Landscape Function Analysis: Procedures for Monitoring and Assessing Landscapes – with Special Reference to Minesites and Rangelands

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LANDSCAPE FUNCTION ANALYSIS:

PROCEDURES FOR MONITORING AND ASSESSING LANDSCAPES

With special reference to Minesites and Rangelands

D J Tongway and N L Hindley

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CONTENTS

FIGURES

TABLES

PREFACE

Since first settlement by Europeans major changes have occurred in Australian landscapes. This has occurred through both lack of knowledge and understanding of the climate, soils and vegetation. The necessity to feed both man and his domesticated animals has lead to the large scale degradation of some of the landscape as settlement moved inland from the coast. The discovery of minerals and their subsequent exploitation has also impacted on the landscape. The landscape functional analysis (LFA) method was developed to assess this degradation and track any subsequent recovery. The functional status of the landscape was monitored by creating indices based on simple field indicators that reflect the measured variables of stability, water infiltration and nutrient cycling.

The two earlier manuals (Tongway 1994, and Tongway and Hindley 1995) were prepared specifically for the monitoring of rangelands and looked at 'soil features' leaving the vegetation to be monitored by existing well proven traditional methods. Since these manuals were published the use of LFA method has been extended into monitoring minesite rehabilitation and the need for a more functional interpretation of the role of vegetation emerged. This new manual provides a more holistic and integrated approach to the monitoring of landscapes by assessing the functionality of the soils and vegetation. This method does not replace the traditional botanical methods of monitoring vegetation but adds a functional interpretation to link vegetation structure and organization more closely with soil function and the development of the habitat for mammals. A framework for the interpretation of this data is also provided, to aid management decisions.

The method has been tested and implemented widely throughout Australia by the authors with good correlations between the accessed indices and the measured variables. It has also been used by other researchers in Africa, Middle East, Southern Europe and Asia. The red dots on the map of Australia (Fig. 1) indicate where the method has been used by the authors in Australia. Indonesia and New Guinea.

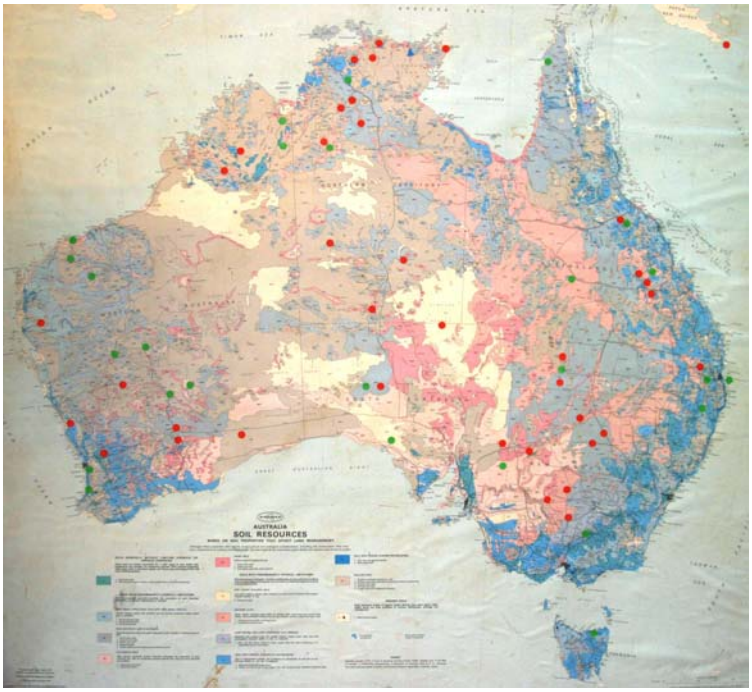

Figure 1. Locations in Australia (red dots) where the LFA methodology has been applied. The base map is Commonwealth Copyright © Geoscience Australia. All rights reserved. www.ga.gov.au.

INTRODUCTION

Monitoring is defined as observing, detecting, or recording the operation of a system; watching closely for purposes of control; surveilling; keeping track of; checking continually; detecting change (James et al 2003).

Monitoring landscape "health" over time in response to environmental, management or regulatory drivers has importance for land managers ranging from individuals to governments, especially when the monitoring output has direct relevance for management decision-making. Monitoring may be seeking to look for evidence of landscape degradation or of rehabilitation and the procedure needs to have equal facility in dealing with these scenarios. Monitoring may also provide information for day-to-day property management.

Landscape function analysis (LFA) is a monitoring procedure that uses rapidly acquired field-assessed indicators to assess the biogeochemical functioning of landscapes at the hillslope scale.

Since the publication of the *Rangeland Soil Condition Assessment Manual* (Tongway 1994) and the *Manual for Assessment of Soil Condition of Tropical Grasslands* (Tongway and Hindley 1995), the use of the proposed procedure in a wider range of landscapes has developed an improved understanding of the processes underlying landscape functioning. Advances in conceptual thinking (Ludwig and Tongway 1997) have enabled a greater understanding of these processes. The procedure has been applied in natural landscapes and those rehabilitated after mining, in climatic regimes ranging from the arid zone (150 mm annual rainfall) in Australia to tropical rainforest near the equator in Indonesia (4000 mm annual rainfall) and in land-uses ranging from traditional rangelands through mining to conservation of biodiversity. The basic field methods have changed very little, but enhancements have been made to some of the indicators to make them more readily assessed across the broad range of ecosystems in which the procedure in now used.

This development process has been characterized by several iterations of an adaptive learning loop as depicted in Figure 2, but with a broad range of client groups, only one of which is depicted in the above figure. A major contribution to the development process has been through a project funded through Australian Centre for Mining Environmental Research, working at nine mines from hard rock (arid to equatorial), sand mining (semi-arid), bauxite (tropical) and open cut coal mining (sub tropical). The changes made have enabled the understanding and prompt interpretation of the data to be developed into more useable information sets for direct use by land managers and regulators.

The adaptive learning loop used to enhance this indicator system for the mining industry is illustrated in Figure 2.

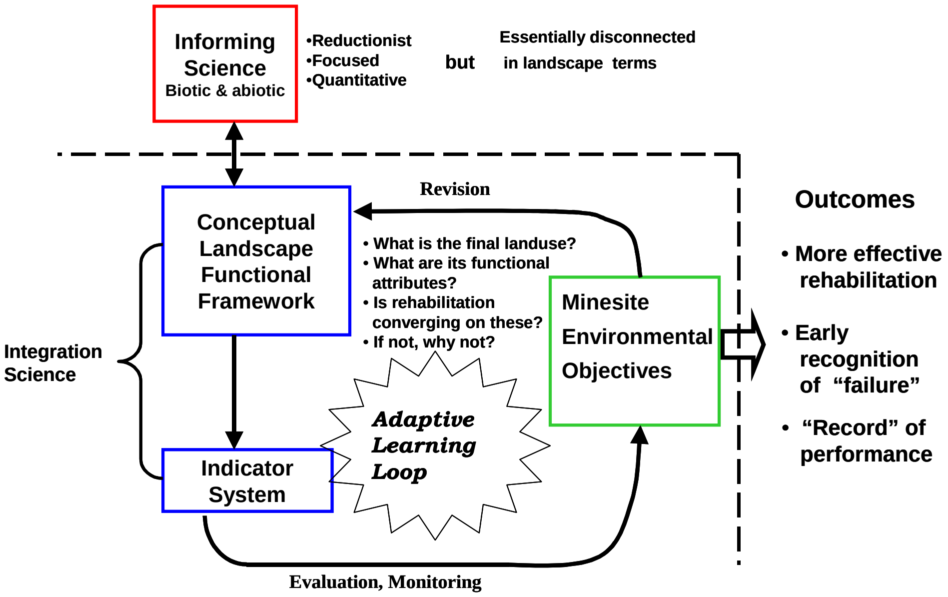

Figure 2. The adaptive learning loop that allows the development of an indicator system by explicit interaction between the client/stakeholders (in this case, a minesite) and science. It is important that the imperatives of science are communicated to the end users and that appropriately integrated scientific information be communicated to the end user. Information from a wide range of scientific sources was analyzed and re-synthesised or integrated for the benefit of end-users.

The original procedure has been broadened to include information about the functional role of vegetation structure and habitat quality for fauna in a more comprehensive assessment. This expanded procedure is comprised of three modules depicted as a central core with annular layers of related information (Fig. 3).

I. landscape function analysis (LFA), which is the original method that is the central "core" procedure linked to,
II. vegetation and structure composition (VS), with an outer layer of,
III. habitat complexity (HC).

The modules are designed for joint implementation.

Although inner core information tends to "drive" outer components in a cause/effect relationship, there are important feedback loops. The "core" and the "layers" each comprise a methodology module, but their respective sets of information are spatially and conceptually connected.

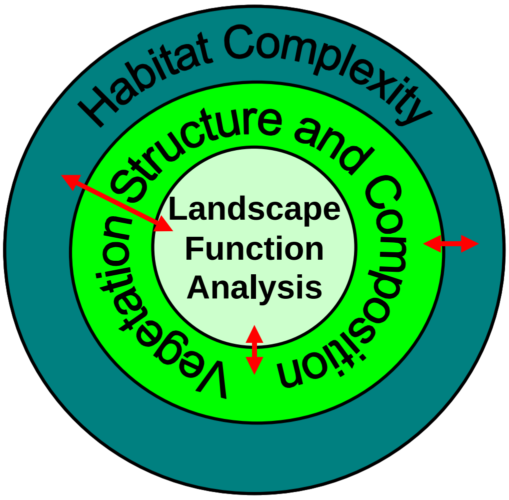

Figure 3. The inter-relationship of the three components of an expanded LFA monitoring procedure.

This manual is particularly concerned with distinguishing “pasture utilization” from “landscape degradation”. In the former case, a relaxation of utilization intensity would result in a return to higher production, but in the latter case the loss of soil productivity would restrict production and probably affect the composition of the vegetation (Fig. 4.) The concept of the environmental envelope, where the interaction of soil and climate affects the vegetation reponse, has considerable utility when transferred to rehabilitation on minesites. The interaction of climate on soil/spoil needs to produce an edaphic habitat appropriate for specified species to establish and flourish.

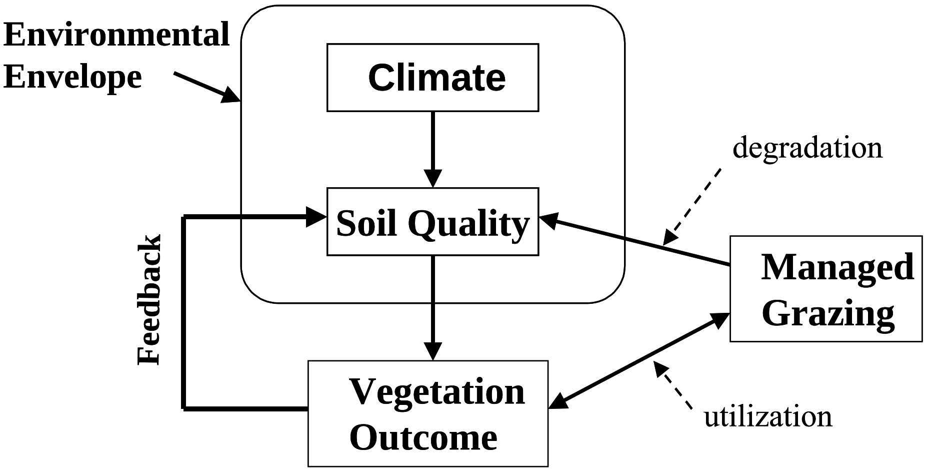

Figure 4. In rangelands, if grazing management degrades the soil productive potential, the soil environment for vegetation may be changed substantially and hence alter the “environmental envelope”. e.g. such that the habitat for desired species is lost. Soil may have altered chemical , physical or biological properties.

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WHAT IS LANDSCAPE FUNCTION ANALYSIS (LFA)?

LFA is the core of the monitoring procedures described in this manual, and uses visually assessed indicators of soil surface processes that gauge how effectively a hillslope is operating as a biophysical system. It is the synthesis of much published material from a variety of sources and is based mainly on processes involved in surface hydrology: rainfall, infiltration, runoff, erosion, plant growth and nutrient cycling. It is comprised of four components:

A a conceptual framework

B a field data acquisition

C a data reduction and tabulation

D an interpretational framework

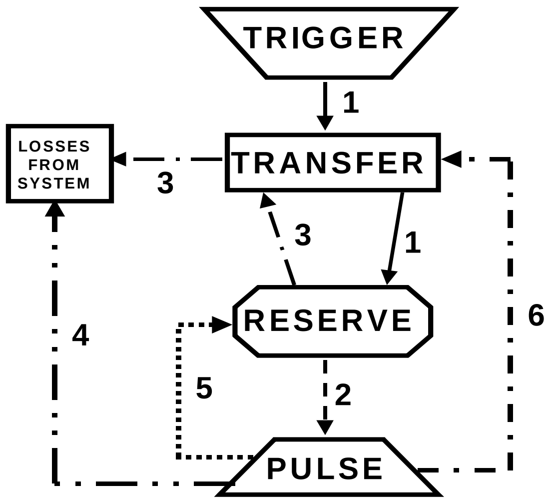
These are discussed in detail below.

******

A THE LFA CONCEPTUAL FRAMEWORK:

Trigger-Transfer-Reserve-Pulse (TTRP)

The concept of landscape function has been fully described in Ludwig *et al.* (Eds) 1997 and Whisenant 1999. Both of these books described a similar approach that deals with ecosystems in terms of processes involved in the transport, utilisation and cycling of scarce and limiting resources, such as water, topsoil, organic matter and propagules, in space and time. This approach specifically examines the functioning of a landscape and is differentiated from biological composition and structure that have been the traditionally assessed characteristics. Ludwig and Tongway (1997) proposed a conceptual framework representing landscape function similar to Figure 5. This framework represents a sequence of processes operating to maintain the biogeochemical “engine-room” of a landscape. Resource losses from the system are assessed against both inputs and feedback mechanisms. Loss of landscape function means that the system “leaks” resources beyond its boundaries, whereas a gain in function means that control over resource loss is increased, as happens in successful rehabilitation.



Ref	Process
1	• Run-on • Storage/Capture • Deposition • Saltation capture
2	• Plant germination, growth • Nutrient mineralisation • Uptake processes
3	• Run-off • 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 • Creation of habitat niches by soil fauna
6	• Physical obstruction/Absorption processes

Figure 5. The conceptual framework representing sequences of ecosystem processes and feedback loops. The table lists some of the processes operating at different locations in the framework.

To summarise figure 5, a trigger, such as rainfall, may result in runoff that is spatially relocated (transferred, 1) across the landscape. Some resources may be lost to the system by runoff (3) and some may be absorbed into the soil (the reserve-1). In addition, some parts of the landscape absorb more of the water than other parts, due to differential inter-patch/patch characteristics (described in more detail below). A pulse of plant growth and of mineralised nutrients (2) may ensue depending on the status of the reserve. Some of the growth may be lost from the system (4) by fire or herbivory and the remainder is cycled back (5) to the reserve. A growth pulse may also feed back (6) to modify subsequent transfer processes by physical means.

The framework recognises:

- the overt spatial redistribution of resources and hence functional connectivity between the ecosystem components in the landscape;
- the importance of considering spatial sequences of processes, rather than composition or structure *per se* in the ecosystem components;
- the importance of feedback processes in regulating ecosystems in the long term. Key or "framework" species may provide major regulatory services to the system;
- the concept of the "economics" of vital resources;
- that specific simulation models can be developed from this general framework (e.g., hydrological, nutrient cycling);
- this framework is generic and summarises the processes by which scarce/vital resources are retained and utilised in the landscape (e.g. Figs 7 and 10 gives two examples of how resources are controlled and utilized in the field situation.

Further, the TTRP conceptual framework implies that:

1. landscapes are often highly patterned, with well-defined source/sink or inter-patch/patch sequences, which are responsible for mediating the processes inferred in Figure 5. This pattern is most efficiently assessed by locating a line transect directly downslope and identifying sequences of inter-patch and patch that are linked by hydrological processes. This is an example of the gradsect approach to understanding ecosystem behaviour (Gillison and Brewer 1984)

2. the scale at which the landscape pattern is monitored comes from the landscape itself i.e. the scale at which the processes are taking place. This can vary from fractions of a metre in grasslands to many tens of metres in semi-arid woodlands. No particular spatial scale is assumed; observation of surface processes establishes the scale.

Figure 6 (after Baird 1990) illustrates the transition from purely structural and compositional descriptions of landscapes to include biogeochemical functioning and to use that information in field circumstances where landscape modification markedly alters all three components. Figure 6a shows the spatial relationship of discrete vegetation assemblages on a topographic catena. Figure 6b shows the same catena but with functional processes reflecting within and between vegetation assemblies with resource flows added. Figure 6c is an example of a typical clearing pattern where large proportions of native vegetation have been cleared for cropping. Bigeochemical processes are markedly changed in the current land use.

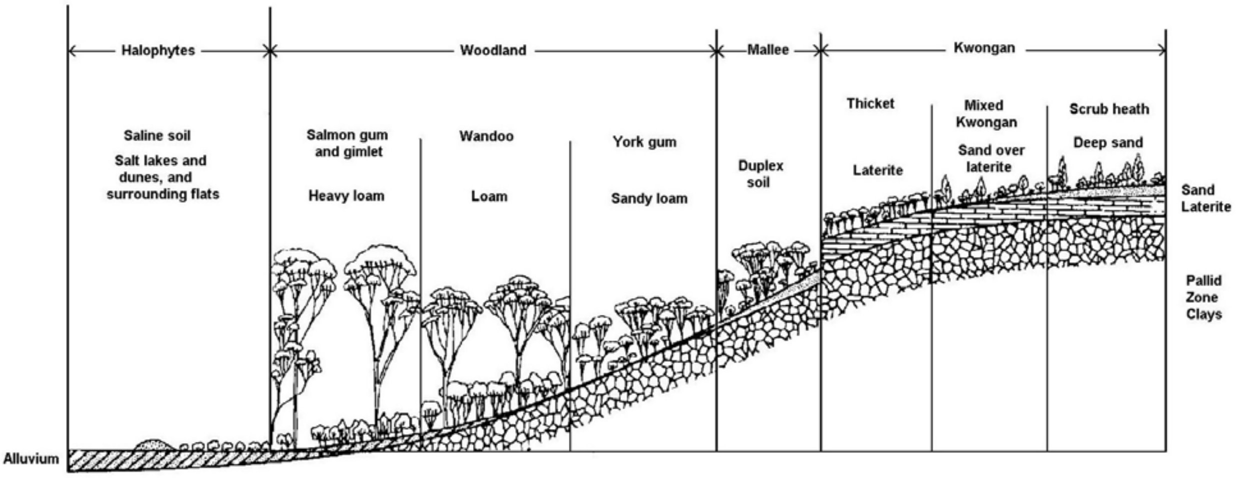


Figure 6a

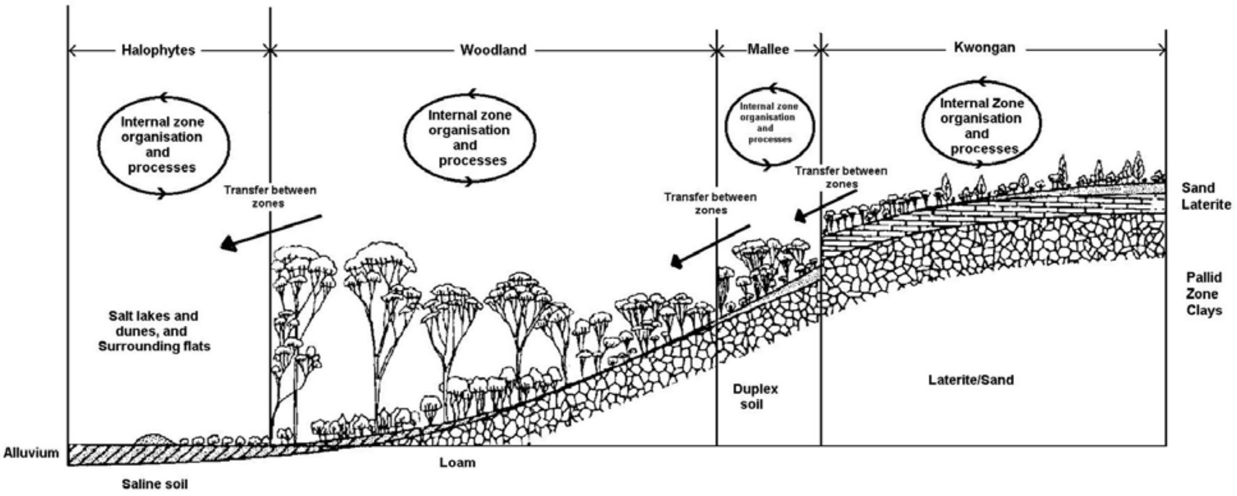


Figure 6b

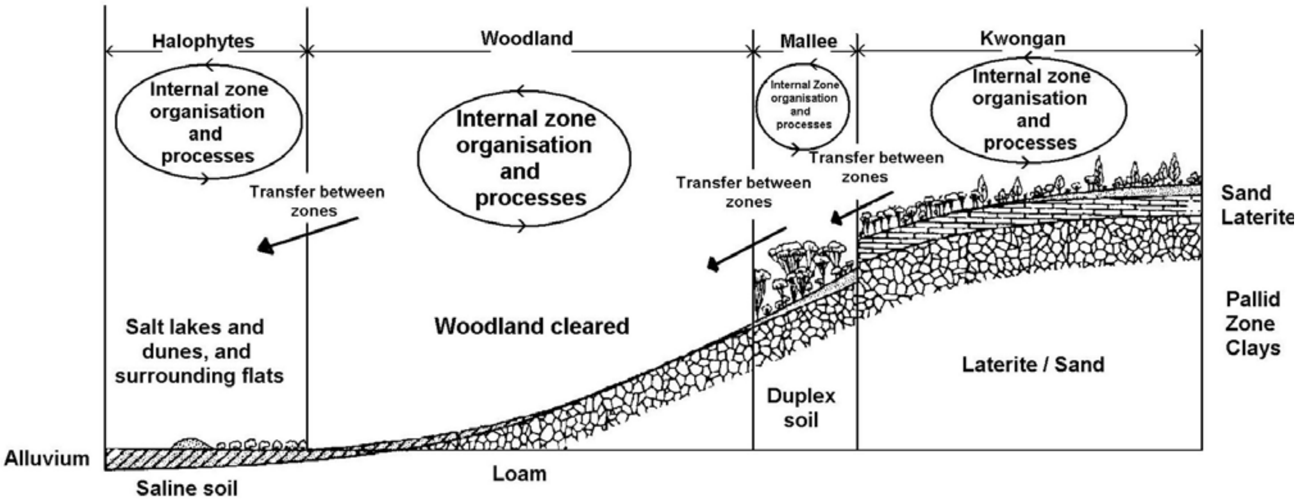


Figure 6c

Figure 6. (after Baird 1990) Illustrating the transition from structural and compositional descriptions (6a) to include biogeochemical functionality in undisturbed (6b) and highly disturbed (6c) landscapes.

Function as a Continuum

Landscape function is a continuum, conceptually ranging from "fully functional" to "totally dysfunctional". "Function" refers to how well the landscape is performing as a biophysical system and is as free of social and economic values as possible. We will discuss the shape form of this continuum later in the Interpretational Framework section.

Once determined, the functional assessment of a landscape is then subjected to a 'societal needs' assessment, which is expressed in terms of the condition of a particular landscape for a particular purpose or land use. For example, what may be acceptable for grazing may be less so for carbon sequestration and unacceptable for conservation of biodiversity (Fig. 7).

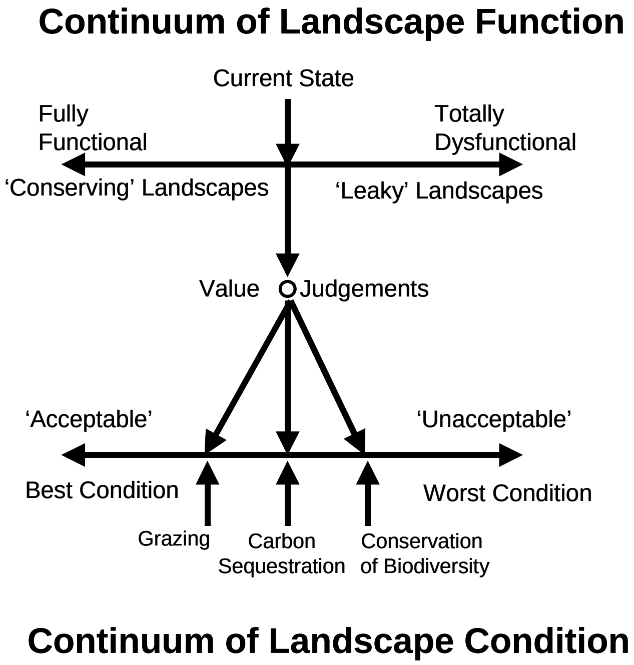


Figure 7. The relationship between landscape function (how well resources are regulated) and landscape condition (how well-suited a landscape is for a particular purpose) is depicted.

Field Examples of TTRP Hillslope-Scale Processes

In landscapes with a high functional status, soil, water and nutrients (collectively called "resources") are strongly conserved within the landscape and used within that system. Internal redistribution processes of depletion and accession can be observed in the field (e.g. Figs 8, 9a and 10a).

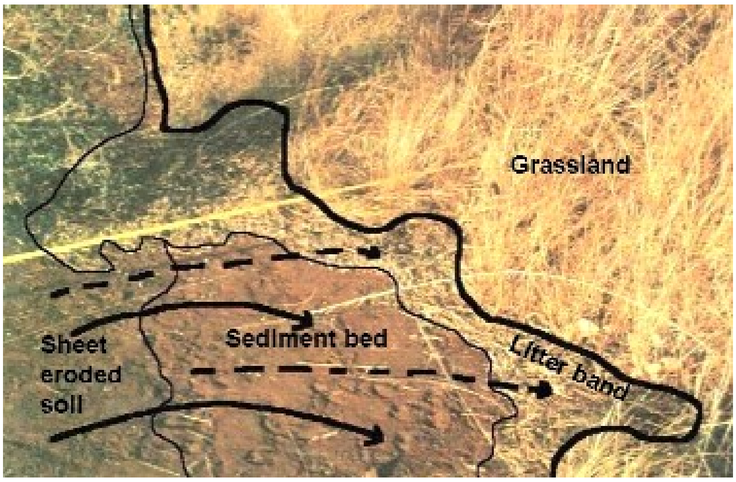
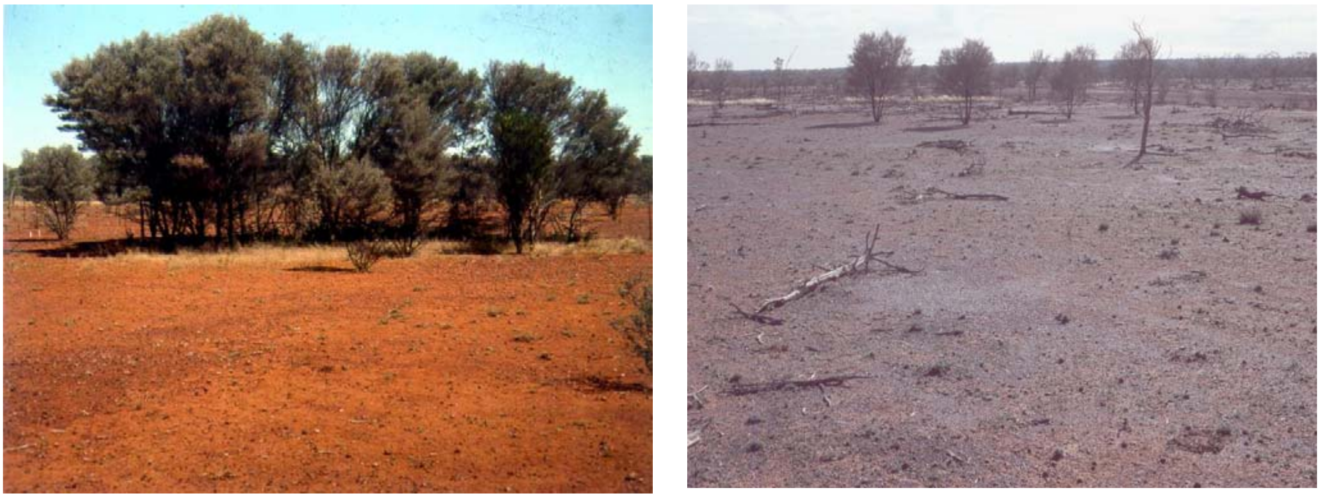


Figure 8. An example of both sediment and litter capture by a grass patch. The solid arrows indicate the deposition of sediment transported by runoff water, and the dashed lines indicate the deposition of litter against the grass plants that are here dense enough to obstruct runoff and "sieve out" litter and soil.

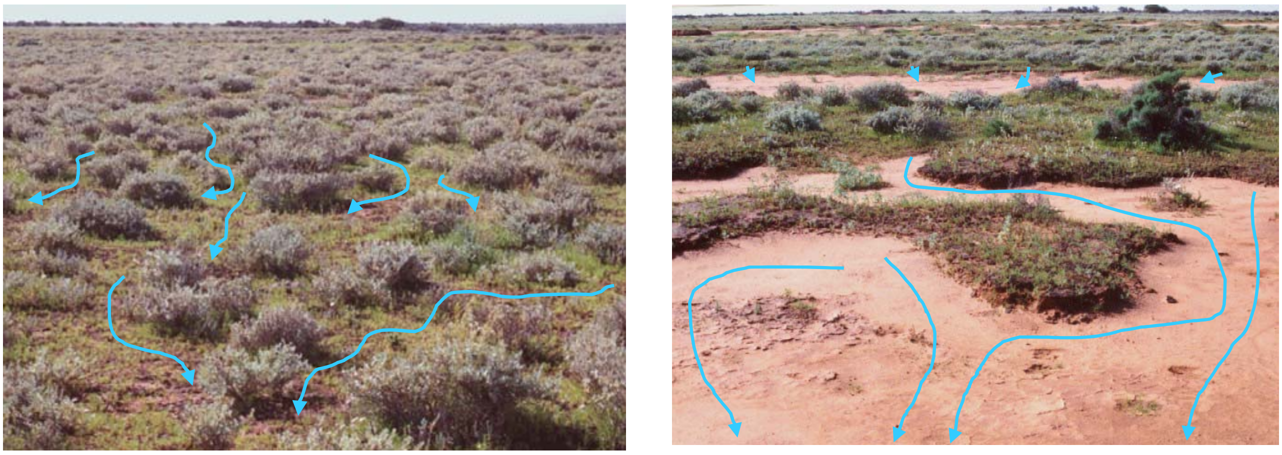
By contrast, landscapes with a low functional status tend to lose existing material resources, fail to capture incident rainfall and are unable to capture replacement materials (Figs 9b and 10b).

An appreciation of the processes by which scarce resources are regulated in landscapes is a pivotal step in the method. The observations by which these data are captured are in step 2 of the Field Methods.


9a

9b

Figure 9. Highly functional (9a) and dysfunctional (9b) groved mulga landscapes in western NSW.



10a 10b

Figure 10. A Chenopod shrubland in contrasting functional status, high where the vegetation has strong control of the resources (10a) and dysfunctional (10b) where there is a net loss of resources. At some stage the vegetation has been removed probably by over-grazing which has exposed the soil surface to sheeting by wind and water erosion removing the A horizon.

Grassland Functioning

Dense patches of perennial grasses cause overland water flow to have a tortuous path, with clumps of plants obstructing and diverting water flow and "sieving out" topsoil, litter and seeds (Fig. 11). The hydrograph of outflow is long and slow (Fig.12a). Dysfunctional grasslands are characterized by little regulation of overland flow, so that mobile resources are transported quickly out of the landscape (see Fig. 13). The hydrograph of outflow would be brief and rapid ("flashy") (Fig. 12b).

Figure 11. Two contrasting but highly functional grassland types, the arrows indicating the fine-scale processes by which densely growing grass plants intercept runoff water, filter out sediment and macro-organic matter and thus tend to conserve resources on site.

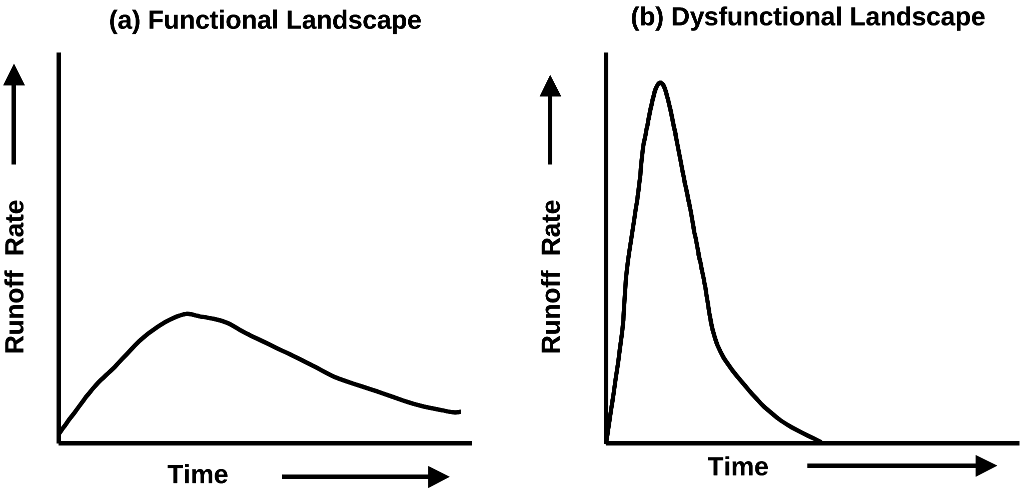


Figure 12. An illustration showing the difference in runoff rate between (a) functional landscape and (b) dysfunctional landscape.

Landscape dysfunction

By contrast, landscapes with a low functional status tend to lose or leak existing material resources, fail to capture sufficient incident rainfall and are unable to capture new replacement materials. A reduction in the size, number, spacing or effectiveness of fertile patches may be an indication of degradation. For example, degraded grasslands with few patches are unable to retain resources flowing across the landscape (Fig. 13).

Figure 13. Two landscape types similar to those in Figure 11, but more dysfunctional, in that runoff water and associated materials flow off more quickly, encountering fewer obstructions, so that resources tend to be transported rapidly out of the local system rather than confined and distributed within it. The arrows on the sketch indicate the more direct, longer, uninterrupted flow paths that tend to mobilize and transport more soil and litter than do the slower more convoluted flow paths.

An appreciation of the processes by which scarce resources are regulated in landscapes is a pivotal step in LFA. The measurements by which these data are captured are in Step 2 of the Field Data Collection module.

Patch Scale Processes

Looking now in more detail at landscape organization, many landscapes are naturally heterogeneous in terms of resource control and possess patches where resources tend to accumulate and inter-patches where the resources flow more freely. The patches may form "runon" zones where overland flow tends to accumulate, due to flats or depressions in the landscape (Fig. 11), or plant patches that accumulate resources by acting as wind or water flow obstructions (Figs 8 and 11). Patches are richer in resources and have enhanced soil properties such as infiltration, nutrient concentrations and stability (Tables 1, 2 and 3). Inter-patches tend to be poorer in resources and have low soil property values compared to the patch. Patches are often called "fertile patches" as a consequence.

Table 1. Soil properties in three contrasting patch types with high landscape connectivity in a banded Mulga community. Different superscripts reflect significant differences when $P< 0.05$

Measured Soil Property	Bare Soil	Grass	Woodland
Organic Nitrogen (%)	0.08^a	0.12^b	0.18^c
Mineralisable Nitrogen (ppm)	8.5^a	12.8^b	25.5^c
Saturated Infiltration (mm hr^{-1})	25^a	47^b	264^c
Cation Exchange Capacity (meq $100g^{-1}$)	7.4^a	8.6^b	10.5^b

The differences between the soil properties of bush-patch and the inter-patch are readily measured and Table 2 and 3 compares the two for nutrient pool sizes and physical properties.

Table 2. Showing the differences in some measured properties between the fertile shrub patch and the inter-patch in a chenopod shrubland. Different superscripts reflect significant differences when $P< 0.05$

Measured Soil Property	Inter-patch	Shrub Patch
% Organic Nitrogen	0.029^b	0.081^a
% Organic Carbon	0.34^b	0.74^a
Soil Respiration (mg CO_2 m^{-2} hr^{-1})	150^b	255^a
Infiltration rate (mm min^{-1})	1.3^b	14^a

Table 3. Organic nitrogen concentrations under grass plants (patch) and between grass plants (inter-patch) in a semi-arid perennial grassland. Different superscripts reflect significant differences when $P < 0.05$

Depth (cm)	Organic Nitrogen between grass plants	Organic Nitrogen under grass plants
0-1	0.042^b	0.061^a
1-3	0.023^b	0.053^a
3-5	0.018^b	0.035^a
5-10	0.015^b	0.025^a

In the more arid areas these 'fertile patches' may be a relatively small proportion of the landscape, but are responsible for a large proportion of the vegetative production through time and are "oases" or "refugia" in times of environmental stress. The patches vary in size, frequency and spatial distribution, depending on the type of landscape, e.g. some landscapes have their fertile patches arrayed in clear spatial patterns (Fig. 11), others are less obviously patterned, but each landscape type has a characteristic patch/inter-patch structure. Figures 14 and 15 shows the same set of processes as illustrated in figures 11 and 13, but observed at the finer scale of the individual grass plant.

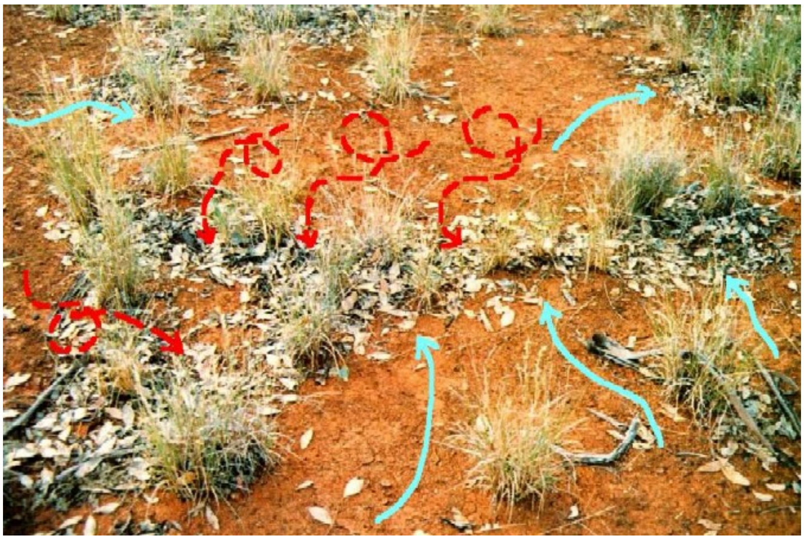


Figure 14. The spatial arrangement of grass plants facilitates the accumulation of resources by both wind and water-mediated processes. Here the grass plants are growing close together, so that resources accumulate around their butts. Straight blue arrows indicate water flow, red spiral arrows indicate wind-driven processes. The persistence of these processes in time and space results in the production of fertile soil patches. Soil macro-fauna process accumulated litter and relocate it into subsurface layers, thus improving soil fertility and stability. In doing so, soil macro-fauna bring up subsoil material to the surface as well as bury organic matter.

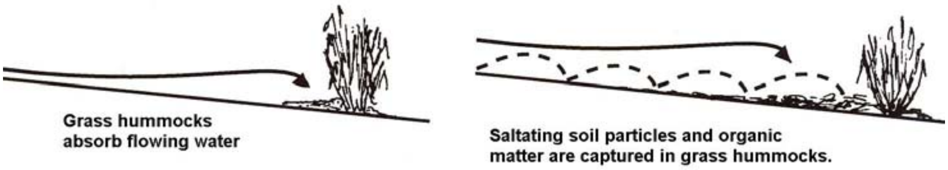


Figure 15. A diagrammatic representation of the role of grass tussocks in regulating the flow of 'resources' across the landscape.

The scale of the patch/inter-patch zones may change in response to rainfall. In dry seasons these patches decrease in size because of insufficient moisture to sustain the whole patch. Plant deaths are most likely to occur on the down-slope edge of a patch because runon water from the upslope inter-patch is insufficient to recharge the whole patch. In arid landscapes, the patch/inter-patch ratio is small but increases with average rainfall. At a critical average rainfall, thought to be about 450 to 500 mm yr^{-1}, the landscape can be comprised of "patch" alone (Fig. 16). The other factors that effect patch size are its position in the landscape, the steepness of the slope and the grazing pressure.

Figure 16. A grass sward in which resource mobilization and transport are strongly regulated by the density of the plants. The surface is protected from rain-splash erosion and water would be unable to gather any momentum to erode.

Mine Rehabilitation

In the rehabilitation of lands affected by mining, mechanical treatments applied to reduce soil compaction caused by the passage of heavy equipment can also be used to create a physical obstruction to overland flow. For example, contour ripping can produce a "bank and trough" surface (Fig. 17) that, if correctly installed, can provide a series of small traps where water, organic matter and seeds may concentrate, thus boosting the potential of the reshaped minesite to retain resources. The procedure for recording data from these "engineered" landscapes is described in the Field Methods section

Figure 17. A "bank and trough" system on a minesite created by contour ripping, showing extensive perennial grass recruitment in the troughs. This indicates the functional value of troughs in the capture and retention of resources shed from the banks. The troughs quickly attain high biological activity and the feedbacks from the growth pulse, as indicated by processes 5 and 6 in the TTRP framework, are rapidly established.

Figure 18 is a diagrammatic representation of figure 17 in terms of resource richness, with the minesite troughs being the fertile patches and banks the inter-patch.

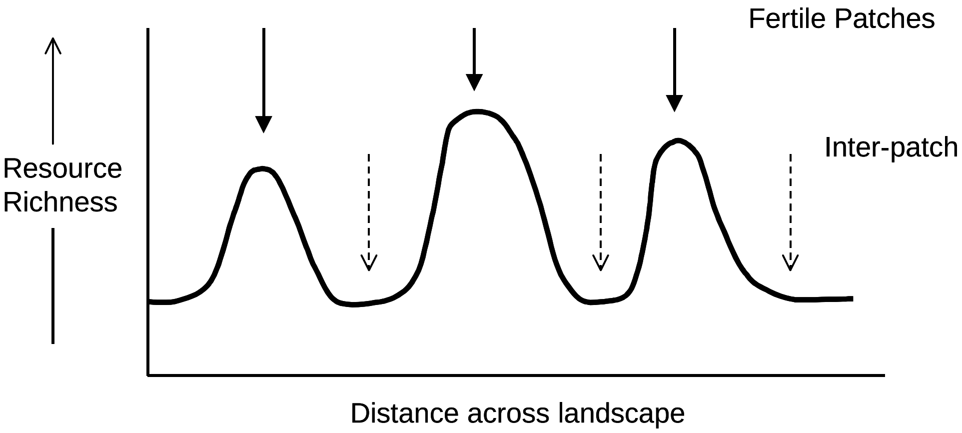


Figure 18. A representation of patches and inter-patches in a landscape, in terms of resource richness, as opposed to species richness. A critical step in LFA is to characterize both the spatial scale of the patch/inter-patch pattern and assess the resource richness of patches and inter-patches respectively, with soil surface indicators.

LFA METHODOLOGY

B FIELD DATA ACQUISITION

Introduction

It is the objective of this section to explain how the field data are collected. The same procedure is used across the full range of soils, landscapes and land uses, because the methods are based on the landscape function principles described in section A rather than being dependent on specific organisms.

There are 3 principal steps in this process.

1. Describing the geographic setting of the site.
2. Characterising landscape organization, the spatial distribution of the fertile-patches and inter-patches.
3. The soil surface assessment (SSA) of each of the patch/inter-patch types identified in step 2.

****

STEP 1 GEOGRAPHIC SETTING OF THE SITE

The objective of this task is to identify the location of the monitoring site in its landscape or watershed so that the nature and magnitude of water run-off processes can be gauged. This process will group land systems or land units, which have similar terrain shape. The classification are those proposed by McDonald *et al.* 1990, without change.

A Site Description

In monitoring it is important to record the location of site and its position in the landscape. The type of detail suggested are position, GPS if available, compass bearing of the transect, slope, aspect, lithology, soils, vegetation type and its landuse.

(Suggested site description recording sheet)

B Topographic Location

This procedure identifies the location of the study site within the overall landform pattern, e.g. rate of runoff increases with slope, chronic dryness (crest) and periodic ample water (closed depression) (Fig.19). These classifications are important for assessment of differential soil water storage and erosion potential at landscape scale.

Monitoring sites located on different land systems but with the same landform pattern/landform element classification should behave similarly. This classification will help to group sites from a wide geographic spread in order to reduce the large number of possible permutations by using a functional rather than descriptive discrimination.
The following topographic classification is appropriate for rangelands:

Crest
Upper slope
Mid slope
Lower slope
Closed depression, or lake
Flat
Open depression or stream channel

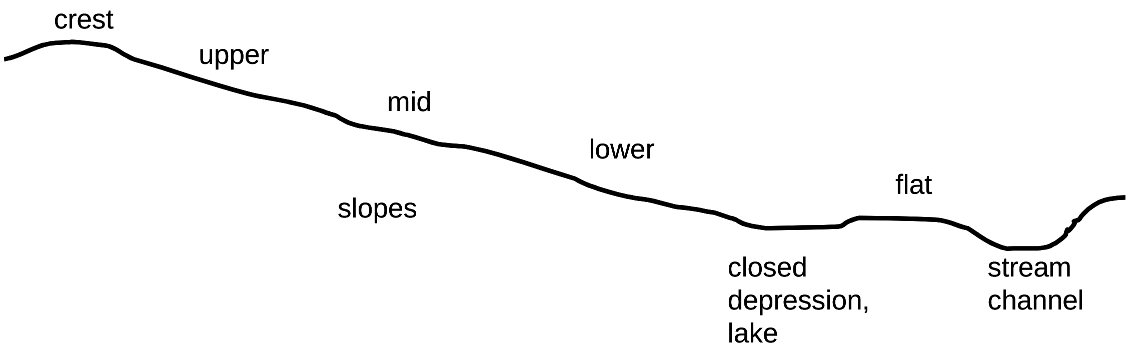


Figure 19. The identification of topographic position in the landscape for monitoring sites.

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STEP 2 CHARACTERISING LANDSCAPE ORGANISATION

The objective of this step is to characterise and map the monitored site in terms of the spatial pattern of resource loss or accumulation.

Procedure

1. Locate the transect directly downslope, bends or kinks may be necessary in some cases to follow the slope.
2. Collect a continuous record of patch/inter-patch classification on the transect as per guidelines for patch/inter-patch classification (see worked example page 24).
3. Complete this task before commencing soil surface assessment (step 3).
4. The transect should be permanently located to facilitate repeated measurements over time. This is essential for long term monitoring to be meaningful. Typically, the transect is located by a GPS reading of the upslope starting point and a compass bearing.

Rules for measuring transect parameters

Transect rules

The transect along which the data are collected must be aligned with the maximum slope. If slope is very low to flat then the direction of the transect is not so critical. In the case where wind is the dominant resource mobilising agent, the transect should be aligned in the direction of the strongest prevailing wind.
To facilitate comparisons overtime, measurements are to be made with a taut, straight tape between two fixed points.

Guidelines for Transect Selection:

Know your site:

Walk over the area that is to be monitored whether it be small area that is being rehabilitated or the whole paddock. How “even” is the landscape? In extensive rangelands a number of sites may be needed along a gradient running out from water to the furthest extremity of the paddock. There is a need to be realistic about how many sites within a paddock that can be handled, so start at the more sensitive areas and add more transects if time and circumstances permit. If there are major variations, e.g. soil type change, transects will need to be established in each variant.

How to set up transects

Start the transect at the upslope edge of the local watershed, at the downslope edge of a patch.
Pull the transect tape straight and tight. This is extremely important if the transect is to be revisited. Permanently located transects are very useful for time-series data collection and assessment. (see interpretational process section page 59). Note that if there is a clear indication of a change in resource flow direction, the transect should follow this by putting a bend or turning point in the line and noting its location and the new compass bearing.

How many Transects?

In most sites, from experience, two transects are sufficient. However, to test this, compare the means and variances for the stability, infiltration and nutrient cycling indices for each patch and inter-patch type**.** Whole-of-site values are not appropriate for this analysis. **Note: Five replicates of each patch/inter-patch type are essential for statistical reliability**. A rule of thumb is that if the patch means are similar for each transect, and the standard errors overlap, then the data from both transects can be combined, giving a new mean and standard error. However, if the means are quite different and the standard errors do not overlap, then measure a third transect and add these data to the existing data for two transects. If the mean for the third transect falls between the first two transects and their standard errors now overlap, then further transects are not necessary. If the standard error changes very little, then 2 transects are sufficient. This exercise only needs to be done once for each site at an early stage of rehabilitation.

Guidelines for correct patch/inter-patch classification

Patches tend to accumulate resources by restricting the downslope flow of water, topsoil and organic matter. If they are in good functional status, they will retain these resources which will be subsequently used by biota. Patches can be comprised of physical features, such as furrows or bays created by active landforming processes, or biological features such as plants or fallen logs. Typically, patches become a combination of both, over time. The patch identification task also involves finding and measuring its boundaries. Deposition of alluvium or litter is a common identifying factor in helping to recognize patches.

The processes identified at this scale are extremely informative about rangeland health and function, and form the backbone of the assessment.

In grasslands, much of the regulation of scarce resources is effected by the vegetation *per se*. In particular, the role of the spatial arrangement of perennial grasses in arresting the flow of runoff water, and filtering out sediment and organic matter is vital.

The processes by which this happens are described and illustrated in detail in Figures 8, 9 and 11). Because of the fine-scale nature of grasslands, it is possible to quickly measure the spatial arrangement of the vegetation elements, and to summarise it in ways that reflect the control the vegetation has on run-off and erosion.

Three parameters are measured to characterise the functional status of the monitoring site

(1) the number of obstructions to overland flow per unit length of transect
(2) obstruction width per unit length of transect
(3) the mean distance, and range, between obstructions (inter-patch length), per unit length of transect.

Figures 20 and 21 show how these 3 parameters are measured in the field, and the rules specified in the boxes below are to ensure that the data are collected in a consistent way between observers over time.

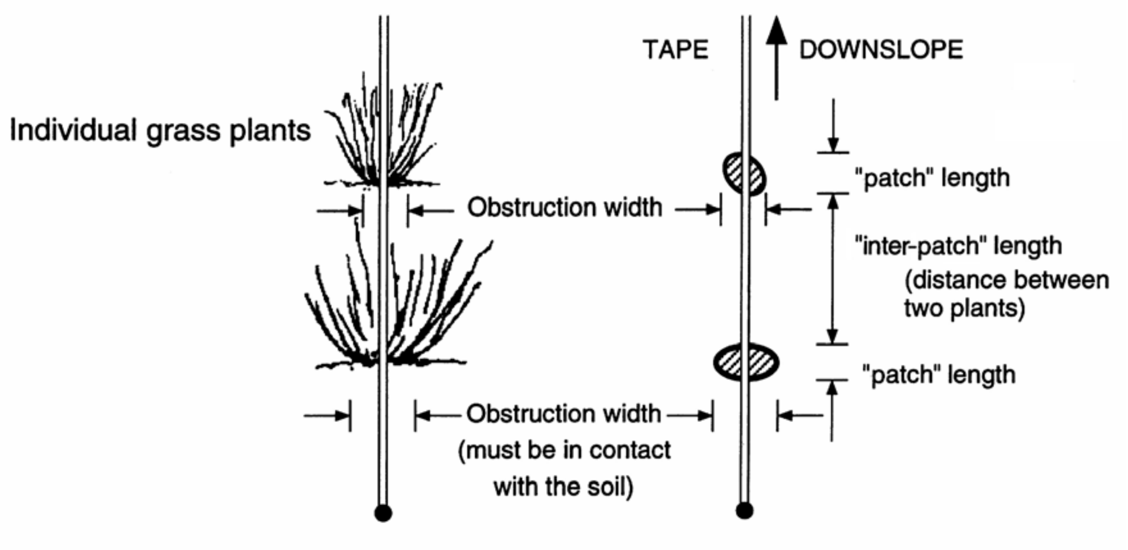

Figure 20. Illustrates the measurements of individual grasses when they form the patches on a monitoring transect.

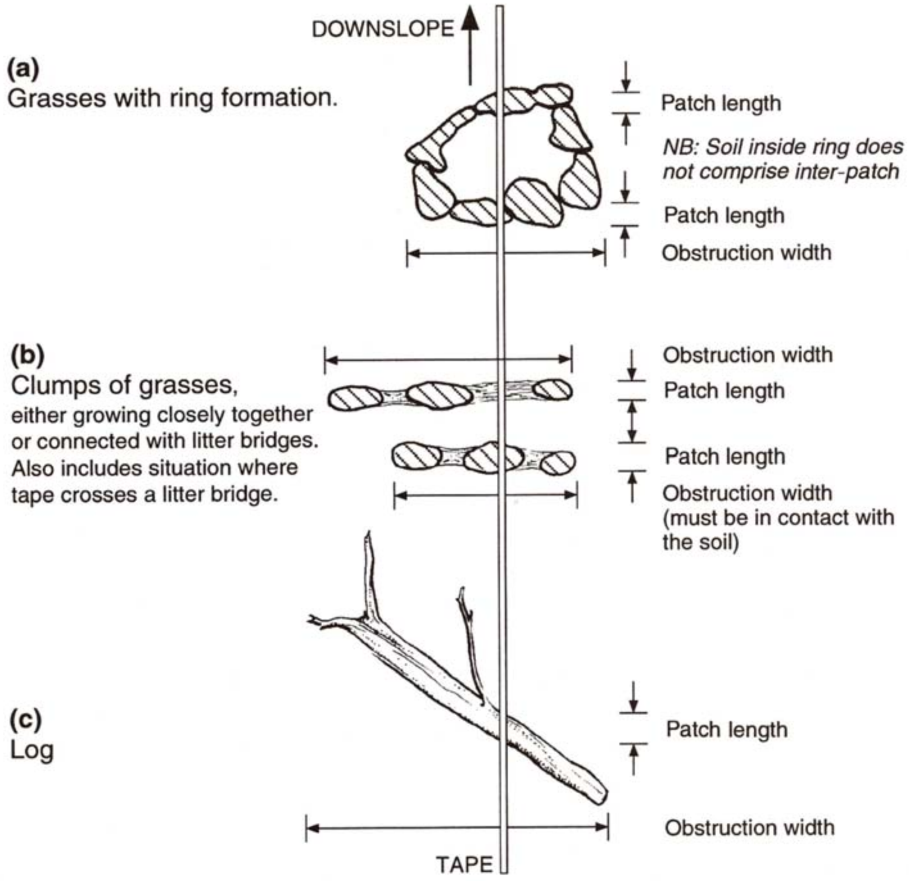

Figure 21. A diagrammatic illustration showing how to measure the length (along the transect) and the width of patches (right angles to the transect).

Patches

Patches are long-lived features which obstruct or divert water flow and/or collect/filter out material from runoff, e.g. perennial grass plants, rocks > 10 cm, tree branches in contact with the soil (example). There should be clear evidence of resource accumulation.

The decision to include, or exclude, biennial plants should be made with available local botanical knowledge, combined with the functional criteria described here. Once the local decision is made, it must be adhered to.
The minimum plant butt size for inclusion in the data is 1 cm.

- All measurements of grass plants for obstruction width and cover length are taken to and from the edge of the grass tussock, ignoring any soil hummock.
- Measure the **obstruction width** at right angles to the transect line, i.e. on the local contour. This is the maximum width of the patch (Fig. 21).
- Measure the **cover length** along the transect line.
- Measure both of these parameters at about 1 cm height above the ground level (as though in an overland flow situation).
- Patches can be **simple** (i.e. a single plant, rock or branch (Fig. 22), or **complex** (Figure 21).

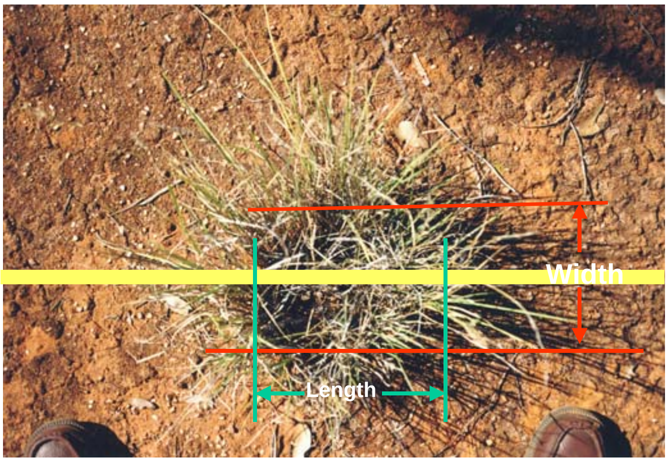

Figure 22. Illustrates a simple patch that captures some resources that are flowing down the transect.

Grass Swards

Not all landscapes have a patch/inter-patch organization. As grasslands become denser, there comes a point when litter and soil are no longer mobilized and transported by flowing water. The patch is then a large area comprised of a sward made up from a large number of functionally linked plants acting as a single unit rather than a series of isolated individuals as is the case with sparse tussock grasslands.

To identify swards look for evidence of alluvium or litter movement between grass plants.

- If there is no evidence of soil or litter transport between or around grass butts, then a sward or very large patch (resource retaining zone) exists. Litter may be present, but should show no evidence of movement. An ideal time to observe this is just after a rainfall/run-off event to judge the extent of litter and alluvium movement (Fig. 23d).
- The upslope edge of a sward may capture large quantities of material out of a transporting flow.
- Landscapes comprised of individual tussocks may have more obstructions per unit length of transect, but the obstruction width will be very low. Many swards will be greater than 10 metres wide.

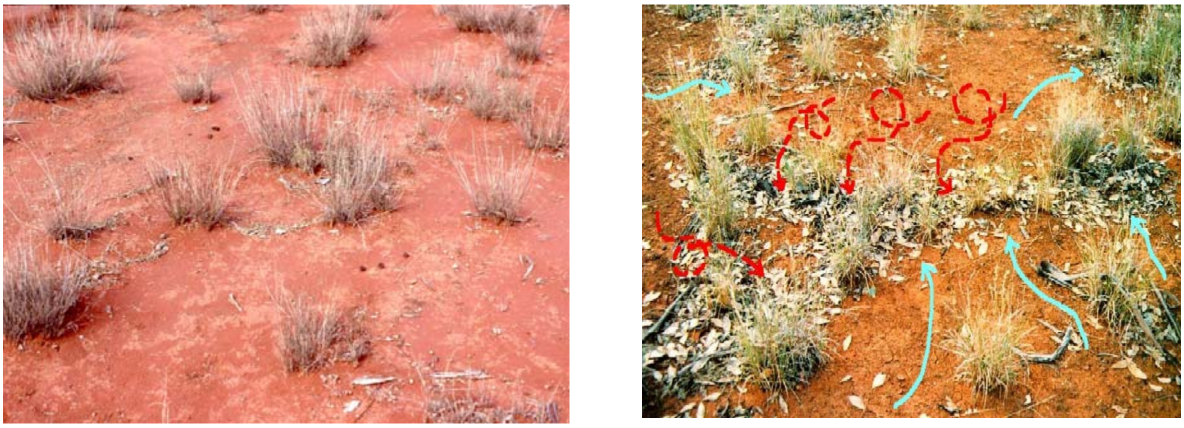

Figure 23a – single grass plants

Figure 23b – several grass plants in a patch

Figure 23c – grass plants acting as a sward

Figure 23d – dense sward. Note the capture of plant litter within the sward.

Figure 23. Showing (23a) a landscape where the only resource control is by single grass plants, and patches of grass plants (23b). 23c shows the litter being retained by the grasses in a sward, and 23d has arrested a large flow of alluvium down the slope.

Inter-patch Type Criteria

Inter-patches are characterized as a zone where resources such as water, soil materials and litter are freely transported either downslope when water is the active motive agent or down wind when aeolian processes are active (Fig. 24).

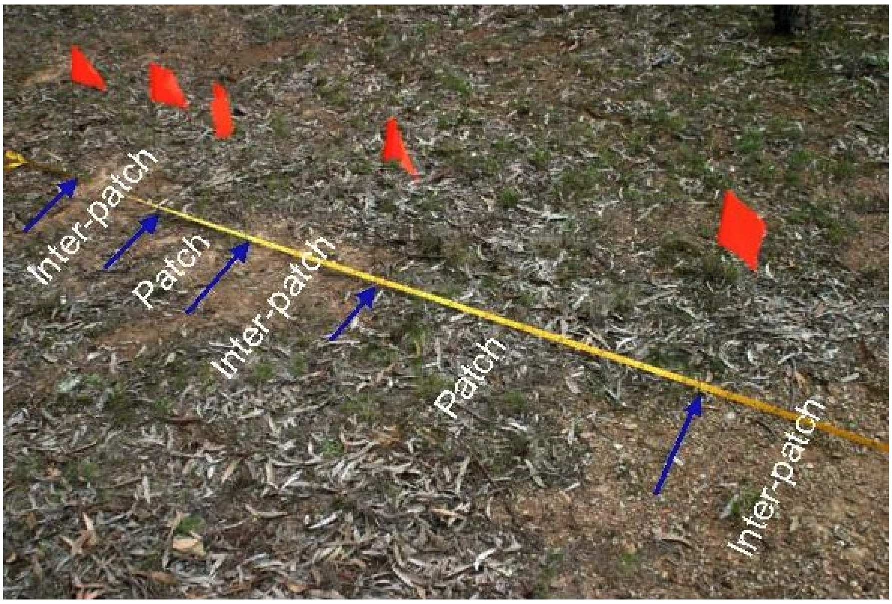

Figure 24. Section of a monitoring transect showing the patch/inter-patch boundaries.

Different types of inter-patch are possible, for example “bare crusted soil” or “bare stoney soil”. This discrimination is useful but should be rapidly determined. Do not make subtle distinctions.

Inter-patch Measurement

- The distance between successive patches. (Figs 20, 21 and 24).
- Measure with a precision of ± 2 cm.
- Inter-patch width (on the contour) is **not** assessed.

Inter-patch Identification

Each patch and inter-patch needs a descriptive name, both to distinguish different types and to use as a record for future reference. For example, bare soil and bare soil with a stoney surface could be describe as ‘bare soil’ and ‘bare stoney’ rather than just “inter-patch”. The nature of the patches may change over time, and the soil surface condition data representing this change will show its magnitude. Photographic records of the individual zones as well as a fixed point general photo are very useful as a reminder of former assessments. Use a simple descriptive term to describe the inter-patch, for example “bare crusted soil” (Fig. 25a) or “bare sandy” (Fig. 25b) or “bare + gravel” (Fig.25c).

25a **25b** **25c**

Figure 25. Showing three examples of bare classification for inter-patch zones.

Worked Example

Figure 26 and Table 4 demonstrate a typical LFA landscape organization data set.

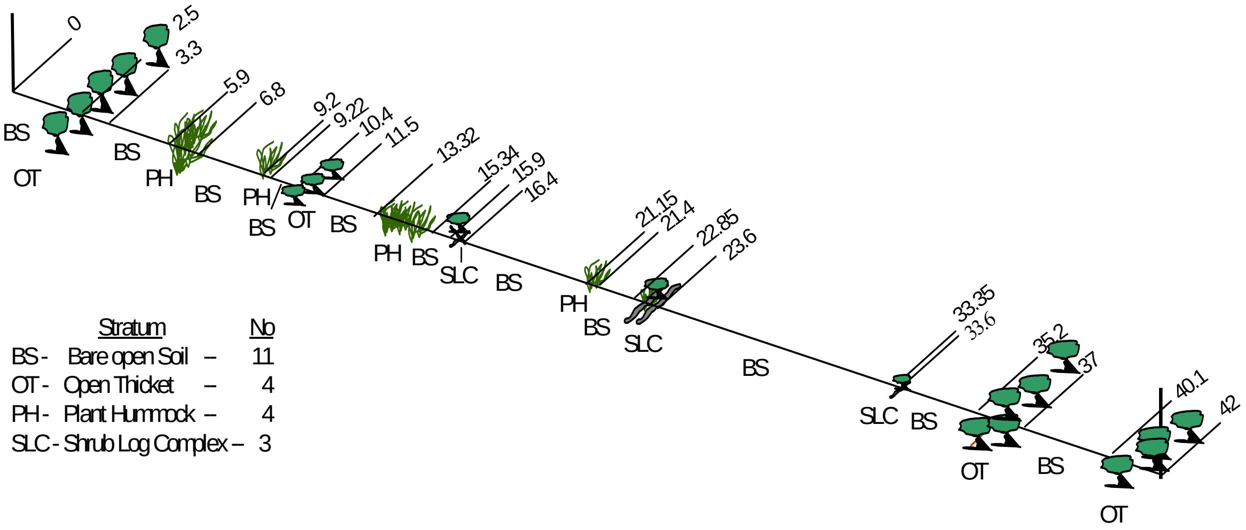

Figure 26. A diagrammatic representation of a monitoring transect showing the "logging of the line" into its inter-patch (bare open soil) and 3 types of patches (open thicket, plant hummock and shrub log complex).

Table 4. The landscape organisation data for the transect line illustrated in Fig. 26.

Distance	Patch width (cm)	Patch/Inter-patch Identification	Notes
0			
2.5		BS	Bare open soil (inter-patch)
3.3	710	OT	Open Thicket (patch)
5.9		BS	
6.8	80	PH	Plant Hummock (patch)
9.2		BS	
9.22	10	PH	
10.4		BS	
11.5	130	OT	
13.32		BS	
15.34	10	PH	
15.9		BS	
16.4	105	SLC	Shrub Log Complex (patch)
21.15		BS	
21.4	30	PH	
22.85		BS	
23.6	105	SLC	
33.35		BS	
33.6	35	SLC	
35.2		BS	
37	650	OT	
40.1		BS	
42	200	OT	

A summary of the organization data is given in Table 5. The landscape organization index is the proportion of the length of patch to the total length of the transect *i.e.*, a totally bare transect would have an index of 0 (zero) or if it was all patch (*e.g.*, a sward) the index would be 1.

Table 5. Summarises the landscape organisation data from Table 4.

No. Patch zones per 10m	Total Patch zone Width (m/10m)	Average Inter-patch Length and *range* (m)	Landscape Organisation Index*
2.44	4.13	3.17 *0.56 – 9.75*	0.22

* length of patches/length of transect

The location of erosion features such as terracettes and rills (Table 6) should also be noted in the landscape organization data record. Erosion features may self-ameliorate or become worse depending on management or seasonal conditions, so assessment of their severity is important, particularly on mine rehabilitation.

Table 6. A sample landscape organization transect log. The position, height and condition of the terracette is noted in the notes column.

Distance	**Patch Width (cm)**	**Patch/Inter-patch Identity**	Notes
0			
0.68		CBS+ litter	CBS. - Crusted Bare Soil
0.89	34	dican	dican - Dicanthium
1.40		litter	arist. - Aristida
1.64	36	dican	Chry. - Chrysopogan
3.10		CBS + litter	
3.66		CBS	
3.73	6	dican	
4.56		CBS	
4.60		CBS + litter	Terracette @ 4.60 – active 1 cm high
5.23		litter	
6.60	113	dican	
7.10		CBS + litter	
7.70		litter	
8.08	72	dican	
8.30		litter	
8.55	105	dican	
8.68		litter	
8.76	8	dican	
8.91		CBS + litter	
9.00	17	dican	
9.60		CBS + litter	
9.80		CBS + litter	Terracette @ 9.80 – stabilized 1.5 cm
9.97	65	dican	
10.60		CBS + litter	
10.80	37	dican	
11.02		CBS + litter	
11.10	6	arist	
11.50		CBS + litter	
11.82	59	chry	
12.70		CBS +gravel	
13.51		CBS + litter	
13.72	40	dican	
14.60		CBS + litter	
14.77	30	dican	

Rill survey

If rills are observed at the site level at less than 30 m. spacing, we recommend surveying their number, spatial distribution and cross-section by the following procedure.
Using the LFA transect as a reference, establish transverse transects ± 25m. (total = 50m) on the contour. Locate these at 25, 50, 75 and 100% of the LFA transect. Record the location of each rill on the contour transect and measure the width and depth of each rill.

(Suggested Rill assessment data sheet)

We adopt the following conventions for rill surveys.

- The zero point is to the left of the transect line looking down slope.
- Note if the rill is short or long.
- Note if rill is "active" by observing the nature of the bed material and shape of the walls

Rills do not necessarily increase with time. If biological response is vigorous, rills can fill with alluvium and cease to conduct runoff. (see table 7 and 8)

Table 7. Example of field data collected from a rill survey. When monitored over time changes both positive and negative can be tracked.

Transect No /rill no	Rill Base	Start Rill (m)	Finish (m)	Rill Width (m)	Rill Depth (m)	X sect area (sq m)
T1/1	Rocky	14.6	15.5	0.9	0.6	0.54
T1/2	Gravel & Alluvium	18.1	19.1	1	0.55	0.55
T1/3	Alluvium	28.6	29	0.4	0.2	0.08
T1/4	Gravel & Alluvium	29.3	29.8	0.5	0.45	0.225
T1/5	Rock & Alluvium	33.3	34.2	0.9	0.45	0.405
T1/6	Rock, Gravel & Alluvium	35.8	37.25	1.45	0.28	0.406
T1/7	Rock, Gravel & Alluvium	39.6	40.4	0.8	0.25	0.2
T1/8	Rock, Gravel & Alluvium	43.3	45.5	2.2	0.54	1.188
T1/9	Gravel & Alluvium	49.4	50.1	0.7	0.11	0.077

Table 8. Number of rills and mean rill cross-section (width by depth), obtained from 4 x 50 m lines aligned on the contour. Although significant in the first years of rehabilitation, rills decreased as biological control was established.

Years since rehabilitation	No of rills per 200 m	Mean rill cross section (cm^{-2})
2	66	341
5	10	102
9	0	0
15	0	0
unmined	0	0

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MINESITE REHABILITATION MONITORING

The method for monitoring minesite rehabilitation is basically the same, but some special physical features are put in place to give greater stability to the system to assist in the rehabilitation process. Typically on mines, deep contour ripping of rehabilitated lands produces a “bank and trough” structure that forms the primary means of resource regulation from the earliest stages and often lasting many years (Fig. 27). In this system the trough is the patch (traps resources) and the bank the inter-patch (sheds resources). Figure 28 is diagrammatic illustration of this process.

Figure 27. A batter slope that has been contour ripped to produce “bank and trough” physical resource regulating means. There are no signs of lateral flow in the troughs and hence no rills or gullies have formed.

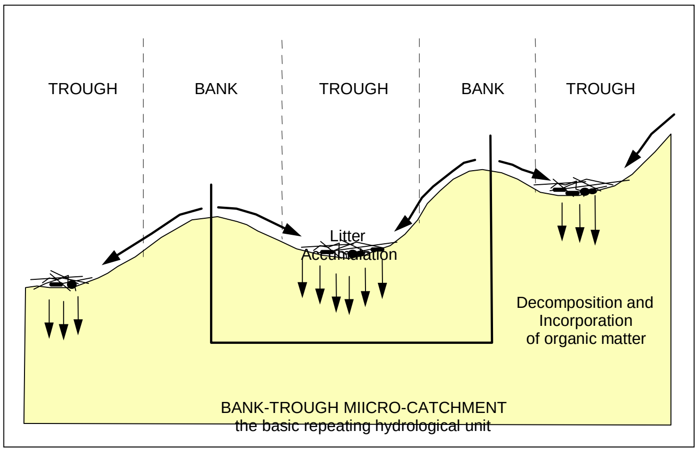

Figure 28. A cross-sectional representation of contour ripping on a sloped landscape showing the functionality of a bank/trough system.

Note that if the ripping is not carefully aligned with the contour, lateral water flow along the trough may well ensue, with ultimately a major failure of the ripping as very large volumes of water move quickly to the lowest point in the trough and break through the banks. In this case the width of the patch (trough) is centered on the transect line and is measured 5 metres each side (max. of 10 m) or to a break in the bank where resources are being lost downslope.

The transect landscape organisation must record the successive bank intercept and trough intercept measurements. Information derived from any other treatment such as woody debris or establishing plants is also collected and used to assess the biological contribution to both landscape and zone quality development over time. Table 9 is a full transect landscape organisation record of a bank and trough system on the batter slope of a waste rock dump and Table 10 summarises that bank/trough data set.

Table 9. There are four landscape zones in this record: Bank (b), Bank with a plant (bp), Trough (t) and Trough with a plant (tp). For a trough to be classified as including a plant, the transect line must run **through/under the canopy** of a shrub or **across the butt** of grass plants.

Distance (m)	Patch width (m)	Patch/Inter-patch identity	Distance (m)	Patch width (m)	Patch/Inter-patch identity
0			12.6	1000	T
0.9		B	13.8		B
1.3	363	T	14	1000	T
2		B	14.8		B
2.3	1000	T	15	690	T
2.9		B	15.8		B
3.2	1000	Tp	16.1	770	T
4.1		B	17.4		B
4.3	760	Tp	17.7	250	T
5.1		B	18.1		B
5.2	1000	T	18.6	220	Tp
6.1		B	19.2		B
6.3	1000	T	19.4	440	T
7.4		B	19.9		B
7.6	1000	T	20.1	565	T
8.2		B	20.8		B
8.6	1000	Tp	21.1	600	Tp
9.3		B	21.9		Bp
9.6	1000	T	22	440	Tp
10.2		B	22.7		B
10.6	1000	T	23	250	T
11.3		Bp	23.7		B
11.5	1000	T	23.9	230	T
12.3		B	24.7		B

Table 10. Summary tables generated from the data collected in Table 9 for the 4 zone types identified.

Transect Patch and Inter-patch Type Summary

Zone	Mean Zone Length (m)	%
Bank	0.78	69.2
Bank + plant	0.75	6.1
Trough	0.25	17.4
Trough + plant	0.30	7.3
Total		100.0

Patch Obstruction Summary

Patch zone	Code	Total Width (cm)	Number	Mean Patch Width (cm)
Trough	t	12558	17	738.7
Trough + plant	tp	4020	6	670.0
Total		16578	23	720.8

Number of Patches/10m	9.3
Total Patch Width (m/10m)	67.1m
Average Inter-patch Length	0.81m
Landscape Organisation Index*	0.24

* length of patches/length of transect

Locating and recording the bank and trough boundaries

Figure 29 is a diagrammatic representation of a recently completed ripped slope, indicating the locations of the boundaries of banks and troughs, based on the concept of the hillslope gradient prior to ripping. The troughs would be below this line and the banks above it. This is not a critical data set and rapid consistency is more important than slow precision. This diagram also shows the "surface roughness" dimension needed in the SSA classification process.

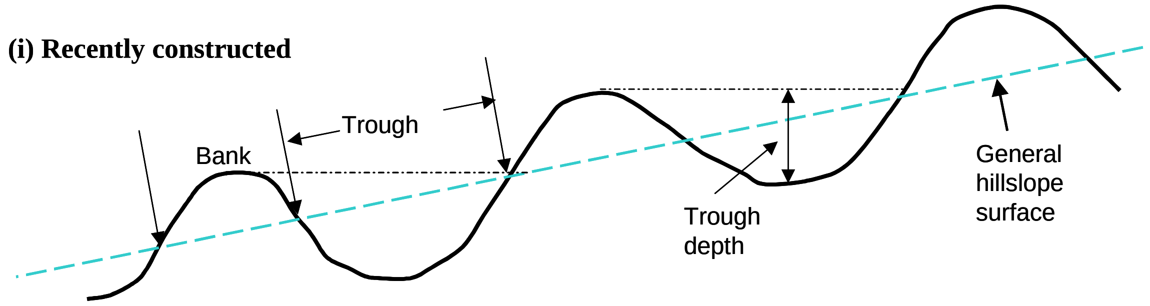

Figure 29. A diagrammatic representation of a bank/trough slope showing the measurements of patch (trough) and inter-patch (bank), and the trough depth used in the surface roughness assessment in SSA.

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Figure 30. shows the bank/trough system a couple of years after initial establishment, with sediment being built up on the bottom of the trough and banks eroding largely by sheet erosion. Troughs are likely to become wider and shallower over time. Note that alluvium in the trough may become more "soil-like" over time as plants establish and nutrient cycling progresses. (see also SSA indicators).

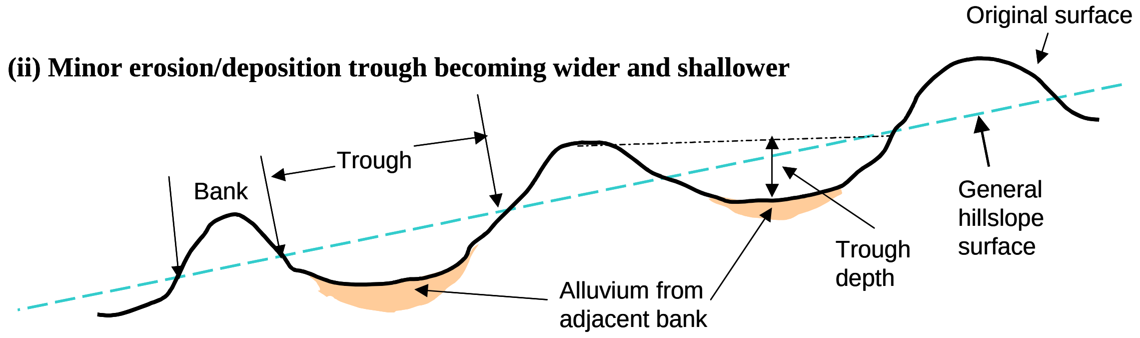

Figure 30. As for figure 29, showing some ageing and erosion processes.

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Figure 31 shows a situation encountered reasonably frequently. The trough has filled with alluvium to its capacity, with the result that a "flat and slope" geomorphic system is created, where the slope is the former downslope edge of a bank. Renewed erosion of the slope may then ensue, depending on the erodability of its materials, the length and angle of the upslope flats and slopes. At this stage, the patch/inter-patch structure disappears to form a continuous inter-patch. [Image]

(iii) Major erosion/deposition. Bank/Trough becomes Flat/Slope

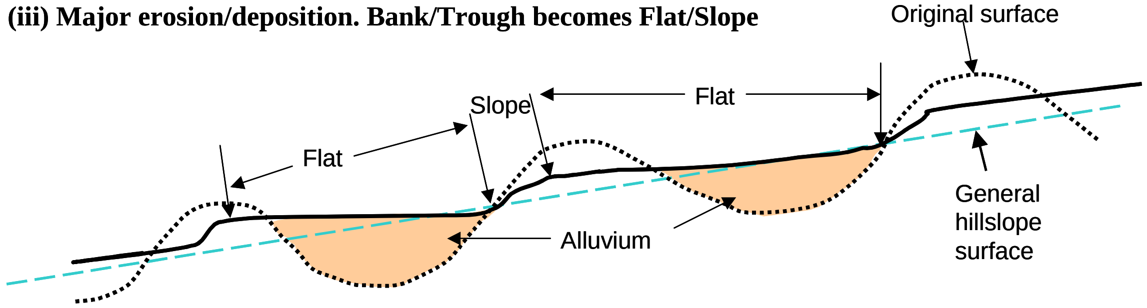

Figure 31. Showing the filling of the trough with alluvium and the resultant loss of resource control.

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Analogue Sites

The selection and use of analogue or reference sites is crucial to the effective use of LFA, on minesites. Data from these sites provide both goal or target values for the LFA indices in rehabilitation and the landscape organization indices that represent a mature, highly functional landscape.

The field procedure for analogue sites is exactly the same as for the monitored sites. Figure 32 illustrates the range of patch and inter-patch zone types typically found in natural landscapes.

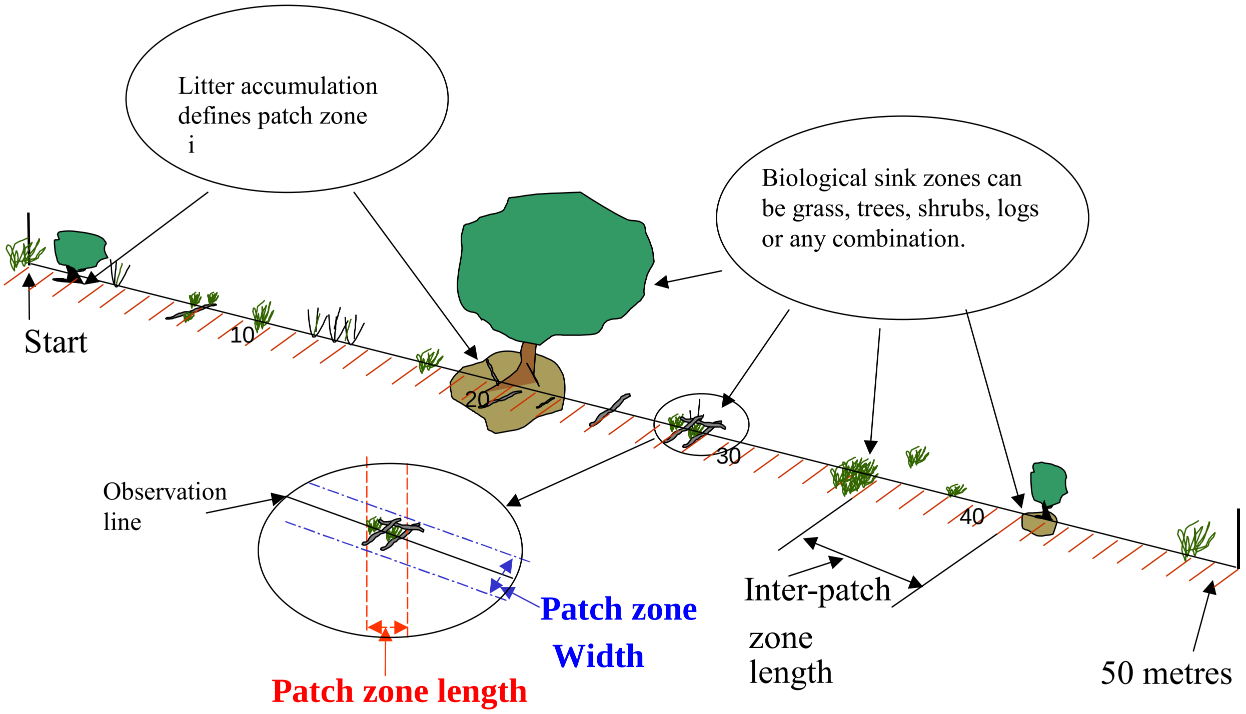

Figure 32. Illustration of an analogue monitoring transect. The short lines indicate metres. The assessment time is about 20 minutes.

An analogue site is one that has many of the attributes of the final rehabilitated landscape and is self-sustaining, particularly in respect to functioning and serves to provide a goal or target for rehabilitation. The objective is to define a bunch of values that the rehabilitation site needs to converge on.

"Functioning" refers to the biophysical efficiency of the site, rather than an inventory of its biological components as such.

A landscape with high functionality has a high retention of vital resources such as water, topsoil and organic matter, whereas dysfunction implies that some of these resources are lost from the system.

Analogue sites would have comparable slope, soil texture, soil cover, resource regulation and many of the vegetation species required in the mature rehabilitation. The biogeochemical functioning would yield values justifiably worthy of emulation in a rehabilitating landscape. Data from analogue sites forms part of the monitoring procedure through time, so that varying seasonal conditions ultimately result in a "band" of values that act as the target region for rehabilitation.

In addition, data recording the response and recovery dynamics to stochastic disturbances of the analogue site (e.g. fire, storm) would provide a test of the resilience of a rehabilitated site (rate of recovery of function after specified disturbance).

The term "homologue" would be used to specify a landscape whose components would be replicated to a high degree in every respect: parent material, soil type, slope, aspect, species composition and land use.

STEP 3 SOIL SURFACE ASSESSMENT

Each patch/inter-patch type identified in the transect organisation log must have its soil surface properties classified according to the Soil Surface Assessment Method detailed below. This assessment is made after the landscape continuous log record is compiled (step 2), on a set of **query zones** located within each patch and inter-patch type. In selecting query zones the following guidelines should be observed:-

1. Observations of soil surface features are made using the tape transect to define the **query zone**. Each SSA feature is therefore estimated on a linear basis and percentages calculated according to the length of the particular query zone.
2. The assessment needs a minimum of 5 examples of each patch/inter-patch type (if possible) for statistical reliability. If fewer than 5 examples are available for a given patch/inter-patch type, more than one query zone can be located in a long single zone.
3. Use the transect log to select the 'query zones'. Avoid looking at the transect itself while making the selection as this can introduce a bias by selecting 'interesting' sites.
4. Ensure that the query zones are distributed along the full length of the transect, e.g. the transect in figure 18 in step 2 the query zones would be (Table 11):-

Table 11. The query zones for the transect in figure 26.

Type/Query zone	1 (m)	2 (m)	3 (m)	4 (m)	5 (m)
BS	0.5 – 1.5	12 - 13	17 - 18	27 - 28	38 -39
OT	2.6 – 3.1	10.5 – 11.5	35.5 –36.5	40.5 – 41.5	
PH	6.1 – 6.6	13.6 – 14.6	21.2 – 21.4		
SLC	15.9 – 16.4	21.2 – 21.4	33.4 – 33.6		

Note:- For OT, PH and SLC there were insufficient number to have 5 query zones for each of these type so use what there is available.

5. The actual query zone should be sited symmetrically within the selected zone patch/inter-patch. e.g. a bare surface is 73 cm long, 50 cm is an appropriate query length. The 50 cm length should be sited in the middle of the 73 cm length.
6. The standard query zone length is **1 metre.** If the patch/inter-patch length is insufficient, for a 1 m query zone, particularly where individual grass plants are patch zones, for convenience, use simple fractions of a metre if possible.
7. The boundary between two zones should be avoided, where possible as it is often diffuse at the cm scale, leading to confusion, unless it is very distinct such as at the start and end of a patch. In the case where the patch is a single plant the query zone will be quite small and may be less then 10 cm, in this case assess the whole patch.

Suggested SSA data collection sheet.

SOIL SURFACE ASSESSMENT INDICATORS

The soil surface assessment is rapidly made by the use of simple visual indicators. We define an indicator as:-

A single piece of information, which acts as a surrogate for an environmental variable or process. We have selected indicators that are:

- sensitive and unambiguous
- quick, simple and inexpensive
- consistent over time and between observers
- applicable to a wide range of landscape types
- capable of providing a predictive understanding of ecosystems.

SOIL SURFACE ASSESSMENT METHOD

The nature, meaning and scope of each surface feature, together with a classification procedure is detailed below. Images are provided to and assist in correctly classifying each indicator. These are accessed by clicking on the appropriate image reference.

1. Rainsplash Protection

The objective is to assess the degree to which physical surface cover and projected plant cover ameliorate the effect of raindrops impacting on the soil surface.

Assess the projected percentage cover of perennial vegetation to a height of 0.5 m. plus rocks > 2 cm and woody material > 1 cm in diameter or other long-lived, immoveable objects. These objects intercept and break up raindrops, making them less erosive and less liable to form soil physical crusts. This indicator relates to the Stability Index.

Exclusions:

(i) Ephemeral herbage. This type of material may not be present when rain events are unpredictable such as in the more arid areas.

(ii) Foliage at heights greater than 0.5 m. “Gravity” drops falling from foliage are much larger than raindrops and have higher erosive capacity when falling from heights greater than 0.5m

(iii) Litter. This is assessed separately (Indicator 3) and inclusion here would “double-up” the contribution of litter when calculating the stability index.

Projected Cover	Class	Interpretation	Image Reference
1% or less	1	No rainsplash protection	1-1, 1-2, 1-3
1 to 15%	2	Low rainsplash protection	2-1
15 to 30%	3	Moderate rainsplash protection	3-1, 3-2
30 to 50%	4	High rainsplash protection	4-1
More than 50%	5	Very high rainsplash protection	5-1, 5-2, 5-3

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2. Perennial Vegetation Cover

The objective is to estimate the “basal cover” of perennial grass and/or the density of canopy cover of trees and shrubs.

This indicator assesses the contribution of the below-ground biomass of perennial vegetation in contributing to nutrient cycling and infiltration processes (example). Grass cover is assessed by summing the butt lengths (example) of perennial grass plants in the query zone. Tree and shrub cover is defined from the cover and density of the canopy overhanging the query zone. (McDonald et al, p 66-71 has photo-references). The contribution of annual plants is included under litter.

Basal and Canopy Cover	Class	Interpretation	Image Reference
1% or less	1	No below ground contribution	1-1, 1-2, 1-3, 1-4
1 to 10%	2	Low below ground contribution	2-1
10 to 20%	3	Moderate below ground contribution	3-1
More than 20%	4	High below ground contribution	4-1

Exclusions:
All plants that are not perennial. Some bi-annual and annual grasses maybe robust enough to act as pseudo perennials. The decision to include them in the assessment will depend on 'local knowledge'. It is essential to be consistent.

****

3. Litter

The objective is to assess the amount, origin and degree of decomposition of plant litter.

"Litter" refers to annual grasses and ephemeral herbage (both standing and detached) as well as detached leaves, stems, twigs, fruit, dung, etc. The position of litter in the overall landscape also assists in defining fertile patches.

Plant litter accumulation is strongly related to the carbon, nitrogen and other elements stored in the surface soil layers and acquired by decomposition processes.

Note: recent fire usually eliminates litter, temporally disadvantaging the nutrient cycling index as it relies strongly on the litter indicator. Unless the effect of the fire itself is being assessed a period of at least one growing season should elapse before assessing burnt sites.

There are three properties of litter that need to be assessed in the following order:

(i) The cover (in 10 classes) as per the table. When litter is more than 100% cover, the depth is assessed my compressing it with the flat of your hand to remove "air-gaps".

% Cover of plant litter	Class	Image Reference
<10	**1**	1-1, 1-2, 1-3
10-25	**2**	2-1
25-50	**3**	3-1, 3-2
50-75	**4**	4-1
75-100	**5**	5-1, 5-2
100 up to 20 mm thick	**6**	6-1
100, 21-70 mm thick	**7**	
100, 70-120 mm thick	**8**	
100, 120-170 mm thick	**9**	
100, > 170 mm thick	**10**	

(ii) The **origin** of the litter:
local (l) (example) = derived from plants growing in very close proximity to the query zone and showing no signs of transport/deposition by wind or water flows and

transported (t) (example) = litter has clear signs of being washed or blown to the current location.

(iii) The **degree of decomposition/incorporation** in 4 classes:

1. Nil decomposition (n) (example): the litter is loosely spread on the surface with few signs of decomposition and incorporation.

2. Slight decomposition (s) (example): litter is broken down into small fragments and intimately in contact with soil; some fragments may be partially buried.

3. Moderate decomposition (m) (example): litter is in several distinct layers; some fungal attack is visible; the layer next to the soil is somewhat humified; some darkening of the soil to a depth of less than 10 mm.

4. Extensive decomposition (e) (example): litter has at least 3 layers or stages in decomposition ranging from fresh material on top to 20 mm or more of comprehensively humified (very dark, with no identifiable fragments) at the soil-litter interface; mineral soil may have significant organic darkening in excess of 10 mm.

Assessment examples

- 25-50% cover, local origin, slight decomposition is recorded as 3ls
- 100% cover but less than 20 mm thick, local origin, moderate decomposition is recorded as 6lm
- 10-25% cover, transported, nil decomposition is recorded as 2tn

Write the full coding into the data-recording sheet and into the Excel template which performs the appropriate calculations.

****

4. Cryptogam Cover

The objective is to assess the cover of cryptogams visible on the soil surface.

“Cryptogam” is a generic term that includes algae, fungi, lichens, mosses and liverworts. Fruiting bodies of mycorrhizas would be included. When these are present, they indicate soil surface stability and elevated levels of available nutrients in the surface layers of soil. They are known to exchange minerals and water with vascular plants in return for carbohydrates.

Typically, they colonise soils with pre-existing stable physical crusts, though not exclusively. They tend to impart flexibility to the physical crust, due to the ramification of hyphae through the surface few mm. Cryptogams may be early colonisers of recovering soil surfaces, but may decline as vascular plant cover increases. Typically, they need high light levels to persist and are seldom found under dense, particularly woody, litter. They have been observed under light grassy litter. Open, crusted soils are their typical habitat.

The soil surface may need close inspection to assess the presence of cryptogams. Adding a little water and observing the “greening” of cryptogams over a period of 10 –20 seconds can be very useful. Some cryptogams are “detached” from the soil surface after long periods of desiccation, but cover is assessed normally.

Exclusions:
Where the soil surface is clearly mobile, e.g. loose sands; “naturally active”, e.g. self-mulching clays or has an extensive deep litter cover, no habitat for cryptogams exists and a “**not applicable**” or zero recording should be made. In rare cases, lichens can grow on sandy soils, or on undisturbed self-mulching clays. Where this is observed, the cryptogam indicator must be assessed. If Crust Brokenness (observation 5) has been assessed as “n/a” (not applicable) then Cryptogam Cover will also be “n/a” as it requires a stable surface for them to grow.

Cryptogam Cover	**Class**	**Interpretation**	**Figure Reference**
Not applicable	0	No stable crust present	0-1, 0-2
1% or less	1	No contribution	1-1, 1-2
1 to 10%	2	Slight contribution	2-1
10 to 50%	3	Moderate contribution	3-1
More than 50%	4	Extensive contribution	4-1, 4-2, 4-3

****

5. Crust Brokenness

The objective is to assess to what extent the surface crust is broken, leaving loosely attached soil material available for erosion (example).

A crust is defined as a physical surface layer that overlies sub-crust material (**example**).
Soils with physical crusts in good condition are crusts that are smooth and conforms to the gentle undulations in the soil surface. These good condition crusts yield little soil material in a runoff event. However crusts can become unstable, brittle and easily disturbed by grazing animals, the materials becoming available for wind or water erosion. Polygonal cracking of the crust without curled edges is not considered broken and scores 4, the maximum value. Typically sections of crust are lost, forming a micro-crater (**example**) that may be filled with loose alluvium. Both the area of and severity of broken crust needs to be assessed.

Exclusions:
Record “Not Applicable” in the following circumstances.
- Loose, sandy soil
- Self-mulching (surface crumb-structure) soils
- Soil under high, permanent perennial plant cover (no crust present, typical in the wet dry tropics)
- When less than 25% of the 1-m line transect is crusted

Crust Brokenness	**Class**	**Image Reference**
No crust present	0	0-1, 0-2
Crust present but extensively broken	1	1-1, 1-2, 1-3
Crust present but moderately broken	2	2-1, 2-2, 2-3, 2-4
Crust present but slightly broken	3	3-1, 3-2, 3-3, 3-4
Crust present but intact, smooth	4	4-1, 4-2, 4-3, 4-4

****

6. Soil Erosion Type and Severity

The objective is to assess the type and severity of recent/current soil erosion i.e. soil loss from the query zone.

Erosion in this context refers to accelerated erosion caused by the interaction of management and climatic events, rather than the background levels of geologic erosion.
There are five distinct types of soil erosion (see box) that are caused by water and/or wind action. It is useful to note which type or types are active and how serious is the soil loss. This involves both the aerial extent and the severity. The conventions of McDonald et al 1990 p 92-96 are used. A number of images are presented to assist accurate classification.

Sometimes the erosion occurred at some time in the past and spontaneous restoration has since taken place. For example; rill edges may be rounded or terracettes may have cryptogam colonization (example) in these cases, reduce the severity by one class.

Forms of Erosion

Five major forms are described here (example) and with the photographs referred to, enable the form/s of erosion on the query zone to be determined.

Rills and gullies (example) are channels cut by flowing water. Rills are less then 300 mm deep and gullies are greater then 300 mm deep (McDonald *et al*). They may be initiated by water flowing down sheep or cattle paths. Their presence is a sure sign that water flows rapidly off the landscape, often carrying both litter and soil with it. They are aligned approximately with the maximum local slope.

Terracettes are abrupt walls from 1 to 10 cm or so high, aligned with the local contour, (example). Terracettes progressively cut back up-slope, the eroded material being deposited in an alluvial fan down-slope of the feature.

The location of a terracette should be noted in the comments of the landscape organisation sheet for the transect so that its progress upslope can be monitored over time. A change of zone will occur at the location of the terracette and it is assessed as occurring in the upslope zone (i.e. it will have a Erosion type and Severity class value of 1 or 2. The erosion type downslope maybe sheeting and with deposition material.

Sheeting, or **sheet erosion** (example) is the progressive removal of very thin layers of soil across extensive areas, with few if any sharp discontinuities to demarcate them.

This is not always easy to detect with assurance, and may need to be inferred from other soil surface features, such as downslope eroded materials, or surface nature. It is sometimes confused with scalded surfaces, but characteristically is associated with gradational or uniform textured soils.

Many sheeted surfaces are covered by layers of gravel or stone (collectively called "lag") left behind after erosion of finer material, when at an advanced stage (example).

Scalding (example) is the result of massive loss of A-horizon material in texture-contrast soils which exposes the A2 or B horizon which are typically very hard (example) when dry and have extremely low infiltration rates.

Scalds have a productive potential of zero, and pond or shed water readily. They are often on flat landscapes, though not exclusively, whereas sheeting is on gentle slopes.

Pedestalling (example) is the result of removing soil by erosion of an area to a depth of at least several cm, leaving the butts of surviving plants on a column of soil above the new general level of the landscape. Exposed roots are a hallmark of this erosion form. This is a sign that the soil type itself is very erodible and that loss of vegetation in the landscape was preceded by erosion, and not the other way about. Often associated with stones in the post mining environment.

Severity	**Insignificant (4)**	**Slight (3)**	**Moderate (2)**	**Severe (1)**
Erosion Type	**Image Ref.**	**Image Ref**	**Image Ref.**	**Image Ref.**
Sheeting (E)	4-1, 4-2	3-1, 3-2, 3-3, 3-4		
Pedestal (P)				1-1, 1-2
Terracette (T)			2-1, 2-2, 2-3	3-1
Rill (R)			2-1, 2-2	3-1
Scalding (S)	-		-	1-1, 1-2

****

7. Deposited Materials

The objective is to assess the nature and amount of alluvium transported to and deposited on the query zone.

The presence of soil and litter materials on the query zone indicates the availability for transport of resources from upslope sources in the landscape and implies some instability. Silts, sands and gravels usually comprise the alluvium. Absence does not necessarily imply a lack of deposition, as erosion may sweep all these materials out of the system. Alluvial fans can become quite stable and productive, depending on the stress and disturbance impacting on the surface. An alluvial fan may become a productive patch within a short time if the right seasonal conditions occur. The amount or volume of deposited material is more important than the simple cover.

Hummocking is an indication of the movement large quantities of materials by wind. It is not to be confused with pedestalling which is the eroding away of material around plants and other objects. It is most often associated with adjacent scalding.

Hummocking is confined to soils with sandy-textured surface layers and is the result of re-sorting of sand by wind, which accumulates around obstructions, often to depths of many centimetres, or even metres.

The soil in the hummock is unconsolidated (**example**), and if sectioned reveals layers of accumulated soil (inter-bedding) and/or organic matter. The soil in pedestals is coherent and has no sign of layering.

A consequence of hummocking is that fine-grained materials and litter maybe widely dispersed during windy phases and are lost to the system. It is rare in the tropical grasslands.

Deposited Material	**Class**	**Image Reference**
Extensive amount available Greater then 50% cover several cm deep	1	1-1
Moderate amount of material available 20 to 50% cover	2	2.1
Slight amount of material available. 5% to 20% cover	3	3-1, 3-2, 3-3
None or small amount of material available 0-5% cover	4	4-1

****

8. Soil Surface Roughness

The objective is to assess the surface roughness for its capacity to capture and retain mobile resources such as water, propagules, topsoil and organic matter.

- Surface roughness may be due to soil surface microtopography which retain flowing resources (depressions, gilgais etc) or to high grass plant density such that water flows are highly convoluted at the 5-cm horizontal scale. High surface roughness slows outflow rates, permitting a longer time for infiltration and may comprise a safe site for the lodgment of propagules and litter. Soil surface relief that does not facilitate resource retention attracts low scores.
- The spatial expression of roughness off the strict line transect may provide context and assist in the assessment.

- On minesites with bank and trough formations, the depth of the trough is the relevant depth to record (look at the integrity of the trough if bank broken within 10 metres downgrade class value, according to loss of water holding ability. Often this is class 4 or 5.

Surface roughness	Class	Image Reference
<3 mm relief in soil surface Smooth	1	1-1, 1-2, 1-3, 1-4
Shallow depressions 3-8 mm relief Low retention	2	2-1, 2-2, 2-3, 2-4, 2-5
Deeper depressions 8-25 mm, dense tussock grasslands Moderate retention	3	3-1
Deep depressions that have a visible base Large retention	4	4-1
Very deep depressions or cracks >100mm Extensive retention	5	5-1

****

9. Surface Nature (resistance to disturbance)

The objective is to assess the ease with which the soil can be mechanically disturbed to yield material suitable for erosion by wind or water.

- This assessment should only be done on dry soil, as all moist soils are soft. All the criteria below assume dry soil.
- A very hard soil surface implies high mechanical strength, but very low infiltration, due to low porosity and massive crusting or hard setting. This is taken into account by the Excel template which weights the indicator appropriately.
- Crust flexibility and coherence are assessed, as per the table. Note that classification here is not necessarily intuitive: barren scald surfaces receive a 4.

Surface Nature	Class	Interpretation	Image reference
Non -brittle	5	Shows some "springiness" when pressed with finger, typically with A_0 layer; **or** Surface is a self-mulching clay; **or** Surface has no physical crust and is under a dense perennial grass sward (i.e. not just an isolated plant).	5-1
Crust is very hard and brittle	4	Needs a metal implement to break the surface, forming amorphous fragments or powder. The sub-crust is also very hard, coherent and brittle.	4-1, 4-2
Moderately hard	3	Surface has a physical crust and moderately hard, needing a plastic tool (e.g. pen-top) to pierce, breaking into amorphous fragments or powder; the sub-crust is coherent.	3-1
Easily broken	2	Surface is easily penetrated with finger pressure (to about first knuckle joint). Surface may have a weak physical crust and sub-crust is non-coherent *e.g.* sandy.	2-1
Loose sandy surface	1	Surface is not crusted, easily penetrated by finger pressure to about second knuckle joint. Sub-surface is non-coherent.	1-1

****

10. Slake Test

The objective of this test is to assess the stability of natural soil fragments to rapid wetting.

The test needs to be done on each landscape stratum type identified. Stable soil fragments maintain their cohesion when wet, implying low water erosion potential. The test is performed by gently immersing air-dry soil fragments (**example**) of about 1-cm cube size in rainwater and observing the response over a period of a minute or so.

- Water quality is important.
- Saline water is unsuitable.
- The soil crust must remain uppermost after immersion.

The fragment can be obtained with a chisel or knife blade, breaking the fragment with the fingers to the appropriate size. Some soils with high organic matter levels may float in the water. Usually, these are stable (Class 4). Soils that do not permit coherent fragments to be picked up and tested (e.g. loose sands) should be scored as "not applicable" (a zero in the spreadsheet).

Exclusions:- Do not test moist soil. Take a sample back to the laboratory, allow it to air-dry, then test

Observed Behaviour	**Class**	**Interpretation**	**Figure Reference**
Not Applicable	0	No Coherent fragments available e.g. sand	0-1
Very unstable	1	Fragment collapses in less then 5 seconds	1-1
Unstable	2	Fragment substantially collapses 5-10 seconds; a thin surface crust remains. >50% of the sub-crust material slumps	2-1, 2-2
Moderately stable	3	Surface crust remains intact with some slumping of the sub-crust but less then 50%	3-1, 3-2
Very stable	4	Whole fragment remains intact with no swelling	4-1

****

11. Texture

The objectives of this test are to classify the texture of the surface soil, and relate this to permeability.

This procedure is an initial measurement at the establishment of the site, and does not require being repeated at each monitoring event. It is done with a pedologists' moist bolus test, and a simplified 4 point scale (Table 12).

The field technique is described by McDonald et al. 1990. Take a sample of soil from a depth of 0-5 cm that will comfortably fit into the palm of the hand. Moisten the soil with water, a little at a time, and knead until the ball of soil, so formed, just fails to stick to the fingers. Add more soil or water to attain this condition, known as the *sticky point*, which approximates field capacity for that soil. Continue kneading and moistening until there is no apparent change in the soil ball, usually 1-2 minutes. The behaviour of the soil ball, or bolus, and the ribbon it produces by pressing out between the thumb and forefinger characterizes the field texture.
The flow-chart in figure 33 enables soil texture to be quickly determined.

Exception:
Self-mulching, cracking clays should be assessed as class 3, because of their moderate infiltration rate.

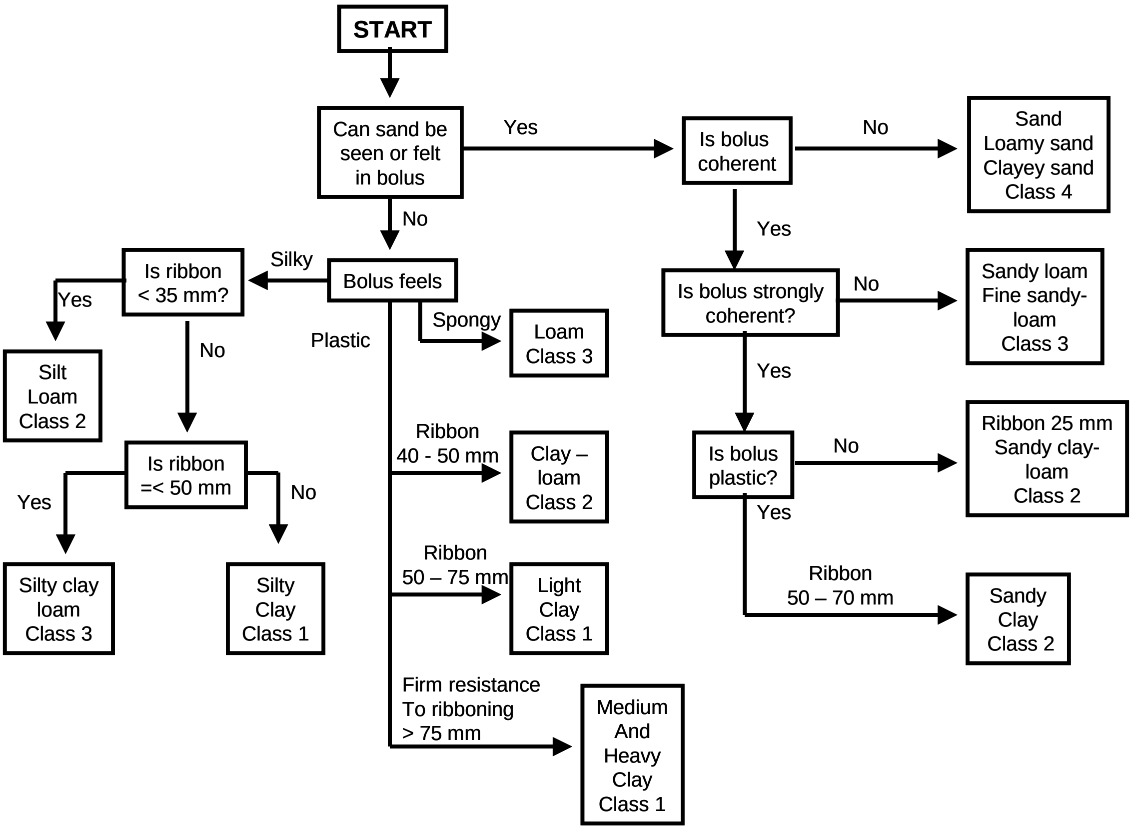


Figure 33. Soil texture flow chart.

Table 12. The rating scales for individual soil texture features.

Texture	Class
Silty clay to heavy clay (very slow infiltration rate)	1
Sandy clay loam to sandy clay (slow infiltration rate)	2
Sandy loam to silt loam (moderate infiltration rate)	3
Sandy to clayey sand (high infiltration rate)	4

TURNING DATA INTO INFORMATION

C DATA REDUCTION AND TABULATION

C1 Landscape Organisation

The landscape organisation data collected in step 2 has two purposes. The first is to identify the patch and inter-patch zones to produce indices describing how effectively the landscape regulates vital resources at the hillslope scale. The second is to facilitate Soil Surface Assessment at the 1 metre scale (see section C2).

Hillslope Scale Indices

The landscape organization indices are:

- Number of patch zones/10 metres
- Total Patch area
- Patch Area Index (total patch area/maximum area if all the transect was patch (transect length * 10))
- Average inter-patch length and range
- Landscape Organisation Index. (derived by dividing the sum of the patch zones by the length of the transect line). These are calculated by the Excel template and are tabulated in the summary worksheet.

C2 Soil Surface Assessment Calculations

The individual observations of the soil surface indicators are grouped as per Figure 34 into **3 indices** each of which have distinct significance for landscape function monitoring.

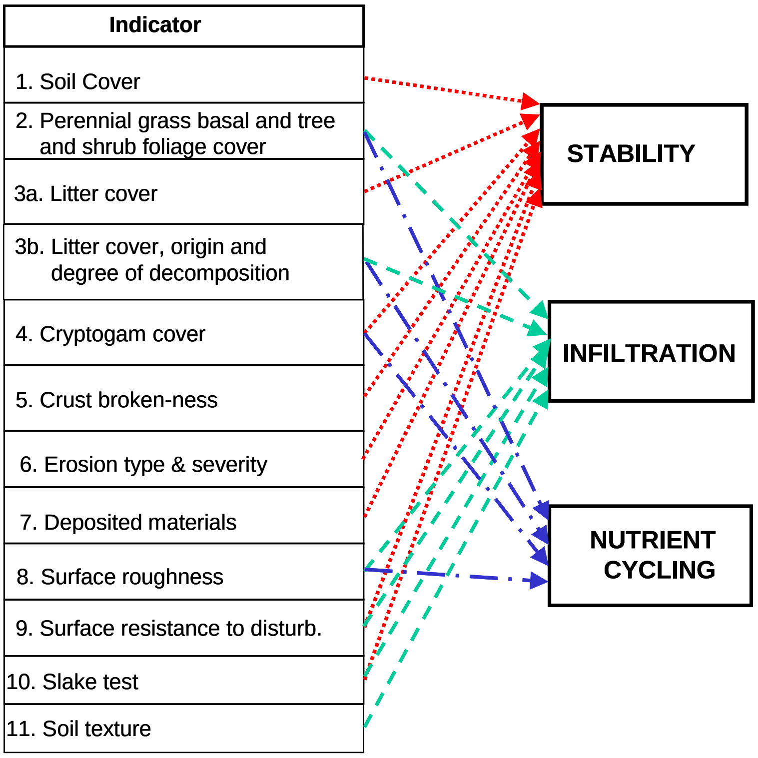


Figure 34. Shows the allocation of the indicators to the three indices of Stability, Infiltration and Nutrient Cycling.

****

1. Stability

Defined as the ability of the soil to withstand erosive forces, and to reform after disturbance.

Indicator	Class range
• crust broken-ness	**1-4**
• surface resistance	**1-5**
• slake test	**1-4**
• erosion type and severity+	**1-4**
• deposited materials	**1-4**
• cryptogam cover	**1-4**
• soil cover (rain)	**1-5**
• litter cover*	**1-10**

If all features are present scale ranges from 8 to 40

+ Note 2: Where there is more than one entry for "erosion type and severity", the score used is the most severe or most abundant, i.e. the lowest class number.

* Note 1: litter cover alone in this category.

****

2. Infiltration/Runoff

Defined as how the soil partitions rainfall into soil-water (water available for plants to use), and runoff water which is lost from the local system, or may also transport materials (soil, nutrients and seed) away.

Indicator	Class range
• perennial basal, shrub and tree canopy cover	**1-4**
• surface rough-ness	**1-5**
• slake test	**1-4**
• litter cover, origin and decomposition+	**1-30**
• surface resistance to disturbance*	**1-10**
• soil texture	**1-4**

If all features are present Scale ranges from 6 to 57

+ Note 2.The full contribution of litter to this category is obtained by multiplying the basic litter cover by the following factors:

a) both transported (T) litter and nil (N) incorporation of litter, multiply cover value by **1** (i.e. no change to cover).
b) for litter of local (L) origin, multiply cover value by **1.5.**
c) for slight (S) incorporation **1.3.**
d) for moderate (M) incorporation of litter, multiply the cover value **1.7.**
e) for extensive (E) incorporation of litter, multiply the cover value by **2.0**.

* Note 1. Infiltration is slowed by compact soil surfaces (e.g. a scald). To allow for this, the assessed surface resistance to disturbance indicator is reallocated in the following way in calculating the Infiltration index. This is automatically done by the supplied spreadsheet.

- Class 5 → 6.6
- Class 4 → 1

- Class 3 → 3.3
- Class 2 → 6.6
- Class 1 → 10

When using the spreadsheet the class values are automatically calculated.

****

3. Nutrient cycling status

Defined as how efficiently organic matter is cycled back into the soil.

Indicator	Class range
• perennial basal, shrub and tree canopy cover	**1-4**
• litter cover, origin and decomposition[+]	**1-30**
• cryptogam cover	**1-4**
• surface roughness	**1-5**

If all features are present Scale ranges from 4 to 43.

[+] The full contribution of litter to this category is obtained by multiplying the basic litter cover by the following factors.

a) both transported (T) litter and nil (N) incorporation of litter, multiply cover value by **1** (i.e. no change to cover).
b) for litter of local (L) origin, multiply cover value by **1.5.**
c) for slight (S) incorporation **1.3.**
d) for moderate (M) incorporation of litter, multiply the cover value **1.7.**
e) for extensive (E) incorporation of litter, multiply the cover value by **2.0**.

For example, for a recording of 3LS, the litter score contributing to the nutrient category is:
3 x 1.5 x 1.5 = 6.75

The final assessment for each category is then converted to a % value of the maximum.

The Excel spreadsheet calculates all the indices automatically as the raw data is entered.

Discussion

These indices are useful at both the query zone and site scale.

- Changes in the spatial location and condition of every query zone can be assessed.
- Soil condition can also be compared directly with independently obtained vegetation data and so that "a cause and effect" understanding of overall site condition is possible.
- By calculating these three indices separately, the activity of processes, which they represent, can be assessed more closely. The indices do not necessarily move in concert: one may remain invariant whilst another changes considerably. The "strengths" and "weaknesses" of a site can therefore be identified.
- If any indicator is recorded as not applicable (n/a) for a given query zone type, the scale of the category is adjusted accordingly. For example, on a sandy site, the soil may be loose, and the slake test is not applicable. The stability index range then changes from 8 to 40 to 7 to 36
- The class values for each observation are added for each index to give a value reflecting the status of a query zone with respect to that index.

VERIFICATION OF SOIL SURFACE ASSESSMENT INDICES

For the generated indices of stability, infiltration and nutrient cycling to be meaningful they need to be verified against established scientific measurements. This has been done at a number of sites in both the rangelands and on mine sites. A limited number of correlations are presented here to illustrate the validity of the method to provide reliable and useful information that has scientific backing. Further data is available at the website (mine).

Measurements were either undertaken in the field in the case of infiltration and soil respiration or soil samples collected for subsequent analysis in the laboratory. These measurements and samples were undertaken at the sites where the soil surface assessment data were collected using the visual indicators.

Stability

To measure soil stability, intact soil cores, in metal rings, were collected in the field. At the laboratory the soil was expressed from the ring in layers of 0 to10mm and 10 to 30 mm. A weighed sample was then wet-sieved through a nest of sieves as a measure of the stability of the soil aggregates (Fig. 35). The method and the procedure are described in Chaney and Swift (1984).

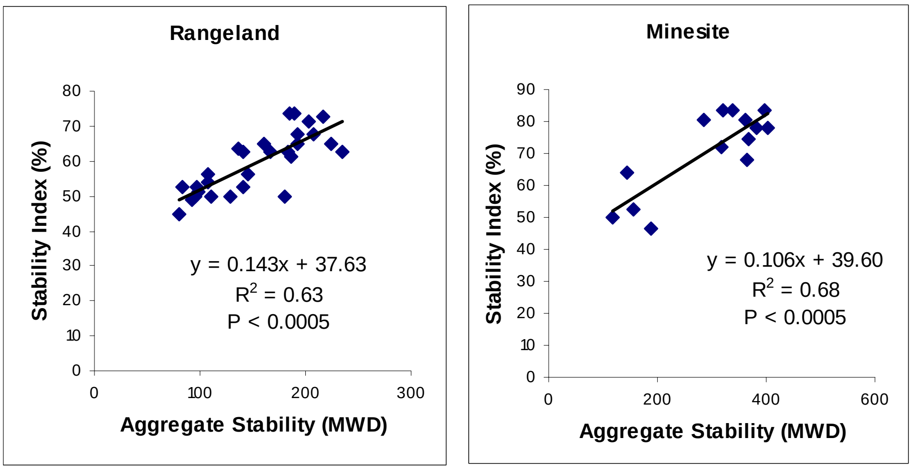


Figure 35. Shows the linear relationship between the laboratory measured aggregate stability, (in terms of mean weight diameter) and the field assessed stability index for rangelands and a rehabilitated minesite.

Infiltration

The infiltration was measured in the field using a disk permeameter, in the saturated flow mode, described by Perroux and White 1988. Measurements were continued until a steady infiltration rate was maintained over several minutes (Fig. 36).

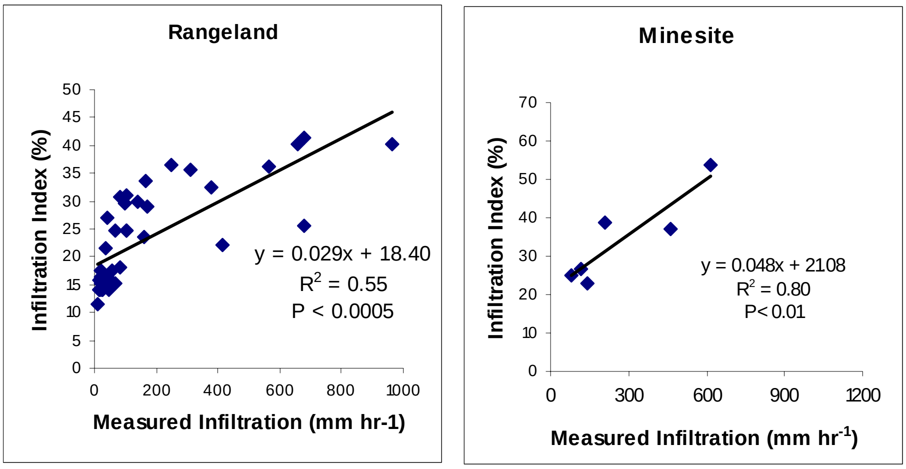


Figure 36. Shows the relationship between the field measured saturated infiltration rate and the assessed infiltration index for a rangelands and a rehabilitated mine site.

Nutrient Cycling

Two procedures were used to verify the nutrient cycling index.

(i) Soil respiration was measured by collecting the evolved CO_2 in the field over a 24-hr period (Hartigan 1980). This reflects the biological activity in the soil (Fig. 37).

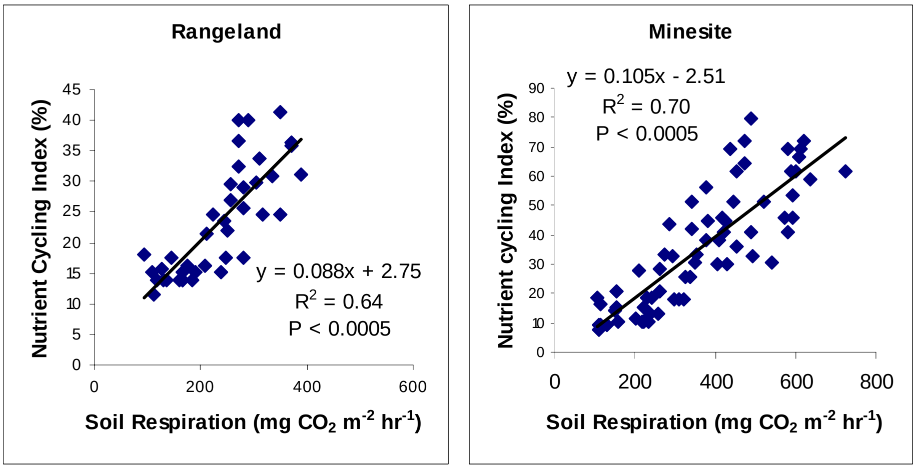


Figure 37. Shows the relationship between field measured soil respiration and the assessed nutrient cycling index for a rangeland and a rehabilitated mine site.

(ii) The size of the nutrient pool of the biological acquired soil nutrients. These included total nitrogen and carbon (Leco 2000) and mineraliseable (available) nitrogen (Gianello and Bremner (1986) (Fig. 38).

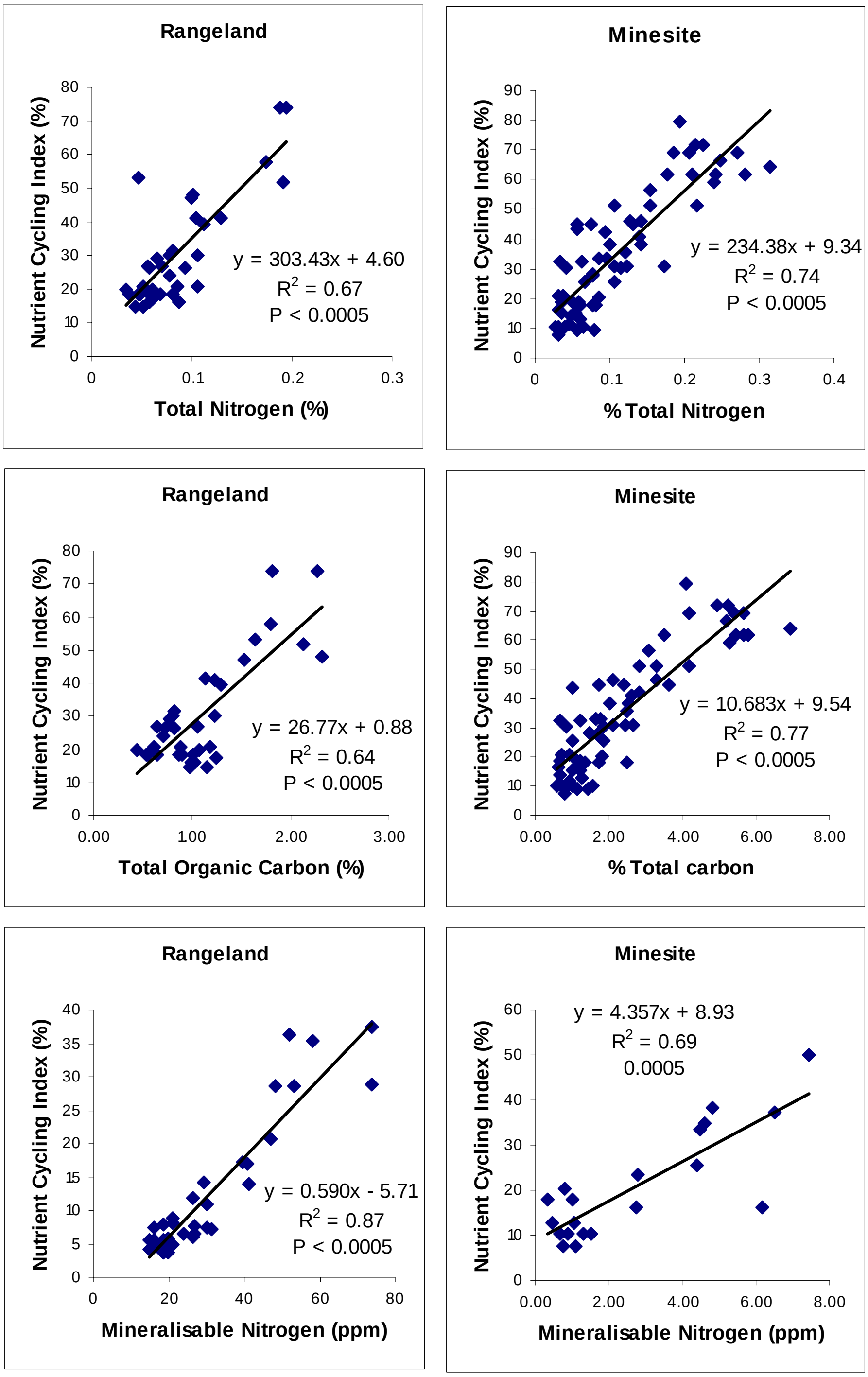


Figure 38. Showing the relationship between measured nutrient pool sizes for total carbon, total nitrogen and mineralisable nitrogen and the assessed nutrient cycling index for rangelands and a rehabilitated mine site.

USE OF THE DATA

The functional status of a landscape can be assessed by LFA, however if it is only recorded once it does not have any predictive capacity. In example 1 the type of information for a natural grazed semi-arid system derived from LFA monitoring as a once only is given.

Example 1

At a grazing trial site in western NSW transects were established to map the landscape organization of 4 paddocks (A, F, G, K). Each transect consisted of 3 zones, a runoff slope (ROS) which was mostly bare (inter-patch), a grassy interception zone (IZ) (patch) and a mulga grove (MG) that consisted of grass and trees (patch). The soil surface was assessed for each of the above zones to enable the generation of indices of stability, infiltration and nutrient cycling for each zone as well the site as a whole.

From the landscape organization mapping data, the boundaries of the functional zones enable the calculation of the proportion of each (Table 13).

Table 13. The % of each functional zone for each of the 4 paddocks.

Paddock	ROS	IZ	MG
A	63	21	16
F	34	45	21
G	49	41	10
K	45	18	37

Within each of these zones an SSA gave us the data to calculated the indices Stability, Infiltration and Nutrient cycling (Table14).

Table 14. The SSA indices of Stability, Infiltration and Nutrient Cycling for the 3 zones delineated in each paddock. Runoff slope (inter-patch), interception zone (patch) and mulga grove (patch).

Paddock	Stability Index			Infiltration Index			Nutrient Cycling Index		
	ROS	IZ	MG	ROS	IZ	MG	ROS	IZ	MG
A	55.8	63.0	78.3	39.7	44.9	56.4	18.5	20.9	53.3
F	51.3	58.5	72.0	38.5	44.9	52.6	14.8	29.9	51.8
G	44.1	54.9	72.0	37.2	41.0	55.1	14.8	20.9	39.5
K	57.6	75.6	78.3	38.5	53.8	38.5	18.5	26.5	41.0

Using the data in Table 13 and 14 the contribution of each zone type to the overall paddock index were calculated. (Table15).

Table 15. The contribution of each zone to the whole of paddock index.

Paddock	Stability Index				Infiltration Index				Nutrient Cycling Index			
	ROS	IZ	MG	Total	ROS	IZ	MG	Total	ROS	IZ	MG	Total
A	34.8	12.9	13.3	61.0	24.8	9.5	9.3	43.6	11.5	4.4	8.7	16.9
F	17.6	26.3	14.8	58.7	13.2	20.2	10.8	44.2	5.1	13.4	10.6	29.1
G	21.8	22.6	6.7	51.1	18.4	16.9	5.2	40.4	7.3	8.6	3.7	19.6
K	25.8	13.3	29.3	68.4	17.2	9.5	23.6	50.3	8.3	4.6	15.3	28.2

The data thus derived can be displayed in many ways. Figures 39 to 41 illustrate one where the index between paddocks can be displayed showing the proportion each zone contributes to the overall paddock index.

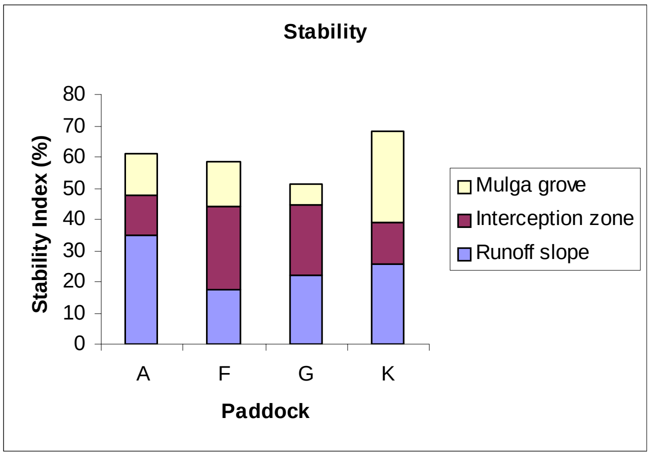


Figure 39. Showing the contribution of each of the 3 zones to the stability index.

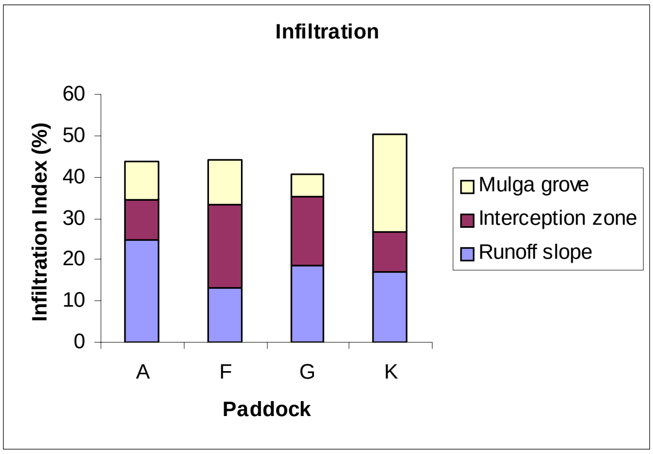


Figure 40. Showing the contribution of each of the 3 zones to the infiltration index.

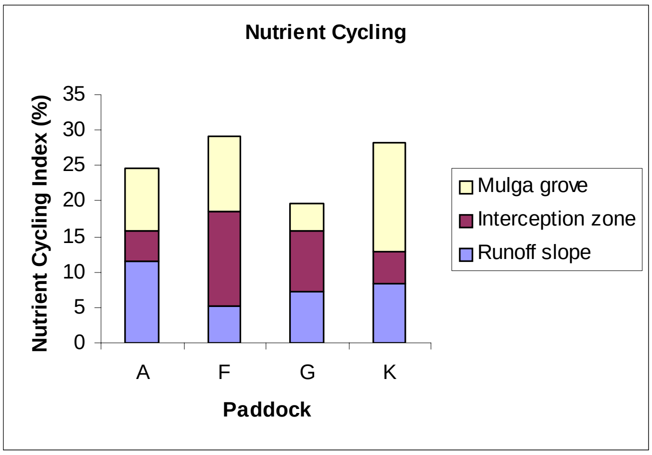


Figure 41. Showing the contribution of each of the 3 zones to the nutrient cycling index.

The data collected by the LFA method has a predictive capacity when regular monitoring provides a time series record of ecosystem change or development. LFA does not automatically classify a site into good, moderate or poor. The significance of a particular numerical value comes from comparing disturbed sites with analogue sites. Index values do not absolutely indicate the functional state: these depend on the biome type e.g. a nutrient cycling index of 25 may represent a highly functional grassland, but dysfunctional woodland. The development of a rehabilitated ecosystem can be quite dramatic. (Figure 42)

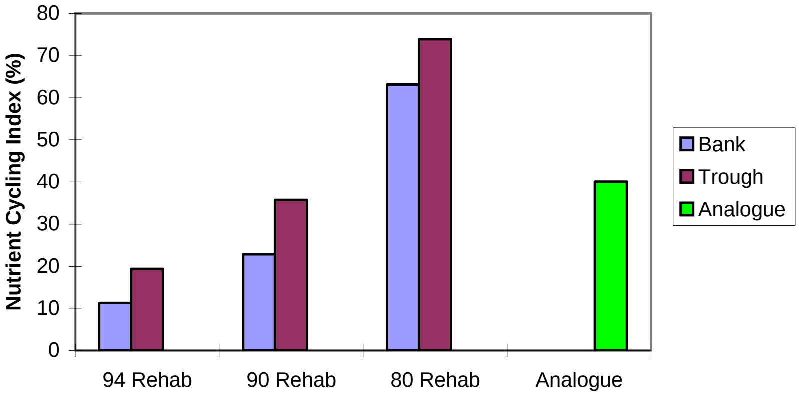


Figure 42. The development of the nutrient cycling index over time in a rehabilitated tropical landscape. The value for the analogue site is considerably lower then what would be expected in a tropical woodland, because it has been burnt annually. The rehabilitated sites have not been burnt at all. Analogue sites need to be used with caution until the effect and role of current stress or disturbance on them is understood.

Conceptual Application

It is the form of the **indicator curve or trajectory** over time, and the concept of thresholds that enables the data to have a predictive capacity. Figure 43 depicts three contrasting ecosystem function responses over time that we have observed at different minesites. **Curve A** represents an appropriate trajectory shape, implying that the rehabilitation is on-track. It is characterised by a steep initial response followed by a steady increase over time. All indices at a given site should exceed the critical threshold value if ecosystem rehabilitation is to be judged successful.

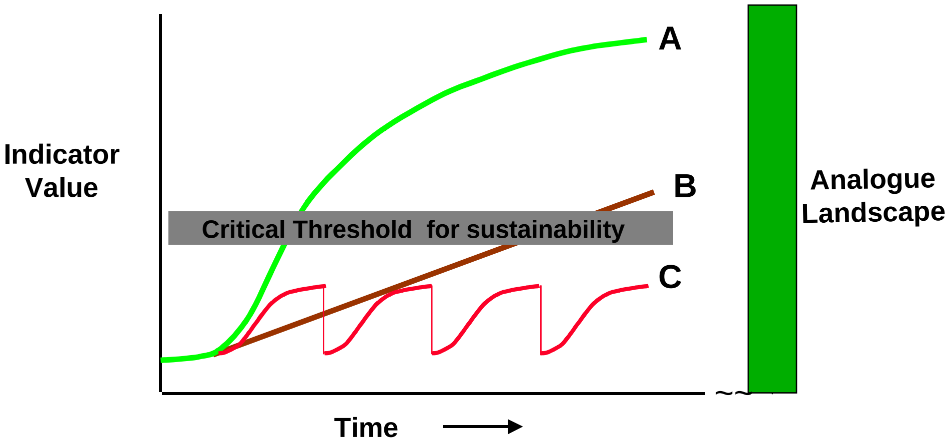


Figure 43. Three contrasting ecosystem rehabilitation trajectories.

A conceptual critical threshold range is shown which represents the index value **for self sustainability**: that is, the ecosystem does not need further additions of nutrients, seed, water or other management inputs in order to be self-sustaining. Whilst an ecosystem remains below this threshold range, it is vulnerable to climatic events like storms or stochastic disturbance such as fire. The longer an ecosystem is below this threshold (e.g. curve B) the more at risk is its ultimate success of not achieving ecosystem sustainability. Curve C represents a system that proved vulnerable to frequent disturbance (for example, periodic fire) and hence does not achieve self-sustainability.

The form of trajectory therefore informs the use like a metaphorical traffic light cluster: A (green) – no problems identified; B (amber) – potential problems identified which need a closer look: and C (red) – problem identified which needs attention.

After initial rehabilitation, a period of instability can be expected when unconsolidated materials settle down and some erosion occurs.

Curve 1 in Figure 44 the rate of erosion decreases rapidly before stabilising at a level well below a critical threshold (conceptually defined as the erosion rate that is too high for biota alone to cope with).

Curve 2 represents an ecosystem where soil stability improves but slowly, so that the ecosystem is vulnerable to environmental or other stresses for some time. This may reflect the basic spoil/soil properties and /or the landform into which they are shaped. There will need to be design criteria to avoid creating a soil/landscape combination with too low a potential to self-organise.

Curve 3 reflects a system where the spoil/soil properties and landform/climate interactions result in continuous uncontrolled erosion.

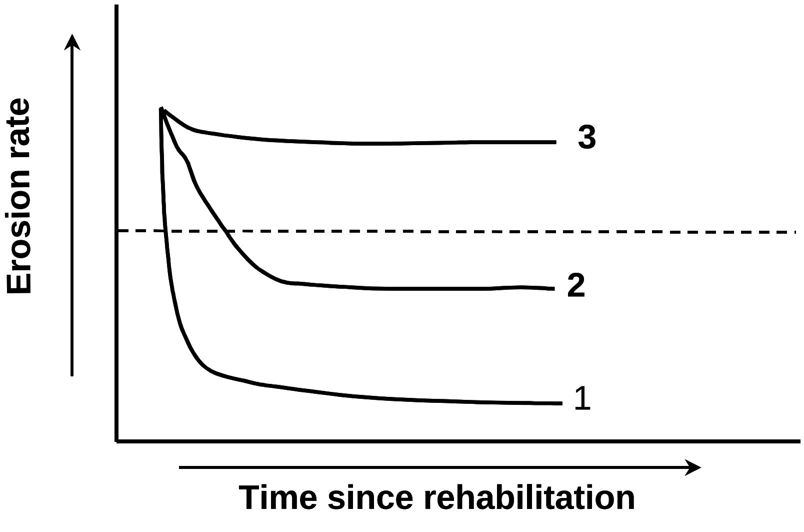


Figure 44. Erosion scenarios derived from stability indices, over time.

Interpretational concept

There needs to be a way of interpreting monitoring data so that practical values emerge that are useful in predicting success. This is an area where relatively little work has been done at the practical level, though complex statistical models of plant species behaviour have had some attention (Friedel 1994).

Sigmoidal curves have been proposed for resource limited landscapes (Noy-Meir 1981), so there is at least a *prima facie* case to utilise this shape for interpretative purposes. The authors had independently looked at the concept in a rangeland context for the National Land and Water Audit (Tongway & Hindley 2000), and found that a sigmoidal curve was particularly useful in describing the behaviour of the data. The sigmoidal curve is intuitively attractive, because landscape values must have upper and lower biogeochemical bounds; the slope of the line between these bounds representing the transition from functional to dysfunctional status may vary, signifying differences in resilience. Noy-Meir (1981) utilised this form of relationship in his model of landscape structure and functioning, and Bastin *et al* (1993) also reported a similar spatial relationship with remotely sensed grazing gradients (Fig. 45).

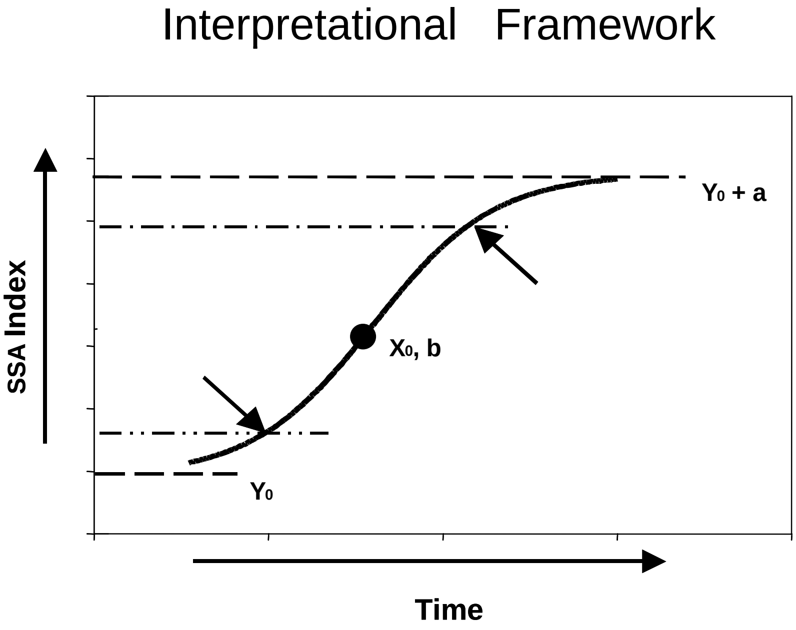


Figure 45. Depicts a fitted sigmoid relationship of the form $y = y_0 + a / 1 + e^{-(x-x_o)/b}$.

$\mathbf{y}$ represents an indicator of landscape function (soil stability in this case),
$(\mathbf{y_0+a})$ represents the value of the upper asymptote,
$\mathbf{y_0}$ the computed value of the lower asymptote,
$\mathbf{x_0}$ represents the location of the inflection point of the curve on the x-axis and
$\mathbf{b}$ the gradient at the inflection point, represents the rate of increase of the assessed index over time.

Low values represent quickly responding ecosystems, high values denote slow response.

The curve parameters represent values related to functional behaviour of the landscape: how stable it can be when fully functional and how unstable when severely stressed. The dynamics of “functional” response in this case are due to the nature of the soil type and its moderate capacity to resist erosion.

The location of the points of maximum curvature (arrows) could be used as threshold values. The upper point could be used to differentiate between self-sustaining landscapes close to the ‘ultimate goal’, and those that are under threat of accelerated erosion. This curve can be fitted, and values for each of the curve parameters calculated by commercial software packages. The points of maximum curvature represent landscape threshold values for management and can be determined easily from the curve plot. The curve parameters can be used to characterise the functional response of different landscape types.

In the minesite rehabilitation scenario, y_0 represents the functional status at time zero (completion of geotechnical phase). As data from periodic monitoring accumulates, they can be fitted to a sigmoidal curve, so that the values of x_0 and b are evaluated. **b** (the slope at the inflexion point) is an important development factor, and should show a steep response. In early years, prediction of **(y_0 + a)** should be ignored, but over time, this value will assume greater importance. Plateauing of the upper curve at low values or at an early stage would constitute warning signals. **(y_0 + a)** values could be derived from analogue sites, **but with caution**. Each of the SSA indices need to be individually fitted to a sigmoidal curve. If sites have been well prepared stability might well have a high initial value and not change much. Nutrient cycling would necessarily start with low values, but increase steeply over time.

Demonstration of the concept

There is insufficient continuous monitoring data available from any single site to give a time series from either rangelands or minesite rehabilitation to fully demonstrate the concept. Typically, a minimum of 6 time-series points with 2 of those represent initial and final values respectively would be needed, with the accuracy of predictions of outcomes improving as more data are included in the analysis over time.

The concept is demonstrated using data collected in a chenopod shrubland in South Australia. (Example 2). Figure 46 is comprised of data from a 10 km long grazing gradient near Kingoonya in South Australia. As depicted, this could be a rehabilitation trajectory for a mine, but with the x-axis as time. The landscape unit under study was a chenopod shrubland on flat to gently undulating landform, with a calcareous shallow loam soil, underlain by calcrete at shallow depths. Distance from water is the surrogate, in this instance, for a gradient in stress and/or disturbance and plotted here as the logarithm. The y-axis is a soil stability index derived from the LFA methodology.

Example 2

The whole transect itself was not logged but sections at 30, 300, 1000, 4000, 7000 and 10000 m were assessed. Bush density and canopy volume were measured using the wandering quarter method, and soil surface for bush mounds (patch) and between bushes (inter-patch) were assessed. Table 16 gives the SSA index data for the sampled sections.

Table 16. The stability, infiltration and nutrient cycling indices for each of the sampled sites on a 10000 m transect out from water.

Distance (m)	Log Distance	Stability (%)	Infiltration (%)	Nutrient Cycling (%)
30	1.48	30.7	38.3	18.8
300	2.48	39.6	27.8	11.5
1000	3.00	48.2	38.2	16.7
4000	3.60	51.3	34.6	16.6
7000	3.85	55.7	35.0	18.2
10000	4.00	51.9	34.0	17.5

In scanning the data only the Stability index has any large dynamic range which indicates the stability index is the important index to monitor along with the factors that have the biggest influence on it. Being a light sandy textured soil with wind being the major erosive force the monitoring of the vegetation density and canopy volume are most important. In the following 3 graphs the data is presented in the form of a sigmoid curve plotted against log distance to water. Figure 46 presents the stability index data, figure 47 the bush (blue bush) density and figure 48 bush canopy volume. These relationships are strongly indicative that the sigmoidal model is a meaningful means of understanding the data collected by LFA.

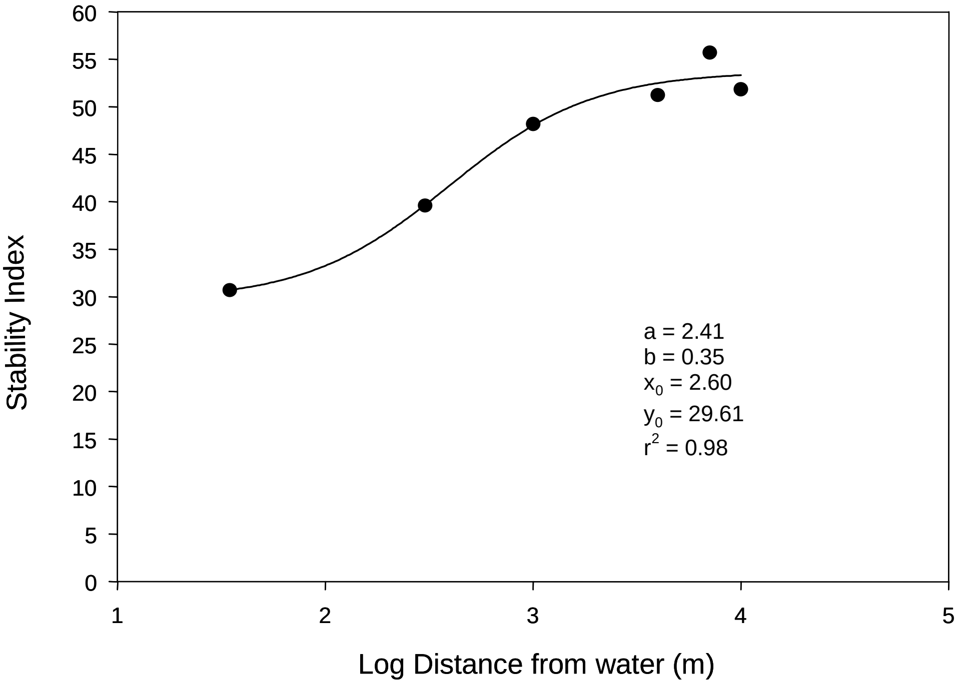


Figure 46. The sigmoidal curve for the Stability Index on a transect out from water. The area greater than about 1 km from water are self-sustaining.

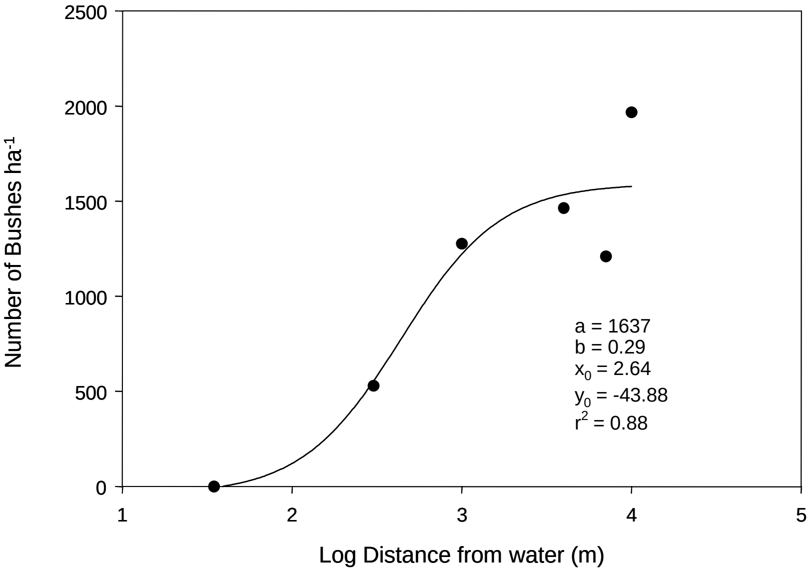


Figure 47. The sigmoidal curve for the number of bushes on a transect out from a water point.

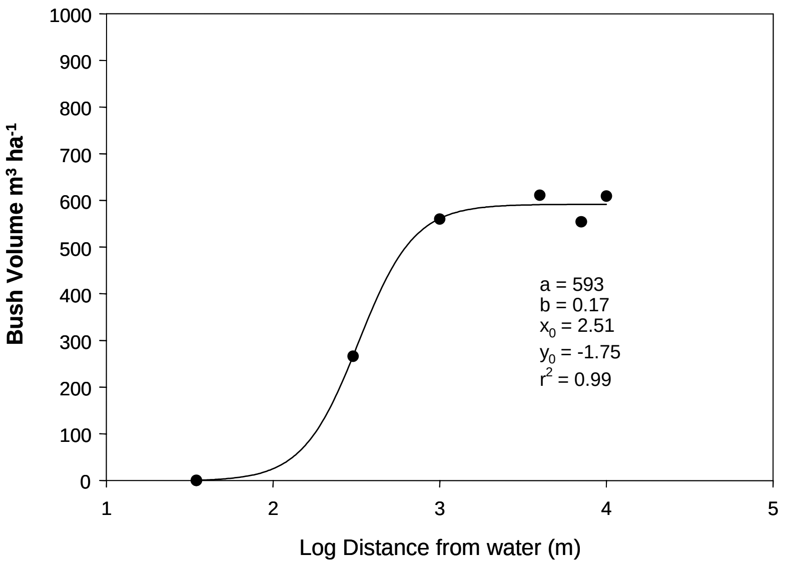


Figure 48. The canopy volume of blue bush on the transect out from a water point.

MINESITES

On minesites the concept in demonstrated from data collected at the Alcan Gove Bauxite mine in northern Australia. (Example 3).

This minesite was the only one where a very similar rehabilitation technique had been regularly used for a continuous 26-year period where the authors have worked. This curve shape indicates that, in the minesite context, after the initial rehabilitation landscape set-up, there was a brief plateau period followed by a rise in landscape function as the biota established and became active in ecosystem processes that gently flattened off after some years, eventually forming an upper plateau representing the biogeochemical potential of the site. This latter region is the "target" or rehabilitation goal and depends on the parent soil material and the climate. In practice, this value in mined lands, would come from a set of analogue sites similar to the final rehabilitation landscape phase in terms of slope, soil surface properties, vegetation composition and land use. Assessing the analogue sites would be an integral part of monitoring rehabilitation and in practice would generate a "band" of values depending on seasonal effects as well as stochastic events like storms, droughts and fire. Figure 49 shows the sigmoidal curve derived from a pseudo time series analysis of the Gove sites over a 26-year time span for the stability index. The sigmoidal shape conforms to the conceptual shape very neatly, with the exception of year 8.

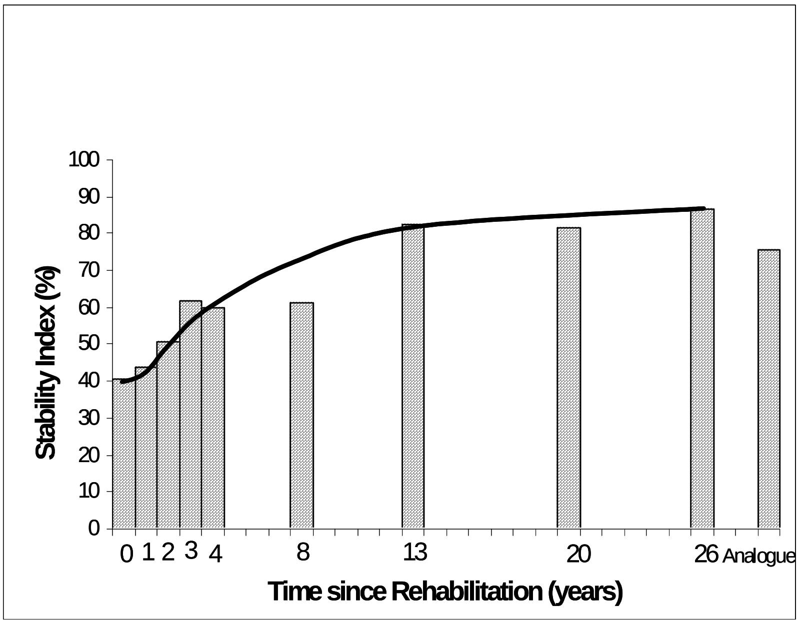


Figure 49. The sigmoidal curve reflecting the trajectory of stability development at Gove. Note that the analogue site value is lower than the older rehabilitation sites, due to effect of frequent burning of the analogue site.

This set of curves shows a considerable difference in the time to achieve plateau values. Both infiltration (Fig. 50) and nutrient cycling (Fig. 51) rely on the long-term development of the Eucalypt woodland and the increasing activity of soil "ecosystem engineer" fauna (Lavelle 1997). However, looking at the rate of increase of the indices at early times remains a powerful tool. At Gove, the utility of the analogue concept is affected by the unremitting fire regime in lands outside the mine.

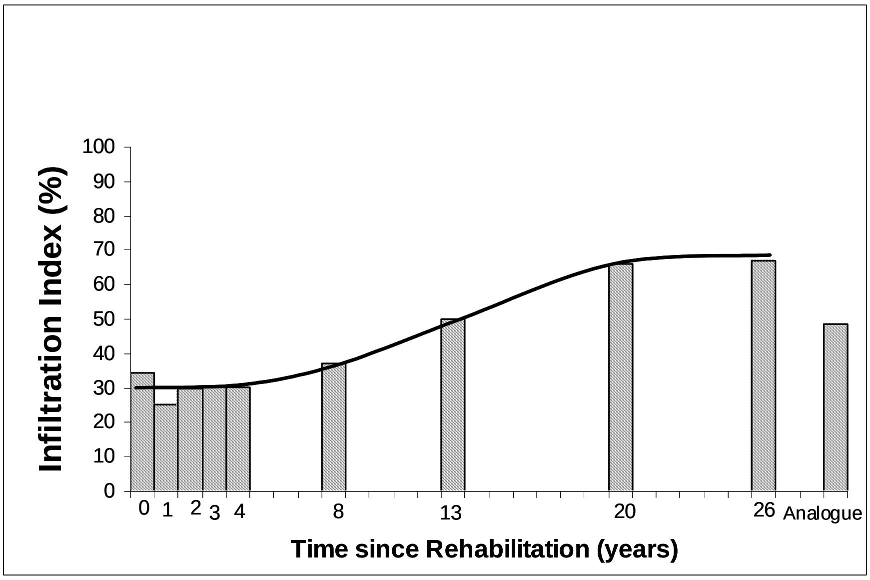


Figure 50. The sigmoidal curve reflecting the trajectory of infiltration development at Gove. Note that the development "lags" the stability curve (Fig. 49).

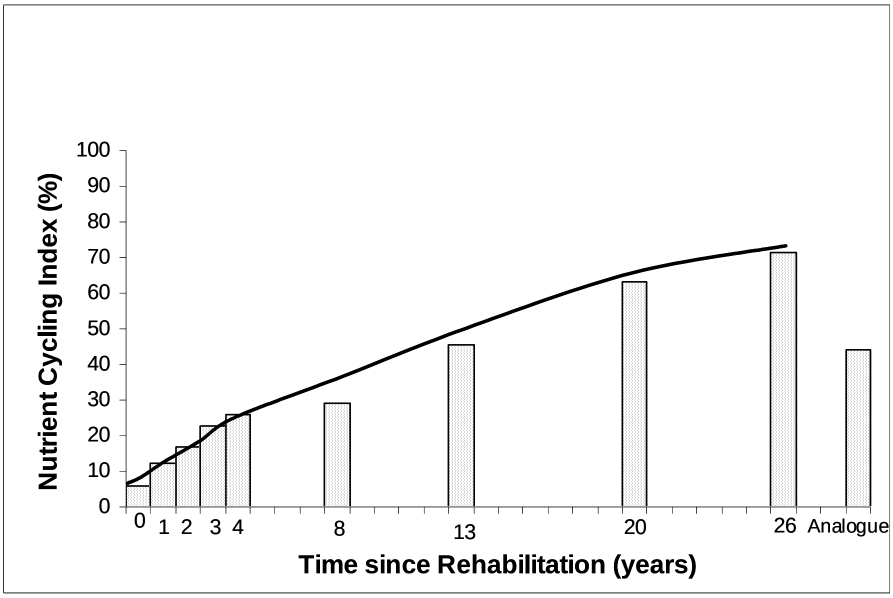


Figure 51. The trajectory of the nutrient cycling index at Gove. The full sigmoidal shape is not evident. The ecosystem has not yet reached a true plateau, even after 26 years, due to the growth of *Eucalyptus tetradonta*, which will continue for some time yet, with increasing canopy biomass and litter fall. However, the utility of the early steep rise of the sigmoidal curve remains as a useful tool in assessing ecosystem development.

VEGETATION DYNAMICS

THE FUNCTIONAL ROLE OF VEGETATION

Vegetation has a highly functional role in providing 'goods and services' for both itself (self sustainability) and as suitable habitat, food and shelter for other biota. Typically vegetation monitoring looks in detail at species composition and structure, with less emphasis on its functional role in the landscape as a whole. The methods of assessment used are well developed and time-honored procedures that have been in the literature without substantive modification for decades and with a history extending back well over a century (e.g. Bonham 1989). These methods are important, but like many other monitoring procedures, represent the outcome of the past behaviour of the ecosystem without a strongly developed innate predictive capacity. That is, if species X is missing from the rehabilitation, there is nothing in the vegetation composition and structure data that can assist in deciding why this is so or what to do about it. Individual observers may use their experience and intuition to make practical suggestions, but these mental syntheses are extrinsic to the data.

The indices of vegetation developed in this module reflect both the traditional factors of structure and composition, but importantly add the functional role of vegetation in regulating vital resources whether wind or water is the mobilizing agent. The data are presented graphically, so that a "picture" of vegetation function emerges (Fig. 55).

Species composition and growth rates of vascular plants can be assessed using the LFA transect as a reference. Typically, plotless, distance-measuring methods are used to obtain data, because of their versatility in sparse and unevenly distributed vegetation. These are "standard" methods as used conventionally in vegetation science (e.g. Bonham 1989, p159 and 169 respectively). Other useful data about the plants that can be collected at the same time as for trees and shrubs (Fig. 52):

- Overall height,
- Height to canopy,
- Width and breadth of canopy and
- Canopy density (McDonald et al page 71)

(Suggested Vegetation assessment data sheet)

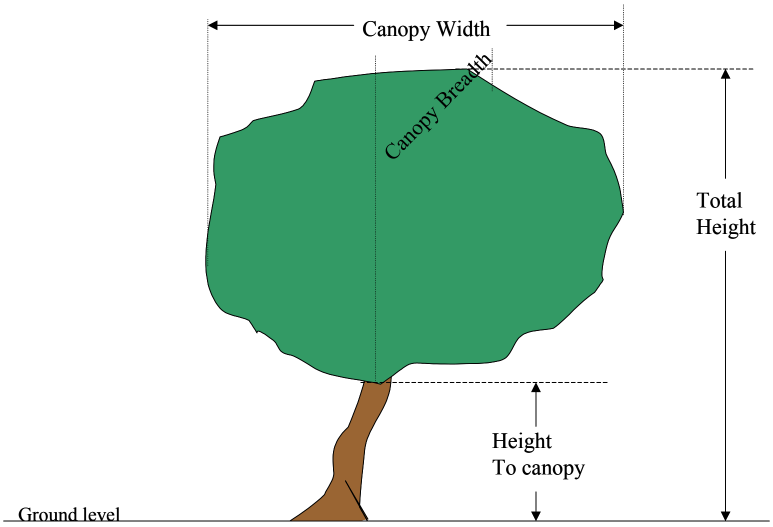


Figure 52. Illustrating data recording on a tree/shrub.

For grasses:

- Width and breadth of the butt of grasses,
- Height, but this is less useful with grasses if they are subject to grazing.

To obtain representative vegetation data a separate measure needs to be made for each of the life forms i.e. grasses, shrubs and trees. Two methods are described here:

1. Point Centred Quarter (PCQ)

Sampling points are established on the LFA transect line at regular intervals. At each point, the distance to the nearest plant of interest in each of the 4 sectors (Figure 53) is measured. The density of plants is calculated from a simple formula. A minimum of 20 points (20 points x 4 plants = 80 plants) is recommended but this may not always be possible if the rehabilitation area is small. The sampling point interval depends on the life-form and density of the plants being sampled e.g. sample points for grasses can be much closer together then for shrubs or for trees. The **same** plant **cannot** be sampled twice, or an unacceptable bias occurs. The procedure is not recommended in plantations where spacing is regular.

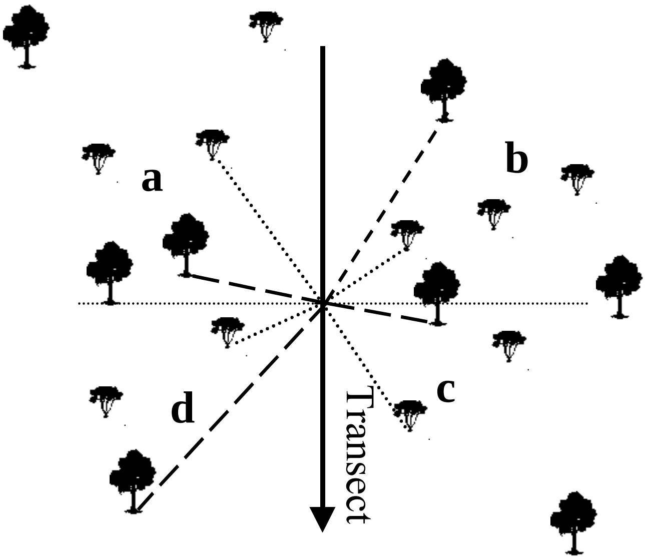


Figure 53. The PCQ method of measuring spatial distribution of Vegetation, showing measurements at a single point.

2. Wandering Quarter (WQ)

This is another "plotless distance measuring" method similar to PCQ and facilitates measurements in sparse vegetation. From the start of the transect and using its compass bearing, measure the distance to base of the nearest plant which is within 90 degree arc centred on the compass bearing. Then move to that plant and on the same compass bearing find and measure the distance to the next plant. Continue to do this until at least 25 plants are recorded or the other boundary of the monitored area is reached. More lines parallel to the original, if practical can be recorded if insufficient plants are found on the first line. **Do not treat these lines as replicates**. Figure 54 illustrates the technique. **The same plant cannot be measured twice even on adjacent lines**.

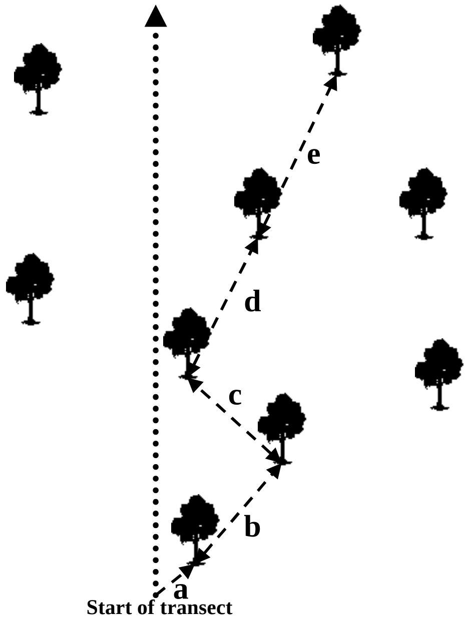


Figure 54. The Wandering-Quarter method of measuring spatial distribution of vegetation

The methodology is conventional, but linking the vegetation data to the landscape and soil indicators is a feature of the expanded LFA. For example, by combining data from vegetation dynamics and soil surface indices, the edaphic habitat, “quality” for species of interest can be specified. Data from sites unaffected by mining can provide perspective: e.g. how close is the rehabilitated site to the edaphic habitat of the analogue?

USE OF VEGETATION DATA

From the PCQ and WQ data the density of plants can be calculated number per hectare or some other suitable area unit. Calculation of plant density are identical for both PCQ and WQ, the mean distance squared is used (see example under Table 17). Because the data are collected on a spatial basis a spatial map may be plotted. From the data collected the following indices can be derived:

(i) Density of plants per unit area for each life form;

(ii) For grasses basal area m^2 per unit area;

(iii) For trees and shrubs

  a. Canopy area
  b. Canopy volume, an index of growth
  c. The horizontal cross sectional area in height classes: an index for wind amelioration (Fig. 55).

For example the following data (Table 17) were collected for shrubs using the PCQ method.

Table 17. Data collected using the PCQ method.

Transect Dist	Quarter	Distance (m)	Species	Hgt (m)	Width (m)	Breadth (m)	Vol. (m^3)
0	a	0.7	Atsp	0.25	0.3	0.25	0.019
	b	1.6	Atsp	0.35	0.25	0.3	0.026
	c	3.5	Acsp	0.2	0.1	0.1	0.002
	d	2	Ddsp	0.8	1	0.9	0.720
10	a	1.1	Ddsp	0.6	0.9	1.1	0.594
	b	0.8	Acsp	0.1	0.12	0.12	0.001
	c	1.9	Acsp	0.2	0.1	0.1	0.002
	d	1.8	Atsp	0.4	0.4	0.3	0.048
20	a	1.3	Ddsp	0.7	0.3	0.4	0.084
	b	0.7	Atsp	0.15	0.1	0.1	0.002
	c	1.5	Acsp	0.2	0.1	0.1	0.002
	d	2	Atsp	0.35	0.25	0.2	0.018
30	a	3.1	Ddsp	0.85	0.9	0.8	0.612
	b	1.7	Atsp	0.25	0.2	0.15	0.008
	c	1.1	Acsp	0.15	0.1	0.1	0.002
	d	1.9	Ddsp	0.75	0.8	0.7	0.420
40	a	2.5	Ddsp	0.65	0.55	0.6	0.215
	b	2.2	Acsp	0.15	0.1	0.1	0.002
	c	1.4	Atsp	0.3	0.2	0.2	0.012
	d	2.8	Ddsp	0.9	1	1.1	0.990
Total	**20 points**	**35.6**		**8.3**	**7.77**	**7.72**	**3.776**

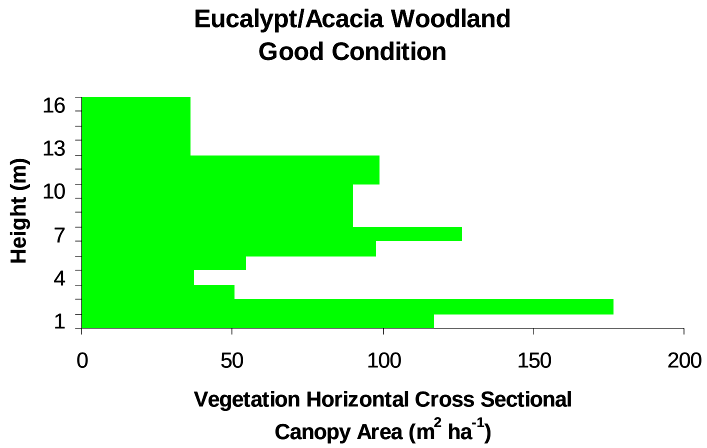
Results

Mean Distance (D) = 35.6/20=1.78 m
Absolute density = Area/ D^2
Number of shrubs per 100 m^2 =$100/(1.78)^2$ = 100/3.17 = 31.5

A simple indicator for vegetation development could be a volume measurement where you measure the width x breadth x height for key species or guilds (perennial grasses, low shrubs, tall shrubs etc) of plants. As the vegetation develops with time this index will increase so that trend can be monitored and remedial action taken if necessary. In the above example (Table 17) the total volume for the 20 plants measured was 3.8m^3.

Functional interpretation of vegetation distribution

Figure 55 summarises the vegetative cover in m^2 ha^{-1} resolved into 0.5 m height slices in a woodland type in the Western Australian wheat/sheep belt. These data were derived from the basic data set as exemplified by Table 17. The loss of ground cover (mainly grasses) and shrubs to about 4 m have important implications in the flow of resources, due to wind and water, across the ground surface. We stress this is an additional way of using vegetation data, with a functional interpretation not a replacement of traditional methods.



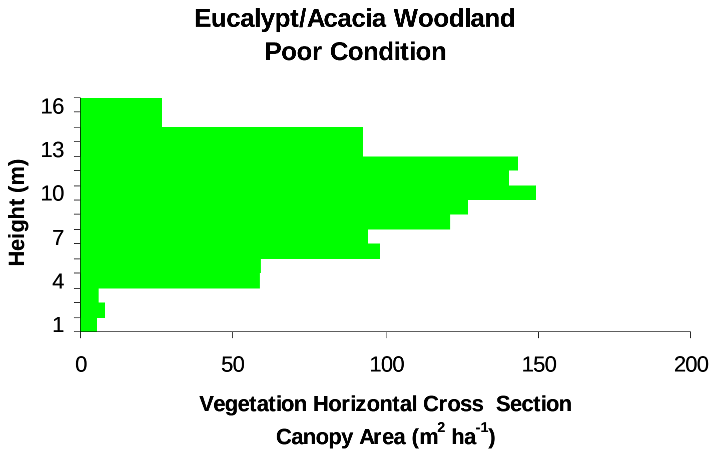


Figure 55. Vegetation foliage cover and height distribution in two woodland remnants. The "good" condition site has high ground and low shrub cover compared to the "poor condition" site.

HABITAT COMPLEXITY

As vegetation develops in size and diversity, more environmental niches for fauna emerge, and the faunal habitat structure becomes more complex and possibly more conducive to faunal colonization. Although the environmental requirements of many species are not fully known, it is likely that as vegetation diversity increases, shade, shelter and food resources for fauna will be created.

The methodology used to assess habitat complexity was developed in the forests of southeastern Australia (Newsome and Catling 1979). Over the past 20 years, many studies have demonstrated relationships between forest structure and abundance of different mammalian species (Coops and Catling 1997). However, this procedure as it currently stands is not as broadly applicable as is LFA. Each biogeographic area needs revised indicators that reflect locally appropriate habitat requirements for the faunal assemblage.

The “habitat complexity” index assesses the extent to which habitat and shelter for vertebrate fauna are developing. This index was developed for arborial mammals in the south east forests where it is regularly used with good results (Coops and Catling 1997). It has not been scientifically verified in other areas, a time consuming and expensive process, but is included as a measure that habitat is developing to provide shelter, and food for native fauna. It is an index of habitat quality not presence of animals. Habitat complexity is assessed on the basis of five features:

(1) canopy cover;
(2) shrub cover;
(3) ground vegetation cover;
(4) the amount of litter, fallen logs and rocks; and
(5) free water availability.

METHOD

From a point about in the centre of the area being monitored assess each of the features in a radius of 11-20 metres if practical. Each feature is assessed on a scale of 0–3 and the scores of the five features are summed to give an overall habitat complexity score. The criteria are given in Table 18.

Table 18. The feature and scores for the habitat complexity scores.

Structure	Score			
	0	1	2	3
Tree Canopy (%)	0	<30	30-70	>70
Shrub Canopy (%)	0	<30	30-70	>70
Ground Herbage	Sparse <0.5m	Sparse >0.5m	Dense < 0.5m	Dense >0.5m
Logs, rocks, debris etc (%)	0	<30	30-70	>70
Soil Moisture	dry	moist	permanent water adjacent	water-logged

(Suggested Habitat Complexity assessment data sheet)

The table was derived for a forest, but for other landscape types, a new table reflecting appropriate levels of structure, and related to faunal abundance would need to be developed. This is beyond the scope of this manual.

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