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INDICATOR SPECIES FOR THE INTERPRETATION OF VEGETATION CONDITION IN THE ST BATHANS AREA, CENTRAL OTAGO, NEW ZEALAND

Summary: Monitoring the effect of management in rangelands is an integral part of the process of adaptive management. An understanding of how individual species react to management has two major benefits. Firstly, monitoring, can be simplified by avoiding species which are reacting mostly to other influences, and secondly the abundance of species can be interpreted in a meaningful way for assessing the influence of previous management. Gradient analysis on a matrix of 69 sample sites and 125 species in the St Bathans area of Central Otago identified a relatively homogenous data set, within which the effects of environmental variation had been minimised so that the major pattern of vegetation composition change was explained by pastoral impact. Ten plant species showed clear responses along the pastoral impact gradient, and were abundant over certain ranges of this gradient. It is recommended that these species be used to monitor trends in vegetation condition.

Keywords: Bio-indicators; gradient analysis; grazing impact; indicator species; monitoring; range condition; vegetation change.

Introduction

Active adaptive management is what land managers do every day by implementing a strategy, observing or measuring the outcomes and adapting their management accordingly. Monitoring, is therefore an integral part of the adaptive management process. It provides not only a basis for decision making, but also for maximising the development of new knowledge (Gibson, Allen and Bosch, 1995).

In monitoring programmes, where the intention is not a detailed vegetation study but identification of the major trends and evaluation of the success of adaptive management strategies, the technique needs to be fast and sensitive to relevant vegetation change. Many methods calculate an index of vegetation condition by using all the species at a recorded site (e.g., Dyksterhuis, 1949; Foran, Tainton and Booysen, 1978; Vorster, 1982). Generally, however, the abundance of only a few species is strongly correlated with grazing, and these would therefore be indicators of a particular condition (Hurt, Hardy and Tainton, 1993; Bosch and Janse van Rensburg, 1987). Monitoring of species that are not responsive to grazing could decrease or distort the sensitivity of the calculated condition index as these species will contribute noise to the data (Hurt *et al*., 1993). The exclusive use of indicator species can simplify monitoring, especially in community-based monitoring programmes, where land managers themselves are involved with condition assessments to determine the outcomes of their management programmes (Hurt and Bosch, 1991).

Various studies on the response of plant species to grazing, and the identification of indicator species in New Zealand have been undertaken in the past. Early work included the observations of Cockayne (1920) on the response of species to various grazing intensities in the unimproved and improved tussock grasslands. Further work by Connor (1964), and Connor and Macrae (1969), has described the history of vegetation change in the high country tussock grasslands. Authors such as Mark (1965), Williams and Meurk (1977), Payton and Brasch (1978) and Payton *et al.* (1986) have also shown how pastoral modification of tall tussock (*Chionochloa* spp.) grasslands by grazing, is inexorably intertwined with changes in the nutrient levels, and subsequently, the palatability of these tall tussocks following burning.

More recently other authors, including O'Connor (1982, 1986), Hughes (1975), O'Connor and Harris (1991), Connor (1992), Treskonova (1991a, 1991b), Scott, Dick and Hunter (1988), and Mark (1994) have widened the understanding of vegetation change in the high country tussock grassland, and interpreted some of the changes within a historical framework of land use. These papers have contributed significantly to an appreciation and understanding of the broad patterns of vegetation change as well as species reactions to environmental and management factors, such as grazing. However, modern condition assessment techniques require quantitative relationships of how species react to these factors, especially to grazing impact. These relationships can be used for modelling vegetation change, and serve as a basis for the objective condition assessment and interpretation of vegetation monitoring data (Bosch and Gauch, 1991).

Ideally, vegetation change models are best constructed from sites repeatedly monitored over time and for which the complete management history is known. As very few data sets of this nature exist, an alternative method is to use an inferential approach where sample sites at one point in time are selected to represent different states of vegetation condition induced by management. In this paper, the approach published by Bosch and Gauch (1991) is used to identify pastoral impact gradients that can be used as a basis for identifying plant indicator species of different conditional states. The approach has been successfully applied in southern Africa and Australia (Bosch and Kellner, 1991; Phelps *et al.,* 1992). The emphasis is on defining and understanding the pastoral impact gradient through ordination studies of data representing differences in composition mainly induced by grazing, and confirming this against known management data. The use of the term "pastoral" impact instead of simply "grazing" impact acknowledges that grazing of the tussock-grasslands studied has also included episodes of grazing following modification by fire.

Methods

Study Area

The study area included nine properties on mountain country in the St Bathans area, near the head of the Manuherikia Valley in Central Otago. The altitudes of the study sites range between 650 m and 1200 m. Annual rainfall recorded at St Bathans township, at 590 m elevation is 784 mm (New Zealand Meteorological Service, 1979). Soils of the lower slopes of the study area are generally Pallic Soils (Hewitt, 1993), equivalent to yellow grey earths (New Zealand Soil Bureau, 1968). Brown Soils (high country yellow brown earths) occur above 900 m. These consist of Orthic Brown Soils up to 1050 m, and Allophanic Brown Soils at higher altitudes.

Sampling

An inferential approach was used in which sample sites were selected in the area to represent different states of vegetation condition. Obvious differences in vegetation composition either side of fencelines and between blocks that were otherwise environmentally similar (e.g., with regard to slope, aspect, altitude) were regarded as different conditional states induced by management. The total number of sites selected (69) covered the range of available different conditional states in the unimproved tussock-grasslands of the St Bathans area. These unimproved sites had never received fertiliser or seed. Vegetation survey work was carried out during March and April 1994.

Percentage cover for each species[1] in the selected sites was measured using the wheel (needle) point apparatus of Tidmarsh and Havenga (1955). A trial was conducted before fieldwork began to determine the appropriate number of points for the surveys. Similarity coefficients were calculated (Walker, 1987), and in all cases 200 points were found to account adequately for within-site heterogeneity. This is in agreement with studies conducted in southern African rangelands (Stalmans and Mentis, 1993; Everson *et al.,* 1990). The vegetation was sampled along randomly placed transects of varying length and spacing, depending on the available area for sampling. Boundaries were carefully identified so that sampling was carried out within a discrete area, within which management influence, vegetation cover, and environmental conditions were relatively homogeneous. The percentage cover for each species was determined as the proportion of the number of strikes on each species and the total number of strikes recorded at each site. Strikes were recorded at ground level.

Habitat factors recorded at each site were altitude, aspect, slope angle, and slope shape. Stock behaviour, such as camping sites, signs of past treading, gateways and foraging paths, was noted. Moist seepage areas or other areas of limited size that were obviously different due to local variation in the environment, were avoided.

Management Data

Detailed long term management data were obtained from land managers where available. These included current and historic management practices such as burning (e.g., frequency, season, time since last burn, patch or complete burn, spelling after burn),

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[1] Plant nomenclature follow Cheeseman (1925), Zotov (1963), Moore and Edgar (1970), Healy and Edgar (1980), Allan (1982), Lambrechtsen (1986), Webb, Sykes and Garnock-Jones (1988), and Connor and Edgar (1987).

grazing (e.g., season, animal type, stocking duration, block area, number of animals, rabbit plague history, block subdivisions), and stock behaviour (e.g., preferred areas).

An index value was also assigned to each sample site to describe the inferred level of accumulated grazing intensity on a scale from low = 1 (e.g., has always been retired or received very light grazing) to high = 6 (e.g., has repeatedly or continuously been a stock focal point, or received very severe grazing). This was done in collaboration with the land managers, using available quantitative information (average stocking rates for blocks both historically and recently) and their knowledge of long term (20+ years) and recent stock behaviour in the blocks. The observations on the movements of stock and how grazing intensity varied through the block due to the patterns described above, were of particular importance. These were used to subjectively weight the known grazing data so that the final index value reflected the accumulated grazing intensity. The final index value for each site therefore relied heavily on available records and the subjective judgement of the land manager involved.

Data analysis

All data analyses were carried out with the analytical module of the Integrated System for Plant Dynamics (ISPD) software package (Bosch *et al*., 1992). ISPD is made up of several modules, some for researchers/developers and others for end users. The analytical module contains ordination and interpretation tools for use by researchers developing vegetation change models.

Habitat variations can occur within any particular ecological zone. For instance, a rainfall zone may also have variations due to altitude or aspect or other causes. This complex variation can lead to large variations or noise in a data set (Austin, Williams and Belbin, 1981; Gauch, 1982) which can make the identification of a reliable pastoral impact gradient impossible. Stratification of sample plots into homogeneous subsets, on the basis of the different soil or other environmental variations would be impractical, since they are too numerous. Furthermore, it is not always known which environmental factors have a significant effect on species composition and should be taken into account during the selection and classification of sample plots (Bosch and Gauch, 1991).

The first step in the analysis was to identify possible relative homogeneous vegetation:habitat groups. For this, Detrended Correspondence Analysis (DCA) (Hill and Gauch, 1980) was used for ordinating the data matrix. This technique is recommended by Gauch (1982) for the analysis of data sets with high sample heterogeneity, and reported by Hill and Gauch (1980) as superior to a number of other ordination techniques for the analysis of a variety of complex field and simulated data sets. It is a unimodal technique, that is, it works well on long gradients where the majority of species have their optima located within the data and the community variation is over a wide range (gradient length is greater than 3 standard deviations). In these situations species abundances will approximate a Gaussian response. Canonical Correlation Analysis (CCA), another unimodal technique may also be used at this stage (Ter Braak and Prentice, 1988).

Species that occurred on less than 10% of the sample sites were considered rare, and were removed from the data set to avoid introducing unnecessary noise (Mentis, 1983). This is justified for two reasons, 1) occurrences of rare species are usually more a matter of chance than an indication of ecological conditions and, 2) most multivariate techniques are affected very little by rare species carrying such a small percentage of the overall information of variance (Gauch, 1982).

The distribution of various habitat factors on the ordination was investigated and used as a basis to identify relatively homogeneous vegetation:habitat groups. Sites (if any) identified as being significantly different from any of these data groups (i.e. outliers) were removed because their relationship to other samples in the data set is not expressed by information in the data. This may also cause problems for the ordination (Gauch, 1982).

A sample centred Principal Components Analysis (PCA) was used for further analyses of each of the vegetation:habitat groups identified through the DCA ordination. A linear response model such as PCA will produce better results than Gaussian response models such as CCA or DCA when the studied gradient becomes short (less than 1.5 standard deviation), and most species are behaving monotonically over the observed range (i.e., their observed response is almost linear) (Gauch, 1982; Ter Braak and Prentice, 1988; Palmer, 1993). As each data subset represented a relatively homogeneous vegetation:habitat group (identified on the DCA ordination), it was considered to have a relatively low heterogeneity and that the majority of species would only have a part of the full Gaussian response (approximating a linear response) within the data subset.

Since the sample sites had been deliberately selected to represent different conditional states, and the effect of other environmental gradients had been minimised through the data set subdivisions on the DCA ordination, the pastoral impact gradient was expected to emerge on the first ordination axis. Further analysis was therefore focused on the first axis. A modification to the sample centred PCA analysis was used to combine the second and higher axes into a single residual value, which provided a measure for each site of its distance off the first axis (Bosch and Gauch, 1991). The PCA ordination was inspected to ensure that no sample sites had residuals larger than 50% of the Euclidean length of the first ordination axis. Any sample sites exceeding this were not considered to fit the ordination model adequately. These sample sites were then discarded and the ordination repeated (Bosch and Kellner, 1991; Bosch and Gauch, 1991).

Confirmation that the first axis represented a pastoral impact gradient was achieved by examining whether known management differences for sample pairs were consistent with the expected increasing accumulated grazing intensity along the first axis. In addition, the positions of samples along the first axis were correlated with the indices of inferred accumulated grazing intensity, as well as with other habitat variables. Pearson's product-moment correlation coefficient (Sokal and Rolf, 1981) was used for this purpose.

Indicator Species Identification and Classification

Once it was confirmed that the first axis represented a pastoral impact gradient for each vegetation:habitat group, the percentage cover of species along the first axis was plotted. Species that showed a possible correlation with the pastoral impact gradient were noted. Regression analyses on these species were performed after fitting a Gaussian (Normal) distribution curve. Although real ecological response curves are often more complex, Gaussian models are useful in describing data showing mostly unimodal responses and are generally accepted (Ter Braak and Prentice, 1988; Palmer, 1993). The usefulness of the Gaussian response has been confirmed in numerous direct gradient studies, and has become the basis for testing and designing multivariate models (Gauch, 1982). It was assumed that most species would have only one optimum along the studied gradient, and decline to either side approximating a bell shaped or Gaussian curve.

The D Statistic (Willmott, 1982) or "index of agreement" was used to determine how well the recorded data fitted the relationship with the first axis (Bosch and Kellner, 1991; Bosch and Gauch, 1991).

Indicator species were classed into response groups on the basis of the strength and nature of their relationship with the pastoral impact gradient. Three broad categories were chosen to identify with which part of the pastoral impact gradient an indicator species was mostly associated. These three categories conform with those suggested by Hurt *et al.* (1993), i.e., decreasers, increasers and invaders, following the pioneering concepts of Dyksterhuis (1949).

Results

Identification of a pastoral impact gradient.

Two relatively homogenous vegetation:habitat groups were identified, and no outliers were present in the initial DCA ordination (Fig. 1). Group "A" consists entirely of sites situated at high altitudes (>1100 m). Sites in group "B" are all situated in the altitude range 700-1100 m. The data set was divided into these two groups. Group "A" consisted of 14 sites, too few to identify any further meaningful gradients. The centred PCA ordination of the samples by species matrix of group "B", is given in Fig. 2.

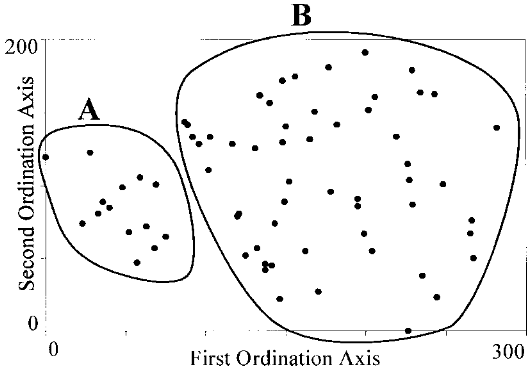

Figure 1: *Diagrammatic presentation of the DCA ordination of 69 sites.*

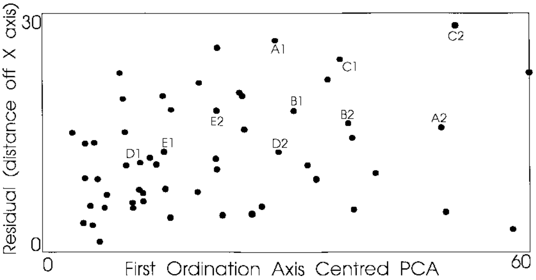

Figure 2: *Position of the sample plots on the first axis of the centred PCA ordination. A1 and A2 - E1 and E2: Five examples of sites separated by fence lines (1 lighter grazing intensity than 2).*

Sites with a high inferred accumulated grazing intensity index value occur towards the right side of the diagram, while sites with a low index value are positioned on the left side. Confirmation that the first axis represents a pastoral impact gradient is found in the strong correlation between the index of inferred accumulated grazing intensity and the position of the sites on the first ordination axis (Fig. 3a). Labelled pairs of sites on either side of fencelines with known grazing histories also confirm this gradient, as the relatively lighter grazed site of each pair is in all cases situated on the left (Fig. 2). The minor variation along the residual axis of pairs of sites is assumed to be due to interacting factors other than management. However, the distances of the sites off the first axis are less than half the Euclidean distance of the X-axis, which implies that these other influences are relatively minor (Bosch and Gauch, 1991).

The relationships of environmental variables that have correlations with the X-axis are given in Figs. 3b and 3c. Sites on high and low altitudes and sunny and dark aspects occur at both ends of the ordination axis (Figs. 3b and 3c). There is a tendency for low grazing intensity sites (better condition) to occur more on the shady aspects (to the left of the diagram). No other correlations were obtained with any of the other management or habitat variables.

Indicator species identification

Of the 125 species encountered during the surveys, 28 potential indicators were initially identified. The regression analyses showed that 15 of these (including bare ground and litter) had relationships that could be quantified with the pastoral impact gradient (X-axis) with a D statistic in excess of 0.5 (Fig. 4).

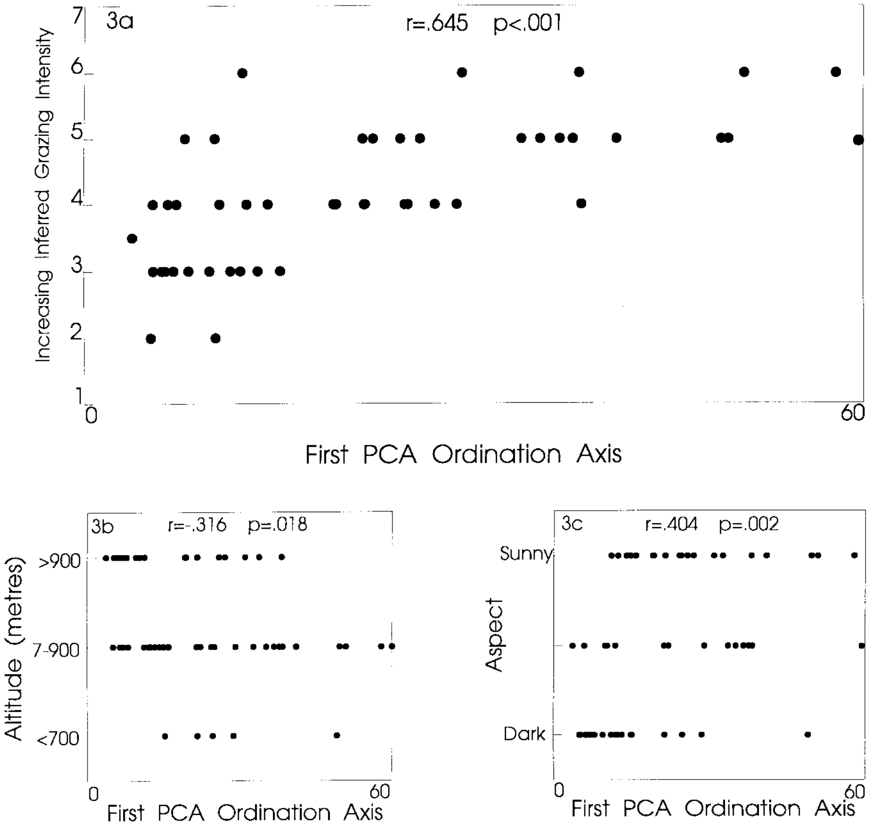

Figure 3: *Relationship of the inferred grazing intensity index (a), altitude (b), and aspect (c), with the first ordination axis.*

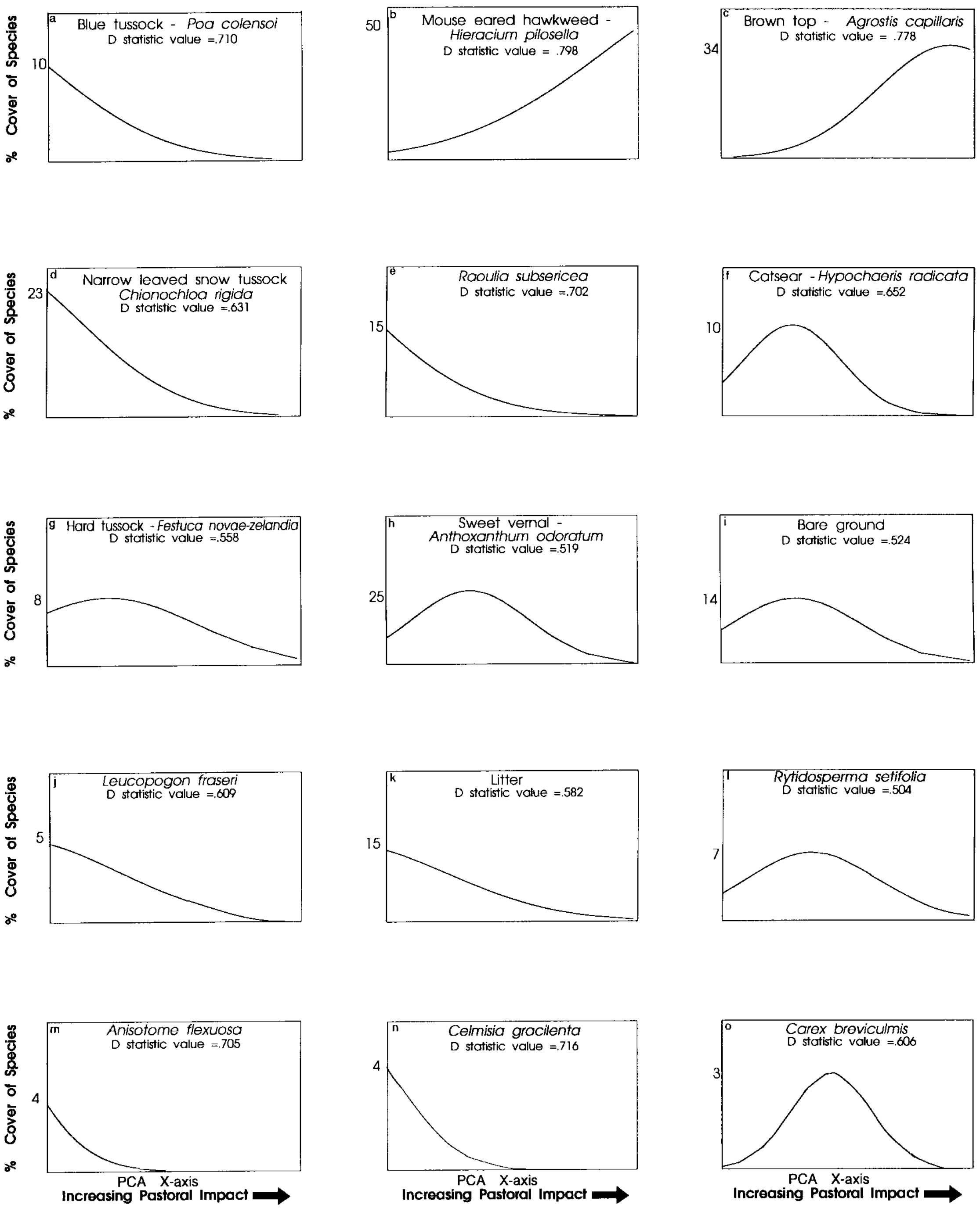

Figure 4: *Indicator response curves with a strong (a-c), a moderately strong (d-f), a moderate (g-l),and a strong relationship but low field occurrence (m-o).*

Indicators of unmodified to moderately modified condition (Decreasers)

Bosch and Janse van Rensburg (1987) define a decreaser as a species which is highly abundant under conditions of low pastoral impact but declines rapidly as pastoral impact increases. The cover of six species, blue tussock (*Poa colensoi*), narrow leaved snow tussock (*Chionochloa rigida*), *Raoulia subsericea*, *Leucopogon fraseri, Anisotome flexuosa, Celmisia gracilenta,* as well as ground litter, follow the trend described for a decreaser (Fig. 4).

The sharp decline in the abundance of *A. flexuosa* and *C. gracilenta* with increasing pastoral impact, indicates that these two species are less tolerant to grazing than the other decreaser species. Although they are also good indicators of vegetation under conditions of low pastoral impact, they have relatively low abundances in the area. Blue tussock, narrow leaved snow tussock, *R. subsericea* and *L. fraseri,* can be regarded as the most useful indicators of low pastoral impact, as they have a strong relationship with this impact and are abundant in the area.

Indicators of moderate to highly modified condition (Increasers)

As the pastoral impact becomes greater, increaser species take advantage of the reduction in cover of decreaser species, and become more abundant. Under a more severe pastoral impact the increaser species start to decline and eventually disappear from the vegetation. The response of catsear (*Hypochoeris radicata*), sweet vernal (*Anthoxanthum odoratum*), the indigenous hard tussock (*Festuca novae-zelandiae*) and *Rytidosperma setifolia* on the impact gradient in Fig. 4 clearly illustrates this process. These four species can also be regarded as useful indicators of moderate pastoral impact. Bare ground also initially increases with increased pastoral impact, after which the bare areas are colonised with invader species. This probably explains the reduction in bare ground towards the severely depleted side of the gradient (Fig. 4). *Carex breviculmis* also fits the increaser category, but has a relatively low cover value.

Indicators of degraded condition (Invaders)

The decline in increaser species is marked by an increase in mouse ear hawkweed (*Hieracium pilosella*), an invader species, and brown top (*Agrostis capillaris*) (Fig. 4). As would be expected, these two species have the highest percentage cover at the opposite end of the gradient from the decreaser species. They are tolerant of intensive grazing. The data suggest that brown top may peak and start to decline under severe pastoral impact, while the cover of mouse ear hawkweed continues to increase.

Discussion

The DCA technique was successfully used to subdivide the original data set into relatively homogeneous vegetation:habitat groups. It has to be pointed out that any technique that deals well with complex data sets can be used for this first analysis. In the case of more complex data sets classification techniques such as two way indicator species analysis (TWINSPAN) (Hill, 1979) may provide a better subdivision of the initial data set before ordination techniques are used.

Where longer pastoral impact gradients are suspected within the final data subsets, unimodal techniques such as DCA or CCA may provide better definitions of these gradients. A partial CCA ordination may be especially useful in the final gradient definition to minimise the influence of the co-variates such as altitude or aspect, whilst maximising the variation explained within the data by the variable of interest (in this case accumulated grazing intensity). However, as in all direct gradient analyses, it is assumed that these measured habitat factors are measured without error (Palmer, 1993). Factors such as altitude and aspect can be measured relatively confidently, but a variable such as grazing index cannot be accurately determined. Using this variable in the partial ordination may well then introduce noise to the ordination. This is an important consideration to take into account for deciding between indirect or direct gradient analysis techniques.

Various factors interact and affect the way stock graze within a block. These include grazing and stock movement patterns, shelter from bad weather, warmth of slopes, access to water (especially if limited), previous burn patterns, animal habits and congregation patterns, as well as size and shape and topography within the block. These interactions, and the inadequate records available for a large number of the blocks in which the sample sites occurred, made it impossible to quantify current and historic grazing intensities for many of the sample sites, and to obtain a significant correlation with the PCA ordination axis for these variables.

As management, in addition to stock behaviour, also interacts with environmental gradients (e.g., diminishing grazing intensity with increasing altitude, or increasing grazing intensity on warmer aspects), correlations between environmental factors and the pastoral impact gradient, can therefore be expected in a study of this type. These correlations may lead to confusion over the nature of the gradient. For instance, in this study it was found that a correlation occurred between aspect and the pastoral impact gradient (Fig. 3c.). However, the fact that both sunny and dark sites occurred on both ends of the gradient confirmed that the pattern of change due to pastoral impact was similar for both sunny and dark slopes. That is to say, sunny slopes in relatively unmodified condition are very similar to dark slopes in unmodified condition, and degrade to a similar species composition to that of dark slopes. The greater number of dark slopes at the low pastoral impact end of the gradient can then be attributed to a higher resilience (ability to cope with and replace grazed material) of vegetation under more favourable growth conditions, and/or a tendency for animals to concentrate on sunny aspects, resulting in more rapid degradation of those landscapes. Overall, pastoral impact still has the most significant influence on the first axis of the ordination.

Descriptions of the origin and patterns of change in tall tussock grasslands by Connor (1964), O'Connor (1982), and Treskonova (1991a), indicate that a more complete pastoral impact gradient would have included a dense narrow-leaved snow tussock grassland on the furthest left-hand side of the gradient in Fig. 2. As no never-burnt or never-grazed sites were available in the study area, the results of this study represent only a portion of the full pastoral impact gradient. In the strict sense it could therefore be implied that blue tussock and native herbs, such as *A. flexuosa,* would initially have increased as the dense sward of narrow leaved snow tussock was opened up through burning and grazing. This would have made these species increasers. However, as the less modified portion of the gradient was not found and probably no longer exists in the study area, these species were defined as decreasers.

Although data from long term grazing trials would have been ideal for a gradient study of this nature, the inferential approach used in this investigation proved to be successful and reasonably quick in developing grazing impact gradients and determining indicator species. We note that Rose's (1983) study of time series data covering 25 years of vegetation change in short tussock grasslands in the Harper-Avoca catchment has over time shown similar abundance curves for hard tussock, browntop, bare ground, sweet vernal and catsear to those obtained in this study.

Indicator species for other areas of the high country could be identified by applying this approach to the many other existing data sets from long term monitoring programmes. Where necessary, these could be supplemented with data from surveying fenceline effects, areas of more intense grazing and retired paddocks.

Conclusion and Application

Out of the original 125 species, ten (excluding bare ground and litter) were identified as useful indicators for monitoring purposes in the St Bathans area. These ten species were more responsive to grazing impact than to other environmental factors, which makes them useful in providing an early warning of changes in the system. The species also have comparatively high abundances over at least a portion of the grazing impact gradient, and are relatively easy to identify. Their response curves are of direct use in models of vegetation change that serve as a basis for condition assessment in long-term monitoring programmes (Bosch *et al*., 1992; Bosch *et al., in press*).

The adoption of the use of indicator species to monitor vegetation condition holds considerable promise for both production and conservation through identifying and alerting land managers to major changes within the ecosystem. The interpretation of vegetation condition data will allow the appropriateness of current management to be assessed, and corrective action to be taken if needed. Where the presence or absence of rare or unusual plants may be important, as in conservation studies or inventory compilation, a more detailed examination of floristic composition may be needed.

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References

Allan, H.H. 1982. *Flora of New Zealand. Volume I. Indigenous Tracheophyta*. Government Printer, Wellington, N.Z. 1085 pp.

Austin, M.P.; Williams, O.B.; Belbin, L. 1981. Grassland dynamics under sheep grazing in an Australian Mediterranean-type climate. *Vegetatio 47*: 201-211.

Bosch, O.J.H.; Allen, W. J.; Gibson, R.G.; Gibson, R.S.; Ogle, G.I.; Wardle, K. (*in press*). Cataloguing existing knowledge and monitoring data as a basis for the development of a decision support system for the New Zealand high country. *Proceedings of the Fifth International Rangeland Conference*, Salt Lake City, Utah, USA.

Bosch, O.J.H.; Gauch, H.R. 1991. The use of a degradation gradient for the assessment and ecological interpretation of range condition. *Journal of the Grassland Society of South Africa 8*: 138-146.

Bosch, O.J.H.; Gauch, H.R.; Booysen, J.; Stols S.H.E.; Gouws, G.A; Nel M.W.; Van Zyl, E. 1992. *ISPD - An Integrated System for Plant Dynamics* (Computer Software Package and Users Guide). Department of Plant and Soil Sciences, Potchefstroom University for Christian Higher Education, Potchefstroom, South Africa. 101 pp.

Bosch, O.J.H.; Janse van Rensburg, F.P. 1987. Ecological status of species on grazing gradients on shallow soils of the western grassland biome in South Africa. *Journal of the Grassland Society of Southern Africa 4*: 143-146.

Bosch, O.J.H.; Kellner, K. 1991. The use of a degradation gradient for the ecological interpretation of condition assessments in the western grassland biome of southern Africa. *Journal of Arid Environments 21*: 21-29.

Cheeseman, T.F. 1925. *Manual of the New Zealand Flora*. 2nd edition. Government Printer, Wellington, N.Z. 1163 pp.

Cockayne, L. 1920. An economic investigation of the montane tussock-grassland of New Zealand. IX. Further details regarding the Earnscleugh (Central Otago) palatability experiment. *New Zealand Journal of Agriculture 20*: 324-334.

Connor, H.E. 1992. The botany of change in tussock grasslands in the Mackenzie Country, South Canterbury, New Zealand. *Review: Journal of the New Zealand Mountain Lands Institute 49*: 1-31.

Connor, H.E. 1964. Tussock grassland communities in the Mackenzie Country, South Canterbury, New Zealand. *New Zealand Journal of Botany 2*: 325-351.

Connor, H.E.; Edgar, E. 1987. Name changes in the indigenous New Zealand flora, 1960-1986 and Nomina nova IV, 1983-1986. *New Zealand Journal of Botany 25*: 115-170.

Connor, H.E.; Macrae, A.H. 1969. Montane and subalpine tussock grasslands in Canterbury. *In*: Knox, G.A. (Editor), *The natural history of Canterbury*, pp. 167-204. A.H. and A.W. Reed, Wellington N.Z. 620 pp.

Dyksterhuis, E.J. 1949. Condition and management of range land based on quantitative ecology. *Journal of Range Management 2*: 104-115.

Everson, T.M.; Clarke, G.P.Y.; Everson C.S. 1990. Precision in monitoring plant species composition in montane grasslands. *Vegetatio 88*: 135-141.

Foran, B.D.; Tainton, N.M.; Booysen, P. de V. 1978. The development of a method for assessing veld condition in three grassveld types in Natal. *Proceedings of the Grassland Society of Southern Africa 13*: 27-33.

Gauch, H.G. 1982. *Multivariate Analysis in Community Ecology*. Cambridge University Press, Cambridge, U.S.A. 298 pp.

Gibson, R.S.; Allen, W.; Bosch, O.J.H. 1995. Condition assessment concepts and their role in facilitating sustainable range management. *Annals of the Arid Zone 34:* 179-189.

Healy, A.J.; Edgar, E. 1980. *Flora of New Zealand. Volume III. Adventive cyperaceous, petalous and spathaceous monocotyledons*. Government Printer, Wellington, New Zealand. 220 pp.

Hewitt, A. 1993. *New Zealand Soil Classification*. Manaaki Whenua - Landcare Research New Zealand, Lincoln, New Zealand. 133 pp.

Hill, M.O.; Gauch, H.G. 1980. Detrended correspondence analysis: an improved ordination technique. *Vegetatio 42*: 47-58.

Hill, M.O. 1979. *TWINSPAN, a FORTRAN program for arranging multivariate data in an ordered two way table by classification of the individuals and attributes*. Department of Ecology and Systematics, Cornell University, Ithaca, New York, U.S.A. 62 pp.

Hughes, J.G. 1975. What sheep eat on developed and undeveloped high country. *Review: Journal of the Tussock Grasslands and Mountain Lands Institute 31*: 20-30.

Hurt, C.R.; Bosch, O.J.H. 1991. The comparison of some range condition assessment techniques used in southern African grasslands. *Journal of the Grassland Society of South Africa 8:* 131-137.

Hurt, C.R.; Hardy, M.B.; Tainton, N.M. 1993. Identification of key grass species under grazing in the highland sourveld of Natal. *African Journal of Range and Forage Science 10*: 96-102.

Lambrechtsen, N.C. 1986. *What grass is that? A guide to the identification of some introduced grasses in New Zealand by vegetative characters*. Government printer, Wellington, N.Z. 151 pp.

Mark, A.F. 1965. Effects of management practices on narrow-leaved snow tussock, *Chionochloa rigida*. *New Zealand Journal of Botany 3*: 300-319

Mark, A.F. 1994. Effects of burning and grazing on sustainable utilisation of upland snow tussock (*Chionochloa* spp.) rangelands for pastoralism in South Island, New Zealand. *Australian Journal of Botany 42*: 149-161.

Mentis, M.T. 1983. Towards objective veld condition assessment. *Proceedings of the Grassland Society of Southern Africa* 18: 77-80.

Moore, L.B.; Edgar, E. 1970. *Flora of New Zealand. Volume II. Indigenous Tracheophyta*. Government Printer, Wellington, N.Z. 354 pp.

New Zealand Meteorological Service. 1979. Rainfall parameters for stations in New Zealand and the Pacific Islands. *New Zealand Meteorological Service Miscellaneous Publication 163*. Government Printer, Wellington, N.Z.

New Zealand Soil Bureau. 1968. General Survey of the Soils of The South Island New Zealand. *Soil Bureau Bulletin 27*, Government Printer, Wellington, N.Z. 404 pp.

O'Connor, K.F. 1982. The implications of past exploitation and current developments to the conservation of South Island tussock grasslands. *New Zealand Journal of Ecology 5*: 97-107.

O'Connor, K.F. 1986. The influence of science on the use of tussock grasslands. *Review: Journal of the Tussock Grasslands and Mountain Lands Institute 43*: 15-78.

O'Connor, K.F.; Harris, P.S. 1991. Biophysical and cultural factors affecting the sustainability of high country pastoral land uses. *Proceedings of the International Conference on Sustainable Land Management*, Napier, New Zealand.

Palmer, M.W. 1993. Putting things in even better order: The advantages of canonical corres-pondance analysis. *Ecology 74*: 2215-2230.

Payton, I.J.; Brasch, D.J. 1978. Growth and nonstructural carbohydrate reserves in *Chionochloa rigida* and *C. macra* and their short-term response to fire. *New Zealand Journal of Botany 16*: 435-460.

Payton, I.J. Lee, W.G., Dolby, R. Mark, A.F. 1986. Nutrient concentrations in narrow leaved snow tussock (*Chionochloa rigida*) after spring burning. *New Zealand Journal of Botany 24:* 529-537.

Phelps, D.G.; Bushell, J.J.; Bosch, O.J.H.; Kent, D.J.; Beale, I.F. 1992. A system for objective condition assessment of *Astrebla* spp. pastures at the paddock level for better grazing management. *Proceedings of the 7th Biennial Conference of the Australian Rangeland Society,* Longridge, Australia.

Rose, A.B. 1983. Succession in fescue (*Festuca novae-zelandiae*) grasslands of the Harper-Avoca catchment, Canterbury, New Zealand. *New Zealand Forest Research Bulletin 16*. Government Printer, Wellington, N.Z. 35 pp.

Scott, D.; Dick, R.D.; Hunter, G.G. 1988. Changes in the tussock grasslands in the central Waimakariri River Basin, Canterbury, New Zealand, 1947-1981. *New Zealand Journal of Botany 26*: 197-222.

Sokal, R.R.; Rolf, F.J. 1981. *Biometry*. San Francisco, W. H. Freeman and Company, San Francisco, U.S.A. 859 pp.

Stalmans, M.; Mentis, M.T. 1993. Development of monitoring procedures for the herbaceous layer on the Northeastern Transvaal escarpment. *African Journal of Range and Forage Science 10*: 129-134.

Ter Braak, C.J.F.; Prentice I.C. 1988. A theory of gradient analysis. *Advances in Ecological Research 18*: 271-317

Tidmarsh, C.E.M.; Havenga, C.M. 1955. The wheelpoint method of survey and measurement of semi-open grassland and Karoo vegetation in South Africa. *Botanical Survey of Southern Africa Memoir 29*. Government Printer, Pretoria, South Africa. 65 pp.

Treskonova, M. 1991a. Changes in the structure of tall tussock grasslands and infestation by species of *Hieracium* in the Mackenzie Country, New Zealand. *New Zealand Journal of Ecology 15:* 65-78.

Treskonova, M. 1991b. Hieracium - an ecological perspective. *Review: Journal of the New Zealand Mountain Lands Institute 48:* 32-40.

Vorster, M. 1982. The development of the ecological index method for assessing veld condition in the Karoo. *Proceedings of the Grassland Society of Southern Africa 17*: 84-89.

Walker, R.S. 1987. Monitoring species composition in mountain catchment grasslands. *Proceedings of the Third Vegetation Monitoring Workshop*. Foundation for Research - Development Occasional Report no. 39, Pilanesburg National Park, South Africa.

Webb, C.J.; Sykes, W.R.; Garnock-Jones, P.J. 1988. *Flora of New Zealand. Volume IV. Naturalised pteridophytes, gymnosperms, dicotyledons*. Government Printer, Wellington, N.Z. 1365 pp.

Williams, P.A.; Meurk C.D. 1977. The nutrient value of burnt tall-tussock. *Review: Journal of the Tussock Grasslands and Mountain Lands Institute 34*: 63-66.

Willmott, C.J. 1982. Some comments on the evaluation of model performance. *Bulletin of the American Meteorological Society 63*: 1309-1313.

Zotov, V.D. 1963. Synopsis of the grass subfamily Arundinoideae in New Zealand. *New Zealand Journal of Botany 1*: 78-136.