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The Hammersley Ranges, Western Australia. A healthy landscape such as this serves as a benchmark, or analogue, for what might be achieved – in the long run – in nearby mining rehabilitation at Mt Tom Price.

Old minesites meet their

A practical, low-cost technique for monitoring the health of landscapes is gaining favour among the rehabilitators of mined land. **Alastair Sarre** outlines the adaptation of an approach originally developed to assess rangeland degradation.

For decades, the mining industry has been searching for something. Ore bodies, yes, but something else, too: a simple technique that would indicate the long-term survival prospects of ecosystems re-established on minesites.

The search has been long and expensive, with much ecological knowledge gathered along the way. Now, with the help of CSIRO scientists, the industry may have struck the motherlode.

Successful ecosystem rehabilitation isn't easy to prove: even defining an ecosystem is a task most ecologists try to avoid. On a small scale, one could – and many mining companies do – bring in all kinds of gadgetry to measure soil development and loss, nutrient turnover, and trends in biodiversity. To do this on a large scale would cost the earth (not to mention the minerals).

What the mining industry needed were indicators of success – things that could be measured in the field easily and cheaply, and which would show the success or otherwise of the rehabilitated ecosystem. It enlisted the help of the Australian Centre for Minesite Rehabilitation Research (ACMRR) – a sort of cooperative research centre involving CSIRO, the University of Queensland, the University of Western Australia, the Australian Nuclear Science and Technology Organisation and the Australian Mineral Research Association – which went digging for ideas.

It didn't need to dig too deep. CSIRO scientists had spent more than a decade developing a technique – called, somewhat dauntingly, landscape function analysis – for monitoring ecosystem health in Australia's semi-arid rangelands (see 'Pastoral patching', *Ecos* 94, p4).

The technique identifies the way in which a landscape conserves, regulates, uses, recycles and redistributes ecosystem resources such as water, nutrients, organic matter and propagules (such as seeds and fungal spores). It is based on three assumptions about the way a landscape works. The first of these, according to CSIRO's David Tongway, a pioneer of the technique, is that a healthy or functional landscape is characterised by its capacity to control its resources.

'In such a landscape, you have slow movement of resources rather than fast movement, and high levels of resource capture and cycling,' he says. 'In a degraded landscape, you are more likely to see rapid flow and loss out of the system.'

measure

CSIRO technician Norm Hindley uses highly technical equipment – a tape measure, a clipboard and a pencil – to assess minesite rehabilitation at Newlands mine in central Queensland.

The second assumption is that most nutrients are moved by water (although wind also plays a role), and the third is that water flows downhill. Thus, if you want to monitor the flow of resources within a landscape, you need to follow them down the slope.

'We see landscapes in terms of the local watershed,' Tongway says. 'Resources flow from the top of the watershed, through the landscape and eventually out the bottom. To monitor that flow, you need to collect information down the flow of resources.'

But how does a landscape hold onto what it's got? As they studied rangeland ecosystems, Tongway and his colleagues realised that obstacles to the flow of resources – such as trees, shrubs, clumps of grass, or even fallen logs – play an essential role in the retention of vital nutrients and propagules. Nutrients accumulate around such obstacles, forming, over time, resource 'sinks' more fertile than the surrounding ground. In this way, the landscape develops a series of patches, which accumulate resources, and bare ground, or 'fetches', which lose resources.

This deceptively simple concept has important implications for ecosystem management. In arid environments at least, there are rarely sufficient resources to achieve good vegetation growth over the entire landscape. Patches are the 'hotspots' in the landscape, the places where life can survive – perhaps only as seeds – in hard times, and flourish on those rare occasions when water is abundant. Tongway and his CSIRO colleague John Ludwig call it Robin Hood in reverse: robbing the poor to pay the rich.

Landscape function analysis is essentially a way of assessing the patch / fetch relationship. When Tongway and his crew go into the field, they walk a transect down the slope, following the line of resource flow. Each obstruction and fetch is identified and measured. On most sites, it takes about 20 minutes to collect about 100 metres of data in this way.

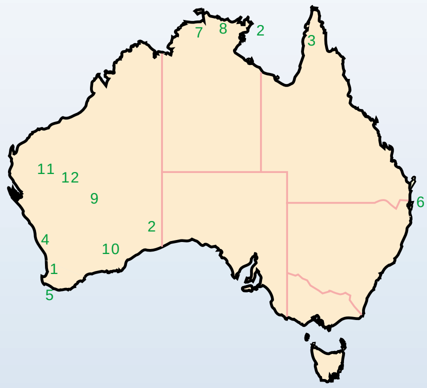
Once the transect has been walked, a sample of obstructions and fetches is subjected to what is called soil surface condition analysis. This involves the visual assessment of 10 surface features such as soil cover, surface resistance to erosion, litter cover and vegetation cover. The scores given to each of these are then grouped together to give three indices of soil quality: soil stability, the soil's capacity to infiltrate water, and nutrient cycling (see page 11).

In effect, these indices are measures of ecosystem function: a healthy, functioning ecosystem will have good soil stability, a large capacity to infiltrate water and high levels of nutrient cycling. Measure the same transect every year, and you can monitor the health of that ecosystem over time.

But the technique is more than a monitoring tool: it offers a fresh way of viewing the way an ecosystem works. Tongway thinks of it as 'reading the landscape'; it could be called the braille of ecology.

The question was whether rehabilitated minesites could be 'read' in the same way. ACMRR and CSIRO Wildlife and Ecology, with research and development sponsorship from about a dozen mining companies and the Office of the Supervising Scientist (a federal agency), began a project in 1996 to test the technique.

Thirteen minesites were selected around Australia across a wide range of mining types and climatic regimes (see map). The plan was to use landscape function analysis on rehabilitated areas of various ages at each minesite. This would give some idea of how the rehabilitation developed over time. The technique would also be used on nearby natural areas (the 'analogue' site); the information collected there would act as a



Location of minesite projects

1. Jarrahdale – bauxite
2. Gove – bauxite
3. Weipa – bauxite
4. Eneabba – mineral sands
5. Capel – mineral sands
6. North Stradbroke – mineral sands
7. Pine Creek – hard rock-gold
8. Jabiru – hard rock-uranium
9. Leinster – hard rock-nickel
10. Kambalda – hard rock-nickel
11. Pannawonica – iron ore
12. Tom Price – iron ore
13. Bowen Basin (Gregory) – coal


Alcoa of Australia Limited

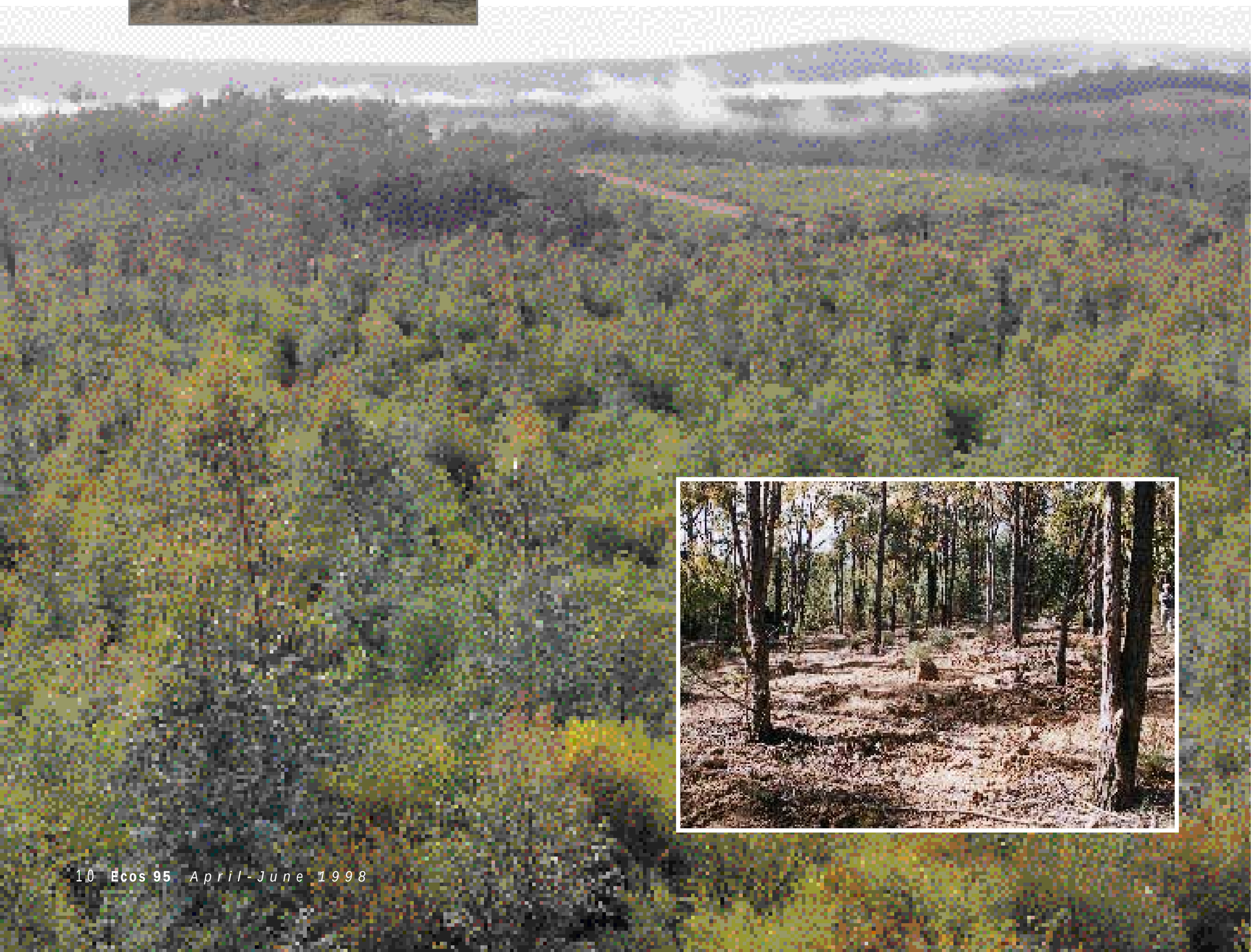

Alcoa of Australia Limited

Left: The miners at work. Bauxite ore is loaded onto dump trucks at Alcoa's Huntly minesite near Perth.

Lower left: The 'winged' ripper on the back of this bulldozer is used by Alcoa to fracture the compacted soil in mined areas, allowing increased water infiltration. The mounds it creates also aid the early establishment of a functional ecosystem by moderating the flow of resources through the landscape.

Below: Young rehabilitation at Alcoa's bauxite minesite near Perth; the original jarrah forest is shown in the background. The early signs are positive that rehabilitated areas such as this are functioning well.

Inset below: Rehabilitation showing signs of ecosystem dysfunction. A *Eucalyptus resinifera* plantation at Alcoa's bauxite mining site near Jarrahdale, WA. A lack of understorey development, poor soil infiltration and little evidence of nutrient cycling all suggest ecosystem dysfunction. The yellowing of the tree foliage is confirmation of this. Alcoa has since improved its rehabilitation techniques to a point where ecosystem function analysis and more conventional monitoring indicate a good chance successful rehabilitation.



benchmark against which the performance of the rehabilitation could be assessed.

Many scientists in the mining industry were sceptical. In particular, they argued, the technique did not give any weight to biodiversity. While landscape function analysis might demonstrate the biogeochemical integrity of a rehabilitated minesite, it didn't say much at all about the return of native plant and animal species to the site.

CSIRO Wildlife and Ecology assistant chief, Allen Kearns, a member of the landscape function analysis project team, agrees that biodiversity is a complex issue. Scientists in one camp think that some species are redundant – while they may be desirable for aesthetic reasons, they are not necessary for the functioning of the ecosystem. Scientists in the other camp believe that all species should be maintained, partly for philosophical reasons and partly because we don't know what is – and what isn't – important for ecosystem function.

'In between is the pragmatic approach,' Kearns says. 'You try to rebuild habitat conditions on a site. It's a sort of field-of-dreams approach: if you build it, they will come.'

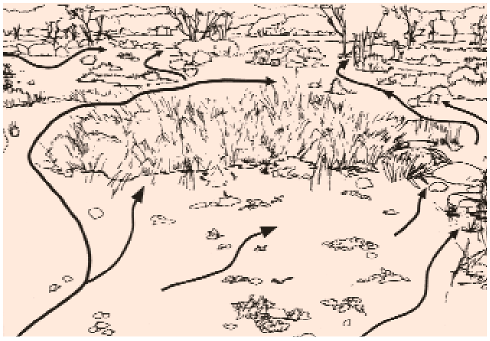
One of the key tests of a rehabilitated area is the way it responds to disturbances such as fire or grazing. Most sites are protected from disturbance in the early years, because stabilising the soil against washouts is seen as the highest priority. But in the longer term, an ecosystem must be able to recover from sudden, unavoidable impacts if it is to be called sustainable.

According to Kearns, this is also part of the biodiversity debate: if you don't have species on a site capable of resprouting after fire, for example, the site is unlikely to become self-sustaining.

'You can't just measure non-biospecific components of an ecosystem and get the big picture on whether that system is going to persist or not,' he says. 'You need to know more about species composition and the role certain species – or groups of species – play in ecosystem processes.'

Recognising these shortcomings in the landscape function analysis approach, the project team expanded it to include measures of vegetation dynamics and habitat complexity (renaming it ecosystem function analysis at the same time). The former would help identify the presence or absence of key species groups thought important for ecosystem function, and the latter would provide a guide to the suitability of the rehabilitation as habitat for local terrestrial fauna.

Slowly, as the research team started generating data at various minesites, the sceptics were won over. The first minesite visited was that of Alcoa, which runs a bauxite mining operation in the Darling Ranges near Perth. Its efforts at



Landscape function analysis identifies how landscapes conserve, regulate, use, recycle and redistribute ecosystem resources.

Top: This grassland shows good resource control. The grass plants cause run-off to have a tortuous path, so that it tends to encounter plants frequently, permitting water infiltration and litter deposition. The arrows indicate the processes of flow and absorption.

Above: A dysfunctional grassland. Runoff water and associated materials in this landscape will flow more quickly ands encounter fewer obstructions, allowing resources to leak from the system.

Ten key features of soil condition

Landscape function analysis involves the assessment of 10 soil surface features at various points along a transect. Each is an 'indicator' of some underlying biogeochemical process.

Indicator	Interpretation
1. Soil cover	Assesses vulnerability to rainsplash erosion
2. Basal cover of perennial plants	Assesses the contribution of below-ground organs to nutrient cycling processes
3. Litter cover, origin and degree of composition	Assesses the availability of surface organic matter for decomposition and nutrient cycling
4. Cryptogam cover	An indicator of surface stability, resistance to erosion and nutrient availability
5. Crust brokenness	Assesses loose crusted material available for wind ablation or water erosion
6. Erosion features	Assesses the nature and severity of current soil erosion features
7. Deposited materials	Recognises mobile soil deposits
8. Microtopography	Assesses surface roughness for water infiltration and flow disruption, seed lodgement
9. Surface resistance to erosion	Assesses likelihood of soil detachment and mobilisation by mechanical disturbance
10. Slake test	Assesses soil stability/dispersiveness when wet

An index of landscape stability is derived by amalgamating values from indicators 1, 3, 4, 5, 6, 7, 9 and 10 and reflects easily-observed factors that affect resistance to erosion. The infiltration index is derived by amalgamating values from indicators 3, 8, 9 and soil surface texture (resolved into four classes), reflecting the soil's capacity to infiltrate water. The nutrient cycling index is an amalgamation of indicators 2, 3, 4 and 8, reflecting the processes of organic matter cycling, not of soil nutrient content – added fertiliser, for example, will only affect the index if there has been plant growth and litter production.

Considering the bigger picture

ALLEN KEARNS believes landscape function analysis could help in the design and monitoring of low-cost rehabilitation across a wide range of degraded landscapes.

'We have a lot of soil conditions in Australia that are far from equilibrium,' he says. 'Millions of hectares of agricultural land have been pushed to their limit by overgrazing, by dryland salinity, soil erosion, a whole range of practices.'

Spending thousands of dollars to rehabilitate a hectare of land – common practice on minesites – is out of the question on agricultural land worth perhaps $100 per hectare, he says. Landscape function analysis can help identify low-cost rehabilitation approaches.

'Take dead trees in a dysfunctional landscape,' he says. 'While they stand up some birds may roost in them, but they don't really contribute much to ecosystem functioning. Landscape function analysis has helped us observe that if you knock the dead trees down, they will start to trap seeds that blow in, as well as accumulate resources such as leaves, soil and moisture. They start to become little islands of ecosystem function that are coming back into the landscape.'

Landscape function analysis has also led some scientists to question the role of tree plantations as a universal solution to land degradation. 'The feeling is that if you get the trees back they will lower the watertable, they're going to fix things up,' Kearns says. 'But we might actually find, as we do on the minesites, that many understorey plants contribute greatly to the build-up of ecosystem function. Without a plan to bring back understorey species, you may not develop the microhabitat necessary to allow invertebrates and soil organisms to kick in and do their bit.'

Landscape function analysis may also prove valuable in broadscale monitoring of ecosystem health. New technologies such as aerial videography are starting to allow relatively cheap monitoring of landscape changes. For David Tongway, this is an intriguing prospect.

'A lot of information on discrete organisms and their interactions is kind of known, but it hasn't been integrated into a landscape context,' he says. 'That's the next big ecological frontier. And being able to use remote sensing at a sufficiently small scale – that's a technological rather than a conceptual frontier. We know what we want to do, it's just a question of having the tools to do it.'

For Kearns, the sky is the limit.

'What will become possible is the use of our landscape function work at a remote sensing level, and then you'll have the ability to look at landscape functioning over entire regions,' he says. 'It will be a very useful tool for monitoring the state of the environment generally.'

re-establishing a jarrah forest on mined areas are held up by the industry as an example of high quality rehabilitation.

Kearns says the reaction to the first report was positive.

'John Gardner, Alcoa's environmental manager, said we'd told them the bleeding obvious, but wondered why they hadn't been doing it themselves,' Kearns says. 'We'd visited their minesite and in a few days had been able to use our indicators to develop a good understanding of what was going on. That was our proof of concept.'

Efforts to establish sustainable ecosystems continue at Oaky Creek, a coal mine in central Queensland.

Gardner says the technique reaffirmed what Alcoa's own monitoring was telling them: that their bauxite mining rehabilitation has a high degree of resource capture, thanks largely to the deep ripping carried out on mined areas.

'Ripping and ripping furrow development are absolutely critical for soil stability and the long term stability of the sites,' Gardner says. 'They aid all sorts of other processes such as infiltration and nutrient capture.'

Early warning

While much of Alcoa's rehabilitation appears to be on the way to 'ecological success', landscape function analysis has demonstrated that some other minesites are not doing so well.

Tongway sees it in terms of traffic lights. In the early years, an orange light of caution would be appropriate for all sites. A green light might be given to sites that show a trend towards attaining similar index values to that of a nearby analogue site and can cope with disturbance. But sites where index values are stagnant or declining well below values of the analogue site may warrant a red light of warning.

Tongway would give the green light to a couple of the minesites he visited and an orange light to most. But one or two are almost red light – in imminent danger of ecosystem collapse. Those minesites must now work to improve their ecosystem rehabilitation practices.

The role of landscape function analysis on minesites in the future may be to act as an early warning sign. It may also provide a scientifically credible and cost-effective means of judging the ultimate success of rehabilitation procedures and play a broader role as Australians contemplate the degradation and rehabilitation of land in the agricultural zones (see story above).

In the meantime, a second stage of the minesites project is planned to provide further verification of the technique against conventional monitoring techniques.

Professor Clive Bell, executive director of ACMRR, says such verification is essential if landscape function analysis is to become accepted, not only by the mining industry, but also by other stakeholders – from government to the conservation movement.

'I think before everyone will be completely comfortable with the technique it is necessary to compare it with the detailed measurements that minesite scientists have been making over many years,' he says.

The project team also aims to use geographic information systems to integrate the minesite area into the regional landscape. This would allow a more objective selection of appropriate analogue sites based on similarity of slope, aspect and underlying geology. It would also benefit land managers.

'We have heaps of information at the local level, albeit fragmented and inadequate,' Kearns says. 'But it doesn't really tell you much about what is happening at the regional level, although this is the scale that is most important to land managers. They need to know how the minesite fits into the landscape.'

Stage 2 of the project will also provide training to minesite personnel so that they are able to conduct the monitoring themselves. This is a relatively straightforward task, Tongway says.

'We just walk down the landscape saying this is what we see, this is what we measure. It's not simplistic, but it requires some thought. It's like the safety pin I guess; you wonder why it wasn't invented a thousand years ago.'

And, like the safety pin, the technique may prove valuable in some sticky situations as we face the task of rehabilitating our degraded landscapes.

More about the method

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Stage 1 of the minesite indicators work was sponsored by BHP Minerals, Carpentaria Gold Pty Ltd, Consolidated Rutile Ltd, Nabalco Pty Ltd, Normandy Mining Limited, North Limited, Office of the Supervising Scientist, RGC Limited, Rio Tinto, Robe River Mining Pty Ltd, Shell Coal Pty Ltd, Westralian Sands Limited and WMC Resources Limited.

Below: Waste rock dumps such as these at the Newlands mine in central Queensland pose enormous challenges to ecologists wishing to establish a functioning ecosystem on them. Ecosystem function analysis can help identify rehabilitation techniques that would promote success.

Right: Mining company personnel are instructed in the ecosystem function analysis technique amid young minesite rehabilitation at Newlands mine.

abstract

A CSIRO technique assessing the ecological functioning of pastoral landscapes has been adapted for mining companies. The technique is based on assumptions about how nutrient cycling is linked to the downslope movement of water through a landscape. Landscapes with more obstacles are better at trapping water and resources. Simple assessments of these features enable indices of soil quality, stability and infiltration to be compared over time. The technique is being tested at 13 minesites around Australia. It's role is likely to be as an early warning signal of rehabilitated landscapes that are not doing well.

Keywords: ecosystem rehabilitation; mined land; environmental assessment; minesite rehabilitation; landscape function and analysis; ecosystem management.