Chapter 11

Resource retention and ecological function as restoration targets in semi-arid Australia

David Tongway and John Ludwig

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Restoring natural capital is a ‘big-picture’ concept that integrates the conceptual frameworks underlying both economics and ecology. Natural capital has been defined to mean “renewable and non-renewable resources that occur independently of human action or fabrication” (Daly and Cobb 1989). However, restoring natural capital is intrinsically a complex, interactive and long-term process, requiring the participation of, for example, land managers, ecologists, economists, sociologists and engineers. Conceptual frameworks can build understanding and enhance communication between participants working to solve complex problems (Low *et al*. 1999), including restoration of degraded rangelands (Walker *et al*. 2002). One such framework labelled “trigger-transfer-reserve-pulse” (TTRP) * views landscapes as dynamic, interacting systems in time and space

(Ludwig and Tongway 2000) and has proven useful for addressing many land management issues and environmental problems in Australia (e.g. Ludwig and Tongway 1997; Tongway *et al*. 1997; Tongway and Hindley 2003).

Natural capital is a concept with an admirable long-term, policy-oriented world view, though not directly providing information about how to assess its variation in time and space. Only by considering landscapes within a temporal perspective can restoration trends be monitored, and hypotheses generated for what causes natural capital to be augmented or lost. A restoration assessment* procedure must be reliable (well tested) and robust (precise and repeatable by different users), as shown successfully by Landscape Function Analysis* (LFA), in the rangelands and mining sites of Australia and elsewhere (Tongway and Hindley 2004).

Extraction of Goods and Services

The capacity of a landscape to provide extractable natural capital in the form of goods and services is an assessable property. However, the historic or current provision rate of goods and services is not necessarily a reliable indicator of natural capital abundance or a guarantee of sustained supply. For example, the wool extracted from Australia's rangelands can be quantified in terms of bales produced, yet these data cannot be used to formulate long-term projections. This is because merino sheep wool grows only marginally less well even when pasture is extremely limited, so that starvation occurs suddenly, interrupting wool production unpredictably (Freudenberger and Noble 1997). Hence, slow-moving variables, such as minor reductions in wool growth, can act as indicators of sudden "flips" in ecosystem functioning signifying that major thresholds have been crossed, affecting a decline in landscape production and function (Scheffer and Carpenter 2003).

Economic capital as extractable goods and services is a human invention and subject to arbitrary rules imposed to meet societal or corporate needs. It may appear more easily understandable than natural capital because of the human "command and control" mindset responsible for its design and structure, as well as its linearity and perceptible impact. Nevertheless, as the TTRP conceptual framework proposed is based on resource availability in space and time, it facilitates a close correspondence between economic and natural capital.

Landscape Function

Restoration of natural capital metaphorically expresses, in economic terms, landscape rehabilitation to a high level of biophysical functioning*. However, it has a more restricted meaning, as natural capital tends to be conceptually "the bottom line" in an accounting procedure, whereas landscape functioning* embraces the spatial and temporal dynamics leading to natural capital accumulation. In effect, many interacting "currencies" in natural ecosystems contribute to natural capital accumulation, which may be continuous, serial and/or periodical, and involve both negative and synergistic effects.

For example, soil sediments eroded from rangelands may flow-on to pollute and damage Australia's Great Barrier Reef (Prosser *et al*. 2001). Soil erosion demonstrates flow-on effects and synergistic interactions between neighbouring landscapes and may be perceived as negative or loss of natural capital. These are easy to observe but difficult to measure. Simple indicators* are needed to rapidly assess soil erosion and deliver this information to land managers for any required remedial action.

Lavelle (1997) and Herrick and Whitford (1999) have summarised factors and processes affecting the physical, chemical and biological natural capital in soils at a range of scales. They document the intimate, sequential inter-dependency of many organisms within the soil and their respective roles in acquiring, utilising, storing and transforming natural capital. In addition, Lavelle and Spain (2001) describe how different processes assume importance as scale increases from clay particle size (10^{-6} m) to catchments (10^{4} m), hence providing an integrated, qualitative articulation of the nested hierarchies of processes from within-soils to landscapes.

A framework for understanding dynamic landscapes

A conceptual framework, called "trigger-transfer-reserve-pulse" (TTRP), describes how natural landscapes function over space and time to retain and use vital resources (Ludwig and Tongway 1997, 2000) or, in the context here, what might be called the "economics of vital resources". This framework was originally developed to understand the interacting processes within a time perspective relevant to Australia's semi-arid pastoral landscapes, which have low and highly unpredictable rainfall. The TTRP framework and many of its underlying assumptions are currently being evaluated in other semi-arid landscapes globally (e.g. Wilcox *et al*. 2003; Ludwig *et al*. 2005).

The TTRP framework specifically examines the processes by which physical and biological resources may be acquired, used, cycled and lost from a landscape (Figure 11.1). A trigger event, such as rainfall, initiates processes including run-off/run-on (1), where some water becomes stored in the soils of vegetation patches (the reserves). If soil water reserves are adequate, a pulse of plant growth is initiated (2), accompanied by animal production and microbial mineralization, all of which contribute to building biomass or natural capital. However, other processes such as run-off and erosion (3) can cause loss of soil and water resources from the landscape (i.e. negative natural capital flow). A feedback loop (5) represents a myriad of largely biologically mediated processes that are the "engine-room" of natural capital accession, transformation and cycling. These vital processes include seed-pool replenishment, organic matter processing, nitrogen fixation, soil carbon sequestration, soil macro-faunal and microbial activities, and soil nutrient transformation (e.g. mineralization of organic nitrogen to available forms: ammonium and nitrate ions). Furthermore, soil macro-faunal (e.g. earthworms, termites) activities create pores and galleries, resulting in higher levels of "soil health", due to increased water infiltration and availability, and root and microbial respiration. An additional feedback loop (6), represents other biophysical processes, including how plant growth pulses build denser vegetation patches, which in the next trigger event reduce run-off and enhance water infiltration and retention (Ludwig *et al*. 2005). Denser vegetation cover also prevents physical crust formation (Moss and Watson 1991).

[Insert Figure 11.1]

Natural capital at any time can be assessed by measuring the Reserve and Pulse box contents (Fig. 11.1). For example, the Reserve box could be examined for the size of its soil seed or mineralizable nutrient pools, amount of water stored in the root zone, plant population size, or biomass of soil fauna. Concurrently, the biomass or size of the Pulse box, represented by plant and animal populations, can be determined to quantify natural capital. In the TTRP framework the dynamics and efficiency of the processes shifting and transforming the Reserve and Pulse box contents are more important than content sizes at any one time.

Landscape Function Analysis (LFA)

The TTRP framework has facilitated assessment and monitoring* procedures that rapidly examine the status of the processes by which natural capital is acquired, used and retained. These procedures are encompassed within Landscape Function Analysis (LFA), which is described in detail in a series of manuals (Tongway 1995; Tongway and Hindley1995; Tongway and Hindley 2004). Briefly, LFA collects data at two scales. At a broader scale, the locations of patches and inter-patches* are mapped; patches tend to accumulate natural capital, whereas interpatches tend to shed it. At a finer scale, nested within the patch and interpatch pattern, 11 simple, rapidly collected soil surface indicators are assessed which estimate the effectiveness of a range of processes. These indicators are then combined into three general indices reflecting the landscape's surface stability, infiltration capacity and nutrient cycling potential. In conjunction with other measures, such as vegetation patch structure*, these three landscape surface indicators* are interpreted to assess whether natural capital is being lost, maintained or enhanced over time, as illustrated by a mine site rehabilitation example (Table 11.1).

[Insert Table 11.1]

As LFA procedures focus on landscape processes and not on any particular form of soil, vegetation or biota, they can be implemented across a range of landscape types, uses and managements. For example, Tongway and Hindley (2003) applied and verified the methodology to nine mines in Australia and Indonesia, with landscapes varying from sandy deserts to tropical rain forest, and in different geological settings from which were extracted gold, nickel, bauxite, coal, uranium and mineral sands. In addition, LFA procedures have been widely used to assess landscape processes and attributes, reflecting natural capital, across Australia's rangelands (Tongway and Smith 1989; Tongway *et al*. 1989; Tongway 1993; Ludwig and Tongway 1995; Karfs 2002).

Perspectives on the TTRP Framework

Prior to development of the TTRP framework, rangeland degradation was described mainly in terms of vegetation composition and structure. Soil erosion status was reported in vague terms and not connected to the vegetation assessment by an explicit framework. Processes mediated by various biota were implicit in the monitoring* information, but not quantitatively assessed. Hence, these descriptive and compositional assessments were unable *per se* to specify degradation levels or the means for designing successful rehabilitation. The TTRP framework facilitates a much more "econometric*" examination of landscape function, as it is based on the availability and use of limited vital resources by biota in space and time. More recently, the loss of native species and other issues of biodiversity have been included in the definition of landscape function (Ludwig *et al*. 2004).

The TTRP framework is more directed to the processes by which natural capital is acquired than its quantification. The former is perhaps of greater interest to ecologists, whereas the latter is more the focus of economists, though within the framework, natural capital valuation is entirely compatible across both disciplines. For example, the accession of “new” exogenous natural capital* and the loss of existing natural capital are an integral part of the framework, and as such it is well-suited for use in a participative approach (e.g. adaptive learning workshops) to better understand the issues of RNC.

Knowledge of the multiple “currencies” in the ecological world (such as organic matter, mineralizable N, soil stored water) and the timescales and processes affecting their interactions is still incomplete. Because of the need to deal with management issues “today”, the TTRP framework is an inclusive concept, which while explicitly acknowledging ecological complexity, measures only net outcomes of intimate interactions, rather than waiting for a complete knowledge. Nevertheless, the temporal and spatial sequence of processes represented in the framework has been observed to be appropriate for assessing ecosystem functioning across a range of landscape types and management systems at different scales (Ludwig *et al.* 1999, 2000, 2002; Ludwig and Tongway 2002; Tongway and Hindley 2003).

A continuum of Landscape Functionality

The TTRP framework recognises a continuum of functionality in every landscape, ranging from highly functional to highly dysfunctional (Figure 11.2). Highly functional semi-arid woodlands have been shown to possess high levels of natural capital, in terms of top-soil retention, nutrient pool size and cycling, and above-ground biomass (Tongway and Ludwig 1990; Ludwig and Tongway 1995). Moreover, in TTRP terms, landscape analysis* indicates that the biophysical mechanisms for natural capital retention are active: mobile resources* flowing off bare slopes are effectively captured in grassy and woody vegetation patches (Figure 11.2a), while the biological feedbacks from Pulse to Reserve and Pulse to Transfer are both complex and efficient. This also indicates that functional biodiversity is high and structurally complex (Ludwig *et al.* 2004; McIntyre and Tongway 2005).

[Insert Figure 11.2]

Conversely, a dysfunctional landscape has fewer surface obstructions (Figure 11.2b), resulting in a lower capacity to intercept and retain resource inputs such as water, soil and seeds in run-off. Thus, stored natural capital is at a greater risk of being rapidly transported from the local landscape, such as rangeland hillslopes. Depletion of natural capital to low levels may transform the landscape system into a different state (Gunderson and Holling 2001).

Responses to stress and disturbance

The functionality of landscapes can differ in terms of their response to stress* and disturbance* (Tongway and Ludwig 2002). For example, robust landscapes are able to maintain a high delivery rate of goods and services as stress and disturbance increase (Figure 11.3a), although they will eventually drop to a lower capacity. In contrast, fragile landscapes rapidly lose functionality (Figure 11.3b), that is, they rapidly lose accumulated vital resources and the capacity to acquire fresh resources, and hence the capacity to deliver goods and services. The resilience* of the landscape will determine its response, for example, to human-driven disturbance with a rapid fall in functionality being viewed as a critical threshold (Tongway and Ludwig 2002). Above this threshold, natural capital storage and accumulation processes are sufficiently effective for a self-sustaining landscape. Below this threshold (Figure 11.3c), stored capital is too low and the processes for retention are ineffective (i.e. the landscape is dysfunctional). Certain goods and services may still be extracted from dysfunctional landscapes, but their continuity in space and time is liable to disruption.

[Insert Figure 11.3]

In nature, there are typically parallel sub-systems leading to similar outcomes. This structural complexity is sometimes called redundancy* (Walker 1992). Indeed, nature is typically endowed with multiple pathways and processes to achieve similar ends or outputs, depending on which mechanism is more active at a particular time. It is this complexity that confers landscape buffering capacity to oppose stress and disturbance, and that restores the system after a natural or induced perturbation.

Trajectories of Natural Capital Restoration

There are four principal questions to be answered in restoring natural capital:

1. Is natural capital accumulating?

2. If so, at what rate?

3. Is the level of accumulation sufficient for self-sustainability of the rehabilitating landscape?

4. Have the mechanisms for natural capital accumulation become sufficiently complex to confer buffering capacity on the landscape, enabling it to survive stress and disturbance.

In our work on 35 minesites across Australia (Tongway et al. 1997; Tongway and Hindley 2003), three main types of rehabilitation trajectories were observed (Figure 11.4), which indicate how landscape functionality changes over time. Trajectory A represents the accumulation of natural capital and landscape function, so that after a reasonable time, the landscape passes through a conceptual critical threshold for self-sustainability, and at longer time scales continues to improve. Trajectory B illustrates a slowly responding treatment, where, although there is a detectable increase in landscape function, the rate is so slow that the critical threshold is not exceeded for many years. During this time, the rehabilitation may be subjected to severe perturbations such as fire or storms that could threaten its success. At the extreme, Trajectory C includes settings where site preparation and species selection are inappropriate, to the extent that disturbances result in no net natural capital accumulation.

[Insert Figure 11.4]

[Insert Figure 11.5]

Stages of Natural Capital Restoration

Tongway *et al*. (1997) proposed a stepped pyramid for the rehabilitation of minesites (Figure 11.5), in which recovery proceeds through four stages to a fully functional landscape. Success particularly depends on applying ecological principles in the initial landform design and site preparation stage. A complex landscape will emerge that possesses a multiplicity of life forms (biodiversity) and regulatory processes (functional diversity). Such landscapes will be buffered against environmental and management disturbances both by their accumulated natural capital and by the complex diversity of the processes responsible for new natural capital accession. It is important to re-assign some commonly used indicators of landscape health into those that are explicitly involved in fundamental biophysical functioning and those which simply reflect reaction to change. The key test would relate to their relative contribution to resource retention, use and transformation. Finally, social acceptance of the rehabilitated landscape is part of the final evaluation of whether the restoration targets have been achieved.

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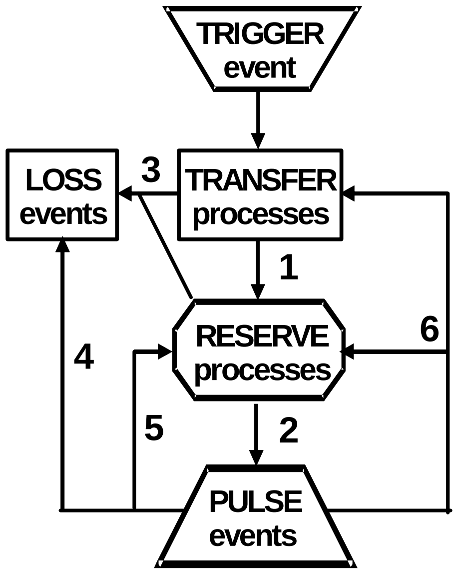
Table 11.1. Indices of stability, infiltration and nutrient cycling, scaled from 0 to 100, are derived from 11 measures obtained by using the LFA monitoring procedure. All the indices increase over time, implying that landscape function is improving, as is the accession of natural capital

Rehabilitation period (years)	Stability Index	Infiltration Index	Nutrient Cycling Index
zero: Freshly prepared, unseeded land	40.6	34.2	14.1
1	43.9 (2.1)	25.1 (1.7)	12.1 (0.9)
2	50.9 (4.2)	29.6 (1.5)	16.7 (2.6)
3	61.6 (2.6)	30.1 (1.3)	22.8 (2.2)
4	60.0 (4.9)	30.4 (4.7)	25.8 (5.3)
8	61.5 (4.1)	37.2 (2.4)	29.3 (2.9)
13	82.5 (1.2)	50.2 (4.1)	45.6 (5.2)
20	81.5 (1.4)	65.9 (2,5)	63.4 (2.5)
26	86.7 (0.9)	66.9 (2.0)	71.3 (4.2)
Reference site	75.5 (3.7)	48.4 (2.9)	44.3 (4.2)



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 11.1. The Trigger-Transfer-Reserve-Pulse framework. Numbered arrows represent processes where a triggering event causes resources to be acquired, spatially transferred, transformed by biota and cycled or lost from the landscape (after Ludwig and Tongway 1997).

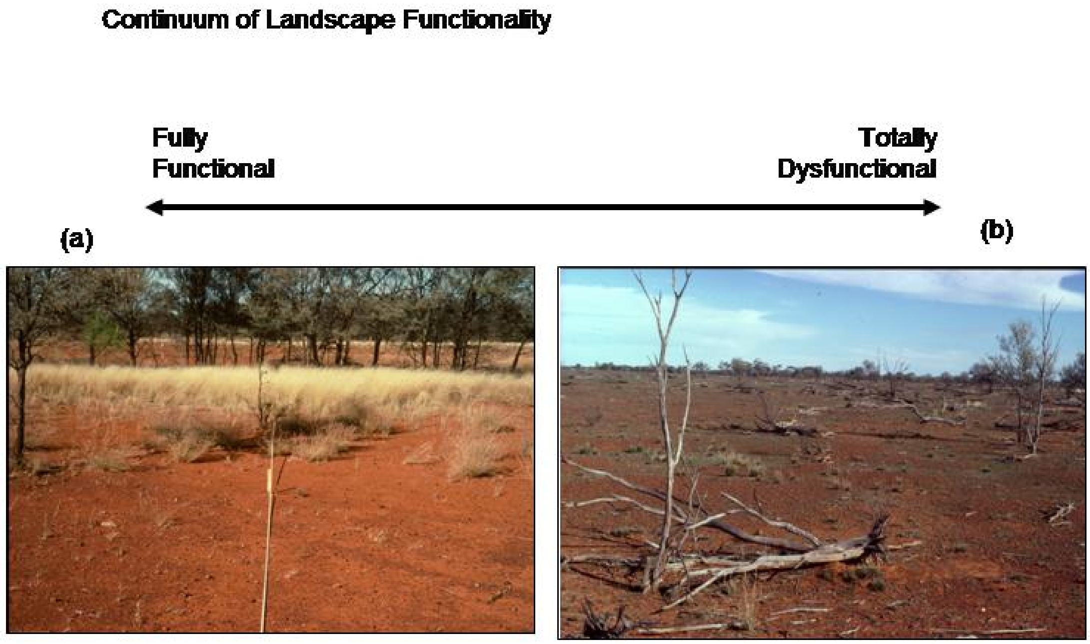


Figure 11.2. A continuum of landscape functionality in the semi-arid woodlands of eastern Australia from (a) highly functional, where natural capital is acquired and stored (soil enrichment in patches of grass and trees) to (b) totally dysfunctional, where natural capital is lost (through death of plants, soil erosion).

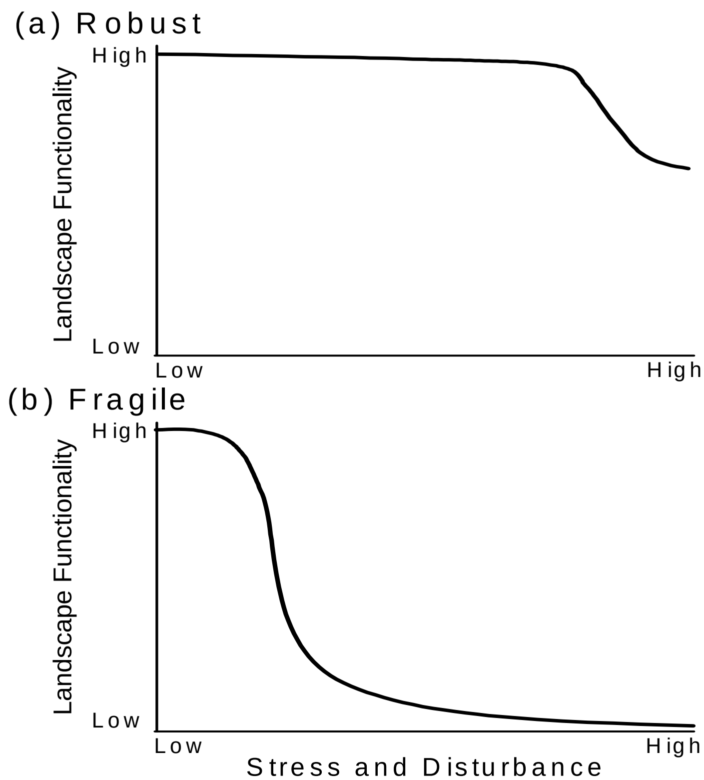


Figure 11.3. The response of landscape functionality to stress and disturbance for (a) robust and (b) fragile landscapes. The landscape functionality axes could also be labelled as low to high natural capital.

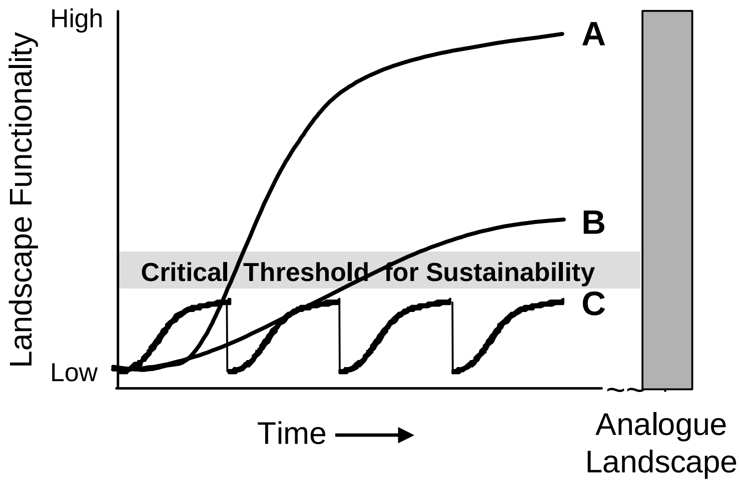


Figure 11.4. Three trajectories of landscape functionality for rehabilitating minesites towards that of nearby reference sites: A = successful, B = moderately successful, and C = unsuccessful. The landscape functionality axis can be equated with restored natural capital.*

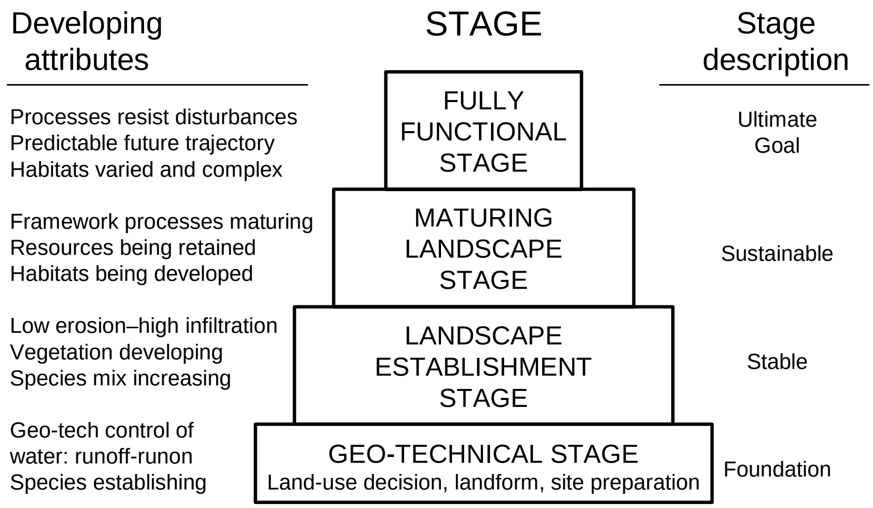


Figure 11.5. Four stages in landscape restoration as natural capital accumulates.

TONGWAY INDEX

TONGWAY/LUDWIG GLOSSARY (oposed definitions by John & David]

Assessment. An evaluation of ecosystem attributes relative to a natural ecosystem (a reference site)

Biophysical functioning. How biological and physical processes work and interact to maintain ecosystems

Disturbance. Natural or anthropogenic events that significantly change the structure and

function of ecosystems.

Econometric. Methods to measure losses and gains of natural capital

Exogenous natural capital. Sources of natural capital that are not spatially or structurally restricted to the ecosystem

Indicators. Easily measured surrogates for difficult to measure ecosystem attributes

Inter-patches. Areas between defined landscape patches where natural capital is mobilised, transported and lost

Landscape Function Analysis (LFA). A methodology and procedure for defining landscape structures and measuring landscape surface indicators

Landscape surface indicators. Attributes of ecosystems that can be readily measured by observing the ground

Landscape functioning. How landscape processes work and interact to retain, utilise and cycle natuarl capital

Mobile resources. Natural capital that can be transported into or out of an ecosystem

Monitoring. Repeated assessments of ecosystems

Redundancy. The presence of multiple species that play similar roles in processes that maintain ecosystems

Reference sites. Natural ecosystems used as the basis for comparing rehabilitated ecosystems

Resilience. The capacity of an ecosystem to persist in the face of disturbances

Restoration assessment. An evaluation of a rehabilitated ecosystem in reference to a natural ecosystem (reference site)

Stress: The impairment of ecosystem functioning caused by abiotic and biotic factors

Trigger-Transfer-Reserve-Pulse (TTRP). A conceptual framework for how landscape systems function in time and space

Vegetation patch structure. Areas within a landscape defined to have a specific type of vegetation with specific attributes