Grassland structure in native pastures: links to soil surface condition

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Sue McIntyre (GPO Box 284, Canberra, ACT 2601, Australia. Tel. 61-2 6242 1604. Fax. 61-2 6242 1565. Email: Sue.Mcintyre@csiro.au) and David Tongway (GPO Box 284, Canberra, ACT 2601, Australia. Tel. 61-2 6242 1641. Fax. 61-2 6242 1565) are from CSIRO Sustainable Ecosystems. This work was part of a longer-term study identifying the practices associated with ecological sustainability of grazing enterprises. Detailed research has focused on how management affects patterns of plant diversity in the subtropical grassy woodlands of southern Queensland. Here, they examine how well the appearance of a patch of grassland can predict its ecological health.

Summary When grassland is grazed by livestock, the structure of the sward changes in a patchy manner. With continuous selective grazing there is a mosaic of short and tall patches but as grazing intensifies the area of short-grazed patch increases until the paddock has a lawn-like appearance. This mosaic of patch structures can be stable, as short patches tend to attract repeated grazing and tall patches tend to be avoided. Because heavy grazing can detrimentally affect soil and water functions in grassland (ultimately resulting in erosion), we aimed to assess how well the physical structure of the sward reflects soil surface condition. We described four grassland patch structures that were assumed to reflect different levels of present grazing, and to some extent, past grazing pressure. We assessed patch structure and two other grass-related variables (basal area of a 'large tussock' functional group and basal area of all perennial grass) as possible indicators of soil surface condition. Three indices of condition were measured in the field. The infiltration and nutrient cycling index declined progressively across patch structures, consistent with increasing grazing pressure. The stability index was found to be reduced only for the most heavily grazed grass structure (short patches). We found the 'large tussock' grass functional group to be a more sensitive indicator of soil surface condition than the group consisting of all perennial grasses. We found no evidence of sudden soil surface condition decline beyond a certain level of grass basal area, that is, there was no evidence of thresholds, rather, incremental loss of condition accompanied grass decline. We are thus not able to further refine an earlier proposed management recommendation 'Graze conservatively to maintain dominance of large and medium tussock grasses over 60–70% of the native pastures', except to suggest the use of short patches as a more practical indicator, rephrasing the recommendation as 'Graze conservatively to allow a maximum of 30% short-grazed patches in native pastures'.

Key words *ecological thresholds, grassland, grazing, Landscape Function Analysis, sustainability.*

Introduction

Selective choices of forage by domestic livestock in grassland result in a sward containing areas of varying height. Patches of closely-grazed pasture are often the result of minor initial preferences being perpetuated (Spedding 1971). The term 'patch grazing' refers to the phenomenon whereby small areas of intense defoliation enter a positive feedback loop of repeated heavy grazing as herbivores are attracted to the nutritious green foliage that rapidly resprouts after defoliation (Stuth 1991). Over time, this process will lead to the short patches having changed plant composition with low-growing, grazing-tolerant plants becoming more abundant (Stuth 1991; McIntyre *et al*. 2003).

As short patches generally represent the most heavily grazed parts of paddocks, the symptoms of overgrazing should be most evident in these areas. Symptoms include plant mortality and erosion (Ash *et al*. 1997), reduced fertility and water holding capacity (Dormaar & Willms 1998), and fewer large tussock grasses, leading to reduced soil carbon and nitrogen pool sizes (Derner *et al*. 1997). As total grazing pressure increases in a particular paddock, the proportion of short patch within the pasture increases. If short patches are sufficiently overgrazed, another positive feedback loop can be created between deteriorating soil conditions and the further decline of plant growth under the pressure of continuing livestock impacts (Thurow 1991; McIvor *et al*. 1995).

Using this understanding of grazing effects, an indicator and threshold of pasture use was identified by McIntyre *et al*. (2000) and further discussed in McIvor (2002). The recommendation was to 'Graze conservatively to maintain dominance of large and medium tussock grasses over 60–70% of the native pastures'. The proposed threshold is hypothetical and based on a number of considerations: (i) a compromise between maximizing livestock production and leaving sufficient biomass to support critical soil and vegetation processes; (ii) providing areas of lenient grazing within pastures for the persistence of grazing-sensitive plants; and (iii) providing a range of grassland structures as habitat for grassland invertebrates, and ground dwelling and feeding vertebrates.

The use of the term 'threshold' implies that there will be a maximum level of grazing beyond which there will be a rapid decline in at least one index of grassland health. A key component of the reasoning behind the proposed threshold is the high level of connectivity that is provided to the landscape when 60–70% of habitat is retained. Assuming that areas of large and medium tussock (tall patches) support biota that do not persist in heavily-grazed patches, this proportion should prevent small-scale fragmentation of habitat for organisms with low levels of mobility (McIntyre *et al*. 2000). It should also maintain important soil-water processes by providing connectivity in high quality grass cover as well, although this has not been tested.

In this paper we explore the proposed threshold by reporting on field measurements of subtropical grasslands in southern Queensland. The specific aims of this paper are to: (i) sample patch types that are evident to the casual observer in terms of variation in sward height. Characterize these patch types in terms of structure, and the abundance of large tussocks and other grasses; (ii) characterize patch types using three indicators of soil surface condition (stability, nutrient cycling and infiltration) as used in Landscape Function Analysis (Tongway & Hindley 2000); (iii) compare various potential indicators in terms of their relationship to soil condition indices and their ease of use by managers in the field; and (iv) assess the proposed threshold of grassland use in terms of soil surface condition.

Methods

The study area

The survey was conducted in the Brisbane River catchment, in the Crows Nest district. The sample area was bounded by 27–28°S and 151–153°E. The climate is subtropical with most of the 800 mm of rain falling in summer, and frosts occurring between May and September. Much of the landscape is grassy eucalypt woodland used for cattle grazing. The understorey is unfertilized, mainly native grasses and herbs. The density of trees has been modified to maintain open areas, clumps and scattered trees. More details of the study area are in McIntyre & Martin (2002).

Field sampling of patch types

In total, 52 patches were sampled using transects 20 m long which were located to cover a relatively uniform patch type (tall, intermediate, short) within native pastures. Patch types were selected by eye as a casual observer might identify them. This was done by identifying two extremes of height within pastures, and recognizing an intermediate height class. This sampling enabled us to test whether informal observations of patch height were able to be correlated with differences in soil surface condition. Tall patches were also sampled in areas not grazed by livestock. These were the tallest uniform patches of native grass found on roadsides or in reserves. The 52 samples consisted of the following: 'tall-ungrazed', $n = 9$; 'tall-grazed', $n = 16$; 'intermediate (grazed)', $n = 10$; 'short (grazed)', $n = 17$; and these are the names used for these 'treatments' in the rest of the paper.

We sampled the major geological substrates occurring in the study area (metamorphic, sandstone and granite) but as there were no effects of lithology on soil condition indices this variable is not discussed further. The influence of trees was generally avoided in the placement of transects in pastures but could not be avoided in the ungrazed samples, where trees were more evenly distributed. We also generally avoided sites that had a known history of, or evidence of, recent burning (i.e. in the previous 12 months). Nonetheless, amongst the 43 patches sampled within paddocks, four had been recently burnt and six had some influence of tree canopies.

Perennial grass basal areas

Basal area and density of all perennial grasses and sedges was measured at 1 m intervals along the transects, providing 20 estimates per patch. A point centred quarter method was used after Bonham (1989). This is a distance measuring, plotless procedure that provides unbiased density data in dense swards. Only plants with basal diameters of > 0.5 cm were measured.

Large tussock functional group: definition and measurement

We identified a subset of perennial plants that might be more sensitive to pasture condition than the group 'all perennial grasses' described above. Previous studies have shown that species with the following traits are likely to be more sensitive to grazing (McIntyre & Lavorel 2001): height (> 20 cm); width (26–100 cm); and low plasticity (i.e. plants that do not markedly change in tiller orientation or growth form under heavy grazing). The species list used to identify the group was derived from a previous survey (McIntyre *et al*. 2002) and the traits that we used in defining this functional group were: (i) native; (ii) perennial; (iii) tussock growth form; (iv) low plasticity (remove species that change form under-grazing, e.g. tillers angled close to ground, reduced, prostrate infloresences); and (v) height and width of ungrazed plants as described above;

A total of 20 species were classified as 'large tussock': *Alloteropsis semialata*, *Aristida queenslandica*, *Aristida ramosa*, *Aristida vagans*, *Aristida calycina*, *Aristida caput-medusae*, *Austrostipa verticellata*, *Bothriochloa bladhii*, *Capillipedium parviflorum*, *Capillipedium spicigerum*, *Chloris ventricosa*, *Cymbopogon refractus*, *Elymus multiflorus*, *Hyparrhenia filipendula*, *Imperata cylindrica*, *Poa sieberiana*, *Sorghum leiocladum*, *Themeda triandra.* We included two non-grass groups, *Dianella* spp. and *Lomandra* spp., based on the similar morphology and grazing responses to other large tussock species, especially in relation to plasticity.

For each of the 52 samples, we measured 'large tussock' basal area at the same points on the transect as for perennial basal area (1 m intervals). Basal area was measured by recording the diameter of all plants > 0.5 cm in diameter in a quadrat 0.5 m × 0.5 m at each point.

Indices of soil surface condition

For each of the 52 samples, 11 indicators of soil surface condition were visually assessed on five replicate 1 m transects at regular intervals on the patch. Each indicator examines the status of a specific surface process and is assessed as described in Tongway and Hindley (2000). Three indices reflecting the emergent soil properties of stability, infiltration and nutrient cycling were derived by compiling subsets of these 11 indicators (Table 1). Their values are expressed as a proportion of a total maximum score, converted to a percentage.

Table 1 Eleven indicators and their use in the calculation of three resource control indices used in this study

Resource control index			Indicator
Stability	Infiltration	Nutrient cycling	
X			1. Soil cover
	X	X	2. Basal area of all perennial grasses (including large tussock species)
X	X		3a. Litter cover
		X	3b. Litter cover, origin, degree of decomposition
X		X	4. Cryptogam cover
X			5. Crust brokenness
X			6. Erosion type and severity
X			7. Deposited materials
	X	X	8. Micro-topography
X	X		9. Surface resistance to disturbance
X	X		10. Slake test
	X		11. Soil texture

X, the use of an indicator in calculating the index.

Illustrating patch structure

To illustrate the structure of the patch types we measured basal diameter, crown diameter, crown height, and crown and basal separation ratio. We used the plotless zig-zag transect method outlined in McDonald *et al.* (1990) to obtain a measure of plant density. Measurements were taken along the transect until 20 'large tussock' and 20 'all perennial tussocks' had been measured. For each of the four patch types (tall-ungrazed, tall-grazed, intermediate, short), we collected data from two to six transects. We illustrated one transect for each patch type, the selection being based on the closest match of the transect to the average perennial and large tussock basal for each patch type.

Data analysis

Characterization of patches

The four patch types were characterized by averaging large tussock and perennial grass basal areas and each of the three condition indices. Means were compared using the Tukey–Kramer test (Zar 1984) performed with the software SAS version 8.2 (SAS Institute Inc., Cary, NC, USA).

Testing for thresholds of basal area within transects

Average basal areas of patches were plotted against each of the three soil surface condition indices. This was done for both the large tussock and perennial grass data. Relationships were explored by fitting regression lines to the data. Consistently better r^2 values were obtained when the basal area data were square-root transformed.

Testing for thresholds of short patch proportion within transects

Although the transects were placed to represent uniform examples of patch types, there is always variation in height and basal area within them. This could be used to assess the proportion of short patch within each transect independently of its original label (intermediate, short etc).

Proportion of short patch was derived by determining the number of 20 (0.5 m × 0.5 m) quadrats within each transect that were 'short' or 'not short'. Unfortunately, we had not made a visual assessment of the structural patch types for individual quadrats. Instead, we used basal area of large tussock species as a surrogate to identify 'short patch' quadrats using the following steps:

- We used the 'short' and 'intermediate' samples to identify average basal area of large tussock species for short patches (mean, 33; SD, 30; $n = 17$) and intermediate patches (mean, 134 cm^2/m^2; SD, 109; $n = 10$)
- The mid point of where the standard deviations overlapped was defined as the upper limit for short patches. Short patches were defined as areas with < 44 cm^2/m^2 basal area of large tussock species
- Each of the 20 quadrats (0.5 m × 0.5 m) making up the individual patch samples were classed as short patch or not according to the criteria in the second bullet point above
- Patches (i.e. transects, ignoring their original patch type labels) where then described in terms of the proportion of short patches they contained (as indicated by the proportion of their 20 quadrats classed as short)
- The proportion of short patches in each transect was plotted against the average values for the three condition indices of each transect.

Results

Structure of patches

Figure 1 shows how livestock grazing alters the morphological structure of the grassland. The tall-ungrazed patch (Fig. 1a) has a low density of large plants with overlapping crowns. Typically, there is a thick litter layer (not shown) if the patch is unburnt. Within the pastures, the plants become progressively smaller as areas become more closely grazed. However, total basal area and plant densities are highest in the tall-grazed and intermediate patches (Fig. 1b,c) as the 'large' tussock spp. are progressively displaced by smaller perennial species such

a) Tall - ungrazed

Crown height (cm)	43
Crown width (cm)	64
Crown separation ratio	−0.3
Crown gap (cm)	−21
Basal width (cm)	15
Basal separation ratio	2.5
Basal gap (cm)	37
Basal area (cm m^{-2})	650

b) Tall - grazed

Crown height (cm)	12
Crown width (cm)	9.9
Crown separation ratio	0.02
Crown gap (cm)	0.1
Basal width (cm)	2.9
Basal separation ratio	1.9
Basal gap (cm)	5.5
Basal area (cm m^{-2})	960

c) Intermediate

Crown height (cm)	7.3
Crown width (cm)	6.9
Crown separation ratio	−0.03
Crown gap (cm)	−0.2
Basal width (cm)	2.1
Basal separation ratio	2.3
Basal gap (cm)	5
Basal area (cm m^{-2})	730

d) Short

Crown height (cm)	5.3
Crown width (cm)	5.9
Crown separation ratio	1.6
Crown gap (cm)	9.6
Basal width (cm)	1.9
Basal separation ratio	6.8
Basal gap (cm)	13
Basal area (cm m^{-2})	130

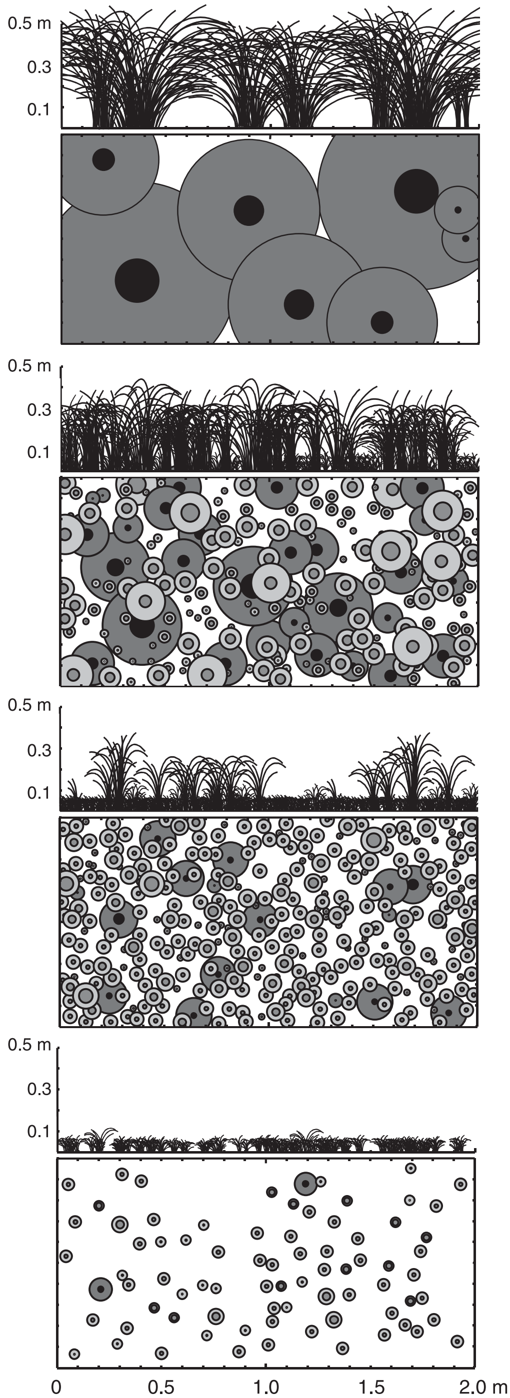

Figure 1. Maps (1 m × 2 m) and belt transects of four patch types illustrating size and density of 'large' tussocks (black basal areas, dark grey crown areas) and the other perennial grasses (lighter-shaded). Drawings are depictions of the data given in the accompanying boxes and represent typical examples of actual patches in the field. Data listed in the figure represent all perennial grass (including 'large' tussocks) for the particular patch illustrated.

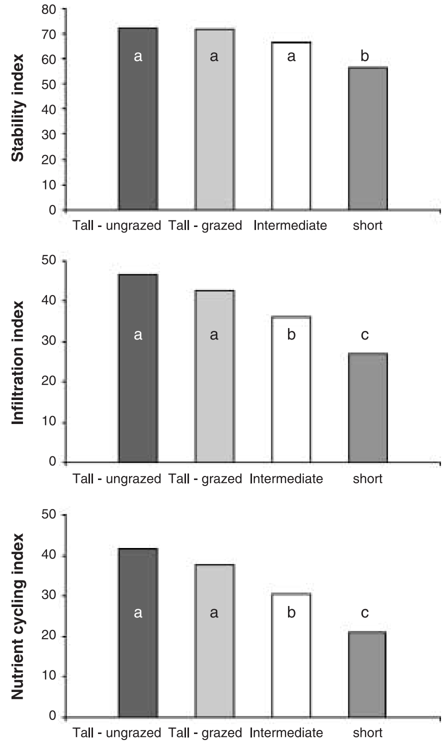

Figure 2. Characterization of patch types in terms of three soil surface condition indices (nutrient cycling, infiltration, stability). In this data set, the patches were classified visually in the field. [Bars with different letters are significantly different ($P < 0.05$).]

as *Bothriochloa* spp., *Paspalidium* spp., *Sporobolus creber* and *Eremochloa bimaculata*. Variation in plant size is also greater in the tall-grazed and intermediate patches. In the tall-grazed patch, although the sward height appears to be 30–40 cm high, the large number of small plants between the 'large' tussocks reduces the overall average height to 12 cm (Fig. 1b). In the intermediate patch, the 'large' tussock species appear as emergents over the dense, shorter sward (Fig. 1c). These tend to be the less preferred species (*Cymbopogon refractus* and particularly *Aristida ramosa*). The short sward (Fig. 1d) is relatively even in height, and the less preferred species are more heavily grazed, fewer in number and smaller.

Characterization of patches

For each of the three soil surface condition indices, there were significant differences between some of the patch types (Fig. 2). In all cases, tall-ungrazed patches had significantly higher values compared to short patches. In terms of the index of stability, averages for patch types were very high, with only short patches having a small but significant reduction in this index. Both the infiltration and nutrient cycling index values declined progressively in patches that were increasingly closely grazed. The basal areas of large tussock species declined

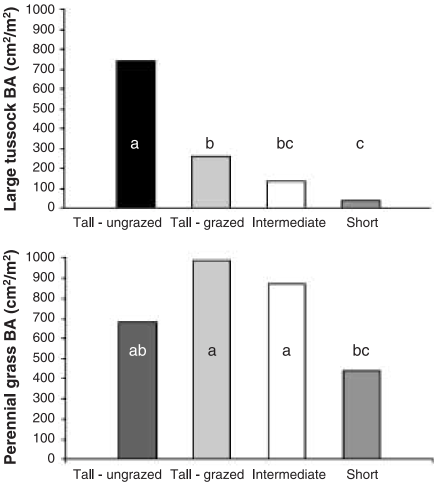

Figure 3. Characterization of four patch types in terms of large tussock basal area and perennial grass basal area. In this data set, the patches were classified visually in the field. [Bars with different letters are significantly different ($P < 0.05$).]

dramatically moving from ungrazed areas into pasture, and continued to decline in patches that were increasingly closely grazed within pastures (Fig. 3). In contrast, basal area of all perennial grasses was similar at the extremes of grazing, with highest basal areas in the tall-grazed and intermediate patch types.

Testing for thresholds of basal area within transects

We used linear regressions to plot basal area of the 'large tussock' group and all perennial grasses against the indices of soil surface condition, ignoring the patch type classification of individual transects. Our exploration of the data indicated that the basal area of the 'large tussock' group was a generally better predictor of stability, infiltration and nutrient cycling than were perennial grasses. However, two factors i) the presence of trees in paddocks and ii) the recent occurrence of fire at the sites, reduced the predictability of site condition for basal area for 'large tussocks' but not for perennial grasses. We, therefore, removed 14 sites that had been affected by these two factors from the data set and used the remaining 38 sites to look for response thresholds (Fig. 4). For perennial grasses, slightly better r^2 values were obtained when a power curve was fitted to these data, compared with linear regressions. This is consistent with the fact that the large tussocks generally disappear before the pasture has reached its lowest levels of resource control, resulting in an interception of the regression line with the Y axis. However, r^2 values were still very low for perennial grasses and there is no strong indication of a threshold except towards the very end of the degradation gradient.

Testing for thresholds of short patch proportion within transects

Figure 5 illustrates the relationship between the proportion of short patches within transects and the averages of condition indices for transects. It is evident that in all three cases, the responses are linear and there is no indication of thresholds in the sense of a critical amount of short patch above which condition declines dramatically. Our originally hypothesized threshold of minimum of 60–70% large and medium tussock dominance, can be interpreted from these data to be a maximum of 30–40% short patch. This putative threshold is indicated with dotted lines in Fig. 5. The letters depict the original visual assessment of the patch structure attributed to the transects before sampling are superimposed on the data points. Although the tall, short and intermediate sites broadly occupy the appropriate sections of the gradient (expressed as proportion of short patch) there is variation, with some short patch sites appearing to have only a small percentage of short patch and some tall patch sites appearing to have a large amount of short patch. We attribute this variation to there being some short-grazed patches containing recently grazed-down large tussocks and some tall patches that have very low basal areas of large tussock species, that is, grazing history being inconsistent with current grazing pressure.

Discussion

Assumptions about patch types and grazing intensity

Our assumption is that patches of different heights reflect the effects of livestock grazing rather than variation in soil conditions restricting plant heights. Evidence for this assumption is (i) that grass swards in areas without livestock grazing are greater than 10 cm and relatively uniform in height; and (ii) while the height of the short patches sampled were well under 10 cm in the otherwise uniform-grazed areas, the grasses that dominate them (*Bothriochloa macra*, *Eragrostis cumingii*, *Heteropogon contortus*, *Chloris divaricata and Dichanthium sericeum*; see McIntyre *et al*. 2003) grow to heights above 10 cm. Consistent with this assumption, is that the height of the sward reflects the degree of closeness at which livestock have recently been grazing the pasture. A survey of species composition in these patch types suggests that sward height also broadly reflects a difference in grazing pressure in previous years or decades (McIntyre *et al*. 2003). This is plausible, as the native pastures have been consistently stocked by cattle over the twentieth century.

Structural and floristic attributes of patch types

Conceptual models of grassland change under heavy livestock grazing in northern Australia emphasize the decline in large palatable perennial grasses and their replacement by annual grasses under heavy grazing (McIvor & Scanlan 1994). However, the subtropical grasslands in this study demonstrate a remarkable persistence of perennial grass. Perennial basal area in the short patches was not significantly different from that in tall-ungrazed patches (Fig. 3), even though there are differences in soil surface condition. The dominance of perennials is reflected in the small number of native annual species recorded in a survey in the study area, and their low frequency. Five of the six native annual species recorded in the study area had a frequency of ≤ 4% in native pastures (McIntyre *et al*. 2002). While there are some floristic trends for annual grasses and forbs to increase under grazing, we found even closely-grazed patches to be dominated by perennials. We have no explanation for this observation, which is inconsistent with tropical grassland systems.

The large tussock functional group, which was defined primarily by morphology, appeared most sensitive (as expressed through decline in basal area; Fig. 3) to the transition from no grazing (tall-ungrazed) to

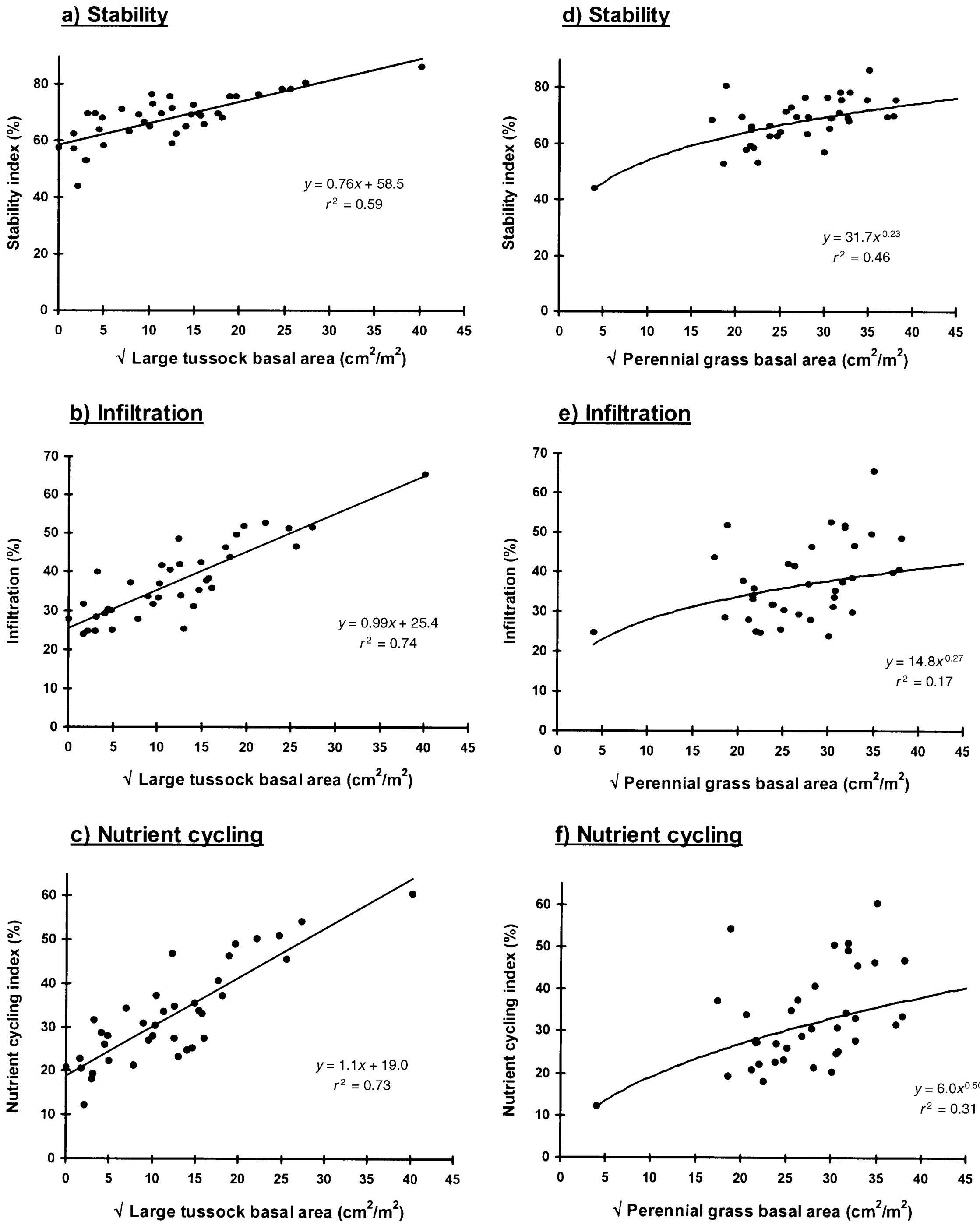

Figure 4. Plots of resource control indices against (a–c) basal areas of large tussock grasses and (d–f) perennial grasses. Data are plotted for all sites except pasture sites with trees and recently burnt sites (n = 38).

selective grazing within pasture (tall-grazed patches). In contrast, the group encompassing all perennial grasses was relatively insensitive to grazing across the patch types. The progression of change under the different patches is illustrated in Fig. 1 and suggests that some grazing (e.g. in the tall-grazed patches) opens up the grass canopy of large tussock species and enables more large tussock and interstitial perennial grass species to co-occur. With closer grazing (intermediate patches), large tussock species are reduced in size and number, while the density of interstitial grasses increases. Where grazing is closest to the ground (short patches), only the least preferred (e.g. *Aristida*) large species persist in a grazed state, while the density of other perennials is lowest.

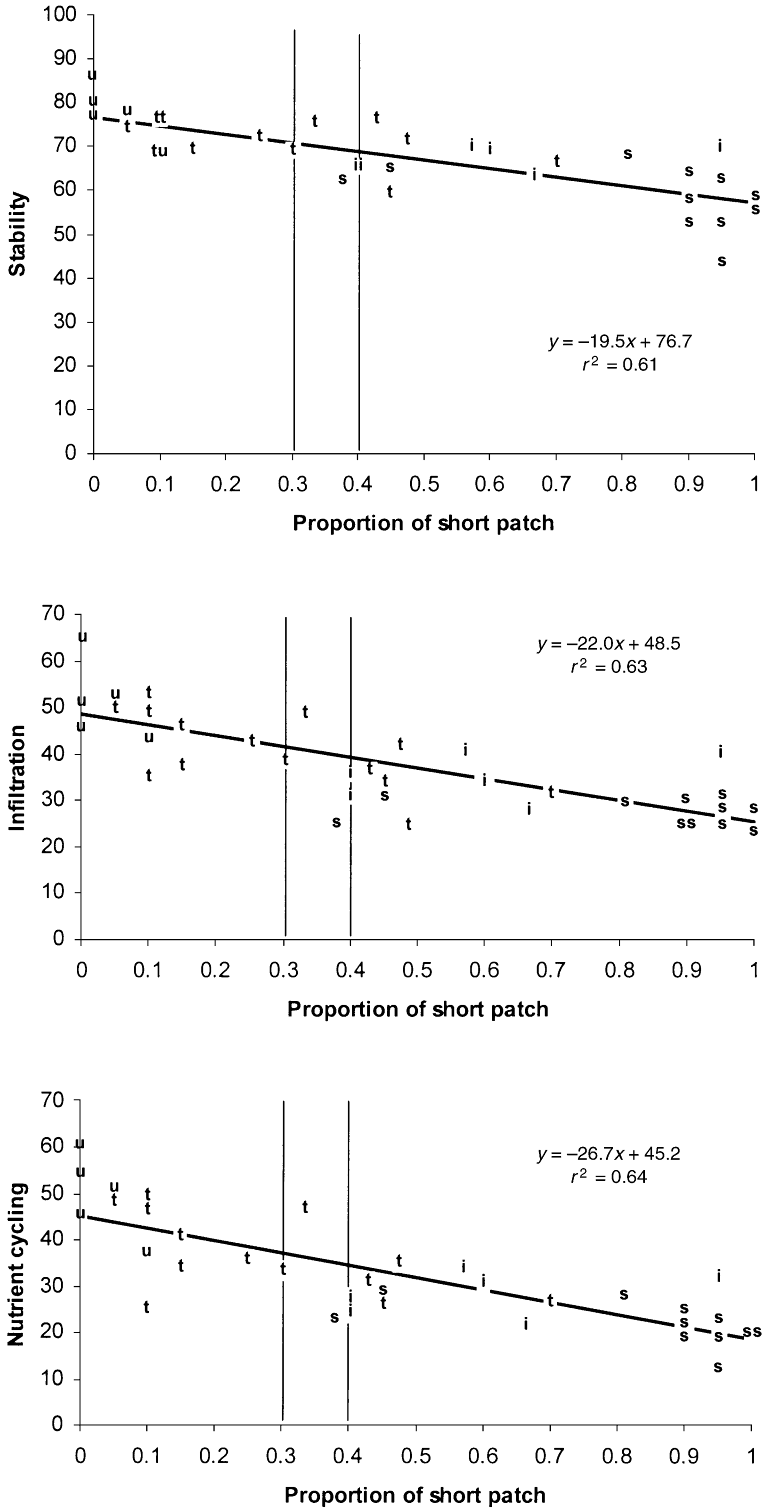

Figure 5. Relationship between the proportion of short tussock quadrats in each transect against the three indices (nutrient cycling, infiltration, stability). Data are plotted for all sites except pasture sites with trees and recently burnt sites. In this analysis, transects were plotted on the basis of the basal area of large tussock grasses in 20, 1 m^2 quadrats, as determined from the data in Figs 2 and 3 (see also methods). Vertical represent the hypothesized threshold of short patch. Letters depict the original visual classification of the transect prior to sampling as short (s), intermediate (i), tall-grazed (t), tall-ungrazed (u).

Patch types and soil surface condition

The soil surface condition indices represent surrogates for, not direct measurements of, stability, infiltration and nutrient cycling. Although Landscape Function Analysis (Tongway & Hindley 2000) is widely used for monitoring land condition, verification data are yet to be published, presenting some problems for their use. Nonetheless, the trend was for patches to decline in condition with decreases in patch height (Fig. 2). Stability, infiltration and nutrient cycling indices all showed this trend. The patch type that was most differentiated in terms of soil surface condition was the short patch. Infiltration and nutrient cycling declined over the four patch types, but soil stability was remarkably resistant to change and only declined significantly when the sward was very closely grazed (short patches).

Indicators of soil surface condition

Further indication of the weak relationship between the soil surface condition indices and perennial grass basal area is provided in Fig. 4d–f, where the r^2 values range from 0.19 to 0.36. Large tussock species seem to be a better predictor of soil surface condition in all three cases with r^2 values ranging from 0.59 to 0.74. Our data suggested that neither 'large' or 'all perennial' grass basal areas are a particularly good indicator of condition when recently burnt sites and sites with tree influences are included in the sample. Fire appears to at least temporarily result in an underestimation of condition, due to the loss of plant litter as an indicator. Allowing accumulation of litter for at least one growing season after burning would appear to be prudent when using the soil indicators in these landscapes.The effect of trees is difficult to determine from the data but field observations suggest that the presence of leaf and woody litter from adjacent trees would contribute to higher levels of surface condition.

We explored an alternative indicator of condition – the proportion of short patch in the pasture measured at the 1 m^2 scale. Regressions of the three condition indices produced r^2 values close to, or slightly less than, that obtained using large tussock basal area as an indicator (Figs 4 and 5).

The results show that regardless of the indicator used (large tussock, perennial grasses, short patch), the relationship with the condition indices is linear. In our data set, there was no evidence of a threshold response, that is, a level of an indicator beyond which the soil surface condition declines rapidly but this doesn't mean degradation is not occurring nor that a point-based limit should not be identified for managers. The only indicator for which values of zero were not recorded was perennial grass basal area – even the most degraded sites had some perennial grass cover.

A practical indicator for field assessment of grassland condition

Although the large tussock basal area proved to be the best indicator of soil surface condition in grasslands, its use in the field has the following problems: i) field measurement of basal areas is time-consuming and unlikely to be adopted by managers; ii) identification of all large tussock species is difficult; and iii) the species of the large tussock functional group will vary between regions.

Instead, we suggest 'proportion of short patch' as an alternative indicator as it can be identified readily by height of swards, whereas it is harder to discriminate between tall-grazed and intermediate patches. Also, short patches are associated with distinctly lower levels of stability and infiltration (Fig. 2). This study and published measurements (McIntyre *et al*. 2003) suggest that short patches can be defined as areas in which the majority of the sward has a height of less than 10 cm.

A threshold of grassland use?

We conclude that: (i) soil surface condition declines when native grasslands become increasingly impacted by livestock; (ii) indicators of this decline include the basal area of the 'large tussock' functional group and patch structure, as indicated by sward height; (iii) the amount of short patch is suggested as the most useful and practical field indicator; and (iv) across the range of grazing impact that we observed, there was no evidence of a level of livestock use beyond which soil surface condition rapidly declined (i.e. no threshold).

Examining the evidence, there seems, therefore, to be little reason to change the earlier proposed recommendation to 'Graze conservatively to maintain dominance of large and medium tussock grasses over 60–70% of the native pastures' (McIvor 2002). The threshold still rests, as before, on the hypothesis that connectivity of tall and intermediate grassland structure will adequately maintain protection for the soil and connectivity for organisms of low mobility, dependent on these structures (see McIntyre 2005, this issue). In the interests of easier assessment for managers, and in the light of soil condition data that suggest that short patches are the most strongly differentiated, we would propose to re-phrase the management guideline as: 'Graze conservatively to allow a maximum of 30% short-grazed patches in native pastures'. It remains to be proven whether this represents an actual threshold for biodiversity maintenance, or merely a safe level of use of pastures to retain soil surface function. It is also possible that these subtropical grasslands may be unusual in their response, and that thresholds of pasture condition in relation to grassland structure needs examining in a range of environments.

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