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Viewpoint

Linking vegetation type and condition to ecosystem goods and services

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ABSTRACT

Our focus here is on how vegetation management can be used to manipulate the balance of ecosystem services at a landscape scale. Across a landscape, vegetation can be maintained or restored or modified or removed and replaced to meet the changing needs of society, giving mosaics of vegetation types and 'condition classes' that can range from intact native ecosystems to highly modified systems. These various classes will produce different levels and types of ecosystem services and the challenge for natural resource management programs and land management decisions is to be able to consider the complex nature of trade-offs between a wide range of ecosystem services. We use vegetation types and their condition classes as a first approximation or surrogate to define and map the underlying ecosystems in terms of their regulating, supporting, provisioning and cultural services. In using vegetation as a surrogate, we believe it is important to describe natural or modified (e.g. agronomic) vegetation classes in terms of structure – which in turn is related to ecosystem function (rooting depth, nutrient recycling, carbon capture, water use, etc.). This approach enables changes in vegetation as a result of land use to be coupled with changes to surface and groundwater resources and other physical and chemical properties of soils.

For Australian ecosystems an existing structural classification based on height and cover of all vegetation layers is suggested as the appropriate functional vegetation classification. This classification can be used with a framework for mapping and manipulating vegetation condition classes. These classes are based on the degree of modification to pre-existing vegetation and, in the case of biodiversity, this is the original vegetation. A landscape approach enables a user to visualise and evaluate the trade-offs between economic and environmental objectives at a spatial scale at which the delivery of ecosystem services can meaningfully be influenced and reported. Such trade-offs can be defined using a simple scoring system or, if the ecological and socio-economic data exist in sufficient detail, using process-based models.

Existing Australian databases contain information that can be aggregated at the landscape and water catchment scales. The available spatial information includes socio-economic data, terrain, vegetation type and cover, soils and their hydrological properties, groundwater quantity and surface water flows. Our approach supports use of this information to design vegetation management interventions for delivery of an appropriate mix of ecosystem services across landscapes with diverse land uses.

1. Introduction

Human well-being is inextricably linked to the provision of a wide range of goods and services from diverse ecosystems across bioclimatic regions. Human use of ecosystems results in ever changing spatial patterns and resource changes across both landscapes and social-ecological systems (Folke et al., 2004; Foley et al., 2005; Walker and Salt, 2006; Bennett et al., 2009). Several global assessments have shown that the pressures of human population growth and development are increasingly impacting on the resource condition of major ecosystems (e.g. coastal, forest, grasslands, dryland, cultivated and urban) and hence their capacity to meet human needs for goods and services (World Bank, 2004; United Nations (Millennium Ecosystem Assessment (MA)), 2005; World Resources Institute, 2007a). While considerable progress has been made in developing appropriate assessment frameworks, several authors note there is an ongoing challenge to develop practical applications and tools that demonstrate sustainable use and management of ecosystems for the delivery of ecosystem services at a range of scales (Millennium Ecosystem Assessment 2005; World Resources Institute, 2007a; Cowling et al., 2008; Walker et al., 2010). Such developments need to be widely applicable, effectively demonstrated and well publicised if they are to lead to real improvements in decision-making across scales and

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jurisdictional responsibilities. The methodology described here is a step in the direction of helping decision-makers better evaluate the consequences of land use changes on ecosystem goods and services.

When decision-makers set out to explore the possible redesign of landscapes, often at different scales, they need information about their ecological function and how a change in the mix of land uses will impact on trade-offs between production needs and other human well-being needs. Where possible, trade-offs should be quantified in terms of the sustainable delivery of ecosystem goods and services from resilient ecosystems and be matched to human well-being (Bennett et al., 2009; Cork et al., 2007). Land management practices can influence the resilience of different ecosystem types and their ecological function and in turn suggest which ecosystem service or set of services can be sustainably restored or maintained in the long term. Much of the recent literature in this field is covered in Maltby et al. (1999), Alcamo et al. (2003), Walker and Salt (2006), Rapport et al. (2003) and the Millennium Ecosystem Assessment (2005).

Three examples of practical approaches for developing information to support policy development and planning and natural resource management, and which have a focus on the delivery of ecosystem services, can be selected from the literature. First, Alcamo et al. (2003) describe an approach for assessing the condition of ecosystems, the provision of services, and their relation to human well-being. Alcamo et al. also outline a decision process used to determine which service or mixes of services is valued most highly and suggest how to maintain ecosystem services by sustainably managing the ecosystem and its ecological function. This approach was instrumental in underpinning the assessment framework for the Millennium Ecosystem Assessment. Second, Maynard et al. (2010) outline an approach developed in the south-east region of Queensland, Australia to establish relationships between four components to ecosystem-based decision-making; maps of the types of ecosystems, ecosystem functions, ecosystem services, and constituents of human well-being. The authors derived a series of interrelationships between the components using matrices with simple scores to map ecosystem services of the region. Third, The World Resources Institute et al. (2007b) present an atlas showing how people of Kenya currently use the landscape and it's ecosystems. Maps of population and household expenditures are compared to ecosystem types (e.g. mountains, rangelands and forests) and the services (e.g. water availability, food production, wood supply, wildlife populations) they provide. One of the benefits of the atlas is that it highlights the relationship between economy and ecosystems, e.g. revenues raised from tourism in various ecosystems and their wildlife resources and revenues from forests and timber production.

Our approach is to build on the observation that vegetation is a major driving force in the dynamics of terrestrial ecosystems such that, in Australia, it is often used as a proxy to classify ecosystem type and function. The nature of vegetation in a landscape – its type and condition – strongly reflects environmental variables related to soils and climate but it also reflects land use disturbances such as clearing and the replacement of deep-rooted perennial plants with annual crops. To a large extent, it is the mix of intact, disturbed and replaced vegetation cover types and their relative condition classes which characterise a region's natural ecological function and its capacity to deliver a set of ecosystem goods and services (Folke et al., 2004). The main environmental issues that need attention in the Australian context are water quality and quantity, habitat loss and biodiversity, soil structure decline, dryland and irrigation salinity, food and fibre security and fuel management for fire control. These are common issues in other countries with large-scale broad-acre agricultural land uses.

Characteristics of vegetation (e.g. extent of uniform types and condition classes) provide easy to identify practical focal points that become the focus for decision-makers and land managers to develop and apply appropriate land management practices (i.e. maintain or restore or modify or remove and replace) to meet the changing social and economic needs of society (Maltby et al., 1999; Bennett et al., 2009). Few enterprises manage only a single vegetation type. Most manage the mosaic of ecosystems that make up a landscape. The challenge is to provide a practical framework to strategically assist policy, planning and management within the inherent limits of social and economic realities and ecological function across the landscape and with sufficient flexibility to provide for change in the mix of ecosystem services required at local, regional, national and international levels (Fisher et al., 2008; Walker et al., 2010; Maynard et al., 2010).

We outline a way to describe vegetated ecosystems and their management to support policy development and planning and natural resource management, in this case at the regional level. This requires a stepwise approach to (i) classify vegetation, (ii) recognise vegetation condition classes (termed VAST classes) based on structure, regenerative capacity and composition, (iii) relate the VAST classes of vegetation condition to land use and ecosystem function, (iv) estimate the effect of changes in land management and/or land use on VAST classes (in accordance with scale, position in the landscape and likely cost) and (v) select and invest in vegetation management actions that will deliver required outcomes in ecosystem goods and services.

2. Vegetation classes, vegetation condition and ecosystem services

The ecosystems that comprise landscapes are complex entities featuring intricate interactions between above and below ground living and non-living elements, food-webs and biophysical processes of assimilation and renewal. Vegetation is the most evident component of terrestrial ecosystems and so is widely used, along with information on soils and landforms, to simplify ecosystems and landscapes into manageable units. The genesis of a systematic, landscape-oriented approach can be traced from the development and application of the Land Systems methodology, applied between 1949 and 1974 mainly by scientists in CSIRO, Australia and its continuing development in the discipline of "landscape ecology" (Christian, 1952; Stewart, 1968; Hills, 1976; McDonald et al., 1984; Forman, 1995; Jiangui and Taylor, 2002). Because vegetation is relatively easy to describe, vegetation classes are often defined and mapped as a first approximation of the underlying ecosystems (Zhiyuan et al., 2003). In Australia, native vegetation is commonly used to recognise and name ecosystem types, assess their condition and act as a surrogate for a range of values including biodiversity.

The yield of ecosystem services from Australian landscapes is strongly influenced by the kind of vegetation at a place and, in particular, how vegetation assets are managed in environments that have been subjected to large temporal variations in climatic conditions. Vegetation composition and dynamics are closely linked to a range of environmental variables that operate at a range of scales. Distributional patterns of vegetation are usually highly correlated and frequently causally related to a range of other ecosystem components such as soil fertility and water availability for plant growth, and to land use and land management practices – e.g. grazing, browsing, and tree removal with their unintended consequences such as erosion, soil acidification, water logging and salinisation on lower slopes and fire intensity. An additional complicating factor is that, over much of the Australia, soils are of ancient origin and consequently are nutrient and structurally poor and often fail to recover from large-scale disturbances (Walker and Reddell, 2007).

At a general level, we know how most vegetation types function in terms of biological and ecological processes across the soil-

Table 1
Vegetation functions (dependent on vegetation type and condition) that influence the provision of ecosystem services.

A. Regulating and supporting services	Vegetation influence on ecological processes and life support systems
1. Effect of structure on the regulation of climate and microclimate	Produces litter that reduces evaporative losses
	Moderates soil temperature
	Shading moderates stream temperature
	Maintains the water cycle through evapotranspiration
2. Structure and regenerative capacity mediate environmental disturbances	Protects shorelines, riverbanks, etc. and minimises negative impacts of floods
	Binds and protects soils
3. Structure, regenerative capacity and composition regulate water cycle processes	Retains water in the landscape
	Supports wetland systems and aquatic biodiversity.
4. Structure, composition and regenerative capacity support soil health	Roots bind soils and ground cover reduces saltation, channelling, sheetwash, etc.
	Maintains nutrient cycling and nitrogen fixation; leaf litter and debris feed soil organisms
	Soil carbon store increased
	Filtration and trapping of pollutants
	Roots assist decomposition of parent material (physical and chemical)
5. Structure, regenerative capacity and composition support critical life cycle requirements and provide structural and nutritional niches	Provide conditions for soil fauna and micro-organisms
	Provide habitat and food sources for pollinators, etc.
	Provide habitat/niches for wildlife
	Move nutrients between above and below ground environments
B. Production services	Vegetation influence on provision of consumable natural resources
6. Structure and composition provide direct and indirect sources of energy, genetic material and biochemicals	Provides variety of food types for humans, domestic and native animals
	Provides fibre and materials for human uses such as paper products, structural timbers for buildings, etc.
	Source material for pharmaceuticals
C. Cultural services	Vegetation influence on opportunities for human (cognitive) development
7. Structure and composition contribute to sites and features with cultural significance; and provide varied and attractive landscapes and scenery	Provides varied and attractive landscapes for amenity and recreation, wilderness quality and can be part of sacred or spiritually important sites
8. Structure, regenerative capacity and composition contribute to landscapes and features with scientific and educational value	Natural systems for scientific research, formal education and training, individual learning, etc.

vegetation-atmosphere continuum. The linkage between changes in vegetation and many ecosystem drivers is also known at a general level – e.g. the changes to water flows given different land use/vegetation types ranging from crops, perennial pastures, woodlands and forests (Walker et al., 2002). The eWater program in CSIRO has developed a suite of process-based models and decision support systems that apply to land use changes and hydrological quantity and quality outcomes (Argent et al., 2009).

There are many ways to classify vegetation and these entail the grouping of vegetation characteristics according to some defined criteria or purpose. Species composition, structure or architecture and plant functional attributes are the most commonly used as a link to ecosystem goods and services (Thackway and Lesslie, 2008). Table 1 provides examples of broad linkages between ecosystem function and the provision of ecosystem services and the influence that vegetation has on these.

In Table 1 we identify eight functions and show some of the effects that vegetation type and condition has on ecosystem services across a landscape. It shows how, at any location, these effects can be linked to the structure, regenerative capacity and composition of vegetation. These are the three criteria that are used here as indicators or surrogates to determine vegetation function.

The primary requirement is for a vegetation description (classification) that is applicable at the broad scale, applies to agricultural systems as well as intact systems, and gives a relative set of differences in terms of ecosystem services. It is also essential that its classes can be recognised across large areas using remote sensing and that it is understandable to a range of end users and, in particular, to policy and planning decision-makers.

The structural classification deemed suitable for this purpose is described in detail in the Australian Soil and Land Survey Field Handbook (Hnatiuk et al., 2009), and the spatial distribution of this kind of structural information is readily accessible in Australian databases (NLWRA, 2007). Interpreting satellite imagery in terms of this structural classification is technically well established (Lu et al., 2003) and is used to map land cover classes across landscapes (Thackway and Lesslie, 2008).

In summary, the classification uses cover classes (seven foliage or crown cover from dense to very sparse) and height classes (11 from <5 cm to >50 m). The structural classification has evolved in Australia since the 1930s and was used by Carnahan (1973) to produce the current pre-European vegetation map of Australia. The methodology was updated by Walker and Hopkins (1984, 1990) and the most recent update to enable coverage of the range of vegetation from intact to agricultural ecosystems was completed recently by Hnatiuk et al. (2009). Structural classes can be qualified by floristic or specific functional attributes depending on the level of detail required. The structural classes are qualified by regenerative capacity to give a functional base on which to map vegetation condition classes. Details and derivations of vegetation condition we use here are given in Thackway and Lesslie (2008) and Lesslie et al. (2009).

For practical purposes, we have developed an approach which uses information on the condition of individual occurrences of vegetation types (sites and patches) on the grounds that:

- The condition of vegetation types can be observed to be the result of land management practices operating on the dominant characteristics of the vegetation type – structure (height, cover, growth form, strata), regenerative capacity (resilience), and composition (species diversity).
- Vegetation condition is described as the difference between observed or measured values for diagnostic attributes or criteria relative to a benchmark. [In Australia the 'original' natural vegetation is often used as a benchmark because of its assumed relationship to biodiversity – a highly valued ecosystem service outcome. Residual patches of native vegetation types can be use to define this biodiversity benchmark.]

Table 2
The VAST vegetation condition classes.

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 been entirely removed (i.e. subject to primary succession).
Increasing vegetation modification		
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 and regenerative capacity has been significantly altered by land use/land management practices.
IV	Largely replaced and degraded	Native vegetation largely replaced by invasive native and/or exotic plant species (commonly areas abandoned or burnt).
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 forestry. Various types are recognised in the vegetation classification.
VI	Replaced with man-made structures	Settlements and cultural features – e.g. buildings, roads, water reservoirs; gardens, parks and amenity plantings.

- The observed 'distance' of these diagnostic criteria from any 'fully natural' benchmark provides relative scores that can be summed to assign condition classes. A system for scoring these attributes for biodiversity assessments of sites or patches of vegetation has been developed by Parkes et al. (2003).
- For vegetation managed for economic production, benchmarks can be represented by the condition where best practice is deemed to result in ecologically sustainable ecosystem service outcomes. Systems for scoring these attributes for productive grasslands have been developed by the Department of Primary Industries and Fisheries (2006).

Our approach classifies vegetation types and condition classes to indicate the likely balance of ecosystem services – including what services have been decreased or increased by changes in vegetation condition. As such this approach is similar in concept to that described by Czúcz et al. (2009). Our approach – called the VAST (Vegetation, Assets, States and Transitions) Framework – is outlined below. The seven classes are fairly broad and it is easy to place an ecosystem or asset or part of a landscape into the broad VAST classes using the descriptions in Table 2.

3. The vast approach to vegetation condition

Broadly, vegetation condition indicates the capacity of a unit of vegetation to produce a range of goods and services such as food and timber, clean water or wildlife habitat. Condition changes as the vegetation type responds to the pressures applied to it.

Vegetation condition is best considered as a relative term that depends on the values, perspectives and aspirations of those assessing and managing the vegetation. It can be assessed from a number of different perspectives, such as production capacity for economic goods, degree of land cover to estimate degradation, ecological productivity and regeneration capacity, extent and type of past disturbances, the presence of different plant species, or important habitat features for wildlife.

The Vegetation Assets, States and Transitions (VAST) framework (Thackway and Lesslie, 2008) provides a practical approach. It uses the structural classification of vegetation that can be applied to the issue of ecosystem services. Table 2 shows the broadest VAST vegetation condition states. VAST uses a metric approach to classify and map vegetation 'condition states' that are determined by land use and/or land management practices – i.e. by the extent to which the dominant vegetation structure and constituent plant species remain intact or, if changed, have been modified, replaced or altogether removed. In the Australian context, change is considered against a baseline of the 'expected' vegetation that characterised an area prior to European settlement in the late 18th century. VAST states can be subdivided if required, for example, to better link with process-based models of the water cycle. The production oriented VAST V can be divided into perennial systems (pastures) and annual crops (e.g. wheat). Further sub-division to recognise different grazing intensities can also be included as in Table 3.

Table 3 shows illustrative rankings for the three vegetation components (structure, regenerative capacity and composition). These attributes are correlated with land use and landscape patterns. The table summarises the basis for allocation of various parts of a landscape to different VAST classes.

The VAST assessment method has been applied at national, state and regional scales to derive a national map of vegetation condition. We show a section of this map for the State of Victoria in Fig. 1. Landscape units were 'scored' on a scale from 0 to 5, primarily based on land use. A full description and maps at this scale are given in a Technical Paper describing the VAST Framework and scoring method (Lesslie et al., 2009).

More detailed scoring using the three criteria, structure, regenerative capacity and composition of vegetation, is very useful for assessing changes both within and between the VAST classes. The more detailed calculations and modelling from representative sites have been used for regional and special purpose assessments. Composite scoring, in a range from 0 to 100, is now being widely used for regional assessments at a landscape scale. For an example of a regional assessment, including derivation of scores, see Department of Environment and Conservation (2004).

Vegetation types and their condition states which arise from land use and land management practices are increasingly being used for promoting change across landscapes at a range of scales (Shelton et al., 2001; McIntyre and Lavorel, 2007; Bennett et al., 2009).

In such initiatives, the aim of investments and policy development can be to change the mosaic of vegetation condition states across a landscape to meet specified targets for desired ecosystem goods and services. This forces planners and policy-makers to recognise and state partial trade-offs between goods and services benefits. Table 4 gives a hypothetical example of the effects that an action to selectively modify vegetation condition could have across the eight categories of ecosystem services.

When condition states are defined and mapped across the whole landscape, management actions can be used to facilitate transitions between one VAST state to another or to monitor changes within or between VAST states. The VAST framework allows for the recognition of 'vegetation thresholds' that mark the

Table 3
Relationships between land use, ecosystem function and vegetation condition.

Land use impact within 60 years	Modification or reduction of 'natural' vegetation			VAST class
	Structure	Regenerative capacity	Composition	
Arid landscapes				
Naturally barren or sparsely vegetated	Nil	Nil	Nil	0
Ungrazed by domestic stock	Low	Nil	Low	I
Intermittent low intensity grazing	Low	Low	Low	I
Frequent low intensity grazing	Low	Moderate	Moderate	II
Regular grazing of marginal lands	Low	Moderate	High	II
Regular medium intensity grazing	Moderate	Moderate	Moderate	III
Non-native replacement – grazing pressure reduced or eliminated	Moderate	Moderate	High	IV
Production from irrigated agriculture and plantations	High	High	High	V
Settlements and infrastructure	High	High	High	VI
Non-arid landscapes				
Natural water features and naturally bare ground	Nil	Nil	Nil	0
Never logged or grazed by domestic stock	Nil	Nil	Nil	I
Not logged or grazed for 60 years	Low	Nil	Low	I
Occasional grazing and/or a single selective logging	Low	Low	Moderate	II
Low to medium intensity grazing and/or repeated selective logging	Moderate	Low	Moderate	II
Intensive grazing and tree removal – some clear fell operations	High	Moderate	Moderate	III
Degraded or abandoned land with non-native vegetation replacement	Moderate	Moderate	High	IV
Intensive animal industry, dryland and/or irrigated agriculture and horticulture, and plantations (native and exotic)	High	High	High	V
Settlements and infrastructure	High	High	High	VI

transition between adjacent condition states. The identification of thresholds is a complex issue (Thackway and Lesslie, 2008). It is possible to recognise certain ecological thresholds – e.g. an amount of vegetative cover below which there is a high (perhaps unacceptable) risk of soil erosion or flooding or salinisation. For example, in VAST class V, a modelling approach can be used to define the proportions of pastures, annual crops and trees needed to reduce the occurrence of salinity across a Western Australian landscape and has been modelled by Dunin (2002). Nevertheless the decision as to whether a risk is unacceptable requires attention to 'social' thresholds and should not be made solely on ecological criteria. The VAST framework includes diagnostic criteria but an understanding of criteria relevant to 'social' thresholds is necessary if VAST is to be used as a planning as well as a mapping tool.

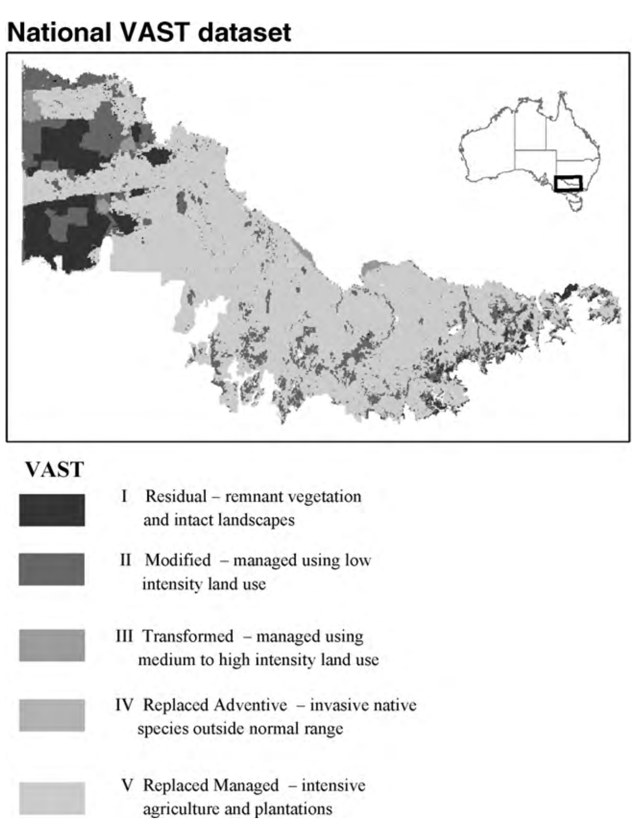

Fig. 1. National map of vegetation condition: excerpt for north-west Victoria.

The problem is that if it is only possible to recognise that an ecological threshold has been passed when change becomes irreversible, the concept has limited value (Yapp and Barrow, 1979). This is why we suggest that decision-making needs to be based on full recognition that ecosystem service goals have equally important biophysical and socio-economic components.

Trade-offs involve choosing how to change the balance between the different ecosystem services available from across a landscape – and who will receive the benefits. In a 'perfect world' choices would be well informed and there would be no unintended losses of benefits and no unanticipated change in beneficiaries. That would require a clear understanding of limits to the type and intensity of changes and, in some cases, their duration (Folke et al., 2004; Foley et al., 2005). An example of such an understanding and the options that are available for trade-offs in the agro-pastoral zone of eastern temperate Australia is presented in McIntyre and Lavorel (2007). It is worth noting that there is a direct correspondence between the states and transitions described by McIntyre and Lavorel (2007) and the VAST framework (Thackway and Lesslie, 2008).

4. Decision-making and its information needs

The vegetation condition frameworks we have described can guide understanding of the information that needs to be made available and how it can be used in a decision-making model. We suggest a model with five key stages that can be repeated in progress towards long-term objectives or, as necessary, in response to changing environmental conditions or priorities (Fig. 2).

Fig. 2 shows how a stepped 'cycle' would apply to vegetation management plans and goes beyond the more familiar pressure-state-response model, which is relevant to step 4 in the cycle. This 'cycle' model provides a framework that can be used for clarifying and addressing issues related to why, how, when and where future national resource management programs can deliver better

Table 4
Effect of vegetation management actions on ecosystem services.

Ecosystem services	Outcomes changed by management action (may be positive or negative)	Degree of impact
1. Regulation of climate and microclimate	Shade and shelter for plants and animals	Medium
2. Mediation of environmental disturbances	Protection of banks of waterways	High
	Flood mitigation	Low
3. Regulation of water cycle processes	Surface and groundwater availability for	
	Environment	High
	Agriculture	Medium
	Forestry	Low
	Domestic use	Medium
	Surface and groundwater quality	High
	Lowered water table for salinity control	High
4. Controlling contaminants; recycling organic matter; and regulating nutrients and soil condition	Soil health	
	Physical	High
	Chemical	Medium
	Biological	Low
5. Generation and supply of raw materials, food, mineral and energy resources	Food and fibre production	Medium
	Genetic and biochemical resources	Low
6. Creating and regulating habitats and controlling reproduction and dispersal of species	Biodiversity	Low
	Biotic environment	Medium
7. Providing conditions for culture, health, amenity and social and personal development	Amenity	Medium
	Social well-being and community health	Low
	Life fulfilment	Low
8. Providing opportunities for research, teaching and learning	Science and educational resources	Low

Action: Change in vegetation condition state through establishment of deep-rooted plants to replace annuals (e.g. native, exotic or mixed tree and/or shrub species or other perennials for forestry, windbreaks, riparian buffers).
Intentions: Change in sediment generation/supply, wash-off of herbicides; reduced surface run-off/groundwater accession; change in biochemical cycling and rates of accumulation and decay of soil organic matter; change in rates of acidification, salinisation and other threats such as nutrient loss in fires; altered habitats and opportunities for wildlife movement.
The assessments of degree of impact are illustrative, and would need to be agreed by a panel.

ecosystem service outcomes through a comprehensive and integrated approach to vegetation management. The framework also should demonstrate how issues of scale, accuracy and reliability of data can best be understood and how this information can be used at each step of a strategic decision-making approach at different levels (national, regional, local).

The framework has key decision-points for developing and implementing the multiple ecosystem services concept in public and private policies and programs. It is based on the premise that interventions should only be made in the context of a clear appreciation of needs and priorities, a sound understanding of availability of suitable resources and options for their use, and a capacity to measure, monitor and report changes in on-ground attitudes and land management practices.

5. Two examples of the VAST system

5.1. Restoring ecosystem services on degraded farmland

Thackway et al. (2006) describes a farm-level application of a landscape approach to sequential restoration of vegetation and ecosystem services on a 250 ha grazing property in the southern tablelands area of New South Wales, Australia. On commencement in 1980, much of the property was in degraded condition with poor pasture cover and areas of salinity, soil acidity and erosion. A combination of land management practices was applied across 38 irregularly shaped 'land units' having common position in landscape, soil type and depth, aspect, slope and productivity. Thackway et al. (2006) used an aerial photo archive to map the change in vegetation condition (the area in different VAST states) for five periods between 1962 and 2004. The results – such as the regeneration of more than 200,000 trees on the hill tops and planting of an additional 20,000 trees and other native species in other land units – yielded the desired enhancement of ecosystem services, including measurable improvements in pastures and productivity, effective control of soil erosion and salinity, and recovery of native flora and fauna.

5.2. Assessing ecosystem services from 'intact' and modified vegetation

In Australia many native wooded areas are used for round-the-year grazing by sheep and cattle. Trees are thinned out using chemical and/or physical methods or removed with bulldozers to give a landscape with varying densities (or clumps) of trees and shrubs. Fig. 3a and b illustrate changes in condition which have occurred in the box gum woodland vegetation communities found on the south western slopes of NSW, Australia – an example of non-arid landscapes as they are described in Table 3. For each condition class of the box gum woodlands, i.e. for a transition from VAST I and VAST III, we illustrate the delivery of the eight ecosystem services listed in Table 1 using amoeba plots and supported by a site-based photograph.

Box-Gum Woodlands were formerly widespread along the western slopes and tablelands of the Great Dividing Range, throughout southern central Queensland, central New South Wales and the Australian Capital Territory and central and northern Victoria. The dominant tree species include White Box (*Eucalyptus albens*), Yellow Box (*Eucalyptus melliodora*) and Blakely's Red Gum (*Eucalyptus blakelyi*). In some parts of the range of this diverse community, Grey Box (*Eucalyptus macrocarpa* or *Eucalyptus moluccana*) may be either dominant or sub-dominant. This community

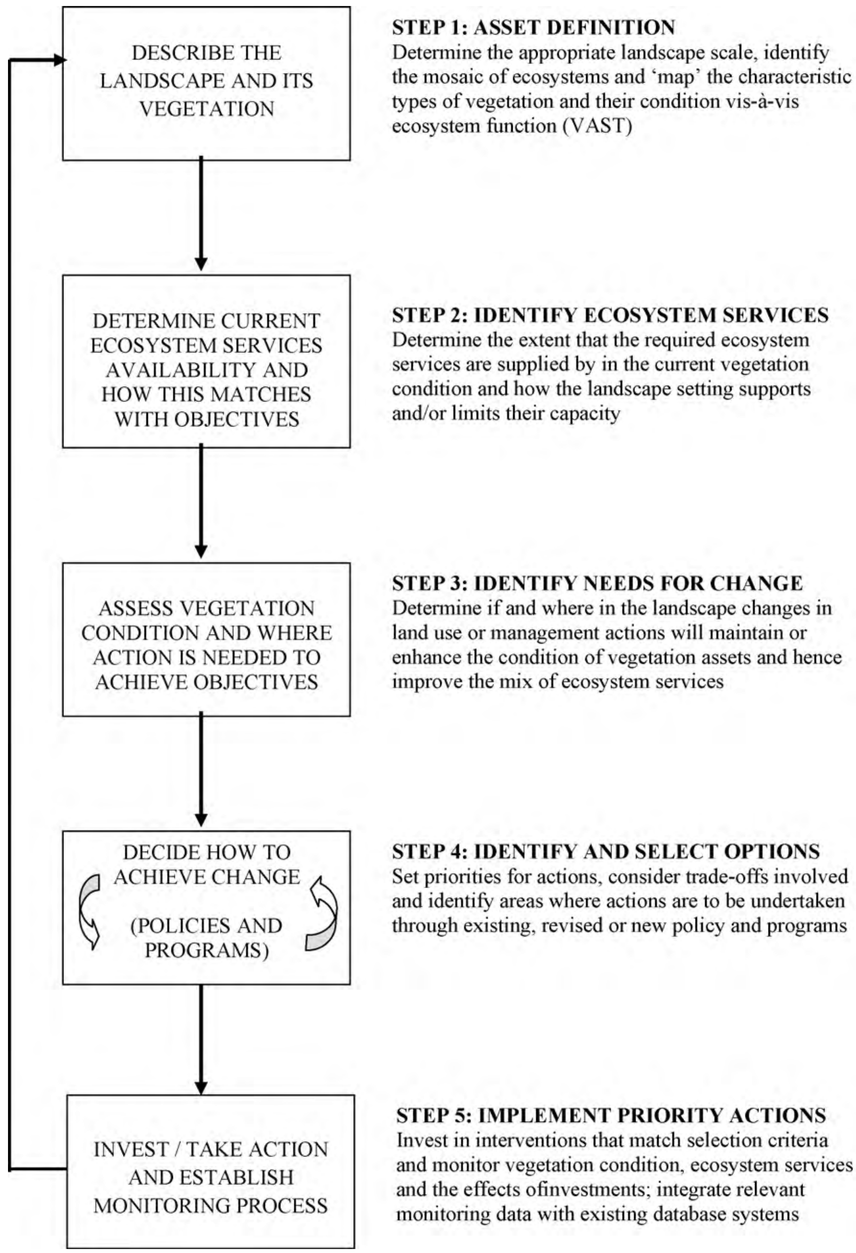

Fig. 2. Steps in vegetation management actions for ecosystem service outcomes.

may have a scattered shrub layer and a diverse ground layer of mixed grasses and herbs (see: Department of the Environment and Heritage, 2006).

The two amoeba plots in Fig. 3a and b show an assessment of eight goods and services in two VAST classes and these are presented in more detail in DECCW (2009). The plots show outside circles which represent an optimum value for ecosystem services delivery, values below the inner circle show services that could be targeted for improvement using land management practices that aim at enhancing the structure, regenerative capacity and/or the composition of the vegetation. The photos depict the vegetation condition class.

Fig. 3a shows the original native vegetation type, VAST class I (Residual). Scores are relatively high for all ecosystem goods and services except 'production'.

Fig. 3b shows an area where the original Box-Gum Woodland vegetation has been heavily modified for and by grazing to become VAST class III (Transformed). In this case, only production functions have a high score and management interventions are required to increase the delivery of other ecosystem services. This kind of presentation has proven to be a useful way to present results to decision-makers.

More information can be obtained by comparing particular ecosystem service vectors in each star plot, as well as groups of ecosystem service vectors, to observe the relative trade-offs in the delivery of ecosystem services between the condition classes. The choice to maintain, enhance or reverse a particular vegetation condition depends on the values, perspectives and aspirations of those assessing and managing the vegetation. It can be assessed against a variety of measures, such as the capacity to produce economic goods, the degree of land cover for degradation control, ecological productivity, the extent and type of past disturbances, and the presence of different plant species or important wildlife habitat.

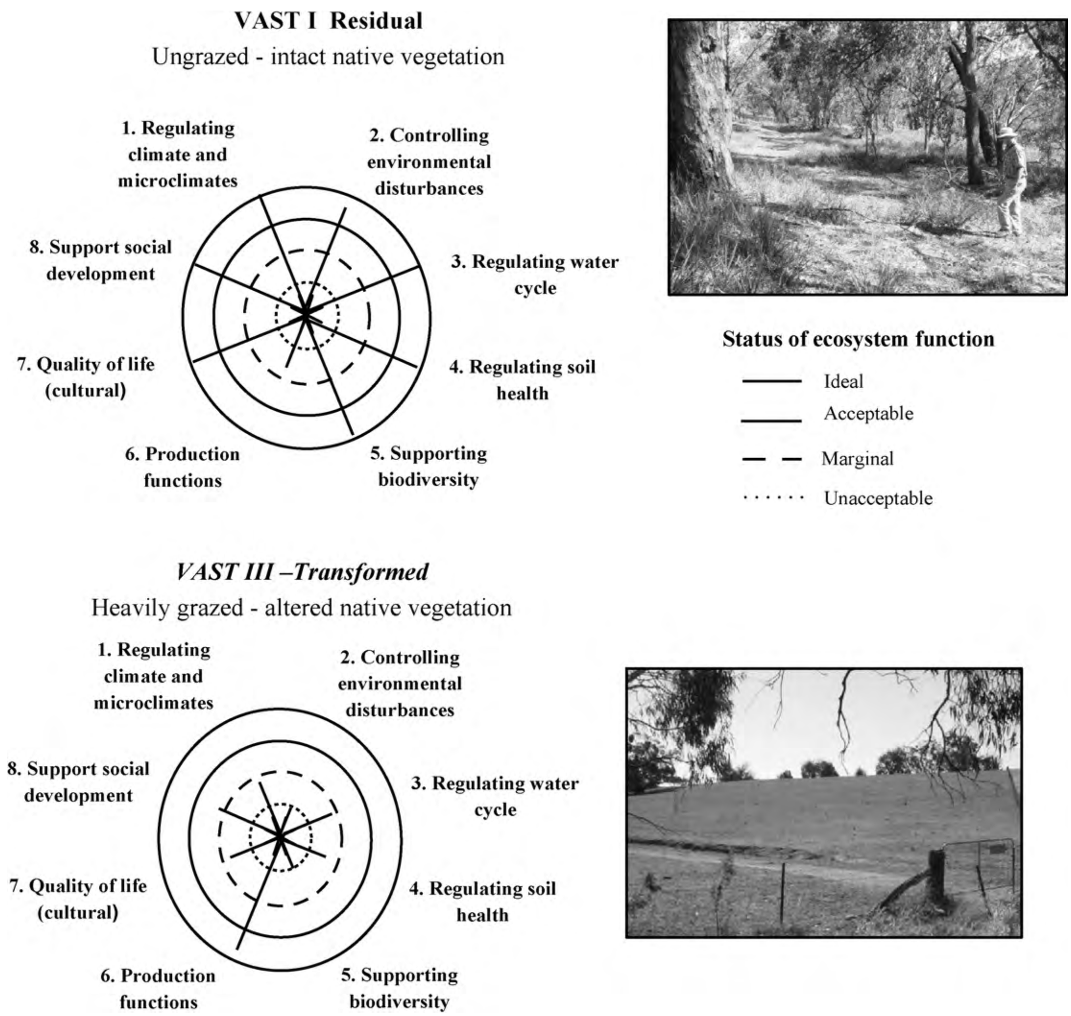

Fig. 3. (a and b) Hypothetical amoeba plots for the eight ecosystem services from two landscapes to illustrate trade-offs as vegetation condition is changed.

6. Discussion and conclusion

Classifying landscape units according to the condition of their vegetation relative to benchmarks (e.g. to the original type and structure of the native vegetation or to best practice for sustainable land use) is a practical approach that can be applied to the full range of ecosystem functions and ecosystem goods and services in Australia. Because it accommodates all vegetation types and the modifying effects of all land uses, it can effectively move to a more comprehensive view that takes in the interdependence of the mosaic of ecosystems that provide goods and services from across whole landscapes. This approach seems suitable for application beyond Australia especially in countries with diverse landscapes and large-scale broad-acre land uses and with suitable spatial data sets.

We suggest that decision-making on manipulating vegetation needs to be better directed at achieving a balanced suite of ecosystem service outcomes because there is a high risk of failure in any approach that almost exclusively focuses on biodiversity without due attention to interactions across the mosaic of ecosystems that make up a landscape. Presenting results as in Fig. 2 emphasises the likely impacts across a range of goods and services that otherwise may not have been considered by decision-makers. The approach described above recognises the use of vegetation as a surrogate for underlying ecosystems and extent to which it is acceptable that, on this basis, vegetation condition can be manipulated to maintain the delivery of preferred and required ecosystem services (Thackway et al., 2006). The strength of this approach, like that described in the Kenyan atlas (World Resources Institute et al., 2007b), is that it readily translates into outcome-based programs and on-ground actions that can be readily assessed and, if necessary, altered in response to current information.

Maynard et al. (2010) note that decision-makers – those who formulate policies and the investment and management strategies for their implementation – can make better judgements on the likely impacts of their decisions where they have access to improved information on a range of ecosystem types, ecosystem functions, ecosystem services, and constituents of human well-being. This is critically important to an enhanced understanding of the trade-offs involved in actions to increase the quantity and/or quality of particular set of ecosystem services (Alcamo et al., 2003).

The information required for implementation and further development of this approach has been steadily increasing over the past decade through vegetation assessment programs. In large part this can be attributed to advances in coupling economic and resource science inputs (e.g. The H. John Heinz III Centre for Science, Economics and the Environment, 2002). Other relevant assessments have been undertaken to meet national requirements – for example Australia's State of the Forests report (Bureau of Rural Sciences, 2008). The framework suggested here extends this kind of report to all vegetated ecosystems and the full range of ecosystem functions and ecosystem goods and services obtained from regional landscapes. Monitoring and evaluation of program performance against a suite of realistic ecosystem goods and services targets is much better than evaluating single outcomes and will be relevant to a broader range of constituents (Millennium Ecosystem Assessment (MA), 2005).

Work is in progress to better define the VAST scoring system in a way that improves compatibility between small-scale and large-scale assessments. An increase in the number of applications over a broader range of arid and humid environments would have two significant advantages. First, it should improve the ability to explain to decision-makers how the system can be linked to existing policy objectives. Second, it would demonstrate to on-ground managers how the approach can be linked to existing databases and landscape-scale process-based models and provide new and additional information to fill gaps.

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