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SHORT COMMUNICATION

EFFECT OF EXCLOSURE ON SOILS, BIOMASS, PLANT NUTRIENTS, AND VEGETATION, ON UNFERTILISED STEEPLANDS, UPPER WAITAKI DISTRICT, SOUTH ISLAND, NEW ZEALAND

Summary: We sampled soils and vegetation within and outside two sheep and rabbit exclosures, fenced in 1979, on steep sunny and shady slopes at 770 m altitude on seasonally-dry pastoral steeplands. The vegetation of sunny aspects was characterised by higher floristic diversity, annual species, and low plant cover. Here the exotic grass *Anthoxanthum odoratum* dominated on grazed treatments, and the exotic forb *Hieracium pilosella* on ungrazed. Shady aspects supported fewer, and almost entirely perennial, species. Here *Hieracium pilosella* dominated grazed treatments, but co-dominated with the exotic forb *H. praealtum* and the native grass *Festuca novae-zelandiae* on ungrazed treatments.

There was 43% more biomass in exclosures ($P<0.01$). Most of the biomass difference (4285 kg/ha) was from greater root mass (2400 kg/ha). 1385 kg/ha of the difference was from herbage and the remainder (500 kg/ha) from litter. Exclosures had 50 to 100% more Ca, Mg, K and P in the biomass ($P<0.05$), but the effect on soils was limited to significantly higher concentrations of total N ($P<0.05$) and exchangeable Mg ($P<0.01$) in 0-7.5 cm soils.

We conclude that stopping grazing for 16 years on seasonally-dry steeplands results in greater plant cover, approximately double the biomass of standing vegetation, greater biomass in roots, and more biomass nutrients relative to grazed areas. However, it does not favour native species and has little effect on soil nutrients or soil carbon. Stopping grazing alone therefore cannot be regarded as a comprehensive short- or medium-term vegetation or soil rehabilitation option.

Keywords: grazing; high country; biomass; nutrients; soil; rehabilitation; floristics.

Introduction

Maintaining nutrient and organic matter levels in grazed rangeland pastures is essential if the pastures, and grazing, are to be sustainable. Several temporal studies outside New Zealand have demonstrated that grazing causes measurable changes of nutrient pools and soil properties in semiarid rangeland soils (Johnston, Dormaar and Smoliak,1971; Smoliak, Dormaar and Johnston,1972; Dormaar, Smoliak and Willms, 1989; Bauer, Cole and Black, 1987; Coughenour, 1991). These papers show that the effect of grazing on soil properties varies. Animal excretion will normally increase availability of nutrients in the soil, but in hilly and steep landscapes there is strong evidence that this effect is negated by patchy redistribution of nutrients (Saggar, Mackay, Hedley, Lambert and Clark, 1988; Rowarth, Tillman, Gillingham and Gregg, 1992). On hilly and steep land in seasonally-dry South Island high country the net result of grazing, without replenishment of nutrients by fertiliser and oversowing, is topsoil nutrient decline over time (O'Connor and Harris, 1991; McIntosh, Ogle, Patterson, Aubrey, Morriss and Giddens 1996; McIntosh, 1997), accompanied by a decline in vegetation cover, and displacement of native by exotic species (Treskonova 1991), as has been demonstrated in other grasslands exposed to novel grazing by large herbivores (Milchunas and Lauenroth 1993). Although some researchers have concluded that soil nutrient pool differences between unfertilised grazed and ungrazed areas are generally insignificant (Milchunas and Lauenroth 1993) others (e.g. Frank, Tanaka, Hoffmann and Follett 1995; McIntosh, Allen and Scott 1997) have demonstrated significant differences for some nutrients. In New Zealand, Basher and Lynn (1996) attributed lack of difference between grazed and ungrazed sites in Canterbury to slow soil change, but McIntosh et al. (1997) suggested that lack of difference was due in part to indirect effects of grazing, such as soil erosion, continuing within ungrazed areas after exclosure. Wang and Ripley (1997), in semi-arid China, and McIntosh et al., who studied a site close to that investigated in this study, demonstrated an increase in root biomass in rangelands from which stock were excluded, but Coughenour (1991) found there was no effect of grazing on roots.

This study used replicated sheep- and rabbit-proof exclosures on two aspects to determine whether 16 years of no grazing on steeplands had an effect on native vegetation composition and biomass, and on plant and soil nutrient pools.

Methods

Site

The study site is on Glencairn Station, in the upper Waitaki Valley, South Island, New Zealand (latitude 44°S), on sunny and shady slopes (29-31°) of a ridge at 770 m elevation, at map reference NZMS 260 H39 835454. Mean annual rainfall is 500–600 mm. At this location droughts are common in the summer months. Soils are formed from thin loess overlying greywacke slope colluvium (McIntosh, Backholm and Smith,1981). In the New Zealand Soil Classification (Hewitt, 1992) soils are classified as Weathered Orthic Recent Soils, angular-stony (McIntosh, Lynn and Webb, 1995). In Soil Taxonomy (USDA 1994) the soils are Typic Ustochrepts, coarse-loamy, mixed, mesic. The area has been grazed by rabbits and sheep at variable intensities for about 130 years. Since 1978 the area has been grazed by sheep at the rate of about 0.6 adult animals per hectare, but there are no data for rabbit density. On both sunny and shady slopes fenced exclosures were established in 1979 and partly used for trial plots (McIntosh, Sinclair and Enright, 1985; Boswell and Swanney 1990).

Soil and vegetation sampling and preparation

Sampling for the present study was done in late spring, on 23 November 1995, and followed the strategy summarised in Table 1. At this time plants have generally reached maximum vegetative stature.The pastures were being grazed at the time of sampling. Two 10 m transects were positioned randomly within each of four exclosures (two on shady and two on sunny aspects) on areas not used for experimental plots, and in each of four adjacent grazed areas outside the trials. Cover values for plant species, litter (including standing dead tussock material), gravel, and soil were measured by point intercept (200 points per transect). Vegetation in 15 x 15 cm quadrats (5/transect) was cut at ground level and samples were separated into litter and living components (herbage), dried at 60°C and weighed. Soil cores (0-7.5 cm) were taken from the same quadrats, air-dried, and sieved through a 2 mm sieve to remove roots and stones. Samples from 7.5-25 cm depth were taken from two of the quadrats on each transect and treated the same way. Roots were separated and cleaned by successive decantings through a 0.25 mm sieve. Final cleaning was by c. 1 minute agitation in an ultrasonic bath and washing in tap water and distilled water. Herbage, litter and root samples were dried at 60°C and weighed. Subsamples of the fine earth (<2 mm) soil fraction were dried at 110°C for volume-weight determination.

Chemical analyses

Vegetation samples (herbage, litter and roots) were analysed for total nitrogen (N) by a micro-Kjeldhal method (Blakemore Searle and Daly, 1987)**.** Other total and trace elements were measured by XRF spectroscopy. The total element concentration of 0-7.5 cm and 7.5-25 cm soils was also measured by XRF spectroscopy. On the basis of the titanium content of soils and sampled herbage, litter and

Table 1: *Sampling strategy.*

Treatment	Design	Soil sampling	Vegetation sampling
Grazed by sheep and rabbits	2 x 10 m transects adjacent to each of 4 trial blocks, 2 on each aspect	*Soil samples:* 15 cm x 15 cm at 0-7.5 cm depth, 5/transect; and at 7.5-25 cm depth, 2/transect	*Herbage and litter samples*: 15 cm x 15 cm, 5/transect *Root samples*: 15 cm x 15 cm at 0-7.5 cm depth, 5/transect; and at 7.5-25 cm depth, 2/transect
Ungrazed by sheep or rabbits	2 x 10 m transects in each of 4 trial blocks, 2 on each aspect	As above	As above

roots, element concentrations in biomass were corrected for soil contamination, on the assumption that titanium content of plant tissues is generally less than 3 ppm (Underwood 1973, p. 452-453).

Soil samples were analysed by the methods of Blakemore et al. (1987), which in brief, are as follows: pH(H_2O) in water using a 1:2.5 soil:water ratio and overnight standing; pH($CaCl_2$) in 0.01*M* $CaCl_2$ solution, using a 1:2.5 soil: solution ratio; total carbon (C) using a high-frequency LECO induction furnace; total N by a micro-Kjeldahl method; acid-soluble phosphorus (Pa) by extraction with 0.5*M* H_2SO_4; acid-soluble P after ignition (Pi) by extraction with 0.5*M* H_2SO_4 after ignition of the soil at 550°C; organic P (Po) by subtraction of Pa from Pi; exchangeable cations by ammonium acetate extraction at pH 7 using a shaking method.

Analysis of variance was by the Genstat program (Lawes Agricultural Trust, 1993), based on the 2-factor orthogonal replicated nested structure outlined in Table 1. For above-ground biomass and 0-7.5 cm soils the structure was 2 aspects x 2 treatments x 2 blocks x 10 replicates. For 7.5-25 cm soils, total biomass and roots the structure was 2 aspects x 2 treatments x 2 blocks x 4 replicates.

Results

Biomass and biomass nutrients

Differences between aspects and between ungrazed and grazed treatments are shown in Figure 1 and Tables 2-3. Aspect/treatment interactions were significant ($P<0.05$) only in one instance, therefore interactions are not shown in the tabulated data.

Mean herbage, litter and root weights were all higher in the ungrazed treatment than in the grazed, and the difference was significant for the root component and for total biomass (Table 2). The ungrazed treatment had, on average, 43% more total dry matter than the grazed treatment and the greater part of the biomass difference was attributable to roots.

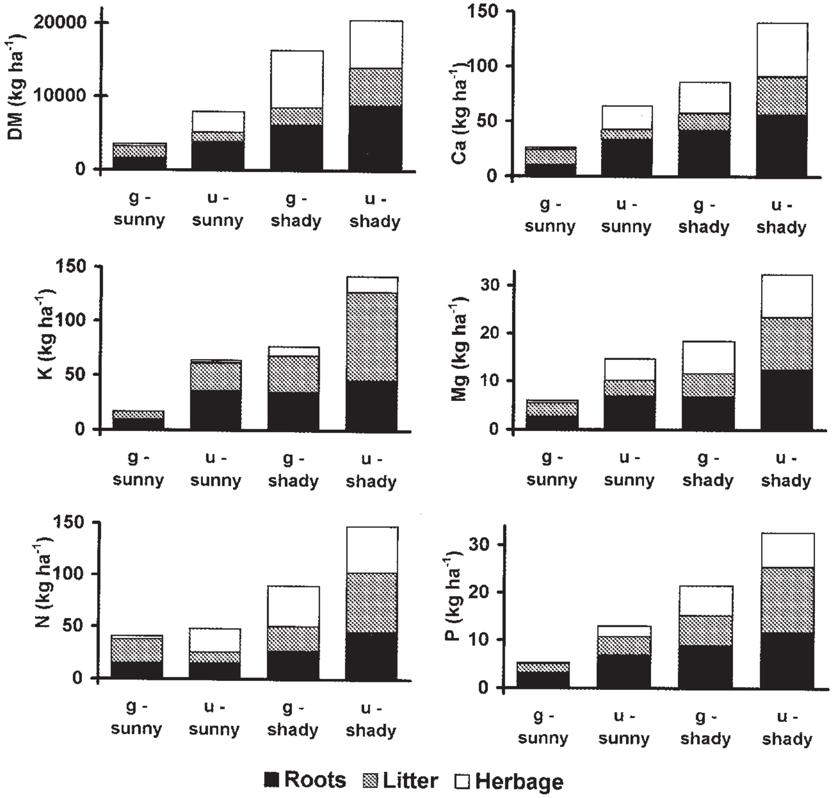

Figure 1: *Biomass and nutrients on different aspects.*

Table 2: *The effects of exclosure on biomass in herbage, litter and roots.*

Plant component	Treatment means (kg ha^{-1}) grazed	ungrazed	*s.e.*	Significance (*P*<)
Herbage	1857	3244	701	*N.S.*
Litter	4195	4693	434	*N.S.*
Roots	3900	6300	502	0.05
Total	9952	14,237	266	0.01

n = 40 for herbage and litter means; *n* = 8 for roots and total biomass means

Nutrient trends (Table 3) followed biomass trends. Mean content of Ca, Mg, K, P and N in the biomass on the ungrazed treatment was about double that on the grazed treatment. Only the N difference was not significant (*P*>0.05) in at least one plant component.

Soils

Mean measures of soil fertility (N, exchangeable Ca, Mg, K and Pi) tended to be higher in 0-7.5 cm soil in ungrazed treatments, but differences between ungrazed and grazed treatments were significant only for N and exchangeable Mg (Table 4). However, neither of these differences were significant on a weight per unit area basis (results not shown). In deeper soils no differences were significant (Table 4).

Flora

There were marked differences between the floras of sunny and shady aspects within each grazing treatment (Table 5). Sunny aspects had a more diverse flora. Ephemeral exotic annuals (e.g., *Arenaria serpyllifolia*, *Erodium cicutarium*, *Vulpia bromoides*), some exotic (*Rumex acetosella*) and native (*Convolvulus verecundus*, *Raoulia australis*) perennial herbs, and the exotic shrub *Rosa rubiginosa*,were recorded only on sunny aspects. Conversely, species largely confined to the floristically less diverse shady aspects were all perennials, and included native and exotic grasses (*Festuca novae-zelandiae*, *F. rubra*, *Poa colensoi*) and exotic herbs (*Taraxacum officinale*, *Trifolium repens*).

Floristic differences between grazed and ungrazed treatments on sunny aspects were confined to annuals and some low-statured perennial herbs and grasses, which were present only with grazing. There were no marked floristic differences between grazed and ungrazed treatments on shady aspects.

Vegetation

The vegetation of ungrazed treatments was dominated by *Hieracium pilosella* on sunny aspects, but *H. pilosella, H. praealtum* and *Festuca novae-zelandiae* were similarly important on shady aspects

Table 3: *Nutrients in herbage, litter and root biomass.*

Element	Plant component	Treatment means (kg ha^{-1}) grazed	ungrazed	*s.e.*	Significance (*P*<)
Ca	Herbage	15	22	4	*N.S.*
	Litter	15	35	3	0.05
	Roots	26	44	6	*N.S.*
Mg	Herbage	3.6	7.2	1	*N.S.*
	Litter	3.7	6.8	0.3	0.05
	Roots	4.9	9.6	0.4	0.01
K	Herbage	20	54	13	*N.S.*
	Litter	5.5	9.1	0.8	0.05
	Roots	22	40	2	0.01
P	Herbage	4.0	8.8	2.3	*N.S.*
	Litter	3.4	5.1	0.3	0.05
	Roots	6.1	9.2	0.1	0.001
N	Herbage	23	34	12.8	*N.S.*
	Litter	21	34	1	0.01
	Roots	21	30	5	*N.S.*
Ca	all biomass	56	102	5	0.05
Mg	all biomass	12	24	1	0.01
K	all biomass	48	104	12	0.05
P	all biomass	16	23	2	0.05
N	all biomass	65	98	10	*N.S.*

n = 40 for herbage and litter means; *n* = 8 for roots and total biomass means

Table 4: *Soil properties.*

Soil property	Units	Treatment means grazed	ungrazed	*s.e.*	Significance (P<)
0-7.5 cm sampling depth					
Fine earth (<2 mm)	t ha^{-1}	615	524	40	*N.S.*
Stones (>2 mm)	t ha^{-1}	283	277	37	*N.S.*
pH (H_2O)		6.12	6.03	0.08	*N.S.*
pH ($CaCl_2$)		5.61	5.47	0.15	*N.S.*
C	%	2.8	3.2	0.2	*N.S.*
N	%	0.21	0.24	0.00	0.05
C/N		13	14	0.52	*N.S.*
Exch. Ca	cmol(+) kg^{-1}	7.44	7.88	0.59	*N.S.*
Exch. Mg	cmol(+) kg^{-1}	1.56	1.90	0.02	0.01
Exch. K	cmol(+) kg^{-1}	0.89	1.01	0.13	*N.S.*
Exch. Na	cmol(+) kg^{-1}	0.03	0.03	0.05	*N.S.*
Pa	mg 100g^{-1}	39.9	39.0	0.7	*N.S.*
Pi	mg 100g^{-1}	79.7	82.4	1.7	*N.S.*
Po	mg 100g^{-1}	39.8	43.4	2.4	*N.S.*
7.5 cm - 25 cm sampling depth					
Fine earth (<2 mm)	t ha^{-1}	1479	1234	102	*N.S.*
Stones (>2 mm)	t ha^{-1}	1521	1496	366	*N.S.*
pH (H_2O)		6.11	6.16	0.12	*N.S.*
pH ($CaCl_2$)		5.68	5.50	0.10	*N.S.*
C	%	1.81	1.89	0.11	*N.S.*
N	%	0.15	0.15	0.01	*N.S.*
C/N		12.1	12.1	0.4	*N.S.*
Exch. Ca	cmol(+) kg^{-1}	6.69	6.53	0.75	*N.S.*
Exch. Mg	cmol(+) kg^{-1}	1.31	1.36	0.03	*N.S.*
Exch. K	cmol(+) kg^{-1}	0.66	0.80	0.07	*N.S.*
Exch. Na	cmol(+) kg^{-1}	0.03	0.05	0.01	*N.S.*
Pa	mg 100g^{-1}	30.4	28.9	1.5	*N.S.*
Pi	mg 100g^{-1}	72.4	71.5	2.7	*N.S.*
Po	mg 100g^{-1}	42.0	42.6	2.8	*N.S.*

n = 40 for 0 - 7.5 cm sampling depth; *n* = 8 for 7.5 - 25 cm sampling depth

(Fig. 2a). *Poa colensoi* and *Anthoxanthum odoratum* contributed less of the cover on both sunny and shady aspects. All other species had <5% cover in all treatments. There was almost no bare ground in ungrazed shady treatments, where mean litter cover was relatively high (Fig. 2b), but bare soil and gravel were almost as important as litter in ungrazed sunny treatments.

Anthoxanthum odoratum was the dominant plant of grazed treatments on sunny aspects (Fig. 2a), where bare soil and gravel provided most of the ground cover and *Hieracium pilosella* was almost absent (Fig. 2b). *Hieracium pilosella* provided most plant cover on grazed shady aspects, with smaller contributions from *Festuca novae-zelandiae* and *A. odoratum,* and little *Poa colensoi* or *Hieracium praealtum*. Here bare ground was rare, and litter cover was similar to that of the ungrazed shady treatments.

Discussion

The 43% greater biomass (Table 2) and higher biomass nutrient content for all elements except nitrogen (Table 3) in the ungrazed treatments indicates that when grazing is stopped, nutrient conservation is first expressed in plants rather than in soils. We use the term "conservation" since grazing in the unfertilised New Zealand high country is associated with nutrient loss (O'Connor and Harris 1991; McIntosh 1997), therefore the apparent gain of biomass nutrients on the imposed treatment (the exclosures) is more likely to be a result of

Table 5: *Flora of vascular plant species present (+) in sunny grazed, sunny ungrazed, shady grazed, and shady ungrazed treatments. Native species are denoted by *.*

	sunny grazed	sunny ungrazed	shady grazed	shady ungrazed
Agrostis capillaris	+			
Anthoxanthum odoratum	+	+	+	+
Arenaria serpyllifolia	+			
*Carex breviculmis**		+		
*Convolvulus vericundis**	+			
*Dichondra repens**		+		
Erodium cicutarium	+			
*Festuca novae-zelandiae**			+	+
Festuca rubra			+	
*Geranium microphyllum**	+			
Hieracium pilosella	+	+	+	+
Hieracium praealtum		+	+	+
Hypochoeris radicata	+	+	+	+
Leontodon taraxacoides	+			
*Muelenbeckia complexa**	+	+		
Myosotis discolor	+		+	
*Olearia odorata**			+	
*Oxalis exilis**	+			
*Poa cita**	+	+		
*Poa colensoi**	+	+	+	+
*Poa pratensis**				+
*Raoulia australis**	+	+		
Rosa rubiginosa	+	+		
Rumex acetosella	+	+		
*Rytidosperma sp.**	+	+		
Taraxacum officinale			+	+
Trifolium arvense	+	+		
Trifolium dubium		+		
Trifolium pratense				+
Trifolium repens			+	+
Vulpia bromoides	+			
*Wahlenbergia gracilis**	+	+	+	+

conservation of nutrients rather than increase relative to grazed areas.The 62% greater root mass of plants, and the substantially different proportions of species present, in ungrazed areas, demonstrate that the effects noted are more than transitory effects resulting from recent grazing prior to sampling. The results support previous observations both overseas (e.g., Marrs, Rizand, and Harrison 1989) and in New Zealand (Basher and Lynn 1996; McIntosh et al. 1997) that rates of change of soil properties following cessation of grazing are very slow, presumably because, in the absence of fast weathering or parent material inputs (e.g. loess accumulation) the total nutrient pool is relatively constant and plants take up most surplus nutrients. In addition, in dry areas, carbon accumulation may take several decades before being detectable (Burke, Lauenroth and Coffin, 1995; Parshotam and Hewitt, 1995).

The cessation of grazing for 15 years resulted in little change in the diversity or abundance of the dominant native grasses and forbs, although there were increases in the cover of major perennial exotic species. This is to be expected, given that perennial species, and tussock grasses in particular, are more likely to decline under grazing than are other life forms and annuals, and that species without a long evolutionary history of grazing are particularly vulnerable to herbivory (Milchunas, Sala and Lauenroth 1988). Similar patterns of vegetation change have been recorded following exclusion of grazing elsewhere in the inland basins of South Island. For example, Allen, Wilson and Mason (1995) observed a trend towards perennial species and vegetation stability after 6 years' grazing exclusion in semi-arid Central Otago, but could not attribute this directly to cessation of grazing rather than to unspecified endogenous trends. On the sunny steepland site studied in this paper greater *H. pilosella* cover in ungrazed areas than in grazed areas, combined with the higher incidence of surface gravel in the grazed treatment, suggest that physical disturbance of the grazed sunny steeplands and/or erosion may create an unfavourable site for *Hieracium pilosella* establishment. Rose, Platt and Frampton (1995) also observed that protection from grazing did not prevent an increase in *Hieracium pilosella* cover in mesic montane South Island grasslands. They concluded that this observation could not be explained either by the hypothesis that *H. pilosella* is an aggressive weed ideally suited to this grassland environment (e.g., Scott 1985), or the hypothesis that depletion of the environment by pastoral farming has been so severe that *H. pilosella* has little competition, even in the absence of grazing (e.g., Treskonova 1991). We agree with Rose *et al.* (1995) that a better understanding of the mechanisms of species replacement in this environment is a prerequisite to a satisfactory explanation of vegetation change in the absence of grazing.

This study provides only a "snapshot" of nutrient pools in the late spring. Further work is required on seasonal change in nutrient pools, and fluxes between pools, so that mechanisms of nutrient gain and loss can be better understood.

Conclusions

Sixteen years' freedom from grazing in these seasonally-dry steeplands resulted in increased plant cover, an approximate doubling of standing above-ground biomass and nutrients, and a 62% greater

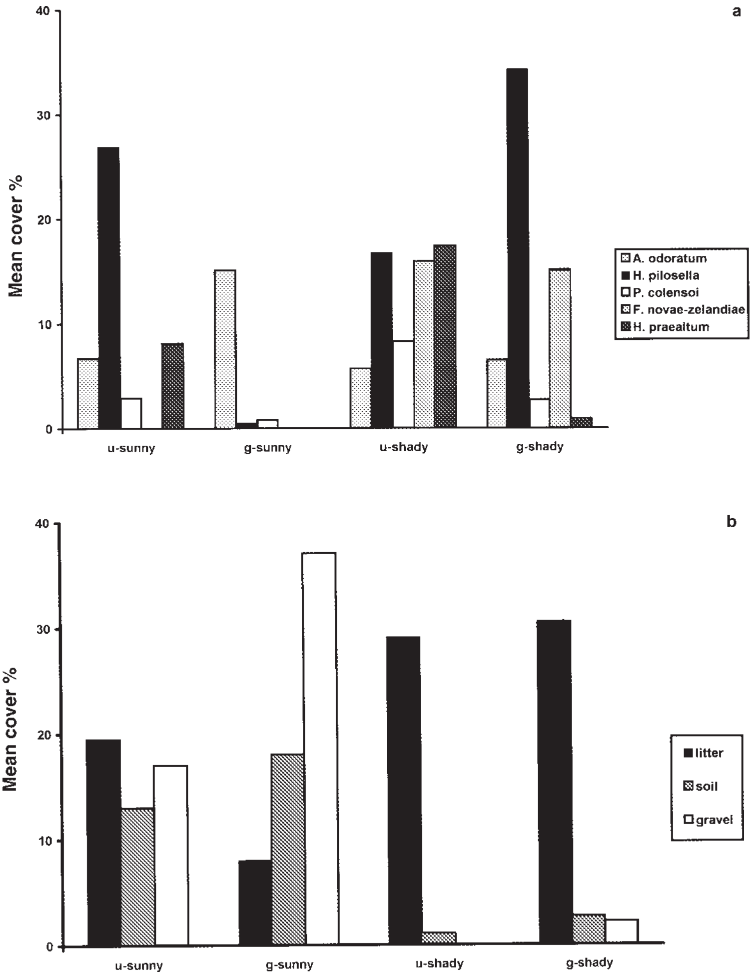

Figure 2*: a) Mean cover of dominant plant species on ungrazed and grazed sunny and shady aspects. b). Mean cover of litter (including standing dead tussock material), bare soil (particle size <3mm), and bare gravel (particle size >3mm), on ungrazed and grazed sunny and shady aspects.*

root biomass relative to grazed areas. However, it has not favoured the native flora, and has had little effect on soil nutrients or soil carbon. Stopping grazing alone therefore cannot be regarded as a comprehensive short- or medium-term vegetation or soil rehabilitation option in this environment.

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