Landscape Function Analysis:
The rapid assessment of soil health
Part 1: Introduction to the field procedure

David Tongway
CSIRO fellow and Visiting fellow, ANU
dtongway@iinet.net.au
Talk Structure:

1. What is Landscape Function Analysis (LFA)?
2. Scientific development of LFA
3. The Field procedure
4. Data into Information
5. Potential Uses of LFA
Wet/dry tropical savanna, Northern Territory
Coastal “Kwongan” Heathlands, Western Australia
Wheat/Sheep zone, Western Australia
Graasy Eucalypt Woodlands, Toowoomba area
What is Landscape Function Analysis?

• LFA is a monitoring procedure, using simple indicators, to assess how well an ecosystem works as a biogeochemical system.

• It is intended for repeated measurements to present the data as a time series (trajectory).

• It can be applied to a wide variety of landscape types and land uses.

• It is a synthesis of many years basic scientific work across a number of disciplines, followed by integration.
Background

European style settlement in the last 150 years initiated marked changes in landscape function, but pockets of remnants remain and these act as guidelines for assessment of function and for designing rehabilitation.
Sustainable Ecosystems

Notional pre-settlement landscape: many perennials, pasture utilisation limited by availability of surface water, fire a frequent controlling factor.
All too frequent post settlement scenario; Loss of perennial vegetation, soil erosion exposing dispersive sub-soil, but continued, unremitting grazing pressure.
What sort of data collected from here…

Can predict this response to good rainfall?

Clearly, the productive potential of the soil was substantial.
Earlier monitoring procedures were limited to:

• **Composition:** What species (of vascular plant) are present (or not present) ? and

• **Structure:** What are the morphological forms of the biota?

• LFA explicitly addresses **FUNCTION** (“how does it work?”).
First attempt to link pasture production with soil indicators
These data were promising, suggesting that soil surface indicators had potential use. The data had been collected on a rectilinear grid – an agronomic mindset -- implying that the site was intrinsically homogeneous and any site variable could be represented by a “mean” with an associated (tight) “variance”. eg the phosphate level for fertilizer application.
Subsequently, spatial analysis of substantially natural landscapes suggested that heterogeneity was much more *functionally structured*, (amounting to “self-organisation”) than had been previously assumed.

This heterogeneity was both measurable and informative. This approach explicitly looks at the “hillslope” scale.
Development of a new paradigm.

Our approach is based on treating landscapes as biogeochemical systems.

3 Key Questions:
• What are the landscape components? (inventory)
• How do they “fit” together? (pattern)
• How do they “work” together? (processes and function)

The synthesis of this approach is as follows....
Woodland bands in Niger
Woodland bands in western NSW
Soil properties in 3 contrasting patch types with high landscape connectivity in banded *Acacia* woodlands

<table>
<thead>
<tr>
<th></th>
<th>Bare soil runoff</th>
<th>Grassy</th>
<th>Woodland</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Organic N (%)</strong></td>
<td>0.08&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.12&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.18&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td><strong>Mineralisable N (ppm)</strong></td>
<td>8.5&lt;sup&gt;a&lt;/sup&gt;</td>
<td>12.8&lt;sup&gt;b&lt;/sup&gt;</td>
<td>25.5&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td><strong>Sat’d infiltration rate (mm hr&lt;sup&gt;-1&lt;/sup&gt;)</strong></td>
<td>25&lt;sup&gt;a&lt;/sup&gt;</td>
<td>47&lt;sup&gt;b&lt;/sup&gt;</td>
<td>264&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td><strong>Unsat’d infiltration rate (mm hr&lt;sup&gt;-1&lt;/sup&gt;)</strong></td>
<td>13&lt;sup&gt;a&lt;/sup&gt;</td>
<td>14&lt;sup&gt;a&lt;/sup&gt;</td>
<td>15&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
</tbody>
</table>
Pattern → Properties → Function
Grasslands also superficially appear homogeneous
GRASSLAND FUNCTIONING

Dense Grasslands cause water flow to be tortuous, with hummocks absorbing water in transit.

Degraded Grasslands have long, straight fetches, allowing flowing water to run out of the local ecosystem.

Grass Hummocks Absorb Flowing Water.

Siltating Soil Particles and Organic Matter are captured in grass hummocks.
Grassland patch/interpatch differences

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>% Organic nitrogen under grass plants</th>
<th>% Organic nitrogen between grass plants</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-1 cm</td>
<td>0.061&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.042&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>1-3 cm</td>
<td>0.053&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.023&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>3-5 cm</td>
<td>0.035&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.018&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>5-10 cm</td>
<td>0.025&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.015&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
</tbody>
</table>
Functional heterogeneity at fine scale: rhizosphere sheaths
These and other studies developed the notion of “functional heterogeneity”: namely that landscape heterogeneity was not just random variance (causing problems in data handling), but an information-rich phenomenon that enabled us to develop cross-scale field metrics that recognised the role of surface and near-surface processes in the allocation and re-allocation of vital resources in space and time to biota.
• These studies implied that each natural landscape had characteristic spatial self-organisation, often expressed as patchiness, such that overall resource loss was low and resource utilisation and cycling was high.

• Patchiness can be characterised by size, orientation, spacing and soil surface “quality”.

• Deviations from the “characteristic” or “natural” patchiness are therefore seen as degrees of dysfunctionality, which is a long continuum from highly functional to highly dysfunctional.
SO,

• The LFA mindset and methodology involve a purposeful change of focus from listing the biota/species present, or absent, to an examination of the degree to which biophysical processes deal with vital resources with respect to stresses arising from management and climatic events.

• This makes it significantly different but complementary to traditional monitoring procedures.
Continuum of Landscape Function

Continuum of Landscape Condition

- Totally Dysfunctional
- ‘Leaky’ Landscapes
- ‘Conserving’ Landscapes
- Fully Functional

Current State

Value

Judgements

‘Acceptable’

‘Unacceptable’

Best Condition

Worst Condition

Grazing

Carbon Sequestration

Conservation of Biodiversity

Sustainable Ecosystems
Functional: highly resource retentive

Dysfunctional: resources flow out of system
The key question in LFA becomes –

“How can we assess the status of the surface processes that regulate the availability of vital resources in space and time?”

We developed a conceptual framework depicting sequences of landscape processes operating in an explicitly spatial manner.
Ref | Processes
---|---
1 | Runon and runoff
2 | Infiltration, deposition, saltation capture
3 | Germination, Plant growth, Nutrient mineralisation & uptake
4 | O/M decomposition, seed pool replenishment, harvest/concentration
5 | Physical obstruction to resource flow and capture
6 | Erosion, herbivory, fire, harvest, deep drainage
C. A test of concept: application to rehabilitation:

If this process-based understanding of landscape function is correct, then rehabilitation of dysfunctional landscapes should occur if processes designed to regulate the flow of resources, minimise losses and foster cycling are put in place.
Vegetation response after 7 years
Response after 13 years.
Changes in soil properties in response to mulga branch treatment after 3 years

<table>
<thead>
<tr>
<th>Property</th>
<th>+ Branches</th>
<th>- Branches</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil Surface Elevation (mm, 1991-1998)</td>
<td>+ 1.9**</td>
<td>-2.7**</td>
</tr>
<tr>
<td>% Total Soil Nitrogen</td>
<td>0.103**</td>
<td>0.072**</td>
</tr>
<tr>
<td>% Organic Carbon</td>
<td>1.00**</td>
<td>0.71**</td>
</tr>
<tr>
<td>Infiltration rate (mm hr(^{-1}))</td>
<td>118**</td>
<td>11.6**</td>
</tr>
<tr>
<td>Soil Respiration rate (mm CO(_2) m(^{-2}) hr(^{-1}))</td>
<td>221*</td>
<td>151*</td>
</tr>
<tr>
<td>Ant numbers m(^{-2})</td>
<td>12.7**</td>
<td>2.9**</td>
</tr>
</tbody>
</table>
The Golden Rule for rehabilitation is:

“Restore/replace missing or ineffective processes in the landscape in order to improve the soil habitat quality for desired biota.”
Converting principles to procedures

• The landscape function principles were converted to a structured information gathering system working at the hillslope and patch scale.

• Uses Indicators of landscape processes, easily and quickly collected in the field.

• LFA has been implemented as a monitoring system in the WA rangelands since 1994
There are two scales of data accession, arranged in a nested spatial hierarchy:

1. “landscape organisation” and
2. “soil surface condition assessment” (using simple visual indicators)

Followed by --

3. a data → information step (deriving a variety of indices reflecting functional strengths and weaknesses of the landscape. Excel template)
4. an interpretational framework (How to make sense of the numbers. Is the landscape fragile or robust, how close is it to a critical threshold, what are the rehabilitation options?)
A. Landscape Organisation.

Key Question: How does this landscape use and regulate vital resources in space and time?

• Looks for “patch” and “interpatch” zones on line transects oriented in the direction of resource flow i.e. surface hydrology is the driver.

• Identifies the location, size and nature of each zone type at the hillslope scale.
Biological Patches can be grass, trees, shrubs, logs or any combination.

Geomorphic entities such as flats and slopes may also be patches and interpatches, respectively.
Three indicators of landscape organization observed in a heavily grazed paddock, and an exclosure within the paddock, located within a semi-arid savanna near Charters Towers, Queensland.

<table>
<thead>
<tr>
<th>Savanna Landscape</th>
<th>Number of runon patches per 10m</th>
<th>Total runon patch width (m/10m)</th>
<th>Average runoff interpatch length (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ungrazed exclosure</td>
<td>12.0</td>
<td>4.45</td>
<td>0.56</td>
</tr>
<tr>
<td>Cattle grazed</td>
<td>2.6</td>
<td>0.37</td>
<td>2.95</td>
</tr>
</tbody>
</table>
This is a grassy sward patch. The slope is from top to bottom in the image.

The grass plants are close enough together that the water run-off is unable to generate enough energy to redistribute the grassy litter, which is evenly distributed. There is also no evidence of sediment transport (not visible in this image). This is because of the tortuous path and short inter-grass distance. It would be possible to derive the critical grass plant spacing for “sward” function.
Grassland in patch-interpatch mode. Slope is from top to bottom.

Litter and sediment have both been washed off the interpatch and have been arrested by a down-slope grass patch. Note the orientation of the grassy litter strands.
B. Soil Surface Status

Key question: What is the respective “quality” of patches and interpatches?

• Deployed on each patch and inter-patch type identified in the L/O analysis.

• Uses 11 simple, visually assessed indicators, each reflecting the activity/status of a specified surface process. Decision making is assisted with guidelines and photographs.

• All classification can be done in the field. No laboratory analysis is needed.
<table>
<thead>
<tr>
<th>Indicator</th>
<th>Process Addressed</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Soil cover</td>
<td>Rain-splash erosion</td>
</tr>
<tr>
<td>2. Basal cover of perennial Grass and/or canopy cover of shrubs and trees</td>
<td>Below-ground biological activity</td>
</tr>
<tr>
<td>3. Litter cover, origin and degree of composition</td>
<td>Decomposition and nutrient cycling of surface organic matter</td>
</tr>
<tr>
<td>4. Cryptogam cover</td>
<td>Surface stability, resistance to wind and water erosion and nutrient availability</td>
</tr>
<tr>
<td>5. Crust broken-ness</td>
<td>Wind ablation or water erosion</td>
</tr>
<tr>
<td>7. Deposited materials</td>
<td>Upslope soil stability</td>
</tr>
<tr>
<td>10. Slake test</td>
<td>Soil stability/dispersiveness when wet</td>
</tr>
<tr>
<td>11. Soil texture</td>
<td>Infiltration rate and water storage.</td>
</tr>
</tbody>
</table>
Below ground processes are not ignored
### Indicator

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Soil Cover</td>
<td></td>
</tr>
<tr>
<td>2. Basal cover of perennial grass</td>
<td></td>
</tr>
<tr>
<td>3a. Litter cover</td>
<td></td>
</tr>
<tr>
<td>3b. Litter cover, origin and degree of decomposition</td>
<td></td>
</tr>
<tr>
<td>4. Cryptogam cover</td>
<td></td>
</tr>
<tr>
<td>5. Crust broken-ness</td>
<td></td>
</tr>
<tr>
<td>6. Erosion type &amp; Severity</td>
<td></td>
</tr>
<tr>
<td>7. Deposited materials</td>
<td></td>
</tr>
<tr>
<td>8. Microtopography</td>
<td></td>
</tr>
<tr>
<td>9. Surface resistance to disturb.</td>
<td></td>
</tr>
<tr>
<td>10. Slake test</td>
<td></td>
</tr>
<tr>
<td>11. Soil texture</td>
<td></td>
</tr>
</tbody>
</table>

**Emergent soil surface Indices**

- **STABILITY**
- **INfiltration**
- **NUTRIENT CYCLING**

**Indices are scaled 0-100**

Each indicator is assigned a class value.
Wheat/Sheep zone, Western Australia
LFA index changes across a fenceline between a conventionally cropped paddock and a protected woodland remnant.
Semi-arid woodland. Five landscape strata are present.
<table>
<thead>
<tr>
<th>Landscape patch/inter-patch</th>
<th>Stability Index</th>
<th>Infiltration index</th>
<th>Nutrient Cycling Index</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stony, crusted</td>
<td>55</td>
<td>29</td>
<td>18</td>
</tr>
<tr>
<td>Bare Soil</td>
<td>56</td>
<td>28</td>
<td>21</td>
</tr>
<tr>
<td>Under saltbush</td>
<td>75</td>
<td>55</td>
<td>54</td>
</tr>
<tr>
<td>Under Eucalypt</td>
<td>68</td>
<td>43</td>
<td>34</td>
</tr>
<tr>
<td>Open plus litter</td>
<td>62</td>
<td>53</td>
<td>45</td>
</tr>
</tbody>
</table>
Summary: Soil surface indicators are the second tier of LFA data and are nested within the landscape organisation scale of observation. They provide a means of discriminating between different aspects of rehabilitation or degradation.
In Part 1, I discussed the background to LFA and the use of simple indicators of soil surface processes to derive indices reflecting soil stability, infiltration and nutrient cycling on a scale of 0-100.

BUT, are these indices related to measurable biophysical variables?

Yes, and across a range of landscape types.
Wet/Dry Tropics (Gove bauxite mine)

Total Nitrogen 0-1 cm

\[ y = 0.0032x + 0.0032 \]

\[ R^2 = 0.85 \]
$y = 0.1221x + 24.34$

$R^2 = 0.75$

WA Wheat/Sheep zone: Woodland near Kellerberrin
WA Wheat/Sheep zone: Woodland

Nutrient Index

Respiration rate (mg CO₂ m² hr⁻¹)

\[ y = 0.3328x - 19.373 \]

\[ R^2 = 0.88 \]
LFA data are intended for use across a wide dynamic range, so that longer term issues of degradation and restoration can be addressed.

Clearly an rapid assessment procedure cannot accurately represent subtle differences in soil property values.

LFA data are designed to act like traffic lights:

- **Red**: A problem exists, needing urgent attention.
- **Amber**: Possible problem—look more closely with more accurate methods.
- **Green**: No apparent functional problem, but keep monitoring.
Landscape Function Analysis:
The rapid assessment of soil health
Part 3: Interpretation of the data

David Tongway
CSIRO Fellow and Visiting Fellow, Australian National University
dtongway@iinet.net.au
Vegetation properties in functional terms. (extended function analysis--EFA)

- Standard methods from Vegetation Science are used for these measurements, but they are spatially registered with the LFA measurements.

- Indices of vegetation structural development reflect:
  - the density, cover and species composition of plants
  - The functional role of vegetation in regulating the mobilisation and transfer of vital resources.
Vegetation data are collected reflecting the density and dimensions of three or four layers, using distance-measuring, plotless techniques such as PCQ and WQ.

The data are:

- Mean distance between plants
- Major and minor axes of grass butts and/or tree and shrub canopy
- Height to canopy
- Canopy density (%)  

These data are keyed into the spreadsheet supplied that calculates plant density and plant cover (m² ha⁻¹) resolved into 0.5-m height classes. Graphs are produced.
• The emergent data reflect the wind and water drag induced by the architecture of the vegetation (“where the vegetation holds its foliage in space”), thus adding the “functional role of vegetation” information to any other vegetation metric.

• This step is not an “indicator” method, but conventional measurements re-packaged for a particular purpose.
Making practical use of the monitoring information

4 questions.

- What do these indicator numbers mean?
- In view of the “continuum” concept of landscape function, what is the shape of the response?
- Can critical thresholds or target values be discerned in the data?
- What are the consequences for management?
• We propose an “S” shaped response curve to represent the progress of rehabilitation.

• This curve type recognises a “dysfunctional state” and a state representing the “biogeochemical ceiling” of a landscape type (limited by parent material and climate).

• The rate of change between these extremes is an important response to assess, whether degradation or rehabilitation is the aim.
Example 1. Sth Aust. Rangelands: 20 m from water
150 m from water
1 km from water
4 km from water
10 km from water
Interpretational framework

Stability Index

Log Distance from Water (m)

$X_0, b$

$Y_0$

$Y_0 + a$
Example 2. Grassy Eucalypt woodland, Qld.


Site LFA Indices
- Stab. = 79.0
- Infil. = 49.8
- N/C   = 50.2
Ex. 2. Trees cleared, dense perennial grassland: Stage 2.

Site LFA Indices

Stab. = 69.1
Infil. = 39.8
N/C = 31.7
Ex. 2. Patchy grassland: Stage 5.

Site LFA Values
Stab. = 48.9
Infil. = 21.0
N/C = 14.7

These values reflect landscape function below the level at which management should intervene. Active or passive action could be taken.
Ex. 3. Gully erosion in heavily utilised patchy grassland
Increasing dysfunction

LFA Indices

Conceptual Interp. Framework
Degradation Scenarios, with potential use in assessing desertification and rehabilitation
(Encyclopedia of Soil Science)

Stress and Disturbance

Fragile

Robust

Landscape Function

Stress and Disturbance
“Robust” landscape type: Atriplex vesicaria shrubland on a stable, gradational texture soil type.
“Fragile” landscape type: Atriplex vesicaria shrubland on a texture contrast soil with a dispersive B horizon.
LFA can be applied to a range of landscape uses, because the central concept is concerned with understanding landscape processes that regulate the availability of vital resources for desired biota.

Issues of “resilience”, “sustainability” and some aspects of biodiversity can be addressed.
E. Who are our clients?

- Governments: Policy, Regulatory and Monitoring
- Land Managers: Pastoral, Agricultural, Land Care

All these groups need to specify “end land use” criteria or have some well-specified target to manage towards.
Summary: LFA...

- Integrates and repackages scientific knowledge for the use of specific client needs.

- Indicators arise from integrated system understanding, not specific narrow disciplines.

- Calls for more/new information when needed.

- Facilitates landscape design

- Facilitates direct interaction with clients in an adaptive learning loop.

http://www.cse.csiro.au/research/efa/