valley	UGR	76.00	3.00	56.00	8.00	35.00	25.00	7.00	38.00
1989	Cope Creek	GR	51.00	18.00	72.00	7.00	27.00	14.00	2.00	5.00
	Cope Hut	GR	62.00	13.00	75.00	8.00	20.00	28.00	< 1	2.00
	Pretty Valley	GR	61.00	19.00	78.00	10.00	3.00	37.00	< 1	1.00
	Pretty Valley	UGR	71.00	5.00	69.00	5.00	39.00	18.00	12.00	29.00
1994	Cope Creek	GR	56.00	16.00	70.00	8.00	18.00	12.00	2.00	10.00
	Cope Hut	GR	66.00	11.00	75.00	8.00	25.00	34.00	1.00	2.00
	Pretty Valley	GR	72.00	10.00	71.00	8.00	3.00	38.00	6.00	< 1
	Pretty Valley	UGR	66.00	3.00	62.00	4.00	45.00	19.00	9.00	25.00
	Plot (UGR vs GR)		***	***	***	***	***	NS	***	***
	Year		***	*	*	**	NS	NS	NS	NS
	Year x Plot		**	***	**	NS	NS	NS	NS	NS

Table 4. Regression analysis of cover data from the Cope Creek and Cope Hut sites, 1979-1994

H0 (null hypothesis): the slope of the regression line equals zero; NS: slope not significantly different from zero; significance levels: * = 0.01 < *P* < 0.05, ** = 0.001 < *P* < 0.01, *** = *P* < 0.001. R^2 (coefficient of determination): proportion of the total variation in pecentage cover explained by the regression line. *Poa* (*P. hiemata*), *Carex* (*C. breviculmis, C. hebes*), *Cel* (*Celmisia* spp.), *Lep* (*Letorhynchos squamatus*), *Cras* (*Craspedia* spp.), *Ast* (*Asterolasia trymalioides*)

Site	Regression	CC1	CC3	*Poa*	*Carex*	*Cel*	*Lep*	*Cras*	*Ast*
Cope Creek	R^2	0.03	0.14	0.53	0.22	0.08	0.06	0.03	0.33
	H0: slope = 0	NS	NS	**	NS	NS	NS	NS	*
Cope Hut	R^2	0.32	0.01	0.10	0.21	0.85	0.10	0.00	0.04
	H0: slope = 0	*	NS	NS	NS	***	NS	NS	NS

Rates of change differed during this period, however (Fig. 12). On the grazed plot, shrub cover increased monotonically, while the rate of increase on the ungrazed plot varied with time. From 1945 to 1960, the rate was approximately twice that on the grazed plot. Between 1960 and 1979, however, the rate of increase was lower on the ungrazed plot. Shrub cover then continued increasing on the grazed plot, while decreasing significantly on the ungrazed plot. Despite an overall similarity in total shrub cover on the plots over time, by 1989 there were major differences in both composition and distribution of the constituent shrub species.

Fig. 11. The Rocky Valley open heathland plots. (*a*) The ungrazed plot in February 1989; (*b*) the grazed plot in January 1990.

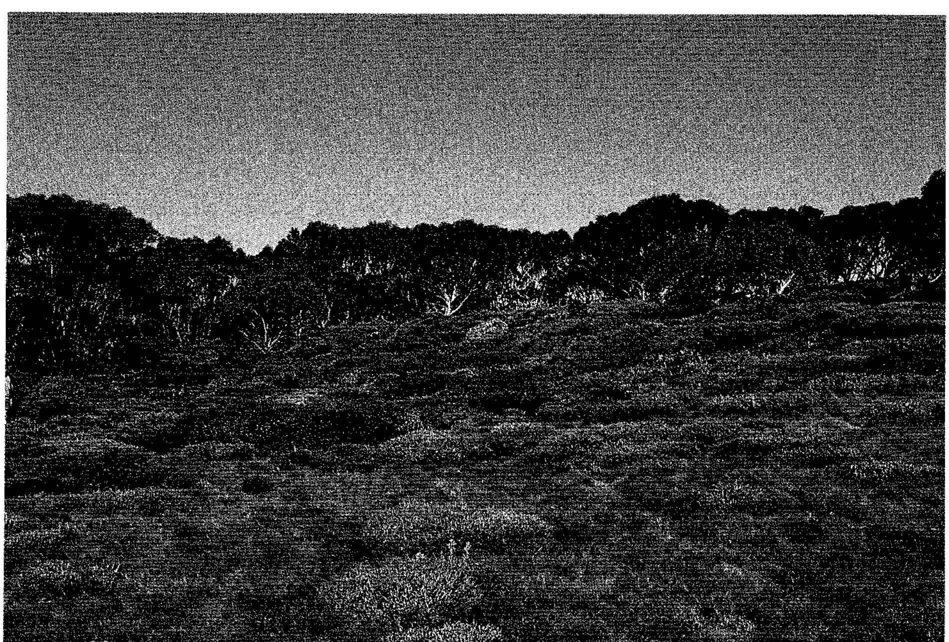

Fig. 11 *b*

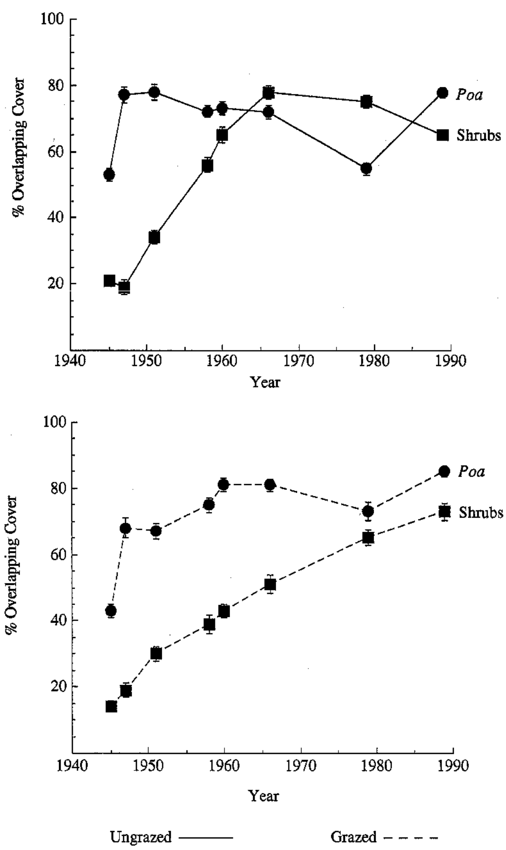

Fig. 12. Changes in percentage overlapping cover of *Poa* and shrubs (± SE), 1945–1989, at the Rocky Valley heathland plots.

At that time, the main shrubs on the ungrazed plot were *Phebalium*, *Grevillea* and *Hovea*; on the grazed plot *Phebalium*, *Prostanthera* and *Hovea* predominated. In 1947, the cover of each of these shrubs was low (< 10%), with few differences in cover between plots (Fig. 13). *Phebalium* increased in cover on the grazed plot, from 5 to 30% between 1947 and 1966, thereafter declining to 23% in 1989. On the ungrazed plot, *Phebalium* continued to increase in cover until 1979, then decreased sharply in cover. In 1989, there was no significant difference in the cover of this species between plots. *Grevillea* differed significantly in cover between plots after 1951, both in trend and amount (Fig. 13). The cover of *Grevillea* was initially similar (< 2%) on both plots. On the grazed plot, the cover of *Grevillea* remained at less than 2% cover over the entire study period. By contrast, *Grevillea* on the ungrazed plot increased in cover from 1% in 1945 to 25% in 1979, declining to 15% in 1989. This was similar to the behaviour of *Phebalium* on this plot. Over the study period, however, the cover of *Grevillea* was considerably less than that of *Phebalium* (Fig. 13). The cover of *Prostanthera*, a common shrub in closed heathland, was initially low (< 2%) on both plots and by 1989 did not occur on the ungrazed plot. On the grazed plot, however, the cover of *Prostanthera* increased from 2–24% during the sampling period, with a noticeable increase in the rate of expansion after 1966 (Fig. 13). By 1989, *Prostanthera* contributed approximately 35% of the cover provided by all shrubs on this plot and, unlike *Grevillea* and *Phebalium*, did not decrease in cover between 1979 and 1989, but continued to increase. The cover of two other closed heathland species, *Orites* and *Bossiaea*, remained low (< 3%). Furthermore, the three closed heathland species, *Prostanthera*, *Orites* and *Bossiaea*, were concentrated in two-thirds of the plot (Fig. 14). Total shrub cover in the other third was low; the vegetation there was clearly grass-dominated (Figs 11*b* and 14). *Hovea* increased in cover on both plots between 1947 and 1989. Trends in cover over time, however, differed significantly between plots. From 1946–1966 the cover of *Hovea* was significantly greater on the ungrazed plot than the grazed plot. Subsequent to 1966, however, the cover of *Hovea* declined significantly on the ungrazed plot and, as a consequence, its cover from 1979–1989 was markedly lower on the ungrazed plot. Thus, by 1989 the ungrazed plot was an open heathland of *Phebalium* and *Grevillea* in a senescent condition. By contrast, two-thirds of the grazed plot consisted of closed heathland and one-third was grassland.

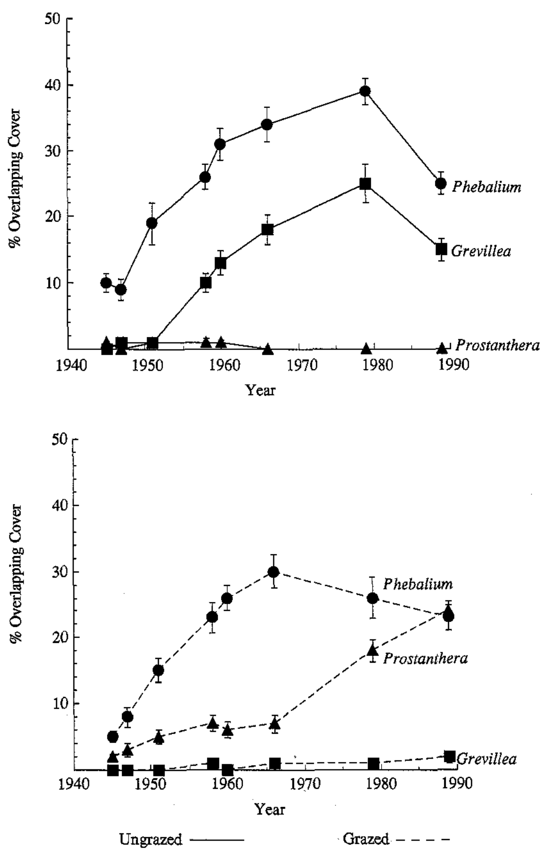

Fig. 13. Changes in percentage overlapping cover of the main shrubs (± SE) —*Grevillea, Orites*, *Phebalium* and *Prostanthera*—from 1945 to 1989, at the Rocky Valley heathland plots.

In 1989, the quality of the ground cover differed between plots, particularly that of CC1, which was 10% higher on the grazed plot (92%) than on the ungrazed plot (82%). The cover of CC3 was 5 and 4% on the ungrazed and grazed plots respectively. These results differ from those at the Pretty Valley plots, where the amount of CC1 was higher on the ungrazed plot, and the amount of CC3 higher on the grazed plot.

Table 5. Morphological measurements of the heathland shrub *Phebalium squamulosum* at Rocky Valley

Measurements taken from ten randomly located 2 x 3 m quadrats within the grazed and ungrazed open heathland plots

Plot		Stem diameter (mm)	Shrub height (cm)	Canopy width (cm)
	Min	4.0	20.0	5.0
Ungrazed	Max	64.0	66.0	216.0
($N = 50$)	Mean ± SE	21 ± 0.4	40 ± 1.5	105 ± 6.4
	Min	5.0	28.0	26.0
Grazed	Max	47.0	63.0	234.0
($N = 56$)	Mean ± SE	19 ± 0.4	45 ± 1.2	105 ± 5.7

Heathland Structure, 1989–1990

Shrub height varied from < 0.5 m to 2 m. The smallest *Phebalium* shrubs were about 20–30 cm high with stem diameters of approximately 0.5 cm (Table 5). Only three *Phebalium* shrubs of this size were found and they are likely to be at least 10 years old (C-H. W. unpublished data). Most *Phebalium* shrubs were about 65 cm high and 1.5–2 m in diameter and in a senescent growth phase (Table 5). Most *Prostanthera* shrubs were about 90 cm high and 2 m in diameter, 1–2 m tall, and in a mature growth phase, with no canopy gaps.

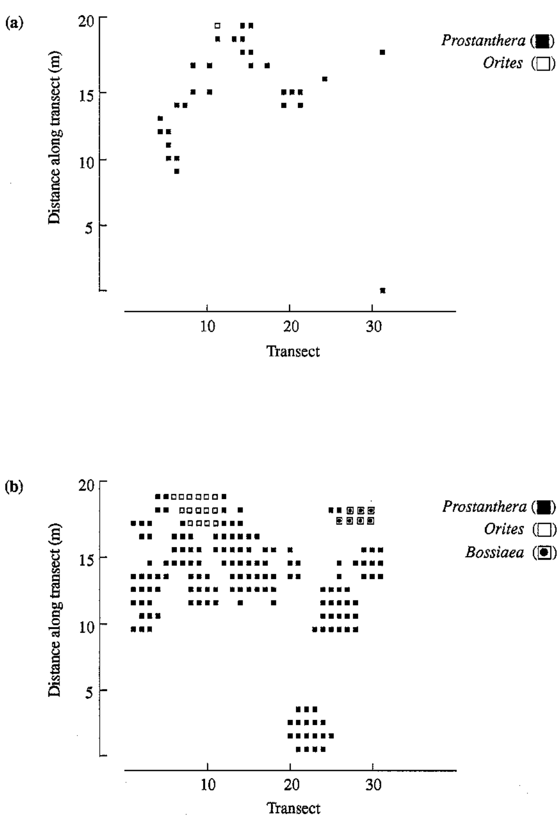

Fig. 14. Distribution of point quadrats contacting *Prostanthera, Orites* or *Bossiaea*; (*a*) 1951, (*b*) 1989, at the grazed Rocky Valley plot.

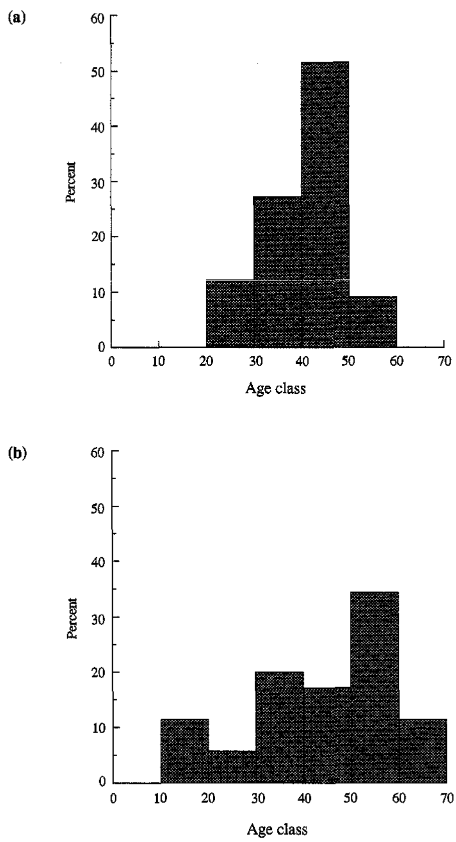

Fig. 15. Age structure of (*a*) *Phebalium* and (*b*) *Prostanthera* shrubs, at the Rocky Valley heathland plots.

The age-structure of the shrubs adjacent to the Rocky Valley site is given in Fig. 15. In 1990, the minimum age of *Phebalium* was 23 years; the oldest, a senescent shrub with a prominent canopy gap and numerous dead stems, was 55 years. Most of these shrubs were 40–55 years old. By comparison, the youngest *Prostanthera* shrub was 14 years and the maximum age was 67 years. There were no *Phebalium* or *Grevillea* seedlings found in any of the quadrats within the Rocky Valley plots.

Discussion

The dynamics of grasslands and heathlands, including patterns of regeneration, have received considerable attention in alpine and subalpine areas of Australia (Carr and Turner 1959*a,* 1959*b*; Costin *et al.* 1959; Carr 1962, 1977; Costin 1962; Wimbush and Costin 1979*a,* 1979*b,* 1979*c*; Leigh *et al.* 1987; Williams 1987*a,* 1987*b*, 1990*a,* 1990*b*; Williams and Ashton 1987*a,* 1987*b*, 1988; Gibson and Kirkpatrick 1989; Good 1989). These authors have stressed the dynamic nature of alpine and subalpine vegetation, in particular the changes that may occur in both the woody and herbaceous components of the vegetation. Such changes depend upon interactions between life history, site and disturbances. Trends in vegetation over the past half century have shown that recovery following disturbance has been slow. Changes in the herb-woody plant balance have been substantial in response to disturbance, particularly disturbances by domestic livestock. In this respect, diet selection has been of key importance, with species palatable to stock decreasing in cover and less palatable species little affected or increasing in cover. Results from this study clearly support the patterns and processes described above: vegetation change has been slow and domestic cattle have had substantial and lasting impact on both the structure and composition of subalpine grassland and heathland vegetation.

The data presented in this paper represent some of the oldest long-term studies of vegetation change in Australia. The experimental design, however, was limited by the lack of replication of treatments when the original plots were established by Turner and Fawcett (1948). Consequently, there were restrictions on statistical inferences dealing with the effects of grazing. Unreplicated treatments are often unavoidable in ecological research and there are alternative designs and statistical methods to deal with this (Carpenter 1990; Jassby and Powell 1990; Reckhow 1990; Stewart-Oaten *et al.* 1992).

In the present study, the difficulty of unreplicated treatments has been partly off-set by the long-term nature of the data, collected at permanent reference plots. These data show that large differences have emerged between the grazed and ungrazed plots. Furthermore, the grazing treatment in grassland has been effectively replicated over the past decade by the inclusion of two sites in similar adjacent grassland areas to the grazed Pretty Valley plot. These mitigating factors increase the strength of inferences we draw with respect to the effect of grazing by cattle on the structure and composition of the vegetation. Moreover, in recent years there have been many replicated experimental studies on the Bogong High Plains, examining both the responses of vegetation to grazing as well as the diet and behaviour of cattle, which permit strong inferences to be drawn concerning the impact of grazing on vegetation between the 1940s and the 1990s.

Vegetation Change in Grassland

There were clear differences between the Pretty Valley plots in both the status of the vegetation and the trends in vegetation cover between 1947 and 1994. On the ungrazed plot, there was a substantial and sustained increase in the cover of major forbs, such as *Celmisia* and *Craspedia*; on the grazed plot there was no change in the sparse cover of these species. The only forb providing substantial cover on the grazed plot was *Leptorhynchos*. At present, there are also significant differences between plots in the cover of the low shrub *Asterolasia*, and in the quality of the ground cover offered by the vegetation. There was little difference between plots in the amount of *Poa*, which fluctuated in cover on both plots over the years. Such seasonal fluctuation occurred elsewhere on the Bogong High Plains (Carr and Turner 1959*b*; van Rees *et al.* 1984) and in grassland at higher elevations in the Kosciusko region (Wimbush and Costin 1979*a*, 1979*b*, 1979*c*).

Grazing clearly affected the abundance of the major herbaceous species in grassland. The contrasting trends in the cover of *Celmisia* and *Leptorhynchos* are probably due to differences in competitive and colonising ability, both of which are affected by differential palatability (Carr and Turner 1959*b*; van Rees 1982, 1984). Carr and Turner (1959*b*) argued that *Leptorhynchos* was a more vigorous colonist of the bare, inter-tussock spaces that result from cattle grazing. In the absence of grazing, however, they suggest that *Celmisia* will eventually displace *Leptorhynchos*. These hypotheses predict that, under grazing, the capacity of *Leptorhynchos* to persist in the long term is greater than that of *Celmisia*. The data presented here strongly support these hypotheses. Both species form substantial proportions of the diet of cattle. *Celmisia*, however, is preferred to *Leptorhynchos* (van Rees 1984, table 8), and the amount of *Celmisia* in the diet is approximately twice that of *Leptorhynchos* over the entire growing season (van Rees 1984, table 5). *Craspedia*, another perennial forb that will also colonise bare ground, is both palatable (van Rees 1982) and sensitive to grazing (Wimbush and Costin 1979*a*); hence, it is a useful indicator of grazing pressure (Wimbush and Costin 1979*a*). On the grazed plot, *Craspedia* remained below 1% over the 47 year sampling period. In the absence of grazing, *Craspedia* contributed about 9% OC on the ungrazed plot by 1994. *Podolepis*, also a palatable forb (van Rees 1984), is relatively uncommon on the High Plains (McDougall 1982) and has been since heavy stocking in the severe droughts of the early 1900s (Carr and Turner 1959*b*). The spread of this plant across the ungrazed plot was a clear consequence of release from grazing pressure. *Carex* spp. are rhizomatous, palatable sedges (van Rees 1984) that will colonise disturbed sites from seed stored in the soil (Williams and Ashton 1987*b*). On the grazed plot, there was little change in the cover of *Carex* spp. over the years, despite fluctuations between sampling periods. Within the fenced plot, however, *Carex* spp. decreased significantly over time, suggesting a reduction in inter-tussock spaces. Similar trends have been found for these species on exclusion plots in the Kosciusko region by Wimbush and Costin (1979*a*). The clear implication is that, on the grazed plot at Pretty Valley, continued disturbance is providing suitable microsites for *Carex* spp. to colonise; these disturbances are likely to persist as a consequence of cattle activity.

Changes in shrub cover in grassland over time, and the effects of grazing, can be interpreted also in terms of interactions between palatability to cattle and life history patterns. *Asterolasia*, which increased considerably in cover within the fenced plot, is highly palatable to cattle (van Rees 1984), particularly sensitive to trampling (Carr and Turner 1959*b*; Carr 1962, 1977; Williams and Ashton 1987*b*) and will regenerate only from seed (Williams and Ashton 1987*b*). Thus, its low cover on the grazed plot was a result of both browsing and trampling. The decrease in cover of *Asterolasia* between 1982 and 1994 within the fenced plot was due to senescence of individual shrubs. Gaps may form in the canopy of this and other shrubs, and these gaps are then subject to eventual colonisation by grasses, forbs and other shrubs (Carr and Turner 1959*a*, 1959*b*; Williams and Ashton 1988). In this study, *Poa* and *Celmisia* were the main species to invade canopy gaps of *Asterolasia* and the current processes of canopy decline and invasion are likely to continue. Furthermore, as *Asterolasia* is an obligate seeder (Williams and Ashton 1988), and there are no seedlings at present within the ungrazed plot, it is unlikely that new generations of this shrub will establish and grow. The growth phases of *Asterolasia* may be estimated from our data, even though the demography of this species has not been followed on these plots. If the largest current individuals were seedlings in 1946, when the plot was fenced, then they are now at least 48 years old. It would therefore appear that the active period of shrub growth occurs over the first 20–30 years, after which senescence begins. *Asterolasia* is likely to decrease in cover over the coming decades within the fenced plot, but trends in the rates of decline in cover of *Asterolasia* are difficult to predict.

Grevillea, like *Asterolasia*, is palatable to cattle (van Rees and Hutson 1983) and an obligate seeder (Williams and Ashton 1987*b*, 1988). Unlike *Asterolasia*, however, the cover of *Grevillea* increased only slightly on the plots, and by 1994 provided similar cover values on both plots. On the grazed plot, the cover of *Grevillea* was ten times that of *Asterolasia*. This is probably due to a greater inherent growth potential in *Grevillea* compared with *Asterolasia*, because there is little difference in either the indices of palatability or the amount of these shrubs consumed by cattle in grassland communities on the Bogong High Plains (van Rees 1984). The greater number of individual shrubs at the grazed site is likely to reflect a greater number of bare ground patches, which shrub seedlings depend on for successful establishment (Williams and Ashton 1987*b*). Canopy gaps in the senescent shrubs will probably expand and the expansion of herbs and grasses within these gaps (Williams and Ashton 1988) is likely to continue. The life span of *Grevillea* is difficult to estimate because of numerous medullary rays that obscure the growth rings (Williams and Ashton 1988). No comparison of the age structure of these shrubs on the two plots was therefore possible. The cover of *Hovea* on the grazed plot was about 3% in 1994 and did not occur on the ungrazed plot. This leguminous shrub tends to occupy inter-tussock spaces and, on disturbed grassland, is often one of the first shrubs to colonise, followed by other shrubs like *Grevillea* (Wimbush and Costin 1979*b*).

Trends in Land Condition

Ground cover conditions were noticeably different on the two Pretty Valley plots over the study period. On the grazed plot, there was no sustained improvement in the quality of ground cover between 1947 and 1958. By comparison, bare ground and loose litter on the ungrazed plot diminished markedly between 1947 and 1958, after which time there was little change. Hence, by 1982–1994 the amount of poor quality ground cover (CC3) was three to five times greater on the grazed plot than on the ungrazed plot. These results are significant in terms of soil conservation, as bare ground or loose litter, with little vegetation cover, are both susceptible to the erosive forces of wind, rain and frost action (Costin *et al.* 1960; Costin 1977). Ground cover condition of the ungrazed plot was also superior to that of the grazed sites at Cope Hut and Cope Creek. Hence, the vegetation on the ungrazed plot provides more adequate protection for the soil surface than at any of the three grazed grassland sites studied.

Within grazed grassland, there was substantial spatial and temporal variability in ground cover conditions and the abundance of main species. In 1994, the cover of *Celmisia* ranged from 3% on the grazed Pretty Valley plot to 25% at Cope Hut. Such spatial variability in the cover of *Celmisia*, however, is not unusual in small (1 ha) areas of the Bogong High Plains. These data and data from other grassland sites (Papst, unpublished data) show that, under the present grazing regime, there is substantial patchiness in the cover of *Celmisia*. Grassland areas where *Celmisia* provides < 5% cover can occur within several hundred metres of areas where the cover may be 20%. Cover Class 1 appears to be especially dynamic at all sites, which reflects the continual conversion of fixed litter to loose litter. Despite this variability between and within grazed sites, the composition of the ungrazed plot at Pretty Valley, both in terms of species abundance and quality of ground cover, has remained markedly different from each of the three grazed plots between 1979 and 1994.

The patchiness in the cover of *Celmisia* within grassland described above implies that there are areas where *Celmisia* is relatively common under present stocking levels. We cannot say whether the cover of *Celmisia* will increase in such patches were grazing to be removed. Trends revealed by the Pretty Valley data, however, suggest that in those areas where the cover of *Celmisia* is low (< 5%), removal of grazing will result in substantial increases in the cover of *Celmisia*, and indeed other tall, prominent forbs such as *Craspedia* and *Podolepis*. In addition, the cover of *Asterolasia*, if present as seedlings, could be expected to increase and the amount of bare ground decrease. The increase in *Asterolasia*, however, would be temporary until individuals begin to senesce and are replaced by forbs and snowgrass.

As a result of the variability within grazed grassland, there was little or no trend in either species abundance or ground cover condition on the three grazed grassland sites between 1979 and 1994. Such an absence of trend has been interpreted to mean that the grassland vegetation is in a stable state, that this state is acceptable, and therefore that cattle have had little or no impact within grassland (Parry 1978; Commins 1988). Such arguments confuse trend with state. Recent trends do not necessarily reveal anything about current condition. Grazing impacts can be determined only by comparative studies of grazed and ungrazed areas, preferably over long periods of time. Although there was little change in the nature of grazed grassland between 1979 and 1994, the condition of these grasslands, in terms of soil and nature conservation values, is inferior to that of the ungrazed plot at Pretty Valley. We therefore conclude that the grazed grassland on the Bogong High Plains is stable but degraded.

Vegetation Change in Open Heathland

In 1945, both plots were similar in composition and structure, and representative of subalpine open heathland. Since 1945, the most significant change has been the expansion of the taller shrubs on both the grazed and the ungrazed plots. The vegetation on both plots at the Rocky Valley site was burned in 1939 and the expansion of shrubs on both plots over the study period is part of the post-fire regeneration process. The age-structure of both *Phebalium* and *Prostanthera* showed that most individuals of both species were between 40 and 50 years old in 1990, indicating that they established in the decade following this major fire. Virtually all the *Phebalium* shrubs established subsequent to the 1939 fire; some 15% of the *Prostanthera* population had established prior to the fire and subsequently resprouted. Unlike the Pretty Valley grassland plots, forb cover on both plots at this heathland site was relatively low for the entire study period; forbs are in general a minor component of heathlands on the Bogong High Plains (McDougall 1982; Williams and Ashton 1987*a*).

Changes in Shrub and Ground Cover

Shrub cover increased on both plots until 1979. From 1979 to 1989, however, the shrub cover declined on the ungrazed plot, while continuing to increase on the grazed plot. The decrease in shrub cover on the ungrazed plot resulted from senescence of both *Grevillea* and *Phebalium*, and is analogous to the senescence of *Asterolasia* on the ungrazed plot at Pretty Valley. The continued increase in shrub cover on the grazed plot reflects the expansion of both *Prostanthera* and *Hovea*. Differences in patterns of shrub behaviour on these two plots, like those at the Pretty Valley site, are also interpretable in terms of differences in life-history characteristics and palatability to cattle.

On the ungrazed plot, the significant decrease in shrub cover of both *Grevillea* and *Phebalium* between 1979 and 1989 was due to senescence of the majority of larger (> 1 m diameter) individual shrubs. The canopy gaps of these shrubs were colonised primarily by *Poa*. The increase in cover of *Poa* is likely to continue, as these shrubs senesce. The cover of both *Grevillea* and *Phebalium* is likely to decrease in the coming decades, as there has been virtually no seedling recruitment of either species over the past 20–25 years and, at 40–50 years old, most extant shrubs are approaching their age limit. Replacement of mature (20–40 year old) individuals of *Grevillea* and *Phebalium* by *Poa*, as canopy gaps expand, is a common phenomenon in open heathland, as shown by a broad survey of these two shrubs in other stands of open heathland both on the Bogong High Plains (Williams and Ashton 1988) and in the Kosciusko region (Park 1975)

On the grazed plot, the shrubs that continued to expand over the entire study period were *Prostanthera*, *Hovea*, *Orites* and *Bossiaea*, all of which are non-palatable to cattle (van Rees 1984). The lack of *Phebalium* seedlings, and decreasing cover of this species on the grazed plot between 1979 and 1989, reflects both the shorter life span of *Phebalium* and its less vigorous colonising ability compared with *Prostanthera*. Closed heathland species, such as *Prostanthera*, are relatively fast-growing (Williams 1990*b*) and may form dense heaths 1 or 2 m tall; such closed heaths are avoided by cattle (van Rees and Hutson 1983). In addition, these shrubs have little grass in the understorey (McDougall 1982; Williams and Ashton 1987*a*) and may resprout vigorously at senescence; any canopy gaps that develop are primarily recolonised by shrubs, not snowgrass (Williams and Ashton 1988; Williams 1992). Thus, due to interactions between life-history characteristics and palatability, *Prostanthera* can persist in the face of cattle grazing. By contrast to these unpalatable shrubs, *Grevillea* did not increase in cover on the grazed plot, probably as a result of selective browsing.

There was little difference in ground cover conditions between the grazed and ungrazed plots over the sampling period. Poor quality cover was similar between plots and high quality cover was higher on the grazed plot, probably a consequence of the high cover of tall, dense shrubs, such as *Prostanthera*, which have thick, relatively stable litter beneath their dense canopies. Although the amount of shrub cover is currently similar on both plots, distribution patterns of shrub and grass cover show that the plots are structurally distinct. The ungrazed plot consists of uniformly distributed shrubs and snowgrass; it is structurally an open heathland. By contrast, the grazed plot is one-third tussock grassland, with few shrubs, and two-thirds closed heathland, with little grass. Moreover, shrubs on the grazed plot have expanded into the grassy section of the plot since sampling commenced in 1945.

Does Alpine Grazing Reduce Blazing?

Evidence presented here does not support claims that shrub cover in general, and thus the risk of fire, is reduced by cattle (Parry 1978; Holth 1980; Commins 1988; Anon 1992). Few shrubs were unequivocally reduced in cover as a result of grazing; the impact of cattle on the cover of shrubs depended strongly on site and species. In this study, the only shrubs to have lower cover values on a grazed plot compared with an ungrazed plot were *Asterolasia* at Pretty Valley and *Grevillea* at Rocky Valley. For all other species-site combinations there were no differences between grazed and ungrazed areas. Indeed, on the grazed Rocky Valley heathland plot, the cover of persistent, non-palatable shrubs has continued to increase since 1966. The only evident reduction in total shrub cover, which has clearly occurred as a result of browsing, is that of *Asterolasia* at the grazed Pretty Valley grassland site. This shrub rarely exceeds 20 cm in height, and is unlikely to be as flammable as the taller, more productive shrubs, such as *Prostanthera* (Good 1982). The inherent fire risk of *Asterolasia* is therefore low, with little scope for 'reduction' of risk due to browsing. In the taller, denser heaths, which were extensively burnt in the 1939 wildfires, and are the most flammable components of the subalpine vegetation (Good 1982), grazing has not reduced total shrub cover.

Conclusions

The data presented in this paper represent some of the oldest long-term studies of vegetation change in Australia. Although the initial design set up in the 1940s lacked replication with respect to grazing, recent experimental and monitoring studies have provided additional evidence with which to assess the impacts of cattle grazing.

Our data clearly show that grazing by cattle has substantial impacts on the composition and structure of subalpine vegetation. In grassland, grazing alters species composition by selective grazing of the taller forbs and short, palatable shrubs. Grazing in grassland also results in persistently greater areas of bare ground that are susceptible to soil erosion by such action as frost heave and wind winnowing. The processes involved have been extensively described by other workers for areas across the Australian high country.

The expansion of shrubs over the past 50 years appears to be primarily the result of post-fire regeneration following periods of high grazing pressure in previous decades. Ecological processes and selective grazing of shrubs have interacted to produce changes in species composition, some transitory and some permanent. In the prolonged absence of grazing, shorter-lived shrubs such as *Asterolasia*, *Phebalium* and *Grevillea* expanded initially, but are now senescing and being replaced by tussock grasses and forbs. Longer-lived shrubs, such as *Prostanthera*, have continued to expand. We found no evidence that grazing reduced total shrub cover in open heathland.

There was little or no significant trend in vegetation cover, litter or bare ground at the three grazed grassland sites from 1979 to 1994. This, however, does not imply that cattle grazing is having no impact within grassland. Grazed grasslands on the Bogong High Plains may be described as stable, but in terms of soil and nature conservation values they are degraded.

These data have numerous implications for effective management of the high country. Alpine and subalpine vegetation is slow to recover from disturbance, and the rate of recovery is unquestionably slower in areas grazed by cattle. In grassland, continued grazing will reduce the abundance of taller forbs and dwarf, palatable shrubs; some shrubs, such as

Grevillea, may continue to expand. Significantly higher amounts of bare ground increases the risk of soil erosion and will provide suitable sites for further shrub establishment. Continued grazing in open heathland is unlikely to reduce overall shrub cover and may lead to an expansion of taller, more persistent, non-palatable shrubs. It will therefore not reduce the risk of fire in such communities.

Vegetation change will continue in the coming decades and monitoring of permanent reference plots is the only effective way of accurately detailing such changes. Therefore, if management of alpine and subalpine vegetation is to be based on sound scientific data, it is essential that the plots on the Bogong High Plains are maintained and reassessed at least once every decade, and that long-term ecological studies are adequately supported.

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Appendix 1

Probability values from single factor ANOVA testing for treatment (grazing) effect; (*a*) Pretty Valley plots, (*b*) Rocky Valley plots. Per comparison significance levels were adjusted using the Bonferroni method; they were 0.006 and 0.008 for the Pretty Valley and Rocky Valley plots respectively. *Poa* (*P. hiemata*), *Carex* (*C. breviculmis*), *Cel* (*Celmisia* spp.), *Lep* (*Leptorhynchos squamatus*), *Cras* (*Craspedia* spp.), *Grev* (*Grevillea australis*), *Ast* (*Asterolasia trymalioides*), *Hovea* (*H. montana*), *Pheb* (*Phebalium squamulosum*), *Prost* (*Prostanthera cuneata*)

(*a*) Pretty Valley grassland plots

Year	*Poa*	Forbs	Shrubs	*Carex*	*Cel*	*Lep*	*Cras*	*Grev*	*Ast*
1947	0.632	0.067	0.558	< 0.001	0.004	< 0.001	0.236	0.051	0.239
1951	0.048	0.002	0.103	0.505	< 0.001	0.141	0.087	0.009	< 0.001
1957	0.477	< 0.001	< 0.001	0.750	< 0.001	0.012	0.004	0.291	< 0.001
1958	0.881	< 0.001	< 0.001	0.323	< 0.001	0.005	0.154	0.323	< 0.001
1966	0.011	< 0.001	< 0.001	0.005	< 0.001	0.913	0.340	0.706	< 0.001
1979	0.582	0.012	< 0.001	< 0.001	< 0.001	< 0.001	< .001	0.062	< 0.001
1982	0.001	0.001	< 0.001	0.001	< 0.001	< 0.001	< 0.001	0.002	< 0.001
1989	0.003	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	0.111	< 0.001
1994	0.003	< 0.001	< 0.001	0.003	< 0.001	< 0.001	< 0.001	0.235	< 0.001

(*b*) Rocky Valley Plots

Year	*Poa*	Shrubs	*Pheb*	*Grev*	*Prost*	*Hovea*
1945	0.001	< 0.001	0.002	< 0.001	< 0.001	0.143
1947	0.085	0.990	0.688	0.090	< 0.001	0.742
1951	0.001	0.159	0.357	0.003	< 0.001	0.107
1958	0.218	< 0.001	0.267	< 0.001	< 0.001	< 0.001
1960	0.002	< 0.001	0.100	< 0.001	< 0.001	< 0.001
1966	< 0.001	< 0.001	0.181	< 0.001	< 0.001	< 0.001
1979	< 0.001	0.005	< 0.001	< 0.001	< 0.001	0.120
1989	0.002	0.016	0.527	< 0.001	< 0.001	0.002

Appendix 2

Probability values from univariate and multivariate repeated measures analysis of variance (URANOVA and MRANOVA), and linear and quadratic polynomial contrasts; (*a*) Pretty Valley plots, (*b*) Rocky Valley plots. Data from the following years could be used in the analyses: 1951, 1979, 1982, 1989 and 1994 (Pretty Valley plots), and 1951, 1979 and 1989 (Rocky Valley plots). Per comparison significance levels were adjusted using the Geisser-Greenhouse method; they were 0.006 and 0.008 for the Pretty Valley and Rocky Valley plots respectively. UGR: ungrazed plot; GR: grazed plot. ** = $0.001 < P < 0.01$, *** = $P < 0.001$

(*a*) Pretty Valley plots
URANOVA and MRANOVA

Species	Test for main effects			Test for interaction between Plot (GR/UG) and year	
	UGR v GR	Difference between years			
	URANOVA	URANOVA	MRANOVA	URANOVA	MRANOVA
Tussock grasses	NS	***	***	***	**
Forbs	***	**	***	NS	NS
Shrubs	***	**	***	**	***
Carex	***	NS	***	***	**
Celmisia	***	**	***	**	***
Leptorhynchos	***	NS	NS	**	**
Craspedia	***	***	***	**	***
Asterolasia	***	***	***	***	***
Grevillea	**	***	***	NS	NS

Polynomial contrasts

Effect Species	Year Function		Year v Plot Function	
	Linear	Quadratic	Linear	Quadratic
Tussock grasses	NS	NS	**	**
Forbs	***	NS	NS	NS
Shrubs	***	***	***	***
Carex	***	NS	NS	***
Celmisia	***	***	***	***
Leptorhynchos	NS	NS	***	NS
Craspedia	***	NS	***	NS
Asterolasia	***	***	***	***
Grevillea	***	NS	NS	NS

(*b*) Rocky Valley plots
URANOVA and MRANOVA

Test for main effects Species	UGR v GR URANOVA	Difference between years URANOVA	 MRANOVA	Test for interaction between Plot (GR/UG) and year URANOVA	 MRANOVA
Tussock grasses	NS	***	***	***	***
Shrubs	NS	***	***	***	***
Phebalium	NS	***	***	**	**
Grevillea	***	***	***	***	***
Prostanthera	***	***	***	***	***
Hovea	NS	***	***	**	**

Polynomial contrasts

Effect Species	Year Function Linear	 Quadratic	Year v Plot Function Linear	 Quadratic
Tussock grasses	**	***	***	***
Shrubs	***	***	**	***
Phebalium	***	***	NS	**
Grevillea	***	***	***	***
Prostanthera	***	**	***	***
Hovea	***	NS	**	NS

Appendix 3

Pretty Valley grassland and Rocky Valley open heathland plots: results from regression analysis, testing the null hypothesis (H0), that the slope of the regression line equals zero; NS: Slope not significantly different from zero; significance levels: * = $0.01 < P < 0.05$, * = $0.001 < P < 0.01$, *** = $P < 0.001$; R^2 (coefficient of determination): proportion of the total variation in pecentage cover explained by the regression line. *Poa* (*P. hiemata*), *Carex* (*C. breviculmis, C. hebes*), *Cel* (*Celmisia* spp.), *Cras* (*Craspedia* spp.), *Lep* (*Leptorhynchos squamatus*), *Grev* (*Grevillea australis*), *Ast* (*Asterolasia trymalioides*). UGR: ungrazed plot; GR: grazed plot

Pretty Valley plots

Plot		*Poa*	Forbs	Shrubs	*Carex*	*Cel*	*Cras*	*Lep*	*Grev*	*Ast*
UGR	R^2:	0.00	0.55	0.92	0.87	0.95	0.80	0.08	0.83	0.79
	H0:	NS	*	***	***	***	**	NS	**	**

Rocky Valley plots

Plot		*Poa*	Forbs	Shrubs	*Grev*	*Pheb*	*Prost*	*Orites*	*Hovea*
UGR	R^2:	0.00	0.19	0.66	0.70	0.49	0.09		0.32
	H0:	NS	NS	*	**	NS	NS		NS