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Detecting environmental change in eastern Australia: rangeland health in the semi-arid woodlands

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Abstract

We examined changes in rangeland health in the semi-arid woodlands of eastern Australia at fixed sites between 1989 and 1999. Over the 11-year period there were significant declines in the quality of the vegetation, and changes in plant species were driven largely by seasonality, and to a lesser extent, amount of rainfall. Three indices of rangelands health (composition, function and stability) developed using site-based vegetation and landscape data, indicated that the majority of sites had intermediate values of the three indices, and few sites had either very low or very high values. The indices of composition and function were strongly correlated with the subjective ratings applied to each site at each measurement period. The results of this study highlight the difficulty of detecting change over extensive areas of rangeland, and of separating management-induced effects from climatic effects in an environment which experiences wide spatial and temporal variation in rainfall.

Keywords: Rangeland health; Rangeland condition; Rangeland monitoring; Semi-arid woodland; Rangeland management

1. Introduction

Regional assessment of rangeland health in the state of New South Wales (NSW), Australia, commenced in the mid-1980s and was formalised in 1989 with the introduction of the Rangelands Assessment Program. Under the program, more than 350 fixed sites were established on large grazing leases (~30 000–80 000 ha) in seven vegetation communities (Green et al., 1994). The objectives of the program were to assess the health of the main vegetation communities in the rangelands on a regular basis, to train both staff and landholders in vegetation assessment techniques, and to enable land managers to make informed decisions about the current and future management of rangelands (Green et al., 1994).

Over the past decade, concerns for sustainable management of arid and semi-arid grazing lands have resulted in an increased demand for management-based information on both the current condition of rangelands and the degree to which it has changed over time. A coordinated national approach to rangelands monitoring is now one of

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the themes of the National Land and Water Resources Audit (Pickup et al., 1998).

We use univariate and multivariate statistical methods to aid in investigating the current health status, and changes in health (trend), of rangelands. In this paper, we focus on the Hard Red rangeland type which is located within the semi-arid woodlands of eastern Australia (Beeston et al., 1980). Our use of the term 'health' is analogous to the term 'condition', which we use interchangeably, and is frequently used to describe the status of rangelands. Using empirical data collected between 1989 and 1999, our aim is to examine environmental change in the Hard Red rangeland type.

2. Methodology

2.1. The study area

The study area is located within a radius of approximately 150 km of Cobar in central NSW Australia (31°45′S, 145°56′E). The semi-arid woodlands in the study area comprise level to slightly undulating plains with isolated ridges, drainage lines and gilgai. The soils are predominantly red earths formed from colluvium or alluvium, with moderately deep profiles, sometimes stony, and increasing clay with depth (Lawrie, 1974). The soils are inherently infertile, and susceptible to surface sealing and reduced infiltration when ground cover is reduced (Johns et al., 1984). Large areas of the Hard Red rangelands show signs of either current or historical erosion. They are characterised by an open to dense woodland dominated by inland red box (*Eucalyptus intertexta*), white cypress pine (*Callitris glaucophylla*) and wilga (*Geigera parviflora*), and a groundstorey vegetation comprising mainly grasses (e.g. *Austrostipa* spp., *Aristida* spp.) as well as a variety of annual and perennial forbs. The mean annual rainfall varies from approximately 300 to 350 mm, but is highly variable from year to year.

2.2. Field methods

Site data on vegetation and soils were collected annually from within large (300×300 m^2) fixed plots using a total of 52 quadrats, positioned as 13 quadrats placed regularly along four parallel transects spanning each site. Sites are located within larger areas (25 ha) of homogeneous vegetation, and located approximately 1.5 km from water, within the watering range of sheep, and at a distance where change in vegetation health is expected to occur. At each of 49 Hard Red sites, quadrat-based measurements are made of species composition and biomass using the dry weight rank–comparative yield approach (Friedel et al., 1988). The cover of vegetation, cryptogams (lichens and mosses), erosion, surface sealing, bare ground and other (e.g. rock) is also assessed within the quadrats. The cover of trees and shrubs is assessed on fixed belt transects. The proportion of quadrats within which a given species was found at a given time was used as the data inputs into multivariate and univariate analyses.

2.3. Statistical analyses

We used multivariate analyses and one-way ANOVA (Minitab, 1997) to examine temporal changes in diversity and cover of groundstorey plants only (i.e. excluding shrubs and trees). Changes in sites (in relation to their complement of groundstorey plant species) over different time periods were examined using only those species which had a total frequency over all sites and times of >35. The resulting matrix of 208 species by 481 site$\times$times was subjected to the indirect gradient analysis detrended correspondence analysis (DCA) using the CANOCO (Version 4) software (ter Braak, 1991). Data are reported for the period 1989–1999, though not all sites were measured in all years. We examined the interrelationships between each site$\times$time's coordinate from axes 1 and 2 of the DCA, and two variables; (1) rainfall in the previous 3, 6 and 12 months, and (2) time. Individual species were coded according to the life form (perennial or annual) and origin (native or exotic) in order to interpret the DCA axes.

2.4. Development of indices of landscape stability, composition and function

We used empirical data collected annually from each site to develop indices of rangeland health in

Table 1
Attributes, possible scores and maximum scores used for calculating indices of landscape composition, function and stability

Attribute	Composition	Function	Stability
Shrub cover (%)	1–5		
Tree cover (%)	1–5		
Number of shrubs	1–4		
Number of trees	1–4		
Number of vascular plants	1–4		
Cover of cryptogams (%)		1–5	1–5
Cover of ground surface (%)		1–5	1–5
Perennial plants (%)		1–4	
Native plants (%)		1–4	
Cover of erosion (%)		1–4	1–4
Total biomass by perenniality		1–10	
Range of scores	5–22	6–32	3–14

terms of three ecosystem attributes: landscape composition, landscape function and landscape stability (sensu Noss, 1990). This technique has been used to describe the habitat value for mammals in the south-east forests of eastern Australia (Newsome and Catling, 1979), and a variant has been used by the Bureau of Land Management in the US to assess landscape health on a qualitative basis (Pellant et al., 2000).

Nineteen attributes were used to calculate these indices (Table 1). The possible range of each attribute was divided into a number of ecologically meaningful classes (usually 4 or 5), and each class was then assigned a value according to its perceived effect upon composition, function or stability. Thus for example, percentage ground cover, which is an important component of ‘stability’, was divided into five classes thus: 0–10%—1, 10–25%—2, 25–50%—3, 50–75%—4 and > 75%—5. Accordingly, a site×time with 62% of the soil covered by vegetation would receive a value of 4 for ‘ground cover’. For ‘function’, the score for biomass was adjusted by its perenniality in order to derive an index which weights biomass by its persistence. Thus, individual scores for biomass were multiplied by 1.0 if <50% of the biomass was perennial, 1.5 if 50–75% of biomass was perennial and 2.0 if >75% of the biomass was perennial. In this way the index accounts for the quality of biomass, downgrading annual (generally transient) biomass and upgrading more persistent (generally substantial) biomass. Data on trees and shrubs were used as inputs to the ‘composition’ index such that a higher score indicated a greater cover or shrubs and trees and/or a greater diversity of species.

2.5. Subjective assessment of condition

During annual site measurements, recording officers routinely evaluate the condition of sites based on criteria they consider to be important at that site, such as presence of rabbits and weeds, cover of woody shrubs, perennial grasses, forbs and cryptogamic crusts, degree of erosion and groundstorey plant biomass. Site assessments ranged from 1, excellent to 5, severely degraded. Relationships between the three derived landscape indices (described above) and the mean (averaged over all years) officer assessment of condition for each site, were examined using regression techniques (Minitab, 1997).

3. Results

3.1. Temporal changes in site characteristics

Between 1989 and 1999 there were significant declines in the quality of the Hard Red range sites. The length of time since commencement of the study (1989) was associated with significant declines in the diversity of groundstorey plants ($R^2=0.11$, $P<0.05$), declines in the number of both exotic ($R^2=0.24$, $P<0.05$) and annual plants

($R^2=0.22$, $P<0.05$), and increases in the coverage of bare ground ($R^2=0.28$, $P<0.05$). Other relationships included an increase in the number of perennial plants with increases in rainfall during the previous 6 months ($R^2=0.32$, $P<0.05$). Total rainfall in the 6 months prior to measurements explained 46% of the variation in annual biomass and 11% of perennial biomass ($P<0.05$). There were no significant relationships between any attributes and the 3 or 12-month lag rainfalls.

Larger axis 1 scores from the DCA biplot (Fig. 1) were associated with increasing rainfall in the previous 6 months ($P<0.05$), though rainfall explained only 5% of the variance in axis 1 scores. Further, the ordination of sites along axis 1 corresponded to marked differences in plant life form and origin. Annual, exotic plants tended to be associated with high axis 1 scores whilst perennial and native plants tended to have intermediate and low values along axis 1.

The DCA biplots indicated two distinct time periods: 1989–1992 and 1993–1999 (Fig. 1). From 1992 to 1993 there were distinct movements in the location of sites from the top of the DCA biplot to the bottom, although the 1999 data suggest the return to an upward movement (Fig. 1). There was a strong, significant decline in axis 2 scores over time ($F_{1,479}=191.0$, $P<0.001$), and a second order polynomial explained 40% of the variance in axis 2 scores. We failed to find meaningful relationships between rainfall and axis 2 scores for either the lag periods of 3, 6 or 12 months rainfall data ($P>0.05$).

Examination of regional rainfall records suggests that the temporal shifts in sites along axis 2 can be explained by differences in the seasonal distribution of rainfall rather than total rainfall per se, with a shift from high summer rainfalls in 1989–1992 (top of Fig. 1) to a series of winter-dominant or evenly distributed, lower rainfall events in the 1993–1999 period (bottom of Fig. 1).

3.2. Indices of landscape health

The frequency distribution of scores for the three indices indicate that the majority of sites had low ($<50\%$) values for composition (Fig. 2). The majority of sites had intermediate values for function and stability, and, on average, only 7% were at the healthier end and 3% at the unhealthier end of the scale (Fig. 2).

Despite the small amount of variation in annual condition scores for many sites, there were strong and significant relationships between the annual condition scores and indices for both landscape composition ($R^2=0.45$, $P<0.001$) and landscape function ($R^2=0.29$, $P<0.001$; Fig. 3), but not for landscape stability ($P>0.05$). Predictably, function improved as the condition of the sites improved. However, composition declined as condition improved, indicating that increased composition (as scored by higher tree and shrub cover) is viewed by rangeland officers as a sign of declining health. The relationships between average annual condition assessment and both composition and function highlight the narrow range of values for the Hard Red range type, reinforcing the difficulty of detecting meaningful differences between sites which are essentially very similar in their biotic and abiotic components.

4. Discussion

These results, from the semi-arid woodlands in eastern Australia, highlight the difficulties of quantifying environmental health and detecting its change over extensive areas of rangeland. The task of interpreting trends in relation to climate and management were further complicated by the wide spatial and temporal variation in rainfall, the fact that not all sites were measured in all years, and the fact that rainfall records were not always available from close to the site where measurements were made. Consequently, in some cases, falls of rain recorded at the homestead may have been larger (or smaller) than those recorded at the trial measurement site.

Despite these shortcomings, our results illustrate a number of trends in relation to the condition of vegetation in the semi-arid woodlands between 1989 and 1999. Overall, there were clearly defined reductions in the quality of the rangeland sites over time including increases in the amount of bare ground and reductions in plant diversity. Many species were found at only one site and/or

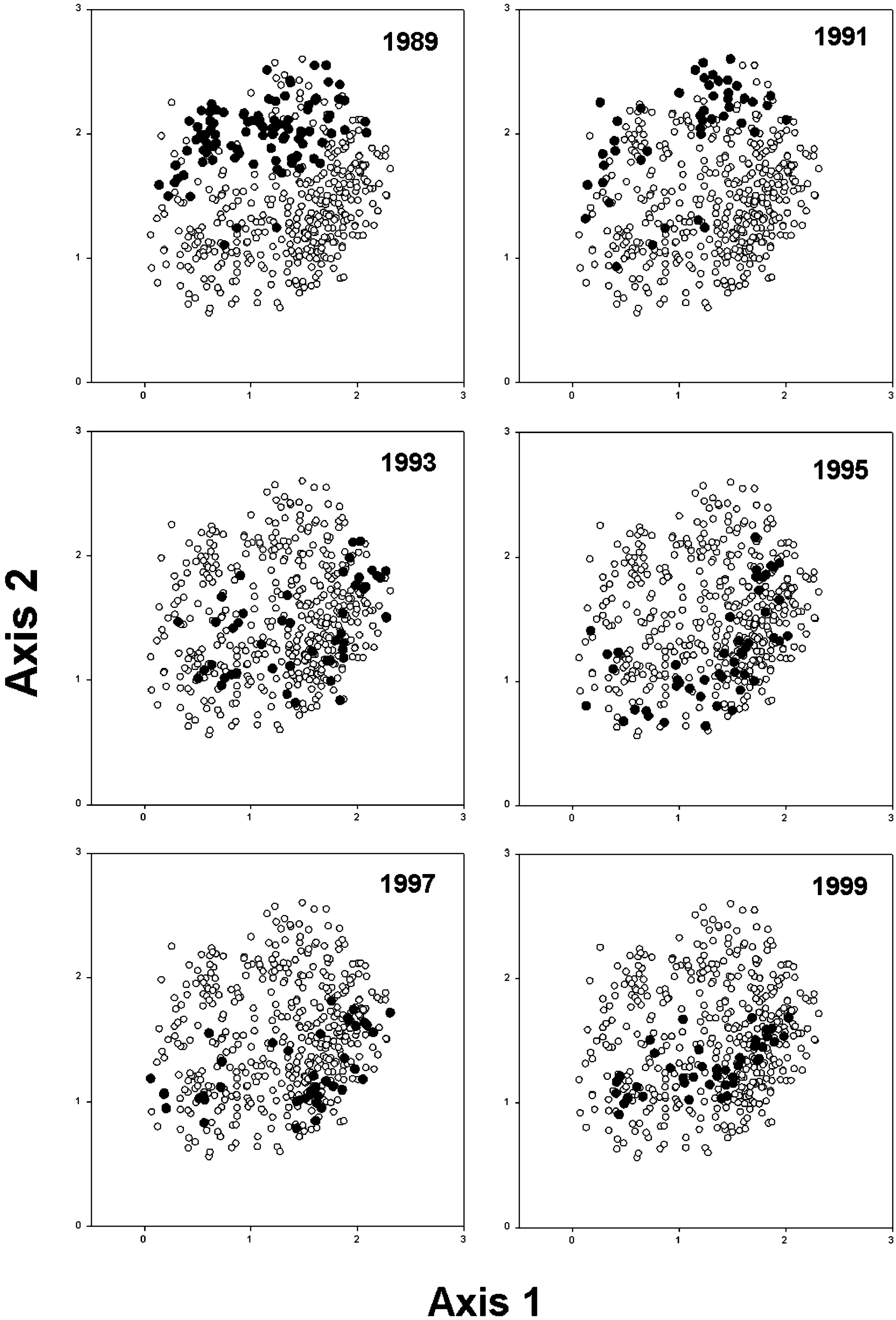

Fig. 1. Axes 1 and 2 of the DCA biplot of species data from the Hard Red range type for every second year between 1989 and 1999. Symbols indicate the positions of all 481 sites × times. Filled symbols indicate sites for a particular year.

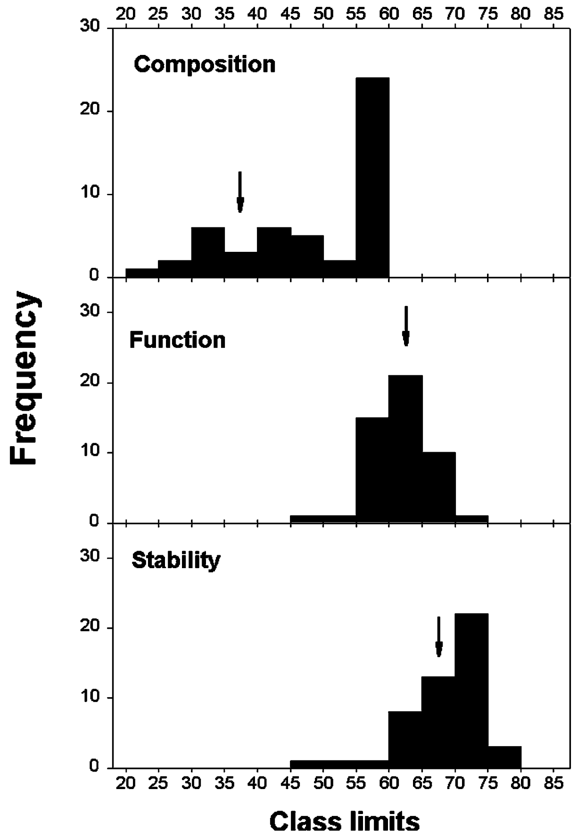

Fig. 2. Frequency distribution of scores for composition, function and stability. Arrows indicate the mean percentage class.

time period, as indicated by the fact that the original sites × times by species data matrix contained considerable (84%) zero values. Rainfall seasonality and amount provided some insights (though weak) into the distribution of species in the multivariate analyses (Fig. 1). As noted in previous studies (e.g. Friedel, 1997; Holechek et al., 2001a), the high temporal and spatial variability in rainfall in arid and semi-arid areas (Stafford Smith and Morton, 1990) tends to mask any differences in plant floristics due to differences in management such as stocking densities. Taken together then, our results suggest that plant composition alone is a poor predictor of change largely because of the strong confounding effect of seasonal conditions.

In our view, the lack of a management effect is partly attributable to the fact that the semi-arid woodlands have been substantially altered by more than 150 years of grazing by domestic livestock and feral animals (Greene et al., 1994). This means that all sites have probably reached a stable, though generally less productive, state (sensu Westoby et al., 1989), and day-to-day differences in contemporary grazing management are therefore unlikely to be reflected in the current status of sites. Native, palatable perennial plants are now absent in many parts of the semi-arid woodlands (Booth et al., 1996), and the majority of species now dominating these range types could be described as increasers or grazing tolerators (e.g. *Austrostipa scabra*, *Calotis* spp., *Medicago* spp.). In grazing-impacted landscapes such as these, the task of detecting early indicators of declining health (Holm et al., 1984) is difficult, if not impossible.

4.1. Indices of rangeland health

Rangelands are by nature highly variable from year to year (Holechek et al., 2001b), and our observations of widespread annual fluctuations in short-lived and perennial plants appeared to occur independently of changes in rangeland health (Friedel, 1997). Rangeland health or condition is a highly value-laden and context-dependent concept which can only ever be described at a qualitative level (Wilson and Tupper, 1982; Wilson et al., 1984; Watson, 1997; Pellant et al., 2000). The weightings we applied to the various site attributes such as cover, biomass and composition are likely to vary according to observer experience, background and personal biases. For example, pastoralists are likely to rate biomass (groundstorey plant production) more favourably than say environmentalists, who are likely to be more concerned with vegetation structure and diversity, and thus its impact upon flora and fauna. The Rangelands Assessment Program commenced in the late 1980s largely within the context of production i.e. it placed strong emphasis on the capacity of the rangelands to produce forage and therefore sustain grazing. Thus a combination of vegetation richness with an emphasis on perennial grasses, groundstorey plant biomass and degree of erosion typically

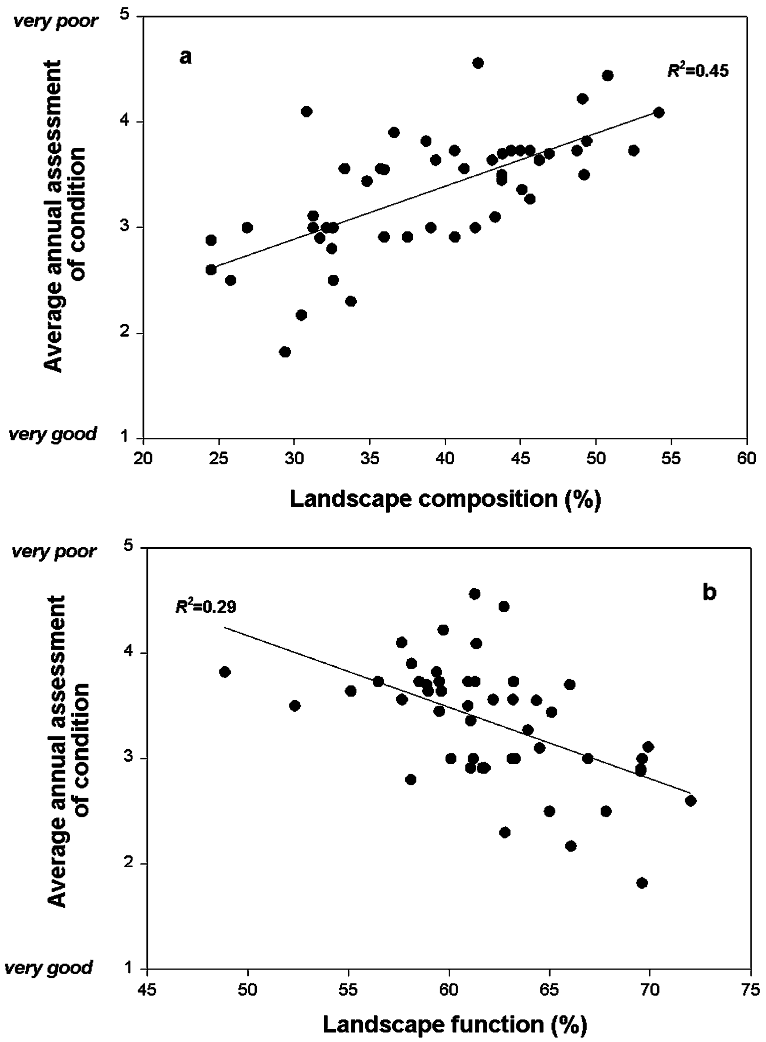

Fig. 3. Plots of the relationships between average annual assessment of condition and (a) landscape composition and (b) landscape function.

form the basis for assessment of health (Green et al., 1994).

In our study, the relationship between 'composition' and average annual condition suggests that rangeland recorders place a greater emphasis on the more obvious components of the landscape i.e. shrubs and trees rather than the groundstorey vegetation, in forming their overall view of site health. Encroachment of native shrubs such as *Acacia*, *Dodonaea* and *Eremophila* spp. into open woodland and its conversion to a shrubland is widely reported in the literature (Ludwig, 1988; Archer, 1989; Booth et al., 1996). In the context of pastoralism, shrubs are generally regarded as a sign of declining landscape health due to their tendency to outcompete with groundstorey plants, reduce pastoral productivity and restrict land management activities (Booth et al., 1996). However, woody plants (shrubs and trees) are essential components of healthy landscapes and provide a range of essential ecosystem services such as clean water, healthy soils, and a diverse plant and animal habitat (Reid and Landsberg, 1999). Clearly, approaches which consider alternative management perspectives are preferred over those which are based merely on pastoralism or even the conservation of biodiversity.

The ecosystem function approach used in the present study has the advantage that it incorporates data on the distribution and abundance of key components of biodiversity (forbs, grasses, shrubs, trees), as well as cover and biomass of plants, with data on soil surface condition (sensu Tongway, 1995) and erosion, to provide indices of function and composition which can be tracked over time. Unlike complex multivariate techniques, it is relatively transparent and readily well understood by land managers i.e. is simplistic, and the indices can be adjusted over time to accommodate the input of new information as monitoring proceeds. The approach provides a useful model within which to examine changes occurring at a site, but should not be viewed as a technique for assigning a mathematical score to sites, though this will invariably happen in some cases (Pellant et al., 2000). Holechek et al. (2001b) showed that annual condition of sites in the Chihuahuan Desert showed considerable annual variation, and values had to be averaged over several years for reliable characterisation. However, long-term monitoring of values of function, composition or stability may provide an indication of the extent to which sites are functioning over time.

4.2. Reporting changes in health

A key goal of monitoring is to guide decision making, often for a range of stakeholders and at a range of different scales (Foran et al., 1990; Burnside and Chamala, 1994). The expectations of the rangeland monitoring system are likely to change over time to match the changing demands and expectations of the current end users (Watson, 1997). Given that different end users have differing perceptions of the status of the rangelands (Wilson et al., 1984), it is difficult to report on changes in health for broad overviews as required for say the National Land and Water Resources Audit of Australia.

Governments, in particular, have a strong need for information on the state of their resources, and want to know which areas are in poor condition, and which sites are improving or declining. In this paper however we have purposely avoided assigning subjective labels such as ‘good’, ‘average’ or ‘poor’ to the Hard Red sites shown in Fig. 3. These labels fail to inform us of how sites function, and invariably they are related only to other sites at the same point in time. The risk is that rangelands in ‘poor’ condition may in fact be in a stable state because the desirable plants have been eliminated, resulting in reduced fluctuation in plant composition and little annual change (Westoby et al., 1989; Holechek et al., 2001a). Added to this are the many problems associated with ground-based monitoring such as the difficulty of separate grazing (or other human effects) from natural variation and the inability to account and correct for observer variation (Pickup, 1996).

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References

Archer S. Have southern Texas savannas been converted to woodlands in recent history? Am Nat 1989;134:545–561.

Beeston GR, Walker PJ, Purdie R, Pickard J. Plant communities of the poplar box (*Eucalyptus populnea*) lands in eastern Australia. Aust Rangel J 1980;2:1–16.

Booth CA, Sanchez-Bayo F, King GW. Establishment of woody weeds in western New South Wales. 2. Growth and competitive potential. Rangel J 1996;18:80–98.

Burnside DG, Chamala S. Ground-based monitoring: a process of learning by doing. Rangel J 1994;16:221–237.

Foran BD, Friedel MH, MacLeod ND, Stafford Smith DM, Wilson AD. A policy for the future of Australia’s rangelands. Canberra: CSIRO, 1990.

Friedel MH. Discontinuous change in arid woodland and grassland vegetation along gradients of cattle grazing in central Australia. J Arid Environ 1997;37:145–164.

Friedel MH, Chewings VH, Bastin GN. The use of comparative yield and dry-weight-rank techniques for monitoring arid rangelands. J Range Manage 1988;41:430–435.

Greene RSB, Kinnell PIA, Woods JT. Role of plant cover and stock trampling on runoff and soil erosion from a semi-arid wooded rangelands. Aust J Soil Res 1994;32:953–973.

Green D, Hart D, Prior J. Rangeland study site manual part 1: site selection and field measurement procedures. Condobolin: Soil Conservation Service of NSW, 1994.

Holechek JL, Pieper RD, Herbel CH. Range management: principles and practices. 4th ed. Upper Saddle River, NJ: Prentice-Hall, 2001.

Holechek J, Galt D, Navarro J. What's the trend? Rangelands 2001;23:10–13.

Holm AMcR, Curry PJ, Wallace JF. Observer differences in transect counts, cover estimates and plant size measurements on range monitoring sites in an arid shrubland. Aust Rangel J 1984;6:98–102.

Johns GG, Tongway DJ, Pickup G. Land and water processes. In: Harrington GN, Wilson AD, Young MD, editors. Management of Australia's rangelands. East Melbourne: CSIRO, 1984.

Lawrie JW. Soils. Condobolin district technical manual. Sydney: Soil Conservation Service of NSW, 1974.

Ludwig JA. Expert advice for shrub control. Aust Rangel J 1988;10:100–105.

Minitab, MINITAB Reference Manual, Release 12 for Windows Minitab Inc, 3081 Enterprise Drive, State College, PA, 16801-3008, 1997.

Newsome AE, Catling PC. Habitat preferences of mammals inhabiting heathlands of warm temperate coastal, montane and alpine regions of southeastern Australia. In: Specht RL, editor. Heathlands and related shrublands of the world: descriptive studies. Amsterdam: Elsevier, 1979.

Noss RF. Indicators for monitoring biodiversity: a hierarchical approach. Conserv Biol 1990;4:355–364.

Pellant M, Shaver P, Pyke DA, Herrick JE. Interpreting Indicators of Rangeland Health. TR-1734-5 US Dept of the Interior, Denver, CO, 2000.

Pickup G. Estimating the effects of land degradation and rainfall variation on productivity in rangelands: an approach using remote sensing and models of grazing and herbage dynamics. J Appl Ecol 1996;33:819–832.

Pickup G, Bastin G, Stafford Smith M. Assessment of rangelands condition and value for the National Land and Water Resources Audit National Land and Water Resources Audit, Canberra, ACT, 1998.

Reid N, Landsberg J. Tree decline in agricultural landscapes: what we stand to lose. In: Hobbs RJ, Yates CJ, editors. Temperate eucalypt woodlands in Australia: biology, conservation and restoration. Chipping Norton: Surrey Beatty and Sons, 1999. p. 127–166.

Stafford Smith DM, Morton SR. A framework for the ecology of arid Australia. J Arid Environ 1990;18:255–278.

ter Braak CJF. CANOCO—A FORTRAN program for Canonical Community Ordination Microcomputer Power, Ithaca, NY, 1991.

Tongway DJ. Monitoring soil productive potential. Environ Monit Assess 1995;37:303–318.

Watson IW. Continuous and episodic demography of arid zone shrubs in Western Australia, 1983–1993; PhD thesis, Macquarie University, Sydney, Australia, 1997.

Westoby M, Walker B, Noy-Meir I. Range management on the basis of a model which does not seek to establish equilibrium. J Arid Environ 1989;17:235–239.

Wilson AD, Tupper GJ. Concepts and factors applicable to the measurement of range condition. J Range Manage 1982;35:684–689.

Wilson AD, Tongway DJ, Graetz RD, Young MD. Range inventory and monitoring. In: Harrington GN, Wilson AD, Young MD, editors. Management of Australia's rangelands. Melbourne: CSIRO, 1984. p. 113–128.