

Mapping and monitoring revegetation activities in Australia – towards national core attributes

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Substantial areas of Australia have been revegetated for land protection and vegetation enhancement through publicly funded programs such as the National Action Plan for Salinity and Water Quality and the Natural Heritage Trust. At present, there are no national monitoring and reporting guidelines for the collection of revegetation data in Australia to assist with monitoring program outcomes or assessing resource condition. Extensive stakeholder consultation was used to develop and evaluate a national set of core attributes to be used in guidelines for describing and mapping revegetation activity. The attributes can be used in the collection of site-based revegetation information to assess whether improvements in the extent and condition of vegetation are occurring and generating a return on investments. Use and adoption of the attributes will assist stakeholders to survey and map as well as to monitor and report on revegetation activities and investments at local, regional, state and national levels. The set of 18 core revegetation attributes has three categories: site, establishment and monitoring. These are incorporated in a revegetation manual being produced by the Bureau of Rural Sciences for land managers. We discuss how these revegetation attributes are likely to be relevant for monitoring and reporting of vegetation outcomes under the Australian Government's Caring for our Country initiative and other community-based programs.

Keywords: Revegetation, core attributes, land degradation, ecosystem services, monitoring and reporting



Over the last two centuries in Australia, inappropriate farming techniques and extensive clearing of vegetation for agriculture has not only caused land degradation (Bird et al. 1992; Saunders & Briggs 2002) but also taken some ecological communities close to extinction (State of the Environment Advisory Council 1996; Beeton et al. 2006). Recognising that some landscapes have been over-

cleared, the Australian and state and territory governments initiated programs in the 1980s to address land degradation through improved land management practices, including revegetation (Saunders et al. 1990; Curtis & Delacy 1996). As a result, revegetation activities have featured in many of Australia's publicly funded programs, including Landcare, Bushcare, Rivercare, the Natural Heritage Trust (NHT), Corridors of Green, Greening Australia, Envirofund and Caring for our Country.

Since 1990, \$6.5 billion has been expended on Australian natural resource management (NRM) programs (Hajkowicz 2009). Public investment in revegetation could range from \$50-\$100 million per year, while private investment could be as high as 4 to 5 times this amount (Paul Ryan, CSIRO, pers. comm., 7 March 2008).

Revegetation activities are increasingly being used to restore and enhance ecosystem services (Donaldson 2001). These services include the provision of wildlife habitat, the sequestration of carbon, the protection of soils from erosion and the maintenance of water quality. Vegetation generally underpins these services (Yapp et al. in press).

As the rural-urban fringe population continues to grow (Fisher 2003; Houston 2005), the subsequent loss of agricultural land and the clearing of remnant vegetation increases pressure on the rural environment (Low Choy et al. 2008), and creates a need to revegetate the peri-urban environment. Revegetation projects in this environment may be aimed at improving amenity; providing 'passive recreational parkland – "breathing space" – for local residents' (Bush et al. 2003, p. 170); as well as biodiversity and conservation.

Despite considerable investment in revegetation activities over several decades, it is not possible to determine what or where activities have been funded (Hajkowicz 2009). This has prevented compilation of a spatially reliable, national revegetation baseline dataset for monitoring changes relative to that baseline. Such information is essential for identifying regional priorities; guiding what information should be collected by land managers for assessing the effectiveness and efficiency of revegetation methods; and gauging the effectiveness of public

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investment. Equally, at the state and regional levels, spatial and temporal information about revegetation activities is unreliable and largely anecdotal (McDonnell 2000; Freudenberger & Harvey 2003).

The Australian National Audit Office, in its review of the Regional Delivery Model for the NHT and the National Action Plan for Salinity and Water Quality (NAP) (ANAO 2008) observed that future NRM will need to be transparent and accountable for Australian Government funds managed by the states and territories, particularly in terms of meeting auditing requirements. We propose that a national set of core revegetation attributes for monitoring and reporting will help to address these needs.

Freudenberger and Harvey (2003) found that there have been only a few assessments of the outcomes of vegetation enhancement activities in Australia. Notably, those revegetation projects that have occurred, have frequently been found to be unsuccessful (Davies & Christie 2001). Zerger et al. (2006) compiled a number of regional revegetation datasets but found that it was not possible to compare them effectively because of the different methods used to describe and map the revegetation. Similar conclusions about the inaccessibility of data and the need to collect more useful revegetation information have been reached by other authors (e.g. Munro et al. 2007; Smith 2008).

These issues highlight the need to develop consistent core attributes and field guidelines for the national monitoring and reporting of revegetation activities to assist with monitoring program outcomes and assessing resource condition. Several frameworks have been developed in Australia to capture detailed information on revegetation activity. However, these frameworks have tended to focus on specific vegetation types (e.g. tropical and subtropical rainforests, Kanowski & Catterall 2006) or have been developed to assess specific revegetation outcomes (e.g. biodiversity benefits, Freudenberger & Harvey 2003; Zerger et al. 2006). While delivering detailed information on many aspects of revegetation, such frameworks generally require extensive data collection, which can be beyond the ability or resources of many revegetation practitioners. Therefore, the revegetation attributes included in a national framework should be as simple as possible to easily capture and report meaningful and comparable information on revegetation activity.

This article outlines the process used to develop and evaluate core attributes that describe and map revegetation activities at a defined point or map unit in

the landscape at a particular time. The core attributes can be applied in any climatic region and are relevant to a wide range of revegetation purposes, including for repeated visits. We discuss how the core attributes might be used for monitoring of, and reporting on, native vegetation outcomes under the Australian Government's Caring for our Country initiative and other community-based programs. This will aid the Australian Government in calculating the benefit-cost ratio of revegetation investments, and assessing the progress of revegetation programs towards efficient outcomes; which it is currently unable to do (ANAO 2008; Hajkowicz 2009).

Defining the context for recording revegetation activities

We define revegetation as the growth of any new vegetation in an area that has been cleared or disturbed, generally for production purposes. Revegetation includes a broad range of activities that restore vegetation to the landscape to meet a variety of conservation and production objectives, including forms of forestry and farm forestry, biodiversity enhancement, land and water protection, amenity plantings and naturally regenerating vegetation.

The revegetation activities considered in this article generally occur on agricultural land where the native vegetation has been significantly modified, replaced or removed. Revegetation in this context is often small scale and involves rehabilitation and environmental protection that can be funded under rangeland, agricultural, farm forestry and NRM programs. This narrower definition of revegetation (Table 1) guided the development of the core attributes. 'Revegetation' occurs primarily in areas dominated by non-native vegetation whereas 'rehabilitation or biodiversity enhancement' is primarily associated with areas of native vegetation. This continuum from revegetation to rehabilitation is shown in relation to six modification states of native vegetation defined by the Vegetation Assets, States and Transitions framework (Thackway & Lesslie 2006).

Development of revegetation attributes

In 2001, the Department of Agriculture, Fisheries and Forestry engaged the Bureau of Rural Sciences (BRS) to develop an agreed set of national core attributes to describe and map revegetation activities. The requested attributes were to complement existing forest and vegetation information in the National Forest Inventory, the National Plantation Inventory, the National Vegetation Information System and the National Carbon Accounting System. In addition, the BRS was asked to

Table 1 Relationship between revegetation and rehabilitation activities in the context of six modification states of native vegetation

		Vegetation condition state (mapping criteria)	Examples
Revegetation (e.g. planting, seeding or encouragement of vegetation regeneration, including by protective fencing)	Non-native vegetation extent Dominant plant species may be indigenous to the locality but cultivated; alien to the locality and cultivated; or alien to the locality and occurring spontaneously	State VI – Removed Native vegetation removed. Alienation to non-vegetated land cover	Water impoundments; urban and industrial landscapes; quarries and mines; transport infrastructure; salt scalded areas
		State V – Replaced, managed Native vegetation replaced with cultivated vegetation	Forest plantations; horticulture; tree cropping; orchards; reclaimed mine sites; environmental and amenity plantings; improved pastures (includes heavy thinning of trees for pasture); cropping; isolated native trees, shrubs or grass species in the above examples
		State IV – Replaced, adventive Native vegetation replaced with species alien to the locality and spontaneous in occurrence	Severe invasions of introduced weeds; invasive native woody species found outside their normal range; isolated native trees, shrubs, or grass species in the above examples
Rehabilitation or enhancement (e.g. weed removal, re-seeding of understorey, controlled burning, stabilisation of dunes, re-establishment of riparian community flooding regimes)	Native vegetation extent Dominant structuring plant species indigenous to the locality and spontaneous in occurrence (i.e. a vegetation community described using definitive vegetation types relative to estimated pre-1750 states)	State III – Transformed Native vegetation community structure, composition and regenerative capacity significantly altered by land use or land management practices	Intensive native forestry practices; heavily grazed native grasslands and grassy woodlands; obvious thinning of trees for pasture production; weedy native remnant patches; degraded roadside reserves; degraded coastal dune systems; heavily grazed riparian vegetation
		State II – Modified Native vegetation community structure, composition and regenerative capacity intact – perturbed by land use or land management practices	Native vegetation types managed using sustainable grazing systems; selective timber harvesting practices; severely burnt (wildfire) native forests and woodlands not of a natural frequency or intensity
		State I – Residual Native vegetation community structure, composition, and regenerative capacity intact – no significant perturbation from land use or land management practices	Old growth forests; native grasslands that have not been grazed; wildfire in native forests and woodlands of a natural frequency and intensity

assess the capacity of the core attributes for national monitoring of, and reporting on, revegetation activities. In 2002, a Revegetation Advisory Committee with state and regional representatives was established by the BRS. The BRS used an open, iterative and consultative process to engage key stakeholders to develop and evaluate the

core revegetation attributes. This involved three steps:

- defining national and regional stakeholder requirements for revegetation information
- developing and evaluating the ability of a revegetation attribute to contribute to existing revegetation datasets
- evaluating the performance of the core revegetation attributes in monitoring and reporting by field workers.

Defining stakeholder requirements

The national and regional stakeholder requirements for national-level revegetation information as specified by the Revegetation Advisory Committee are to determine:

- the amount of area revegetated
- the main purpose of a revegetation project
- the degree of on-going monitoring and management of revegetation sites
- the number of landholders, farm units and groups involved in revegetation projects
- the amount of money invested in revegetation
- how the revegetation activity relates to identified environmental problems or issues
- the total area of revegetation catalysed under the NHT and NAP programmes.

These seven requirements provided the basis for developing a list of attributes to describe and map national revegetation activities.

Existing government-funded revegetation data

We reviewed existing data-sets collected on past government-funded revegetation programs, and found a paucity of nationally consistent, spatial data to report on revegetation activities in Australia. There are several

Table 2 Site, establishment and monitoring attributes for revegetation reporting

	Data attributes	Attribute categories		Notes	
Site data	1	Data record	Record number	Unique number for each revegetation site	
	2	Date	Year/month/day	Date the activity took place	
	3	Data source	Name	Agency/ Contact details	
	4	Locality	State Closest town Distance (km)	Direction Tenure of site Coordinates	For unknown coordinates, use geocode e.g. catchment, Local Government Area (LGA). Site owner to be included where known
	5	Area or length	Area (ha) or length (km) Geographic Information System spatial file	Site shape	The area of the revegetation site. Attach GIS shape file where possible
	6	Site description	Includes land cover and use		Includes species where known
Establishment	7	Species being established	Species name/s Provenance	Age of seedling	Species of seed or seedlings
	8	Revegetation objective	Amenity/ aesthetics Biodiversity/ wildlife Erosion control Farm forestry Fodder	Restoration Salinity Shelter/ shade Weed control Other	For multiple reasons, record primary and secondary ones
	9	Revegetation method	Site preparation Seed preparation Seeding method Seeding rate	Seedling spacing Seedling planting method Other	Describe revegetation assistance methods: mulch, water, fertiliser, guards. Describe works: rip, mounds, cultivation
	10	Funding source and \$ spent	Australian Government State/ territory government Regional organisation	Local government Non-government organisation Landholder contribution Other	Include multiple funding sources and % contribution \$ spent relates to the total amount of money spent directly on the revegetation activity and includes purchase of seedlings, and cost of training, planting and protection works. Hours are also recorded. If possible, provide estimates on the cost of volunteer investment
	11	Threats to revegetation	Climate Disease Fire	Pests Stock Other	Most likely threats to revegetation success
	12	Use of patch	Conservation Environmental (restoration/ rehabilitation) Fodder	Grazing Shelter Plant production Amenity/ aesthetic	Anticipated use of patch
Monitoring	13	Monitoring frequency	Interval	Duration	
	14	Management of site	Fencing Pest control Replanting Slashing/ mowing Thinning	Tree guards Weed removal Weed spraying Other	
	15	Monitoring Revegetation	% revegetated	% planted/ sown survival	
	16	Achievement of objective	Failure Success	Working towards Unknown	Is the revegetation objective being met?
	17	Comments			
	18	Additional data	User specified data		

issues associated with translating and compiling such data: the relatively high cost of data acquisition compared to the perceived value of the information, and problems with spatial accuracy of the data. In addition, no single data-set provided comprehensive revegetation information. While several regional data-sets were largely compatible with the proposed national attributes, they were limited in coverage or repeatability. Other attribute gaps included a lack of information on data collection methods and on the location, purpose and ongoing monitoring of revegetation projects.

Proposed revegetation data attributes

The synthesis of national and regional stakeholder data and information requirements led to 18 revegetation attributes that were progressively refined over the consultation period, 2001 to 2007 (Table 2). The attributes comprise three categories: site data, establishment data and monitoring attributes.

- Accurate site data is essential for identifying and spatially comparing revegetation, nationally. This information should be consistently collected for all projects, regardless of purpose (e.g. carbon sequestration, salinity reduction, biodiversity benefits or shelter belt plantings).
- Through collecting information that describes the revegetation activity, such as fencing, planting or weeding, the establishment attributes allow for more detailed data collection and analysis.
- The monitoring attributes ensure that revegetation activities can be assessed in the future.

- These attributes for revegetation information collection are consistent with the national vegetation guidelines for field survey and classification (Hnatiuk et al. 2009), which form part of the National Vegetation Information System framework.

The attributes for revegetation were developed to be incorporated into regional NRM monitoring and reporting to permit regional people to report regularly against a range of management actions involving revegetation. The set of attributes (Table 1) comprises the minimum required to consistently describe and map revegetation events at a defined point or map unit in the landscape at a particular time. The attributes can be applied in any climatic region and are relevant to a wide range of revegetation purposes, including repeated assessments. Depending on research and other land management requirements, this minimum list can be expanded to meet more specific needs.

Describing the attributes

Location

Location describes the position of the revegetation in the landscape. It is assumed that the location of revegetation strongly influences its role. Water interception with plantings, for example, can reduce erosion or salinity. To report effectively on revegetation according to its role within the landscape, spatial information must be collected. The shape and location of revegetation is essential because simpler measures, such as the total area of revegetation, are not useful for predicting some benefits of revegetation (Freudenberger & Harvey 2003). Remotely-sensed information can be used to provide accurate information on the location of revegetation activities, as well as to record the area revegetated.

Area (spatial extent) of revegetation

Spatial information is necessary to measure the extent of revegetation achieved. While there are few data to demonstrate the functional benefits of patch scale revegetation (Kimber et al. 1999; Freudenberger & Harvey 2003), knowledge of the extent of revegetated area is required to monitor projects and assess their value. However, obtaining accurate data on the areal extent of revegetation activities may be difficult due to:

- difficulty in estimating the net area of regeneration facilitated over large areas through management actions such as pest or grazing control, fire or fencing
- the reliance on proposed (rather than actual) revegetation figures for program-funded work

- the lack of a simple, consistent mechanism for measuring revegetation activities not funded through traditional sources
- the reliance on converting length of fencing to areal extent of revegetation.

Estimating vegetation gain or loss could be improved with the use of high resolution remote sensing technologies. Although much revegetation activity is too fragmented and small-scale to be discerned by traditional remote sensing satellites (e.g. Landsat and SPOT), paddock-level mapping is possible with high spatial resolution satellites such as IKONOS (Reinke & Jones 2006) or Quickbird. However, the high cost and limited frame size of high resolution technologies make them impractical for mapping of extensive areas.

A possible approach to making national imagery available for recording and monitoring revegetation works is to use an information technology package, such as Google Earth Enterprise (GEE). GEE allows owners to manipulate and integrate their own spatial data. As the application is run from a local server, it displays imagery without delay and the interface can be customised. While primarily a presentation tool, it is easy to update, can deal with large datasets quickly, and can be fully customised. The Northern Territory Government has purchased and customised GEE as the application 'NT Visualiser', currently used by several Northern Territory agencies. A monitoring and reporting system similar to this could be built to enable revegetation practitioners enter coordinates and polygon shapes of the extent of their work. Using a satellite image as a backdrop would help in orientation and to keep locations and measurements precise.

Revegetation objectives

The objectives of revegetation activities must be realistic and clearly defined so that progress towards the objectives can be assessed (McDonnell 2000; Crossman et al. 2007; Field et al. 2007). Revegetation activities can be initiated for many reasons, including to protect and enhance natural communities, increase biodiversity, ameliorate environmental degradation, or for amenity and aesthetic reasons. Revegetation activities can be initiated for public or private requirements, be strategic or uncoordinated, and can include combinations of these factors. Goals such as 'to increase plant diversity' or 'to reduce land degradation' do not provide sufficient basis for assessment of progress. The objective to increase plant diversity, for example, could specify target species and the number or density of species or plants required (Adams 2000). The framework allows specification of

site issues to be addressed through revegetation, such as objectives relating to issues of erosion, salinity, shelter or shade, or forestry activities.

As the effects of revegetation are not always predictable and may change over time, alternative states (Table 1), rather than the one desired, may be reached. To avoid setting unattainable goals, Hobbs and Norton (1996) suggested specifying a range of parameters that can measure vegetation in its present state, and as part of a revegetation 'score-card'. Carr et al. (2007) and Kanowski and Catterall (2006) listed attributes for monitoring revegetation in their respective areas of expertise (i.e. direct seeding and rainforests, respectively). However, these attributes are tailored to specific revegetation types. In contrast, the core revegetation attributes discussed in this article were designed to be applicable to all revegetation types.

Funding source and expenditure

Defining funding sources and expenditure on activities enables revegetation practitioners and regional bodies to record the sources of funding for their revegetation activities. 'Dollars spent' is the total amount of money spent directly on each revegetation activity and may include purchase of seedlings, and the cost of training, earth works and monitoring. This does not include the cost of lost opportunity for the landholder, which can be significant (Dorrough et al. 2008).

The number of participants or landholders involved in revegetation works is sometimes considered an important measure of programme success and the degree of attitudinal change effected (Curtis & De Lacy 1996). However, it can be problematic to distinguish the number and type of participants involved in a revegetation activity, so these data are not included in the revegetation framework. Surveys (e.g. Australian Bureau of Agriculture and Resource Economics and Australian Bureau of Statistics surveys) can be used to assess the percentage of landholders undertaking revegetation work in a region.

Monitoring

Monitoring revegetation allows land managers to determine if resources are being used effectively and to evaluate the effectiveness of their revegetation actions (McDonnell 2000; Field et al. 2007). Monitoring can be used also to assess the success of previous work and to undertake additional work such as weeding or supplementary plantings to enhance the revegetation. There is a lack of information regarding the level of follow-up work undertaken at revegetation sites. For

example, the percentage of revegetated sites that are visited to monitor survival and growth of plantings, or to undertake further management, is not known. This information would provide valuable feedback on the success of various establishment techniques under a range of conditions. Without such monitoring, inefficient and inadequate revegetation techniques may continue being used (McDonnell 2000).

While recipients of the first phase of NHT funds who carried out revegetation projects were expected to monitor and evaluate their projects, there was no minimum requirement or standard for such work (Freeman 2004). More monitoring emphasis was required in the second phase (Field et al. 2007), but revegetation practitioners generally lacked the funds or motivation to extensively monitor their revegetation projects. Freeman (2004) researched community group monitoring of Queensland rainforest revegetation sites and found that some volunteers perceived monitoring as ineffective and not gratifying to undertake. Freeman (2004) suggested that monitoring responsibilities would be best given to external professionals rather than the community groups who frequently undertake revegetation activities. However, the cost of professional monitoring may be too great for many private and community revegetation projects. Local community monitoring of revegetation works not only reduces costs but also fosters public involvement in these projects (Mayfield et al. 2001). The veracity of data collected by volunteers has been questioned, although studies have shown that with appropriate training, the quality of data collected by community volunteers is equivalent to that of professionals (Cuthill 2000; Mayfield et al. 2001; Newman et al. 2002).

Conclusion and future directions

Replacing extensive areas of Australia's perennial native vegetation with annual crops has resulted in increased primary production but has frequently negatively affected the flow of ecosystem services (e.g. declining soil health, water quality and extent of species' habitats). Publicly funded programs, such as the NAP, the NHT and the Caring for our Country initiative, have recognised these environmental issues and changing community values, and have funded state and regional revegetation activities to counter land degradation as well as to restore and maintain ecological function to ensure the long-term sustainability of landscapes for multiple benefits.

Tools for recording revegetation activities are required to ensure the integration of all desired outcomes at different management scales. For example, the attributes described

in this article for recording and mapping revegetation also complement the principles of Bennett et al. (2000) for enhancing the value of revegetation for wildlife conservation.

Effective assessment of revegetation activities will only occur through a coordinated monitoring and reporting framework, and this should be integrated into the delivery of these publicly funded environmental management programs. When incorporated into regional and national information systems for monitoring and reporting, these revegetation attributes would permit more accurate reporting against key vegetation type and extent indicators. Recording of revegetation information is best done by collecting data at the local level, with summary and aggregate data reported at the regional level. The BRS is developing a national revegetation database and web-based monitoring and reporting system. A field manual (Atyeo & Thackway in press) also is being developed to provide landholders, researchers and regional bodies with detailed guidelines to consistently record revegetation activities with the aim to improve the ability of these data to be collected once but used for multiple purposes.

Implementation of the revegetation attributes and guidelines for monitoring revegetation will enable regional people to report periodically on the effectiveness of management actions involving revegetation activities. Analysis of this information will assist with development of future activities.

Landscapes that have been over-cleared will require the implementation of sustainable farming practices, which no doubt will include ongoing investment in revegetation management actions. The goal of the Caring for our Country initiative (AGNRM 2008) is to have an environment that is healthy, better-protected, well-managed, resilient, and provides essential ecosystem services in a changing climate. Importantly, this initiative recognises the need for better accountability and the role that vegetation management plays in the delivery of ecosystem services. Not only is there a need to monitor and report on revegetation activities and the outcomes of publicly funded programs, but there is also a need to provide a framework of revegetation attributes that can be used for monitoring and reporting on community-based revegetation initiatives. One such project is Gondwana Link in south-western Australia¹, which is aiming for landscape-scale change through revegetation of relict landscapes (McIntyre & Hobbs 1999; Mutendeudzi & Thackway 2008).

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¹ Refer to <http://www.gondwanalink.org/>.

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