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Chapter 6

# Tracking Anthropogenic Influences on the Condition of Plant Communities at Sites and Landscape Scales

Richard Thackway

Additional information is available at the end of the chapter

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**Abstract**

Deriving vegetation condition assessments from land use classifications and mapping only provides rudimentary and very coarse insights; ones that may be misleading for planning and priority setting by regional planners and policy makers. Standardized indicators of past ecological resilience for a particular landscape can assist land managers and ecologists track, evaluate and report the outcomes of land management decisions. Developing a timetable of the varying goals of land management practices and their past effects on vegetation condition including regenerative capacity is suited to on-ground managers.Access to information about how and why landscapes were transformed helps regional planners and policy makers identify and prioritise areas for investment relative to an ideal state. Tracking the responses of previous native plant communities to a range of land management practices helps decision makers gain an understanding of which outcomes can be realistically achieved in particular landscape contexts.

**Keywords:** Tracking change, Plant communities, Vegetation condition, Management effects, Transformation, Resilience

## 1. Introduction

Anthropogenic management of vegetated landscapes, commonly linked to the delivery of food and fibre, normally changes components of vegetation condition; structure, composition and function of plant communities [1]. Land use and land management practices manipulate ecological patterns and process resulting in various, and sometimes drastic changes to the components of vegetation condition patterns, both spatially and temporally. Repeated interventions usually deliberate but sometimes inadvertent, transform landscapes over time.

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As a result, used by anecologist have been modified and fragmented to varying extents by modern human use and management.

Land management practices, and thus the influences these practices place on criteria and indicators of vegetation condition at site and landscape scales, change over time. Therefore, the responses of landscapes and the landscapes themselves also change over time. Past land use decisions strongly influence current condition, which in turn strongly influence opportunities for future use and management [2].

Depending on the landscape context and the landscape's genesis, land use and land management practices can change or manipulate ecological patterns and process resulting in various, and sometimes obvious changes in land cover patterns, both spatially and temporally. Repeated interventions, involving both deliberate and/or inadvertent management changes to the components of vegetation, can transform landscapes over time. Other anthropogenic factors can influence the health and vitality of plant communities, including the periodicity and severity of stress and disturbance regimes, and the sequences of different impacts (natural and human initiated). In some cases, the management of native vegetation involves an almost complete removal of the components of vegetation condition; structure, composition and function, for example irrigated crops. Other landscapes are minimally managed resulting in no obvious effects on the components of vegetation condition over time, for example conservation and protected areas.

Land planners and managers require information on the status, change and trend of these impacts on vegetation for environmental reporting, land use trade-offs, and to inform future land use scenarios. On-ground managers need more temporally orientated detailed information for the area of ground under their control to inform their operational planning, management and monitoring. While regional and state-wide land use policy and planners need more spatially than temporally orientated landscape scale information to inform decisions on priority setting, setting targets and selecting areas and sites for monitoring, evaluation and reporting. Fundamentally, it is the same space-time-point information but the information needed which has to be presented in a different context and be fit for the intended purpose.

The time to start documenting land use and land management histories is critical. The point at which human action becomes a major factor in environmental change varies with time, location, and culture. Pre- and post-European settlement in many countries represents a key point from which to assess the transformation of vegetated landscapes including changes in vegetation condition. For convenience and to align with various international agreements, in Australia, this date is usually defined as 1750, around the time of the industrial revolution [3]. In Australia, this date is prior to European settlement, in 1788, and thus reflects the pre-European land-use status, which although not without substantial human effects on the landscape, had been relatively stable for many hundreds of thousands of years [4]. Over the last decade, considerable progress has been made in developing information systems for monitoring and reporting the current extent and condition of vegetation types, relative to a pre-European unmodified state [5–8].

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Native vegetation is commonly used as the key descriptor of landscape type, extent and condition. Indicators of vegetation structure, composition and regenerative capacity are widely used to monitor and report sustainable production and biodiversity conservation [9, 10]. However, there is a little agreement on standardised methods for how best to track and report anthropogenic influences on the condition of plant communities at sites and landscape scales, including how land use and land management practices have been used to transform, and continue to transform, the extent and condition of vegetated landscapes. The absence of a consistent approach to monitor and report changes in native vegetation condition over space and time remains a source of contention, and even conflict, between those involved in conservation and protection and those involved in sustainable land use and management of native vegetation [11].

Land use purposes include wood production, biodiversity conservation, water quantity and quality, agriculture production (cropping) and maintaining sustainable grazing systems [12]. Management practices associated with each land use are used to change or modify the ecological building blocks by: modifying, removing and replacing, enhancing, restoring, maintaining and/or improving components of vegetation condition; structure, composition, function [13]. The intent of use and management of vegetated landscapes is commonly linked to the delivery of food and fibre and is affected by changing or manipulating the components of vegetation condition, structure, composition and function of plant communities [1]. As a result, most landscapes have been modified and fragmented to varying extents by modern human use and management.

Integrated spatial and temporal monitoring and reporting of the effects of anthropogenic interventions using standardised assessment and tracking tools can offer new insights into the effects that past socio-economic drivers and their effects on the current condition of sites and landscapes, as well as predicting the likely future condition states expected as a result of changing the goals of management actions and their intended or likely effects on criteria and indicators of vegetation condition; structure, composition and function of plant communities. Such standardised indicators of resilience assist land managers and ecologists track, evaluate and report the outcomes of land management interventions.

This chapter highlights the value of documenting spatial and temporal changes caused by anthropogenic changes to the condition of native vegetation. Access to the long-term data and information on changes and trends in vegetation condition is discussed. Two broad approaches are outlined for generating information on vegetation condition; (1) land use classification and maps and land management regimes suitable for the regional planner and policy maker and (2) developing detailed site-based chronologies of land management practices and their observed effects on criteria and indicators of vegetation condition more suited to on-ground managers. The benefits and shortcomings of both approaches are discussed.

## 2. Sources of vegetation condition information

### 2.1. Land use and land management regimes

Six broad land use classes have been defined for surveying, classifying and mapping land-related land uses in Australia [14]. Classes 1 and 2 relate to the use of native vegetation. Class 1 defines those areas where the primary purpose is minimal use; this includes areas protected primarily for nature conservation. Class 2 defines those areas where the primary purpose includes the sustainable use and management of native vegetation for food and fibre production. Classes 3 and 4 define those land use types where the primary purposes are intensive agricultural production, both dryland and irrigated cropping and forest plantations. Class 5 defines the built environment and infrastructure. These five classes represent level 1, with more detailed sub-classes defined in levels 2 and 3 [14]. Class 6 is water, which includes natural water bodies and those which are built infrastructure, that is part of the human environment. For the purposes of this chapter, that is monitoring and reporting anthropogenic influences on the condition of terrestrial plant communities, class 6 has not been described.

Land use classes 1–5 only describe the purpose for the use of the land and not how it is managed (refer to case study 1). It is an understanding of how the land has been and is managed that will reveal what effect these management practices have had in maintaining, enhancing, restoring, or removing and replacing native vegetation over time.

Because land use and condition can change at different scales, for example a map or site survey data, it is important to know that when the land use data and information were collected and recollected and at what intervals because land use classifications make no assumptions about the resilience of native vegetation; this is particularly the case in agricultural and landscapes used for forest plantations. Great caution is needed in using land use information to derive insights into native vegetation condition. Nevertheless, the types of land use may be reclassified to provide rudimentary information on the likely condition of native vegetation types, based on the types of land management regimes associated with each land use class and the likely effect that these regimes have had on criteria associated with condition of native vegetation, that is its structure, composition and functional characteristics.

Vegetation condition information derived from land use information, particularly for land use classes 3–5, only represents a 'first approximation' because the land use classification for classes 3–5 assumes that native vegetation is extirpated and the resilience of the components of vegetation has been lost (**Figure 1**) [14]. Even though a landscape has been, or is, used and managed under land use classes 3–5, evidence shows that depending on how the land was managed and for how long, key components of native vegetation condition, that is structure, composition and function may still may be present [13].

Land management practices used in the management of native vegetation under different types of land use reveals that six broad land management regimes (**Table 1**). Land management regimes affect the condition of the native vegetation by maintaining, modifying, changing, enhancing, removing or replacing one or more of the 10 key criteria (**Table 1**). Each land management regime is underpinned by a suite of land management practices, which can

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be used by an ecologist to infer whether the broad intent of the land management regime is to maintain, recover, restore, enhance or remove and replace the plant community.

| | **Land management regimes used in managing native plant communities** | | | | | |
|---|---|---|---|---|---|---|
| **Criteria that are either deliberately or inadvertently changed or modified using land management practices** | **No intervention** | **Harvest biomass, seeds, fruit, fibre** | **Encourage regeneration, enhance growth, maturity and reproduction** | **Monitor health and vitality** | **Re-establish, restore and rehabilitate** | **Degrade, remove and/or replace** |
| 1. Soil hydrological status (Fn) | 1 and 2 | 2 | 1 and 2 | 1 and 2 | 1 and 2 | 2, 3, 4 and 5 |
| 2. Soil physical status (Fn) | 1 and 2 | 2 | 1 and 2 | 1 and 2 | 1 and 2 | 3, 4 and 5 |
| 3. Soil chemical status (Fn) | 1 and 2 | 2 | 1 and 2 | 1 and 2 | 1 and 2 | 2, 3, 4 and 5 |
| 4. Soil biological status (Fn) | 1 and 2 | 2 | 1 and 2 | 1 and 2 | 1 and 2 | 3, 4 and 5 |
| 5. Fire regime (Fn) | 1 and 2 | 2 | 1 and 2 | 1 and 2 | 1 and 2 | 2, 3, 4 and 5 |
| 6. Reproductive potential (Fn) | 1 and 2 | 2 | 1 and 2 | 1 and 2 | 1 and 2 | 2, 3, 4 and 5 |
| 7. Overstorey structure (St) | 1 and 2 | 2 | 1 and 2 | 1 and 2 | 1 and 2 | 2, 3, 4 and 5 |
| 8. Understorey structure (St) | 1 and 2 | 2 | 1 and 2 | 1 and 2 | 1 and 2 | 2, 3, 4 and 5 |
| 9. Overstorey composition (Co) | 1 and 2 | 2 | 1 and 2 | 1 and 2 | 1 and 2 | 2, 3, 4 and 5 |
| 10. Understorey composition (Co) | 1 and 2 | 2 | 1 and 2 | 1 and 2 | 1 and 2 | 2, 3, 4 and 5 |

Co, composition; Fn, function; St, structure..

**Table 1.** Groupings of land use classes (i.e. cells) classified by land management regimes and key criteria of vegetation condition that that are either deliberately or inadvertently changed or modified over time.

Numbers 1–5 in the cells of **Table 1** refer to the five Level 1 land use classes described above. These land use classes and the corresponding land management regimes which affect the criteria of native vegetation condition are described below.

### *2.1.1. Land use class 1: conservation and natural environments*

Generally management regimes on land gazetted for biodiversity conservation, wilderness areas and urban water catchment areas do not modify or change the ten criteria (**Table 1**) from the reference state. An important exception to this is the effect of deliberately excluding fire, which is a natural disturbance agency in many ecological communities; excluding fire can lead to major changes in native vegetation structure and composition [15].

Land management regimes associated with this land use tend to maintain and/or enhance the structural, compositional and ecological functions close to the unmodified reference state by

restricting access, preventing harvesting, minimal control and intervention in managing and or reinstating the natural fire regime, the control and intervention in managing weeds and feral animals, and not intervening with natural recruitment, succession or senescence of the dominant structuring species present or known to have occurred in one or more of the dominant vegetation strata.

The primary land management regimes used in landscapes that are managed for conservation and natural environments include:

- Restoration and rehabilitation
- Enhance growth, maturity and reproduction
- Monitor health and vitality
- No interventions

By inference, landscapes that have consistently retained their native vegetation cover over time have the closest to 'natural' vegetation condition, that is the 10 structural, compositional and ecological functions (**Table 1**) are essentially unmodified.

*2.1.2. Land use class 2: production from relatively natural environments*

Generally land uses classified as managed for defence infantry training areas, state recreation areas near urban settlements, grazing native vegetation, for example rangelands, and timber production in native forests, minimally modify or do not modify the function in the long term (i.e. criteria 1–6 in **Table 1**) and modify to varying extents the structure and/or composition of plant communities (i.e. criteria 7–10 in **Table 1**).

Effects of these land uses are reversible in the short term, that is regenerative processes can be reinstated towards a reference state. Under these land uses, the structural, compositional and ecological functions are variously modified or maintained and enhanced by silvicultural practices at different times, managing or preventing the natural fire regime, controlling selected invasive species (weeds and feral animals) and by manipulating natural recruitment, succession and senescence.

The primary land management regimes used in landscapes that are managed for production from relatively natural environments include as follows:

- Restoration and rehabilitation
- Enhance growth, maturity and reproduction
- Harvest biomass or productivity
- Monitor health and vitality
- No interventions

By inference, land use types that more or less consistently retain the cover of native vegetation over time have higher levels of landscape regenerative capacity, that is even though

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structural and compositional components may have been modified, the ecological functions have not been altered.

*2.1.3. Land use class 3: production from dryland agriculture and plantations*

Generally, land uses classified as managed for dry land/rainfed cropping, recently planted tree plantations and horticultural systems involve the complete removal of structural and compositional criteria (i.e. 7–10 in **Table 1**) and moderate to major modification of functional criteria (i.e. 1–6 in **Table 1**).

Moderately, intensive land use includes dry land/rainfed cropping, recently planted tree plantations and horticultural systems. These land uses remove and replace the structural and floristic components while some ecological function is maintained or enhanced through the addition of water, nutrients, monoculture species, weedicides, fungicides, insecticides.

Native vegetation is generally degraded, removed, replaced or reduced to remnants in land use classes 3, 4 and 5.

By inference, land use types that remove the cover of native vegetation (i.e. all structural and species indicators) over time have reduced levels of landscape regenerative capacity and the ecological functions have been altered.

*2.1.4. Land use class 4: production from irrigated agriculture and plantations*

Generally, land uses classified as land managed for production from irrigated agriculture and plantations involve the complete removal of structural and compositional criteria (i.e. 7–10 in **Table 1**) and major modification of most functional criteria (i.e. 1–6 in **Table 1**).

Land uses include improved pasture where one or more exotic species of grasses and/or herbs are introduced and managed to achieve greater levels of production than could achieved by managing native pasture species, for example irrigated lucerne pastures and irrigated cropping systemsin south-eastern Australia. Under this land use type, the structural and floristic components are removed and replaced with local non-indigenous structural and or floristic elements while maintaining or augmenting ecological function through the addition of water, soil nutrients, and/or selected overstorey and understorey species.

Native vegetation is generally degraded, removed, replaced or reduced to remnants in land use classes 3, 4 and 5.

By inference, land use types that remove the cover of native vegetation (i.e. all structural and species indicators) over time and modify and replace the nutrient, hydrological and physical status of the soil have very low levels of landscape regenerative capacity.

*2.1.5. Land use class 5: intensive uses (built landscapes)*

Generally, land uses classified as land managed for intensive uses involve the complete removal of structural and compositional criteria (i.e. 7–10 in **Table 1**) and major modification of all functional criteria (i.e. 1–6 in **Table 1**).

Land uses include intensively managedanimal production systems e.g. feedlots, manufacturing and industrial complexes, urban areas and infrastructure, water reservoirs/impoundments, open-cut mining and waste treatment. Under this land use type, the structural, compositional and ecological functions are removed or prevented.

Native vegetation is generally degraded, removed, replaced or reduced to remnants in land use classes 3, 4 and 5.

By inference, land use types that remove the cover of native vegetation (i.e. all structural and species indicators) over time and modify and replace the nutrient, hydrological, biological and physical status of the soil have the lowest levels of landscape regenerative capacity.

In summary, compiling land use classes over time for a defined soil–landscape map unit and in turn reclassifying these land use classes into land management regimes and what criteria are primarily affected, for example vegetation structure, composition and function, can give insights into the mechanisms that are used in maintaining, enhancing, restoring, or removing and replacing native vegetation over time.

This approach to describing and classifying the condition of native vegetation only enables a generalised and very coarse understanding of the drivers for modifying condition and fragmenting native vegetation. By itself, deriving vegetation condition information from land use information falls far short of what information that land planning and manager stakeholders need to know about the changes and trends in the condition of the native vegetation.

A failure to collect and classify which land management practices that are associated with each land use and to compile and collate the effects that these land management regimes have on criteria and indicators of vegetation condition, that is ecological function (Fn), vegetation structure (St), species composition (Co) deems such derived information of little value to a multiple decision-makers.

Where land planners and managers require information on the status, change and trend of these impacts on vegetation types for environmental reporting, land use trade-offs, and to inform future land use scenarios, more detailed information is needed at the soil–landscape level, that is the operational scale of the land manager. Unless such information is collected in association with on-ground land managers, this will deem inferred vegetation condition information derived land use of little or no use to land managers and on-ground decision-makers. For example, to engage on-ground land managers, in the identification and selection of priority areas for restoration and regeneration of a soil-landscape's indigenous plant communities, and to make recommendations on what land management practices might be changed, it is vital to understand what, when and where the land manager/s have changed and/or modified key criteria and indicators of vegetation condition, that is structural, compositional and ecological functions and over what time periods.

An alternative approach that more adequately satisfies these operational requirements of land planners and managers is presented below.

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### 2.2. Developing detailed chronologies of land management practices and their observed effects

Developing a systematic and comprehensive chronology of land management practices and their effects on criteria and indicators of vegetation condition provides a site-based approach to determining anthropogenic effects on the condition of plant communities.

In managed landscapes, vegetation is either deliberately and/or inadvertently modified or fragmented over time by modifying key criteria and indicators including: natural regimes of fire, soil hydrology, soil structure, nutrients and biology and/or the reproductive potential of the native species in overstorey and/or understorey. Where land management regimes and their associated land management practices, at sites and across landscapes, have been prolonged and intensive with the aim or extirpating the native vegetation (**Table 1**), key vegetation condition criteria are obviously altered, hence the potential to reinstate regenerative landscape processes and over time the original native vegetation is likely to have been variously diminished.

A powerful ecological analysis system 'VAST', which stands for 'vegetation, assets, states and transitions' has been developed to account for the interactions between land management regimes and their effects on transforming ecological function (Fn), vegetation structure (St), species composition (Co). As the name implies, VAST accounts for changes in the condition of vegetation, that is the asset, by assigning a condition state or class to that asset and by tracking transitions between states over time. Tracking vegetation transitions gives different information from mapped vegetation states: it provides decision-makers with information on changes and trends in the resource base due to the environmental and anthropogenic changes, allows land managers to monitor the outcomes of management interventions, and indicates to all stakeholders the link between use and management and observed changes in condition over time.

Using this approach, change is assessed at the site-level (i.e. local soil–landscape unit) over time relative to a fully natural reference [7, 13, 16]. It is also relevant to monitoring and reporting on the transformation at the landscape or regional scale using measures of ecological function (Fn), vegetation structure (St), species composition (Co) over time [7, 16].

To understand the effects of land management practices on key criteria and indicators of vegetation condition over time, it is necessary to compile a systematic chronology of observations of the effects of land management practices. Fundamental to this approach is that site-level qualitative and quantitative data and information are compiled from relevant sources. Where these data are assessed as fit-for-the-purpose (i.e. comprehensive, relevant, and adequate), for the assessment of spatial and temporal changes and trends in condition it forms part of the site history. Where on-ground observations of ecological attributes are determined not fit-for-the-purpose, fine-scale multi-temporal remote sensing and environmental modelling may be used to develop the requisite attribute data to populate criteria and indicators of vegetation condition.

A metric-based system is used to classify and map vegetation 'condition states' which represent a gradient of modification states that are caused by the effects that land use and/or

land management practices on compositional, structural and functional characteristics of the site. The aggregate extent to which indicators remain intact or have been modified or removed altogether determines the score out of an overall index 100%. The total index of 100% is divided equally into six classes (**Table 2**). This framework, combined with criteria and indicators, is relevant for assessing the degree of landscape transformation and for assessing the potential to reinstate regenerative landscape processes.

| Increasing vegetation modification | Vegetation condition classes | Characteristics of the vegetation |
|---|---|---|
| | 0 Naturally bare | Areas where native vegetation does not naturally persist, and recently naturally disturbed areas where native vegetation has naturally been entirely removed (i.e. subject to primary succession) |
| | I Residual | Native vegetation community structure and composition, with regenerative capacity intact—no significant perturbation from land use/land management practices |
| | II Modified | Native vegetation community structure, composition and regenerative capacity more or less intact, perturbed by land use/land management practices such as intermittent low intensity grazing |
| | III Transformed | Native vegetation partly removed but community structure, composition has been significantly altered by land use/land management practices. Regenerative capacity usually minimally modified or moderately modified |
| | IV Largely replaced and plant community is adventive | Native vegetation largely replaced by invasive native and/or exotic plant species (commonly areas abandoned or burnt). Regenerative capacity usually moderately to heavily modified |
| | V Replaced and managed for intensive production | Native vegetation completely removed and replaced with intensive agriculture: rain-fed broad acre crops, feed lots, horticulture, irrigation agriculture and long or short rotation timber production. Regenerative capacity usually moderately to heavily modified |
| | VI Replaced with man-made structures/ infrastructure | Native vegetation completely removed and replaced with settlements and cultural features—e.g. buildings, roads, water reservoirs; gardens, parks and amenity plantings. Regenerative capacity usually moderately to heavily modified |

Based on: [7, 16].

**Table 2.** Vegetation condition classes and commonly observed characteristics.

The method for assessing changes in condition over time involves compiling data and information on the effects of land management practices on 10 criteria and 22 indicators of vegetation structure, composition and function (**Table 3**). As a condition framework that needs to be populated, these indicators also provide a rationale for measurement, monitoring and reporting change in condition at sites and landscapes [13, 17]. A brief overview of the method is documented here.

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| Level 1 | Level 2 | Level 3 |
|---|---|---|
| **Key indicators** | **Key functional, structural and composition criteria** | **Condition components** |
| 1. Area/size of fire | Fire regime | Regenerative capacity |
| 2. Interval between fires | | |
| 3. Plant available water holding capacity | Soil hydrology | |
| 4. Groundwater dynamics | | |
| 5. Effective rooting depth of the soil profile | Soil structure | |
| 6. Bulk density of the soil through changes to soil structure or soil removal | | |
| 7. Nutrient stress—rundown (deficiency) relative to reference soil fertility | Soil nutrient status | |
| 8. Nutrient stress—excess (toxicity) relative to reference soil fertility | | |
| 9. Organisms responsible for maintaining soil porosity and nutrient recycling | Soil biological status | |
| 10. Surface organic matter, soil crusts | | |
| 11. Reproductive potential of overstorey structuring species | Reproductive potential | |
| 12. Reproductive potential of understorey structuring species | | |
| 13. Overstorey top height (mean) of the plant community | Overstorey structure | Vegetation structure |
| 14. Overstorey foliage projective cover (mean) of the plant community | | |
| 15. Overstorey structural diversity (i.e. a diversity of age classes) of the stand | | |
| 16. Understorey top height (mean) of the plant community | Understorey structure | |
| 17. Understorey ground cover (mean) of the plant community | | |
| 18. Understorey structural diversity (i.e. a diversity of age classes) of the plant | | |
| 19. Densities of overstorey species functional groups | Overstorey composition | Species composition |
| 20. Richness—the number of indigenous overstorey species relative to the number of exotic species | | |
| 21. Densities of understorey species functional groups | Understorey composition | |
| 22. Richness—the number of indigenous understorey species relative to the number of exotic species | | |

Based on: [19].

**Table 3.** List of indicators, criteria and components of vegetation condition. Change is assessed relative to an assumed pre-European[1] benchmark. A fourth level results in a vegetation status or transformation index derived by adding the weighted scores from level 3.

. [1] That is, prior to the European settlement of Australia

The 22 indicators (**Table 3**) expand on the commonly used indicators of native vegetation condition: (i) species composition, (ii) vegetation structure and (iii) function [6, 7, 18]. The method comprises an index hierarchy: how to definite a site, what data and information are essential, and the system for scoring and weighting the effects of land management practices using indicators. Multi-criteria analysis (MCA) is used to compile, analyse and report the results including the objective and decision criteria, assemble data inputs, explore and combine data, develop site-based assessments, and review and report [13].

Four levels of assessment underpin the analysis of vegetation condition to enable reporting over time (**Table 3**):

Level 1. Twenty-two *indicators* represent the key vegetation and ecological characteristics that are affected by land management practices;

Level 2. Ten *criteria*. For example, regenerative capacity is affected by soil nutrient state, fire regime and soil biological state and reproductive potential of the overstorey for each year;

Level 3: Three *condition components*: species composition, vegetation structure and regenerative capacity (ecological function); and

Level 4: A *vegetation transformation index* assembled from the scores of the three components.

This hierarchy allows the user to assess change at all levels over time relative to a reference state. Assessments are based on recorded observations and attribute measurements of the criteria and indicators (their magnitude, frequency, duration, seasonality) in parallel with land management practices.

It is assumed that each soil–landscape unit had a homogeneous plant community prior to modern human interventions. Scores for species composition, community structure and regenerative capacity for each site are calculated for different time periods. The scores are weighted approximately 20:30:50 to reflect their relative importance in maintaining resilience and integrity of plant communities, and summed to give a total vegetation transformation index (expressed as a percentage). The index is put into one of five score classes: unmodified (80–100%), modified (60–80%), transformed (40–60%), replaced/adventive (20–40%) and replaced/managed (0–20%). The timeline of changes in the plant community at a site is then set alongside historical and contemporary records, and relationships are established via a set of ecological attributes.

Many land management practices are used to maintain, enhance, restore, degrade, remove, replace or convert vegetation, and to routinely monitor the effects of these practices on plant communities. Relevant data and information on the breadth of land management regimes and land management practices and their effects on vegetation condition at sites over time must be systematically collected and compiled if change is to be monitored. The approach described above provides a format for systematic assemblage and correlation of historical and environmental records at sites. The resulting insight into the origins of the current status of sites can then be used to inform decision-making about restoration and regeneration.

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Two case studies show the compilation of data and information on the effects of land management on 22 key ecological characteristics of ecosystem structure, composition and function.

## 3. Case studies

### 3.1. Case study 1: condition inferred from land use mapping for Australia

Land use attributes in the 2001/2002 Land Use of Australia, Version 3 were reassigned condition classes for the 2001/2002 reporting year based on knowledge of the interactions between land management regimes and the condition criteria affected by each land use class [20]. It is worth noting that this land use dataset has a time series for the years 1992/1993, 1993/1994, 1996/1997, 1998/1999, 2000/2001 and 2001/2002. While the method for reassigning vegetation condition classes to land use classes for each grid cell could be applied to each of the years in the time series, only 2001/2002 is presented here for illustrative purposes.

The 2001/2002 Land Use of Australia is a compiled land use dataset with geographical coordinates referred to GDA94. Land use types were compiled into grids using ARC/INFO (Trademark). **Figure 1** includes variable grid cell sizes; Australia 0.01° cell size and Tasmania were replaced by catchment scale land use mapping 1:25,000 and 1:100,000 to more accurately represent forests managed for timber production.

| **Primary (upper case) and secondary (lower case) land use types** |
|---|
| 1. AGRICULTURE Crops |
| 2. AGRICULTURE Horticulture |
| 3. AGRICULTURE Irrigation |
| 4. FORESTS Agroforestry |
| 5. FORESTS Natural |
| 6. FORESTS Plantation |
| 7. HUMAN ENVIRONMENT |
| 8. LAND Conservation |
| 9. LAND Conservation Reserve |
| 10. WATER Lakes |

| Primary (upper case) and secondary (lower case) land use types |
|---|
| 11. WATER Wetlands |

**Table 4.** Primary (upper case) and secondary (lower case) land use types defined in the 2001/2002 Land Use of Australia, Version 3 [20] which were cross-tabulated with the six land use classes described in the Australian Land Use and Management classification [14].

The extent of non-agricultural land uses are based on existing digital maps covering four themes: protected areas, topographic features, tenure and forest. The extent of agricultural land uses was modelled using the Australian Bureau of Statistics' agricultural censuses and surveys and spatially extended with the aid of Advanced Very High Resolution Radiometer (AVHRR) satellite imagery with ground control data. A detailed data lineage of the 2000/2002 dataset is available http://www.agriculture.gov.au/abares/aclump/Documents/Nat_Luse_Metadata.pdf

The 2001/2002 land use dataset defined a hierarchy of land use attributes including primary classes (upper case) and secondary classes (lower case) as well as tertiary labels (not shown), **Table 4**. These land use attributes and the five land use classes described above are complementary.

Land use attributes (primary, secondary and tertiary attributes) in the 2001/2002 Land Use of Australia were reassigned into seven condition classes based on the knowledge of the interactions between land management regimes and the condition criteria generally affected by each land use class [20]. For example, the *LAND Conservation Reserve* (i.e. land use class 1 Conservation and natural environments in **Table 1**) was assigned a VAST Residual (I) class (**Table 2**). The resulting condition classes are mapped in **Figure 1**, and the classes are described in **Table 2**.

It is acknowledged that relying on the reassignment of land use attribute datasets to derive a vegetation condition dataset provides an incomplete representation of changes in native vegetation condition [20]. To more fully monitor and report, these changes that they used several input datasets to infer the effects of land management on vegetation condition. The input datasets were:

- Native vegetation extent 2004
- Biophysical Naturalness 1995
- Wilderness of potential national significance 1995, 2000
- Australian Collaborative Land Use Mapping Program land use 2000/2001
- MODIS Land Cover Type 2004 (MOD12Q1), International Geosphere–Biosphere Programme Classification.

Condition was modelled by using the above spatial/temporal datasets (derived from 1995 to 2006) and an expert model that compared the effects of land use and land management practices on vegetation with an assumed pre-1750 vegetation condition benchmark.

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Improvements in the mapping of vegetation condition could be achieved by including changes in the extent of native vegetation, changes in the extent, severity and seasonality of unplanned fire (i.e. bushfires) and changes in the cover and density of invasive naturalised pasture species [20].

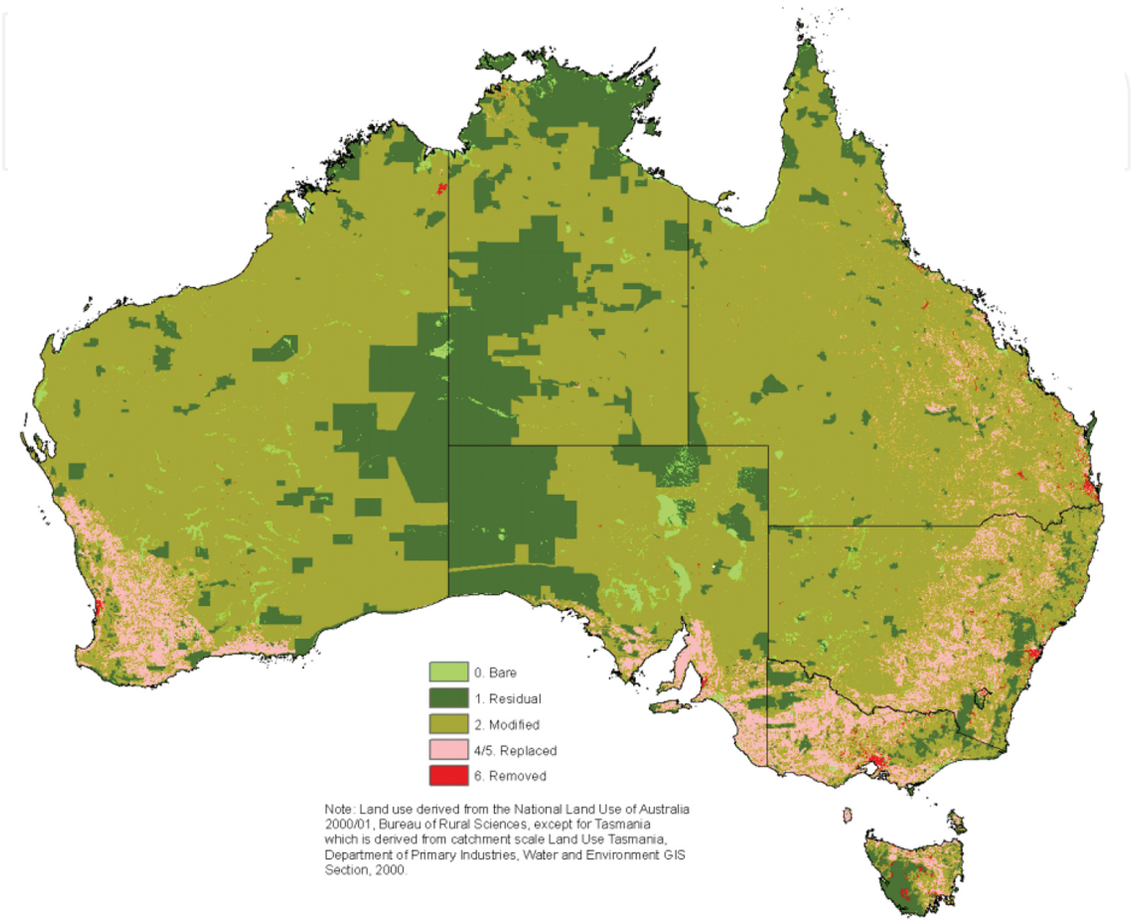



**Figure 1.** Land use 2000/2001: VAST class assignment. Source: Reproduced with permission from Bureau of Rural Sciences, 2010. [20].

### 3.2. Case study 2: condition developed from detailed chronologies of land management practices and their observed effects on indicators

Native forests in South Brooman State Forest (35 28′ 24.01″S 150 18′ 41.26″E), South East Corner bioregion, Australia, have a long history of management for wood production. The tall open Eucalypt open forest (*Corymbia maculata*) in this area has been managed using two levels of management intervention (**Figure 1**) [21]. In 1880, the site was minimally modified by selectively harvesting the larger trees and left to recover. Between 1944 and 1959, the site was intensively managed for timber production refer to 'C' in **Figure 2** where the site was picked over for high-quality sawlogs, and since 2004, the site has been managed to encourage regeneration. Throughout the period from first intervention in the 1870s to 2011, changes in

species composition and regenerative capacity have been minimal. These interventions have focussed on the vegetation structure, by harvesting trees of different age classes and since 1960 by improving the structural diversity of the forest.

The changes shown in **Figure 2** for spotted gum (*Corymbia maculata*) forest in South Brooman State Forest, New South Wales.

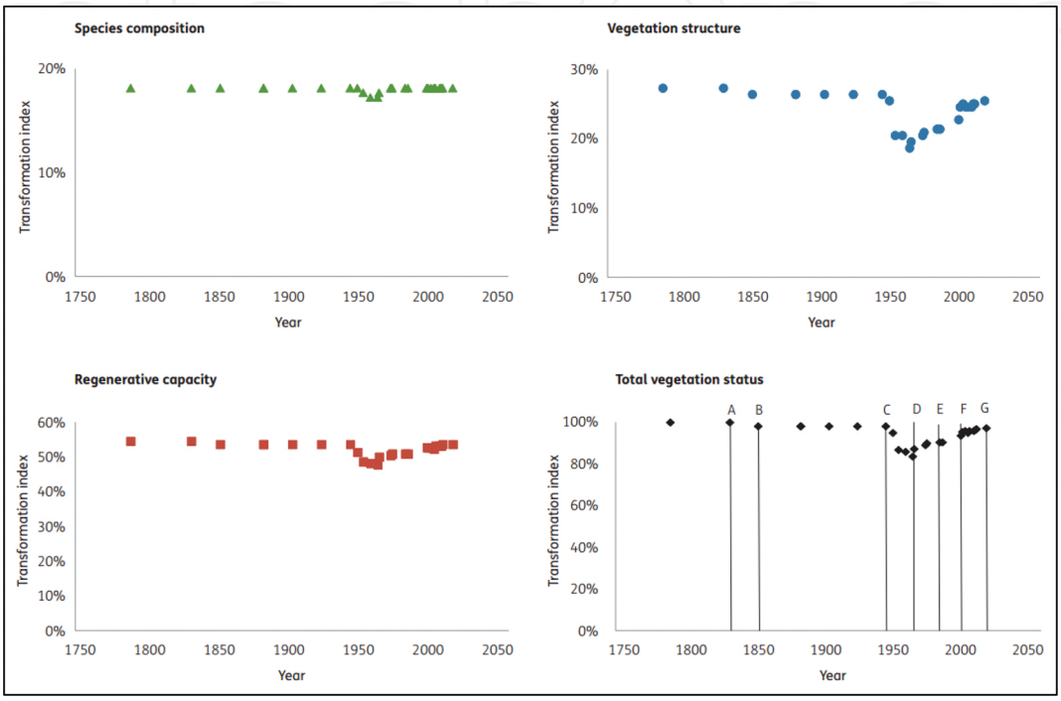



**Figure 2.** Changes in spotted gum forest, South Brooman State Forest, Batemans Bay, New South Wales, Australia. Key management practices: A = indigenous management; B = site picked over for high-quality sawlogs, fire suppressed and/or excluded; C = site again picked over for high-quality sawlogs; D = sawlogs harvested over 85% of site, removing 50% of canopy; E = site rehabilitated naturally; F = wildfire burnt 100% of site; G = site rehabilitated naturally. Source: http://aceas.org.au/portal Vegetation Transformation Study Sites, South Brooman State Forest Site Vegetation Transformation Details [21].

## 4. Discussion

The above approaches to monitoring and reporting vegetation condition differ from other frameworks for monitoring and reporting vegetation condition [5], which are mostly biodiversity-based frameworks that have been widely applied [22]. Those biodiversity-based frameworks consider vegetation attributes in isolation from, or independently of, land management practices and only consider *post hoc* the effects of changes in land management, in order to explain observed patterns of environmental information.

Another landscape condition assessment framework is the landscape functional analysis (LFA), which focuses on attributes including landform, soil, hydrology and nutrient status. LFA was developed to help land managers restore ecological function in degraded ecosys-

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tems [23]. The LFA framework considers attributes of native vegetation (i.e. structure and composition) as a means to an end, being indicators of healthy functioning landscapes. Hence, detailed species lists are not necessary for LFA.

Biodiversity- and landscape condition-based assessment frameworks [22, 23] tend to collate land use and land management to interpret the current condition state but generally do not thoroughly and systematically analyse the effects of historic and contemporary land management practices on criteria and indicators of vegetation condition. They therefore provide little operationally relevant information that is at a scale that is useful to land managers.

The approaches described in this chapter do not seek to supersede nor replace these existing frameworks for assessing condition. Rather, they aim to provide a more integrated system for evaluating anthropogenic effects on the condition of native vegetation communities over time.

The development and application of criteria and indicators of vegetation condition can show which sites and landscapes have not been modified or only minimally modified. This information can help land managers who make decisions about land management practices and to identify areas which have been rehabilitated towards a threshold state as a result of a change/s in land management regimes. Other applications of condition-based decision-making include setting goals or targets for improving vegetation condition across sites and landscapes; identifying and selecting priority areas for restoration and regeneration; or monitoring and reporting the outcome of changed land use and management. It is critical to understand which criteria and indicators of the extent and condition of the native vegetation have been modified or changed relative to a reference state and to what extent, and over what time period [24, 25]. Monitoring and reporting the transformation pathways of native vegetation at site and landscape scales including processes of replacement, removal and recovery are vital but is often poorly implemented and practiced by land managers and scientists alike. Where areas are needed for biodiversity conservation, selecting those areas for treatment that are least modified is likely to result in a more rapid response, following a change in land management practices relative to the reference state.

Modifications and changes due to the anthropogenic interventions occur at the site and landscape scales and change may be slow and almost imperceptible or rapid and both may involve dramatic modification of key vegetation and/or ecological attributes.

Given this setting, the challenge for decision-makers is to develop practical, meaningful and accessible tools and systems for tracking these changes, to monitor and report anthropogenic site and landscape transformations and to link these observed ecological manipulations to ecosystem service benefits and dis-benefits effecting human well-being, biodiversity and ecosystem function.

The development of detailed and systematic chronologies of land management practices and their effects on indicators of vegetation condition places equal importance in collating qualitative and quantitative historical records. Because much of these data and information have not been compiled at the site-level, it is fundamental to work with on-ground land managers to understand the current condition state and what transitions have occurred in key criteria and indicators which have led up to that condition state. Changes include loss of soil

structure and nutrients, regrowth of vegetation structure and incursions of new species and modified fire regimes. Often at the soil–landscape level, it is the land manager (and others) who have observed changes in criteria and indicators over time as a result of their own changes in land management practices.

Where detailed on-ground observations of changes in the above indicators are absent in the chronological record, remote sensing and environmental modelling may be used to develop the requisite essential environmental measures and derived attribute data to populate criteria and indicators of vegetation condition.

Effecting future changes in condition state must also include the land manager. Access to synthesised information generated by compiling a detailed chronology of land management practices and their effects helps land managers to better understand what criteria and indicators they are able to modify and change by changing their land management regimes using appropriate and fit-for-purpose land management practices. Land managers and other decision-makers can use the above approach to gain valuable insights for adaptive management. Decision-makers can in turn use that information for a number of purposes, for example:

1. to enable more reliable identification and selection/s of soil–landscape areas where the structural and compositional have been minimally or moderately modified and where the ecological functions have not been damaged,
2. to inform discussions with land managers on what changes in land management practices and land management regimes that are likely to yield long-lasting changes in condition relative to a reference estate; and
3. to guide the collection of monitoring data and information relevant to the land manager and other interested parties including land management practices and attributes of condition.

## 5. Conclusions

The case studies above illustrate transformation pathways including process of replacement, removal and recovery of native vegetation and provide information about how sites and landscapes have been transformed, for example what, where and when an intervention/s was/were used and what was the observed result. The systematic analytical framework used in these case studies to assess changes in vegetation condition offers certainty for land managers and planners through providing consistent results at sites and landscapes over time.

The above discussion has shown that monitoring and reporting vegetation condition information can be derived by direct on-ground measurement and population of criteria and indicators of vegetation condition or by inferring condition information from available land use maps and a knowledge of land management regimes and criteria that are deliberately or inadvertently changed or modified using land management practices. It is worth noting that the same 10 criteria (**Tables 1** and **2**) are used in both approaches. Condition information

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generated from land use maps alone will, however, only enable generalised understandings, whereas developing a systematic chronology of land management practices linked to on-ground direct measurement and assessing criteria and indicators of vegetation condition will provide decision-makers with greater reliability and flexibility and be relevant to multiple applications.

Where land planners and decision-makers require information on the status, change and trend of these impacts on vegetation types for environmental reporting, land use trade-offs and to help assess future land use scenarios, direct on-ground measurement and population of criteria and indicators of vegetation condition should be preferred.

The two approaches described above can be used to inform land managers and other decision-makers to establish and link patterns in the use and management of native vegetation and the transformation of vegetated landscapes. Only the second approach, of developing detailed systematic chronologies of land management and their effects on indicators of vegetation condition, can help answer the following key questions: What is the condition of the native vegetation at a site and landscape over time based on the impacts on land management on indicators of structure, composition and function? How can I monitor and report the condition of native vegetation resulting from management interventions? As a land manager, how can I use knowledge of the impacts of land management on indicators of structure, composition and function to improve the condition of the native vegetation of my site and landscape?

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## Author details

Richard Thackway

Address all correspondence to: rthackway@netspeed.com.au

School of Geography, Planning and Environmental Management, The University of Queensland, Brisbane, Australia

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