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Landscape function analysis: a system for monitoring rangeland function

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Landscape Function Analysis (LFA) is a monitoring procedure that uses quickly determined field indicators to assess the functional status of rangelands. As such, it complements existing procedures that assess condition. It comprises three modules — a conceptual framework, a field methodology and an interpretational framework — and is intended to generate chronosequences of data. The conceptual framework is based on the economy of vital resources and focuses on the processes that regulate the spatial movement and use of water, topsoil and organic matter in the landscape. The field methodology uses simple, visual indicators closely related to a range of physical, chemical and biological processes, taking only a few seconds per indicator to assess in the field after training. Observations of system dynamics are made in two spatially nested scales ('hillslope' and 'patch'). A patch is an area on a hillslope where scarce, vital resources tend to be accumulated. A software template generates a series of tables containing data at both scales. The interpretational framework is based on a sigmoidal response surface linking the lowest and highest functional examples of a given landscape type across a stress/disturbance gradient. It facilitates the identification of target values for rehabilitation and the propinquity of monitored sites to a critical threshold distinguishing 'sustainable' from 'unsustainable' management/climate combinations. The procedure enables critically vulnerable processes to be identified, so that rehabilitation procedures can be appropriately designed. LFA has been developed, tested and implemented in a range of climate types (200mm to 4 000mm rainfall per year) and land-uses (pastoralism, mining, nature conservation).

Keywords: indicators, interpretational framework, rapid assessment, trajectory

Introduction

Rangeland monitoring has typically been descriptive: restricted to evidence provided by a narrow range of biota or associated with theories of plant succession (Golley 1977, Friedel 1991). The properties selected for monitoring were limited to those describing composition and structure. Functional attributes or ecosystem processes were obliquely alluded to but not directly addressed. In addition, these methods were not designed to prescribe rehabilitation. For example, ants have been shown to be good indicators of the decline in condition (Andersen 1990), but do not of themselves prescribe a restoration procedure. That is, ants are responding to, but not causing, a broader set of environmental constraints. Methods have also been largely tied to pastoralism as the only, or main, land-use. This situation is now changing, with a broader societal use of rangelands and increasing public opinion demanding attention to degradation, sustainability and conservation of biodiversity issues. Monitoring and comparing landscapes on an inter-regional and national basis in, for example, the Australian National Land and Water Audit, would be better facilitated if a single assessment procedure were widely applicable and the data directly comparable. Walker (1996) called for an understanding of how rangelands function by building conceptual models. Ludwig and Tongway (1997) presented a systems-based framework (trigger-transfer-reserve-pulse — TTRP, Figure 1 in combination with Table 1) describing the way in which rangelands function. This framework was based on the manner in which landscapes are self-organised to conserve and utilise and cycle scarce resources. This framework also facilitated the development of more detailed simulation models (e.g. Ludwig and Marsden 1995, Ludwig *et al.* 1999), enabling the models to have a wider, landscape-oriented context.

Method Development

Methods to assess soil productive potential linked to plant performance had been developed to a certain stage (Tongway and Smith 1989, Ludwig and Tongway 1992), but needed the spatial and inter-regional context to become more useful to a range of potential stakeholders. The TTRP conceptual framework (Ludwig and Tongway 1997) represents a sequence of landscape processes and feedback loops in an inclusive, but not overly complex, manner facilitating the structuring of a wide range of environmental information. The 'soil condition' indicators were initially developed from geomorphic processes such as surface hydrology, erosion, crust formation, litter decomposition and their correlates observed in the field. The validity of these indicators was enhanced by laboratory experiments (M cher *et al.* 1988, Greene *et al.* 1994) and field measurements (Tongway 1993, Greene 1992). Spatial analysis of a number

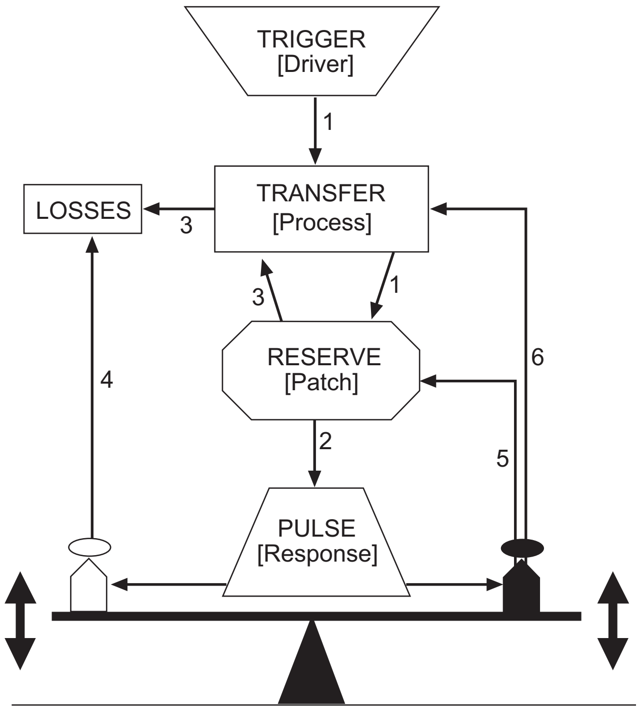

Figure 1: The TTRP framework representing sequences of ecosystem processes and feedback loops. Table 1 lists some of the processes operating at different locations in the framework

Table 1: Some of the processes operating at the different locations in the TTRP framework in Figure 1

Ref	Process
1	Run-on
	Infiltration storage / Capture
	Deposition
	Saltation capture
2	Plant germination, growth
	Nutrient mineralisation
	Uptake processes
3	Run-off into streams
	Rill flow and erosion
	Sheet erosion out of system
	Wind erosion out of system
4	Herbivory
	Fire
	Harvesting
	Deep drainage
5	Seed pool replenishment
	Organic matter cycling / Decomposition processes
	Harvest / Concentration by soil micro-fauna
6	Physical obstruction / Absorption processes

of landscape types (Ludwig and Tongway 1995) suggested a means by which the soil indicators could be packaged for use in different landscape types at the hillslope scale.

In 1992–1995, funding brokered by Agriculture Western Australia under the National Soil Conservation Program facilitated the development of an extensively applicable method by integrating the fine scale procedures for assessing soil surface condition with the emerging TTRP landscape scale conceptual framework (Tongway 1994, Tongway and Hindley 1995, 2000). This resulted in a nested hierarchical information gathering procedure using rapidly acquired field assessment data. The method was overtly linked to existing land system field protocols (e.g. McDonald *et al.* 1990, Mitchell *et al.* 1988, and many others). We particularly recognised 'land units' as distinctive sub-units within land systems and the monitoring sites were located within those defined land units.

The Method of Operation

'Landscape organisation' of the hillslope is the coarsest form of data and is the first step in LFA. Data are collected on a line transect oriented in the direction of resource flow (usually down the slope, but aeolian landscapes would use modal wind direction). The transect line is divided into patches (features that tend to accumulate resources) and interpatches, where those resources tend to be mobilised and transported. A 'map' of patches and interpatches is the product of this procedure and a number of indices of 'landscape organisation' are tabulated. These indices can be compared with data acquired over time, to see if the landscape being studied is acquiring or losing resource regulation in a gross sense. In the second step, each patch and interpatch type is assessed for 11 soil surface indicators, using guidelines and images in the manual. We developed these indicators to address all the processes identified in the TTRP conceptual framework. Most of these observations take about five seconds each to assess with practice. The soil surface data are combined into three major soil habitat quality indices: (i) stability or resistance to erosion, (ii) infiltration / water holding capacity and (iii) nutrient cycling (Table 2). The data are presented as percentage values of the maximum possible. Vegetation parameters (such as density, species composition, size) can also be collected from the same transect using plotless, distance measuring techniques (Bonham 1989) as well as indicators of habitat complexity for mammals and birds (Newsome and Catling 1979).

Relationships of LFA Indices to Measured Variables

We have tested the three indices in Table 2 on a range of landscape types with rainfall intensity varying from 200mm to 4 000mm yr^{-1} and a range of land-uses that include extensive grazing, minesite rehabilitation, conservation of biodiversity and cropping practices. We used existing published measurement types commonly used in soil science to measure soil properties and correlated the LFA indices with measured soil variables. When the full dynamic range of each indicator was examined, we obtained good relationships across the range of landscape types and management regimes studied. Data for three contrasting ecosystems are presented in Figure 2. The equations representing the correlations did not have the same coefficients across landscape types, but Figure 2 indicates the quality of the 'within landscape type' relationships. Verification data acquired

Table 2: The combination of Soil Condition Classes to derive indices of stability, infiltration and nutrient cycling

Indicator	Stability	Infiltration	Nutrient cycling
1. Soil cover	✓		
2. Basal cover of perennial grass and tree/shrub canopy cover		✓	✓
3a. Litter cover	✓		
3b. Litter cover, origin and degree of decomposition		✓	
4. Cryptogam cover	✓		✓
5. Crust broken-ness	✓		
6. Erosion type and severity	✓		
7. Deposited materials	✓		
8. Surface roughness		✓	✓
9. Surface resistance to disturbance	✓	✓	
10. Slake test	✓	✓	
11. Soil texture		✓	

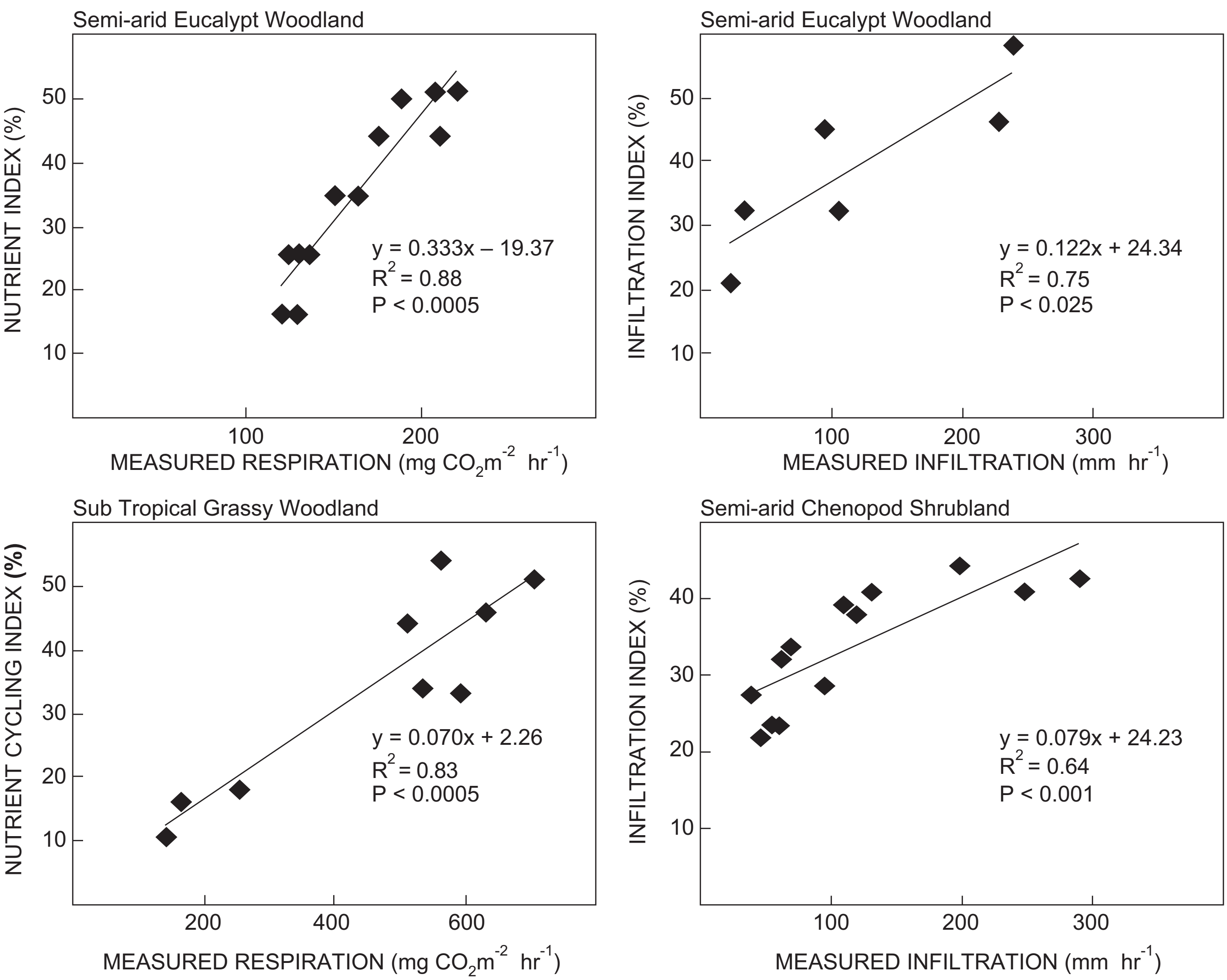

Figure 2: Relationships between LFA indices and measured soil variables in three contrasting landscape types. These data are a subset of those appearing in Tongway and Hindley 2003.

from nine mine-sites across Australia are available from a web page (Tongway and Hindley 2003)

A functional interpretation of vegetation data can augment the basic LFA data set. For example, Figure 3 shows the canopy cover of vegetation resolved into 1m height classes, so that the effect of wind and water as vectors of resource transport can be assessed.

Interpretational Framework

The LFA values need to be interpreted in the whole landscape and land-use context to make the most use of their information potential. With extensive experience, one might be able to place useful interpretations on each of the index values, but this is a subjective process. In the most recent development in LFA, a response surface in the form of a sigmoidal curve is generated from field data (Tongway and Hindley 2000). Noy-Meir (1981) originally suggested this curve form in relation to surface hydrology. Four-parameter sigmoid curves of the form $\mathbf{y = y_0 + a / 1 + e^{-(x-x_0)/b}}$ provide four practical values reflecting the intrinsic nature of the landscape. The curve relates functional status derived along gradients in stress and disturbance. To fit this curve, one needs data from both extremes of the available data space as well as intermediate values representing ‘typical’ sites. The response surface recognises the upper asymptote (y_0 + a) as the ‘biogeochemical potential’ of the site limited by climate and parent material and the lower asymptote (y_0) as the lower limit of function under the existing stress/disturbance regime in a degradation scenario. On mine-sites this would represent the functional status at the commencement of rehabilitation. The slope of the line joining the asymptotes (represented by b) reflects the ‘robustness’ or ‘fragility’ of the system where degradation is the issue and the rate at which function is improving in a rehabilitation scenario. x_0 can represent either a time or space value reflecting ‘self-sustainability’ in the landscape (Figure 4, Tongway and Ludwig 2002). The response of landscape function to stress and/or disturbance is markedly different for robust and fragile landscapes. The fragile landscape deteriorates with low levels of applied stress and potentially has a much lower retained function, $\mathbf{y_0}$, compared to a robust landscape.

Application of LFA Data to Contrasting Land Management Systems

1. Rangelands. LFA can be used to examine rangeland functional state over time within a management context and with the inclusion of monitoring stochastic disturbance events like fire, flood or storm, to see whether a critical threshold has been approached or exceeded. The value of knowing the index value of the best site available as well as the most disturbed site index values facilitates a practical context in which an appreciation of the dynamic range in function can be formed. This becomes important in identifying ‘fragile’ site types. These sites would require more careful or more frequent assessment than sites shown to be ‘robust’ under the prevailing management regime. Even when plant cover is very low or absent, the data reflecting the residual function can still be discerned by LFA.
2. Minesites. LFA has been useful in following the temporal development of rehabilitation on minesites. Here, the use of analogue sites to produce functional data to act as ‘target’ values for rehabilitation is very useful for regulatory purposes, though finding appropriate sites is not necessarily easy. The record of functional development over time, producing either a sigmoidal or some other response surface, may also strengthen the ultimate case for bond return where satisfactory rehabilitation has been demonstrated.
3. Landscape function at management boundaries. LFA can identify critical missing processes in dysfunctional landscapes in many land-use applications, for example road verges and native woodland remnants and thus enable appropriate rehabilitation procedures to be designed. Threatening processes emanating from adjacent but differing land uses can be assessed by examining changes

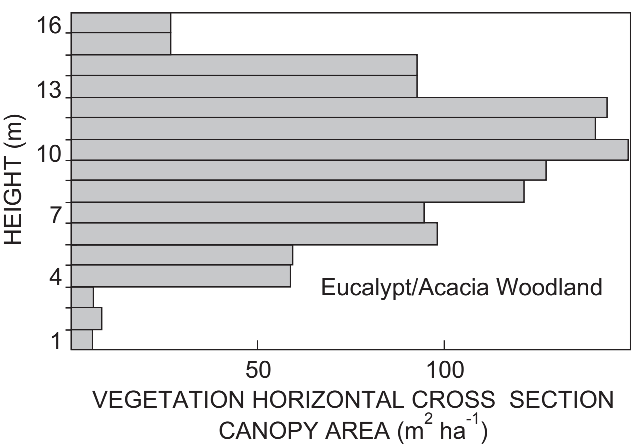

Figure 3: The vegetation horizontal cross canopy area of a Eucalypt/Acacia woodland in 1m height classes

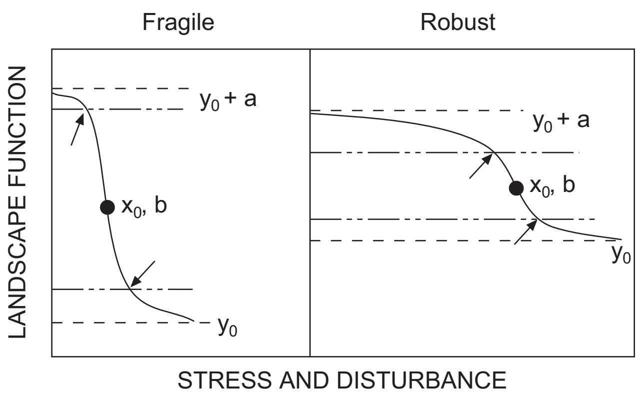

Figure 4: Representations of proposed response curves for fragile and robust landscapes, relating changes in landscape to gradients in applied stress/disturbance regimes. Critical thresholds (arrows) for each of the indices can be identified. The slope factor, b, is also a sensitive indicator of fragility/robustness.

in landscape function across boundaries and looking at the rate of change of LFA indices with distance from the boundary (Ludwig *et al.* 2004).

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References

Andersen NA 1990. The use of ant communities to evaluate change in Australian terrestrial ecosystems — a review and recipe. Proceedings of the Ecological Society of Australia 16: 347–357.

Bonham CD 1989. Measurements for Terrestrial Vegetation. John Wiley and Sons, USA.

Friedel MH 1991. Range condition assessment and the concept of thresholds: a viewpoint. Journal of Range Management 44: 422–426.

Golley FB 1977. Ecological Succession. Dowden, Huthinson & Ross, Stroudsburg, USA.

Greene RSB 1992. Soil Physical properties of three geomorphic zones in a semi-arid mulga woodland. Australian Journal of Soil Research 30: 55–69.

Greene RSB, Kinnell PIA and Wood JT 1994. Role of plant cover and stock trampling on runoff and soil erosion from semi-arid wooded rangelands. Australian Journal of Soil Research 32: 953–973.

Ludwig JA and Marsden SG 1995. A simulation of resource dynamics within degraded semi-arid landscapes. Mathematics and Computers in Simulation 39: 219–224.

Ludwig JA and Tongway DJ 1992. Monitoring the condition of Australian arid lands: linked plant-soil indicators. In: DH McKenzie, DE Hyatt and VJ McDonald (eds) Ecological Indicators. Elsevier, Essex. pp 765–772.

Ludwig JA and Tongway DJ 1995. Spatial organisation of landscapes and its function in semi-arid woodlands, Australia. Landscape Ecology 10: 51–63.

Ludwig JA and Tongway DJ 1997. A landscape approach to rangeland ecology. In: J Ludwig, D Tongway, D Freudenberger, J Noble and K Hodgkinson (eds) Landscape Ecology Function and Management: Principles from Australia's Rangelands. CSIRO, Melbourne. pp 1–12.

Ludwig JA, Tongway DJ, Bastin GN and James CD 2004. Monitoring ecological indicators of rangeland functional integrity and their relation to biodiversity at local to regional scales. Austral Ecology 29: 108–120.

Ludwig JA, Tongway DJ and Marsden SG 1999. Stripes, strands or stipples: modelling the influence of three lanscape banding patterns on resource capture and productivity in semi-arid woodlands, Australia. Catena 37: 257–273.

McDonald RC, Isbell RF, Speight JG, Walker J and Hopkins MS 1990. Australian Soil and Land Survey Handbook (2nd edn). Inkata Press, Melbourne.

Mitchell AA, McCarthy RC and Hacker RB 1988. A range inventory and condition survey of part of the Western Australian Nullarbor Plain, 1974. Technical Bulletin No. 47, Western Australian Department of Agriculture.

M cher HJ, Chartres CJ, Tongway DJ and Greene RSB 1988. Micromorphology and significance of the surface crusts of soils in rangelands near Cobar, Australia. Geoderma 42: 227–244.

Newsome AE and Catling PC 1979. Habitat preferences of mammals inhabiting heathlands of warm temperate coastal, montane and alpine regions of southeastern Australia. In: RL Specht (ed) Ecosystems of the World 9A: Heathlands and Related Shrublands of the World. Elsevier Scientific Publishing Co., Amsterdam. pp 301–316.

Noy-Meir I 1981. Spatial effects in modeling of arid ecosystems. In: DW Goodall and RA Perry (eds) Arid-land Ecosystems: Structure, Functioning and Management Vol. 2. Cambridge University Press, Sydney. pp 411–432.

Tongway DJ 1993. Functional analysis of degraded rangelands as a means of defining appropriate restoration techniques. In: A Gaston, M Kernick and H Le Houérou (eds) Proceedings of the Fourth International Rangeland Congress, Montpellier. pp 166–168

Tongway DJ 1994. Rangeland Soil Condition Assessment Manual. CSIRO, Melbourne.

Tongway D and Hindley N 1995. Assessment of Soil Condition of Tropical Grasslands. CSIRO Division of Wildlife and Ecology, Canberra.

Tongway D and Hindley N 2000. Assessing and monitoring desertification with soil indicators. In: S Archer and O Arnalds (eds) Rangeland Desertification. Kluwer, Dordrecht.

Tongway D and Hindley N 2003. Indicators of Ecosystem Rehabilitation Success. Stage 2 Verification of EFA indicators. http://www.cse.csiro.au/research/program3/efa/

Tongway D and Ludwig J 2002. Desertification, reversing. In: L Rattan (ed) Encyclopedia of Soil Science. Marcel Dekker, New York.

Tongway DJ and Smith EL 1989. Soil surface features as indicators of rangeland site productivity. Australian Rangeland Journal 11: 15–20.

Walker BH 1996. Having or eating the rangeland cake: a developed world perspective on future options. In: N West (ed) Rangelands in a Sustainable Biosphere Vol. II. Proceedings of the Vth International Rangelands Congress. Society of Range Management, Denver. pp 22–28.