Applying a system for tracking the changes in vegetation condition to Australia's forests

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Abstract

Use of forested landscapes changes them. Changes, at both the site and landscape scale, can include degradation, modification, conversion, fragmentation, restoration, regeneration and increased connectivity. To date there has been no standardised national system to account for human-induced changes of plant communities at the site level.

Four case studies are used to test VAST-2, a national system for collecting, collating and analysing historical records of land management for their effects on forest condition. Condition is scored using 22 indicators that cover three components: site regenerative capacity, vegetation structure and species composition. Critical to the approach are the responses of each plant community relative to a reference state and the interactions between long-term rainfall and land management. Results are presented graphically.

Keywords: vegetation; change; management; surveys; land use; practice

Introduction

In Australia, a general conclusion of numerous ecologists is that in 200 years we have markedly changed many vegetated landscapes (e.g. Hobbs and Hopkins 1990; Kirkpatrick 1994; McIntyre and Hobbs 1999; Cocks 2000; Lefroy *et al*. 2000). Land-management decisions over time, reflecting the goals, values and desired outcomes of land managers (Mutendeudzi and Thackway 2010) have resulted in changes to the vegetation structure, species composition and/or regenerative capacity of plant communities. Examples of goal-oriented management include farm forestry for carbon sequestration, manipulating forest structure and function to maximise water yield, removing forest cover for food or fibre production, enhancing forest habitat features for threatened species recovery, and restoring forest cover to ameliorate soil erosion. The continent is now a diverse mosaic of modified native vegetation, 'replaced' vegetation cover types, and fragments of vegetation in 'original' condition (Thackway and Lesslie 2008).

The condition of the vegetation can also be influenced by managing and regulating physical inputs, including water and nutrients, and biological parameters (Trudgill 1977; Maltby *et al*. 1999), for example, by managing fire or grazing pressure (Noss and Cooperrider 1994), and by planting non-indigenous species. The Vegetation Assets States and Transitions (VAST) framework uses information on the effects of such land management practices to define a continuum of modification 'states', with thresholds, to classify changes to Australia's vegetation, relative to each plant community's reference state (Thackway and Lesslie 2008).

Our capacity, however, to track and monitor these changes in the integrity of ecological systems at sites and/or across landscapes is relatively poor (Trudgill 1977; Daily 1997; Resilience Alliance 2010). This reflects the difficulty of understanding and distinguishing spatiotemporal responses of complex ecological systems to natural processes from responses to human use and management. Development of systems to monitor, evaluate and report the responses of naturally vegetated systems to human use and management has been only piecemeal (Thackway and Lesslie 2008).

Documenting historical and contemporary land management and assessing its effects on vegetation can be a complex task. The absence of a consistent national approach to assist with reporting transformations of plant communities over space and time remains a source of contention—and even conflict—between those involved in conservation and protection, and those responsible for sustainable land use and management (Thackway 2012a).

Where practical methods have been developed to explain the interactions between ecological systems and human use, they tend to be narrowly implemented in particular socio-ecological settings including for example forestry, dryland agriculture, nature conservation, rangelands or wetlands. Generally these systems operate independently for monitoring, evaluating and reporting. Examples include state government forest management agency systems for use before and after logging operations; mining company systems for use before and after strip mining; and fire management organisation systems for use before and after control burns and/or forest wildfires. Explanations of these interactions are generally based on rigorous statistical and/or mathematical solutions, but there is no certainty that these proposed solutions provide an adequate description and understanding of socio-ecological patterns and processes, particularly when it involves the wider community (Zellmer *et al*. 2006). Arguably there is a need to develop and implement a consistent monitoring and reporting system that can be applied across any socio-ecological sector and scale, can handle qualitative and quantitative information and can explain the socio-ecological complexity (Resilience Alliance 2010).

Curtis *et al*. (2003) note that progress toward sustainable natural resource management is hampered because diverse sources of information on the responses of the environment to management are not integrated. Numerous other authors (e.g. Hobbs and Hopkins 1990; McIntyre and Hobbs 1999; Thackway and Lesslie 2006, 2008; Resilience Alliance 2010) also argue that better integration is needed to adequately address the links between management intervention and ecosystem structure, composition and function.

Several standardised methods for ecological monitoring, accounting for the effect of anthropogenic practices on ecological systems over time have been proposed (e.g. Resilience Alliance 2010). These systems have been developed to compile, integrate and interpret information from a wide range of social and ecological sources. VAST-2 is one such system proposed by Thackway (for application of the system see Thackway 2012a, b; for a detailed scientific explanation see Thackway and Specht in prep.)

The VAST-2 system aims to answer three questions at the site level (Thackway 2012b):

1. What is the condition of the native vegetation on my site relative to an accepted natural standard?

2. How can I assess the role of historic land management in changing the condition of the native vegetation on my site?

3. As a land manager, what can I do to change the condition of the native vegetation of my site?

This paper reports on the application of the VAST-2 system to native forest communities over time for selected forest sites. The relevance of this site information to decision makers faced with a range of issues affecting forest landscapes including degradation, modification, conversion, fragmentation, restoration, regeneration and increased connectivity, is discussed. The findings have the potential to improve our understanding of change and trend, allowing them to be tracked through time. With this better understanding progress towards more sustainable use and better management of our regional landscapes can be made.

Method

The VAST-2 system builds on commonly used site-based indicators of vegetation condition and landscape function (e.g. Noss 1990; Gibbons and Freudenberger 2006; Thackway and Lesslie 2008; Tongway and Ludwig 2011) to derive an historical record about changes due to management practices and their effects on the condition of native plant communities. VAST-2 uses three widely acknowledged components of vegetation condition (aggregated from 22 indicators): 1) site regenerative capacity or function (i.e. post fire, soil structure, soil hydrology, soil chemistry, soil biota and reproductive potential); 2) vegetation structure (i.e. height, cover and age classes); 3) species composition (i.e. functional groups and species richness) (Table 1). Assessment of change for each of the 22 indicators is relative to an assumed pre-European reference for each plant community (Thackway 2012a, b). Each indicator is treated equally and independently, and scored from 0 to 1.

Indicators are hierarchically structured into attribute groups and assigned weighted scores. The above components (referred to in Step 6) are generated and finally a vegetation transformation index (vegetation status) for each year in a site's historical record (Fig. 1). The choice of indicators, their assignment to attribute groups, and the weighting of the components within the VAST-2 hierarchy reflects the expert knowledge of numerous experienced plant community ecologists (Thackway and Specht in prep.). The weighted components comprise regenerative capacity (55%), vegetation structure (27%) and species composition (18%).

Figure 1 summarises the procedure used to compile, analyse and interpret information for sites. The system compiles historical records starting with explorers' first contacts with indigenous peoples, continuing to present day conditions including metadata records; descriptive documents and spread sheets; Google earth and other sources of remote sensing; land use histories; several branches of

Table 1. List of component attribute groups and indicators of vegetation condition scored at sites. Change is assessed relative to an assumed pre-European reference state.

Indicators: level 1	Attribute groups: level 2	Components: level 3
1. Area /size of fires	(a) Fire regime	
2. Number of fire starts		
3. Soil surface water availability.	(b) Soil hydrology	
4. Ground water availability		Regenerative capacity
5. Depth of the A horizon	(c) Soil physical state	
6 Soil structure		
7. Nutrient stress—rundown (deficiency)	(d) Soil nutrient state	
8. Nutrient stress—excess (toxicity)		
9. Recyclers (vertebrate and invertebrate) responsible for maintaining soil porosity and nutrient recycling	(e) Soil biological state	
10. Surface organic matter, soil crusts		
11. Reproductive potential of overstorey structuring species	(f) Reproductive potential	
12. Reproductive potential of understorey structuring species		
13. Overstorey top height (mean)	(g) Vegetation structure	Vegetation structure
14. Overstorey foliage projective cover (mean)	overstorey	
15 Overstorey structural diversity (i.e. a diversity of age classes)		
16. Understorey top height (mean)	(h) Vegetation structure	
17. Understorey ground cover (mean)	understorey	
18. Understorey structural diversity (i.e. a diversity of age classes)		
19. Densities of functional groups of overstorey species	(i) Species composition Overstorey	Species composition
20. Relative number of overstorey species (richness) as a ratio of indigenous to non-indigenous species		
21. Densities of functional groups of understorey species	(j) Species composition understorey	
22. Relative number of understorey species (richness) as a ratio		

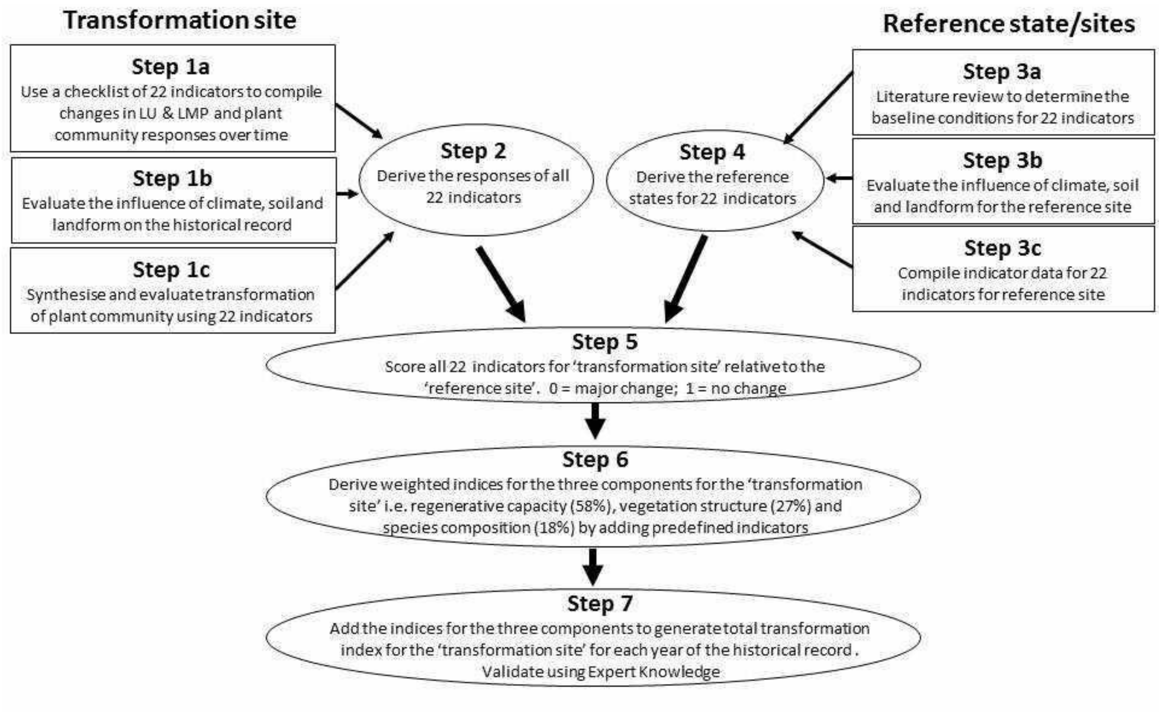

Figure 1. General process for tracking changes in vegetation condition over time

ecological science; landscape, vegetation and restoration; and includes relevant and credible published sources of information, and unpublished reports as well as interviews with forest managers. Information on where, when, and what changes in land use occurred, which forest management practices were used and the observed and measured effects of these practices was compiled, standardised and sequenced chronologically. This process produces a continuous string of information about the cause and effect of changes in vegetation condition.

The system then presents the degree of site modification graphically so that land managers can quickly understand and assimilate the information (Thackway 2012a).

The four forests sites presented here were selected because of the availability and willingness of the current and previous land managers to work with the author to apply the VAST-2 handbook (Thackway 2012a). The four sites are described in Table 2. It should be noted the VAST-2 system has been applied to sites in numerous other ecological settings (http://aceas.org.au/portal/).

The following information was compiled and/or derived for each site:

1. Location of the transformation site
2. Location of the reference site and description of reference state
3. Historical record of the disturbed site:
   a. Year of observed and/or measured land use and land management practices
   b. Year of observed, measured and/or inferred effects of land management practices on the 22 indicators hierarchically structured within 10 vegetation attributes and three components of vegetation condition, that is regenerative capacity, vegetation structure and species composition.
4. Scores of the response of the forest community over time:
   a. Each of the 22 indicators was scored between 0 and 1, using increments of 0.1, for each year of the historical record, where 1 represents a nil impact and 0 represents a complete removal or elimination.

Table 2. Description of four forest sites including plant community, location, current land tenure and overview of the major land cover changes since first settlement

Site	Plant community	Location	Current land tenure	Major land cover changes since first settlement
1	*Callitris* - *Eucalyptus* mallee low woodland	34°59′58.98″S 139°1′48.78"E Wirilda site, Kanmantoo bioregion, Harogate, South Australia	Private land	Native eucalypt woodland > repeated bare ground and sown pasture > improved pasture > mixed planting of local indigenous species and improved pasture > native eucalypt woodland
2	*Eucalyptus saligna* open forest	33°44′35.39″S 151°2′22.15"E Cumberland State Forest site, Sydney Basin bioregion, Pennant Hills, New South Wales	State forest	Native eucalypt open forest > repeated bare ground and sown pasture > sown improved pasture > arboretum planting of mixed species > mixed planting and native regrowth
3	*Eucalyptus saligna* open forest	33°44′39.84″S 151°2′27.88″E Cumberland State Forest site, Sydney Basin bioregion, Pennant Hills, New South Wales	State forest	Native eucalypt open forest > mixed bare ground and native pasture > regrowth native eucalypt open forest
4	*Eucalyptus fastigata* open forest	35°19′10.46″S 148°49′20.07″E Blundells Flat site, South Eastern Highlands bioregion, Cotter River Catchment, Australian Capital Territory.	Water catchment reserve	Native eucalypt open forest > mixed bare ground and native ground covers > *Pinus* plantation > mixed bare ground and native ground covers > *Pinus* plantation > mixed bare ground, sterile rye corn grass and dead pines > native eucalypt open forest

b. Indicator scores were aggregated and weighted to assess changes in the three components of vegetation condition: regenerative capacity, vegetation structure, species composition and the total site transformation indices for each year of the historical record.

5. Reliability scores were assigned to provide transparency by accounting for quality of information e.g. published versus unpublished sources. Expert elicitation and multi-criteria analysis (MCA) were used to enable collaborators from different disciplines to contribute observational and measurement information. MCA was used as a tool to take advantage of expert knowledge and stakeholder advice, and add this information as qualitative observations. Where quantitative measurements were available this information was used to replace qualitative observations.

The transformation of each site was classified relative to the classes defined in the VAST framework (Thackway and Lesslie 2006, 2008), thus enabling the decision-maker to track the pathway of a site over time commencing from reference state (i.e. VAST class I– residual /unmodified = 80–100% of the reference state). Typically over time a site may progress through one or more of the following classes:

For example VAST class II– modified = 60–80%, VAST class III– transformed = 40–60%, VAST class IV– replaced and adventive = 20–40%, VAST class V– replaced and managed = 0–20%, VAST class VI– replaced and removed = 0%. Over time a site may be observed to pass into and out of these classes more than once.

Assessed sites were peer reviewed in consultation with local field ecologists. Final revised site information is then submitted for publication on the Terrestrial Ecosystem Research Network's

(TERN) Australian Centre for Ecological Analysis and Synthesis (ACEAS) Data Portal and the TERN Data Discovery portal. All data for the four sites will be published on the TERN websites including http://aceas.org.au/portal/ and the data portal http://portal.tern.org.au/, for example Thackway (2012c).

Results

Figure 2 shows the transformation pathways for the four forest sites representing various combinations of management, modification, replacement, removal and recovery in three different forest communities. These pathways are described below.

Transformation of Callitris–Eucalyptus *mallee low woodland (site 1):*

Wirilda, Harrogate, South Australia, site shows three broad transformation phases (Fig. 2a):

Phase 1: between 1800 and 1883 the vegetation status of the site remained in the unmodified class (i.e. 80–100% VAST I).

This period included displacement of indigenous people, traverses by explorers and early establishment of pastoralism with shepherds.

Use and management had minimal effects on indicators of regenerative capacity, vegetation structure and species composition.

Phase 2: between 1883 and 1974 the vegetation status of the site was transformed from unmodified class (i.e. VAST I), through modified (i.e. VAST II), and transformed (i.e. VAST III), to replaced/adventive (VAST IV).

This period included very heavy cutting of tree cover to supply timber for Callington and Kanmantoo copper mines; regular ploughing of the soil; sowing the area to oats; continuous stocking with sheep and cattle; regular applications of superphosphate to improved pasture.

Use and management resulted in rapid decreases in the component scores for regenerative capacity, vegetation structure and species composition.

Phase 3: between 1974 and 2010 the vegetation status of the site was transformed from replaced/adventive (VAST IV), through transformed (i.e. VAST III) to modified (i.e. VAST II)

This period included ceasing application of superphosphate; destocking pastures; revegetating with around 25,000 local endemic trees and shrubs; protecting the site in perpetuity; ongoing monitoring and weed control.

Use and management resulted in the gradual increase in the component scores for vegetation structure and species composition. Initial rapid increase in the recovery of the regenerative capacity is slowing compared to recovery in vegetation structure and species composition.

Transformation of E. saligna *open forest (site 2)*

Cumberland State Forest site, Pennant Hills, New South Wales shows four broad transformation phases (Fig. 2b):

Phase 1: between 1820 and 1860 the vegetation status of the site remained in the unmodified class (i.e. VAST I).

This period included displacement of indigenous people; traverses by explorers; and early establishment of pastoralism industry; and selective removal of trees for building materials, fence posts and firewood.

Use and management resulted in minimal change in the component scores for regenerative capacity, vegetation structure and species composition.

Phase 2: between 1860 and 1937 the vegetation status of the site was transformed from unmodified class (i.e. VAST I), through modified (i.e. VAST II) and transformed (i.e. VAST III), to replaced/adventive (VAST IV).

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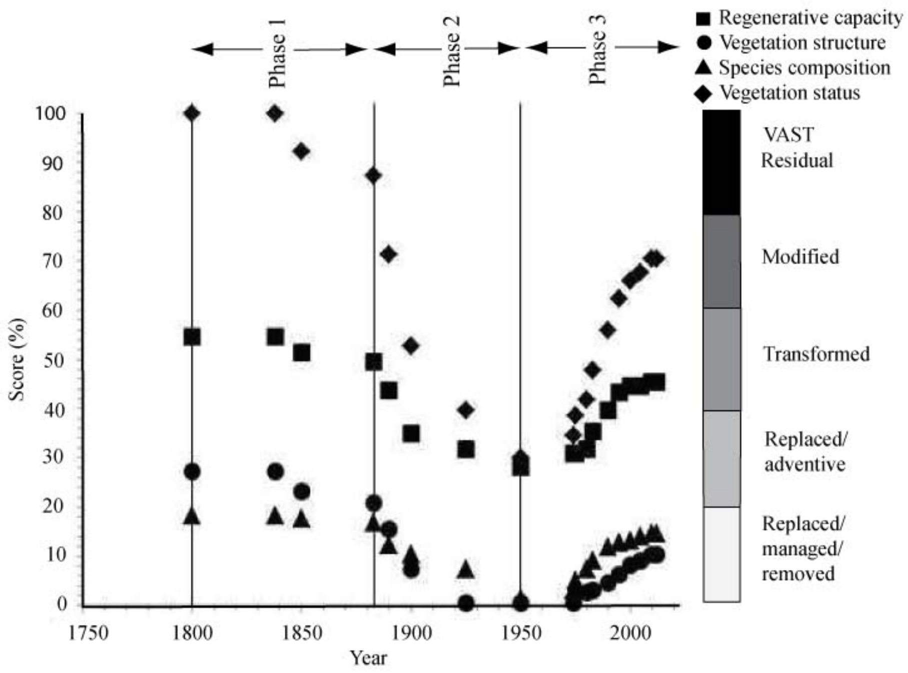

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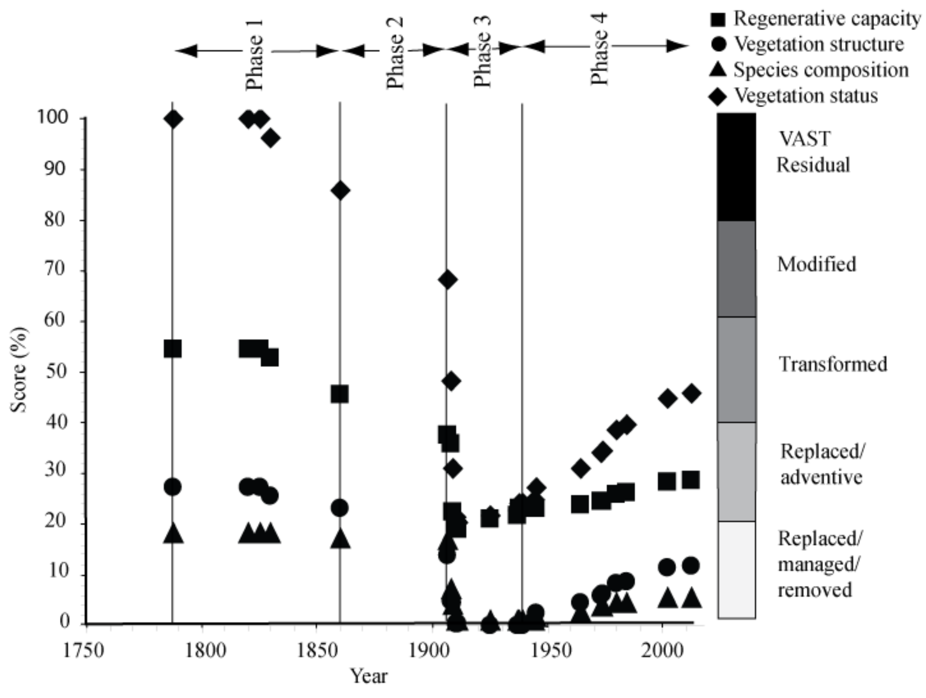

Figure 2. Weighted scores for the three components of vegetation condition (regenerative capacity, vegetation structure and species composition) and total vegetation status scores for sites 1 to 4. VAST class I– residual /unmodified = 80–100% of the reference state, VAST class II– modified = 60–80%, VAST class III– transformed = 40–60%, VAST class IV– replaced and adventive = 20–40%, VAST class V–VI – replaced and managed = 1–20% and VAST class VI– replaced and removed = 0%.

Site 1. Phases in the transformation of *Callitris–Eucalyptus* mallee low woodland at the Wirilda site, Kanmantoo bioregion, Harogate, South Australia. (Thackway, in press; c)

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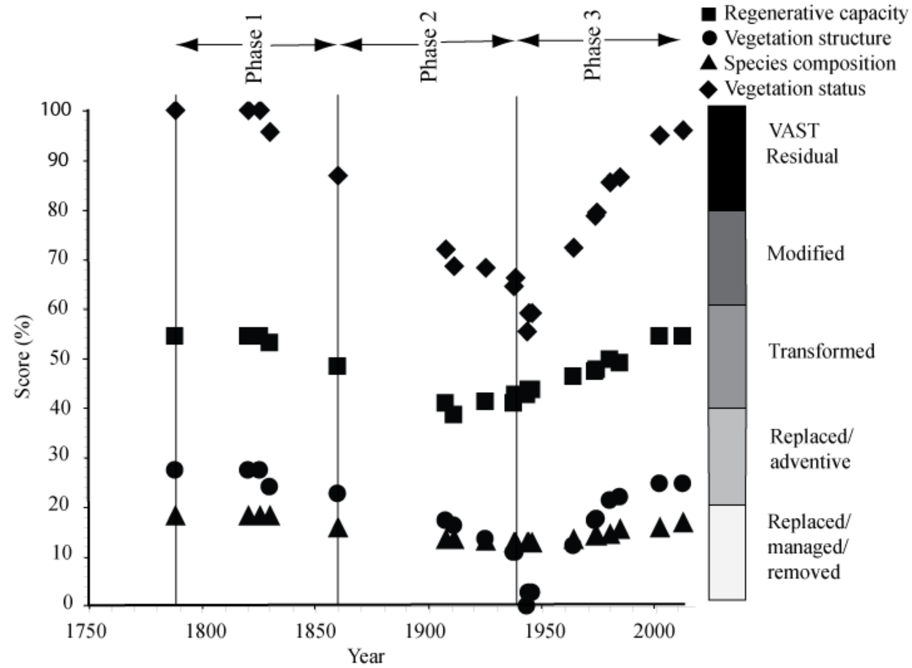

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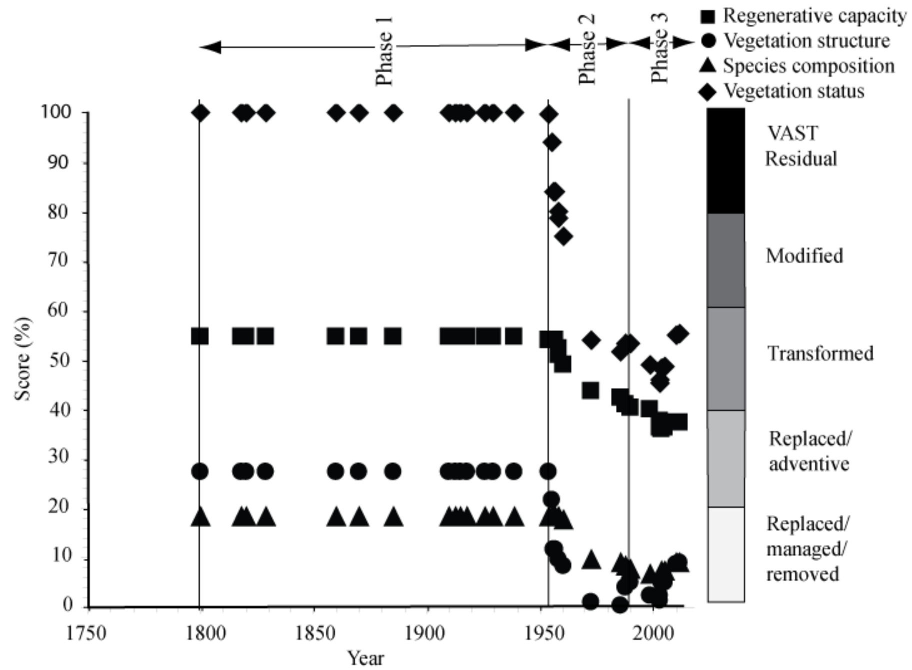

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Site 2. Phases in the transformation of *E. saligna* open forest at the Cumberland State Forest site, Sydney Basin bioregion, Pennant Hills, New South Wales. (Thackway, in press; a)

Site 3. Phases in the transformation of *E. saligna* open forest at the Cumberland State Forest site, Sydney Basin bioregion, Pennant Hills, New South Wales. (Thackway, in press; b)

Site 4. Phases in the transformation of *Eucalyptus fastigata* open forest at the Blundells Flat site, South Eastern Highlands bioregion, Cotter River Catchment, Australian Capital Territory. (Thackway 2012c)

This period included clearing of the open forest, conversion to pasture and management of the pasture for grazing; ploughing and sowing of pasture grasses.

Use and management resulted in moderate to very rapid decreases in the component scores for regenerative capacity, vegetation structure and species composition.

Phase 3: between 1910 and 1944 the vegetation status of the site remained in the replaced /adventive state (VAST IV).

This period included repeated ploughing of the soil and sowing improved pasture for grazing; the establishment of orchards; ceasing of grazing; purchase of the area as a state forest; establishment and management of an arboretum proposed as a future production urban forest; and weed control.

Use and management resulted in a slow increase in the component scores for vegetation structure and species composition. A very slow increase in the component scores for regenerative capacity was well below reference state.

Phase 4: between 1944 and 2012 the vegetation status of the site was transformed from replaced/adventive (VAST IV) to transformed (i.e. VAST III).

This period included managing the arboretum for future urban forest production; de-comissioning the arboretum as an area to be used for production forestry; recommissioning the arboretum as an area to be used for recreation; ongoing weed control; and excluding all fire.

Use and management resulted in a slow increase in the component scores for vegetation structure and species composition. Very gradual increase in the component scores for regenerative capacity was observed, but at present this is well below the reference state.

Transformation of E. saligna *open forest (site 3)*

This Cumberland State Forest site, Pennant Hills, New South Wales shows three broad transformation phases (Fig 2c):

Phase 1: between 1820 and 1860 the vegetation status of the site remained in the unmodified class (i.e. 80–100% VAST I).

This period included displacement of indigenous people; traverses by explorers; early establishment of pastoralism; selective removal of trees for building materials, fence posts and firewood.

Use and management resulted in a minimal decrease in the component scores for regenerative capacity, vegetation structure and species composition.

Phase 2: between 1860 and 1937 the vegetation status of the site was transformed from the unmodified class (i.e. VAST I), through modified (i.e. VAST II) to transformed (i.e. VAST III).

This period included removing trees for building materials, fence posts and fire wood; fencing the area for grazing native pasture; commencing and continuing to graze cattle and horses; ceasing to remove trees and ceasing to graze the area.

Use and management resulted in a gradual decrease in the component scores for regenerative capacity, vegetation structure and species composition.

Phase 3: between 1937 and 2010 the vegetation status of the site was transformed from transformed VAST III), modified (i.e. VAST II) to unmodified class (i.e. VAST I).

This period included declaring the area as a state forest; clear-felling the area; encouraging the native forest to regrow naturally; managing the area as a future urban production forest; ceasing to manage the area as a future urban production forest; managing the area primarily for day-use nature-based recreation; ongoing weed control; initiating the first hazard-reduction burning.

Use and management resulted in a moderately rapid increase in the component scores for vegetation structure. A gradual increase in the component scores for species composition and regenerative capacity was also observed.

Transformation of E. fastigata *open forest (site 4)*

Blundells Flat site, Cotter River Catchment, Australian Capital Territory shows three broad transformation phases (Fig 2d):

Phase 1: between 1818 and 1958 the vegetation status of the site remained in the unmodified class (i.e. VAST I)

This period included displacement of indigenous people; traverses by explorers; declaration of the area as a water catchment area for Canberra; selective logging of mainly brown barrel.

Use and management resulted in a minimal change in the component scores for regenerative capacity, vegetation structure and species composition.

Phase 2: between 1958 and 2003 the vegetation status of the site was transformed from unmodified class (i.e. VAST I), through modified (i.e. VAST II) to transformed (i.e. 40–60% VAST III).

This period included clear-felling remaining forest with chain saws and pushing timber into windrows with a bulldozer; burning the felled timber one year later in summer; hand planting the first and second rotation *Pinus radiata* seedlings; manually applying NPK fertiliser around every seedling; manually controlling competing regrowth native vegetation with axes, slashers, brush hooks, and hoes; thinning and pruning the pines; leaving thinnings on the ground to decay; manually cutting the pine trees and snigging the logs off using a crawler tractor; not ripping because the site was too steep; and using roundup chemical spray to kill regrowth native vegetation.

Use and management resulted in a very rapid decrease in the component scores for vegetation structure and species composition. A gradual decrease in the component scores for regenerative capacity was observed.

Phase 3: between 2003 and 2010 the vegetation status of the site remained in a stable state, that is transformed (i.e. VAST III).

This period included the area being burnt by severe wildfire killing all second-rotation pines; major soil erosion; cutting and windrowing pines using harvesters; sterile rye corn grass seed was sown across the coupe using light aircraft to stabilise erodible soils; contractors removing pine wildlings by hand; managing the area as a minimal-use water catchment; and leaving the area to naturally rehabilitate.

Use and management resulted in a rapid increase in the component scores for vegetation structure and species composition. However, minimal change in the component scores for regenerative capacity was observed. All scores for the three components are well below their reference states.

Discussion and conclusions

The results confirm that the VAST-2 system can be used by decision-makers to answer the three questions posed at the start of the paper.

Interpreting change and effect

Ideally, monitoring involves the regular collection of information over a number of years using the same methods of observation and measurement, but this has not happened in most places (Thackway 2012a). The above application of the VAST-2 system in forested ecosystems overcomes that deficiency because it can use any relevant information available to produce standardised, repeatable and verifiable outputs. Significant potential exists to further explore relationships between the site-based VAST-2 temporal findings and mapped and modelled spatial VAST datasets (e.g. Lesslie *et al.* 2010; Mutenteudezi and Thackway 2010).

Resilience of forest ecosystems

Where land management practices have affected the physical character of a site then the site may or may not be able to recover. For example, if excessive fire frequency has allowed the soil to be removed down to bedrock then recovery would be possible only in geological timescales. If soil fertility levels have changed, e.g. decreased by constant cropping following conversion of forest cover or increased by fertilisation, then it may be several decades before fertility levels return to pre-intervention levels (Trudgill 1977).

Where land management practices have affected the regenerative capacity of the site—that is fire regime, soil health, reproductive potential of the overstorey and/or understorey—the resilience of the site is strongly affected. Such a site will recover more slowly from disturbance than will an unaffected site. In contrast, where land management practices have affected vegetation structure and/or species composition, then the effect on the rate of recovery is relatively less. VAST-2 provides a mechanism to track these three components of forest change, that is regenerative capacity, vegetation structure and species composition.

Resilience Alliance (2010: p. 51) defines resilience as 'The capacity of a system to absorb disturbances and reorganise while undergoing change so as to retain essentially the same function, structure, identity, and feedbacks'. VAST-2 provides a gradient of measured, observed or inferred levels of resilience of a site.

Davidson *et al*. (2011) define 'resilient lands' as areas of native vegetation that conform to the definition of VAST Classes I, II or III. Areas with moderate to high resilience are amenable to prescribed natural regeneration (Clewell and McDonald 2009). Prescribed natural regeneration is intentionally-allowed natural regeneration, planned and managed for ecosystem restoration. This approach requires knowledge of resilience processes, and control of land management activities to encourage restoration. In areas where natural resilience has been significantly altered or removed, the capacity of the site to naturally stimulate the initiation of latent ecological regeneration processes is also removed; such sites conform to the definition of VAST Classes IV, V or VI. These areas are classified as 'non- resilient lands' and require 'reconstruction' (Davidson *et al*. 2010).

McDonald (2000) and Tongway and Ludwig (2011) note that stimulating or re-establishing native vegetation on these 'non-resilient lands' requires 'assisted regeneration', that is management interventions (such as targeted weed control, log installation, and/or introduction of plant propagules by, say, direct seeding) to stimulate the initiation of latent natural processes.

Resilience Alliance (2010) note that all sites exhibit dynamic responses reflecting the interaction between natural and anthropogenic processes, hence each resilience assessment is time bound. From the information in this paper the above four sites can be ordered from highest to lowest based on the current resilience; Figure 2 shows that site 3 has the highest resilience, through site 1, site 4, to site 2 with the lowest resilience.

The above results help us understand history of disturbance, the response of indicators and the current trend of site development. Such information is of key interest to a wide range of stakeholders. For example, people compiling 'State of the Forest' and the 'State of the Environment' reports could use it to monitor recovery in forest height, cover and/or age class following disturbance by prescribed fire, wildfire or timber harvesting.

Benefits for forest managers

The above results describe transformation pathways for forest sites that have been subject to a diverse array of management practices. This information is directly relevant to land managers, specifically those involved in replacement, removal or recovery of native vegetation, such as foresters.

Decision-makers can gain a deeper understanding of the main factors influencing a site through a closer examination of the three components of condition, 10 attribute groups and 22 indicators provided in the VAST 2 system. This information, along with an understanding of rainfall patterns (long-term average rainfall records are available from the Bureau of Meteorology) can be used by decision-makers to consider what land management options might be available to deliberately change a plant community to a desired condition class.

Application of the system to the four forest sites in this paper demonstrates its value to:

- integrate information coming from an extensive network of land managers, research scientists, and the wider community regarding land management and the responses of selected plant communities at sites over time
- provide a consistent national approach for reporting on changes in condition of native plant communities over time
- consistently describe and collate temporal patterns and processes associated with the use and management of Australia's vegetated landscapes, with regard to specific geolocations
- collate, review and revise a national repository of historical records of changes in land management and their effects on the condition of plant communities and to assess the suitability of this information to inform research priorities.

Close analysis of the VAST-2 data highlights the critical importance of tracking the interactions between historic rainfall and land management to the responses of each plant community as seen in the indicators and the components of vegetation condition (Fig. 1). Understanding these interactions is critical to developing an ecological understanding of a site as well as change and trend.

The VAST-2 system offers very useful insights into the effects of historic use and management on the condition of a site over time. The visual presentation of the results allows decision-makers to quickly understand and assimilate complex ecological processes and their effects on degradation, restoration and regeneration.

The system provides a tool for identifying what component needs to be manipulated to improve vegetation condition, demonstrating progress toward the desired vegetation condition, and selecting sites which represent least-cost options for future land use changes. It also highlights the importance of an accounting system that can be used to track the sustainable use and management of native vegetation across all land use types and has relevance for managing biodiversity.

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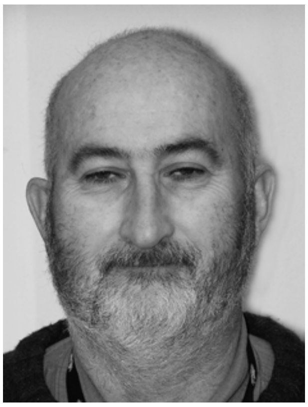

Phil Pritchard

Managing native vegetation on farmland for multiple benefits: results of a national survey

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Abstract

Seventy per cent of Australia's forests occur on privately managed land, including farmland. Farmers play an important role in managing native forests and woodlands, and other native vegetation. Most farmers surveyed recently were managing native vegetation for both environmental and agricultural production outcomes. However, it can be a challenge for farmers to work within existing regulations and programs. Markets for ecosystem services may provide new ways to improve environmental outcomes, although traditional government assistance such as research and development, and extension, will continue to be important given the complexity of managing for multiple outcomes. This paper outlines the findings of an ABARES survey of the role of government policy in supporting management of native vegetation on farmland and implications for how native forests and other vegetation on farmland are used, managed and conserved.

1. Introduction

Around 70 per cent of Australia's forests are on privately managed land (ABARES 2012). Much of these forests occur on land used for agriculture and are best described as woodland (ABARES 2012). The most common use of extant woodlands is livestock grazing. The extent and condition of these forests, as well as the location and enterprise focus of the farm, means that most farms are unlikely to produce significant commercial timber.

Native vegetation includes naturally occurring forests, woodlands, isolated trees and grasslands and refers to the trees, grasses and shrubs indigenous to an area, but not plantations of native trees grown for harvest. Encouraging managing native vegetation by farmers and other land managers has been an increasing focus of government policy and regulation activity. A recent report by the Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES) (Harris-Adams *et al.* 2012) examines the way native vegetation is managed on land used for agriculture, including cropping, grazing and dairying. The report particularly focuses on the role of regulation and government programs. It is based on a national phone survey of 985 farmers that examined farmer attitudes to, and involvement in, native vegetation management, and is supported by case studies. While some farmers are managing native vegetation primarily for timber production, the survey did not examine this explicitly.

The report finds that most farmers are managing native vegetation for both environmental and agricultural production benefits, and many intend to do more. This finding suggests that farmers are factoring native vegetation into their enterprise. It also suggests that there is greater scope for land managers to manage native vegetation for production and conservation, indicating that they may be receptive to managing for multiple purposes and are now more attuned to the potential benefits of managing native vegetation for the longer term. This includes managing for benefits such as carbon sequestration, salinity control and biodiversity conservation.

While there are distinctions between farmers and foresters, a common challenge is to deliver multiple benefits from native vegetation while working within a complex and often prescriptive operating environment.

2. Management of native vegetation

2.1 Native vegetation extent

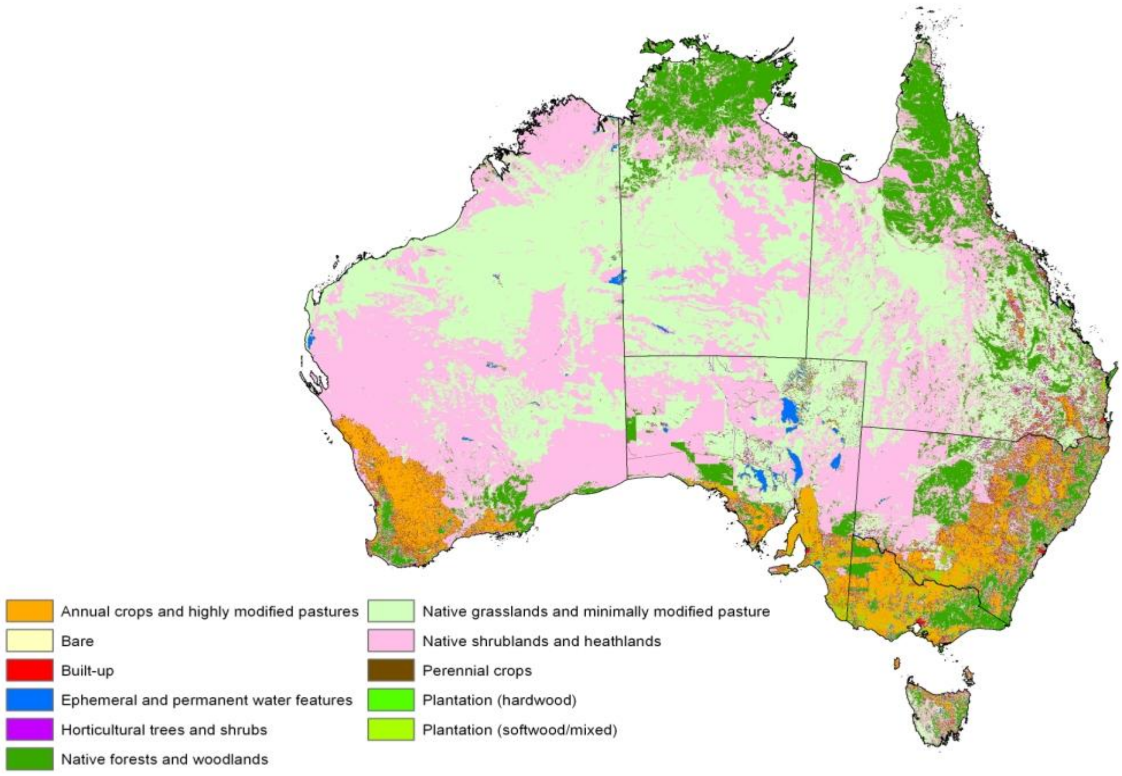
Since European settlement, Australian landscapes have changed significantly through the clearing of native vegetation and expansion of agricultural and urban areas. This was supported by various government policies. However, since the 1990s the states and territories have introduced legislation to restrict broadscale clearing of native vegetation and protect, maintain and/or increase the environmental benefits associated with native vegetation.

In the intensive agricultural zone, vegetation exists as a mosaic of native and non-native (such as crops and plantations) vegetation on land used for a variety of purposes, including urban, agricultural, forestry and conservation. The pattern of vegetation is shown in Map 1. Across Australia, agricultural land carries native vegetation on over 224 million hectares (ABS 2011). Some 103 million hectares of native forest and woodland (excluding sparse woodland) occurs on privately managed land, including agricultural land (ABARES 2012). While open and closed native forest occur in the higher-rainfall areas along the coast, the inland is dominated by grassy woodlands commonly embedded within agricultural landscapes.

2.2 Managing for multiple uses

As so much of Australia's native vegetation occurs on agricultural land, farmers' management of native vegetation is particularly important for landscape health, biodiversity provision, soil and water quality, carbon sequestration and a range of other goods and services, including food and fibre. Managing for multiple uses can include management for environmental, production and conservation benefits and can give rise to substantial public benefits.

Native vegetation has an important ecological function in the landscape. The management of native vegetation, in terms of both extent and condition, can complement the management of other natural resources for such things as soil stabilisation, salinity control and water quality. Management practices used to achieve beneficial outcomes will vary according to local conditions and can include replanting of trees, shrubs and grasses; and fencing to control stock access and encourage native regrowth.



Map 1. Vegetation extent, 2009 (Data source: ABARES)

Management of native vegetation can also have production benefits including wind and shade shelter for stock, crops and pasture; soil stabilisation and erosion control; management of salinity risk; fodder reserves for drought; harbour for beneficial organisms; supply of timber and farm wood; and aesthetic and amenity values (Tisdell 1985; Walpole 1999; Crosthwaite and Macleod 2000). Thus native vegetation management can be important for maintaining farm productivity (Crosthwaite *et al.* 2009), particularly for pastoral systems, though there can be costs involved for fencing and weed and pest control (Walpole 1999).

Farmers manage native vegetation to varying degrees through private action or participation in a stewardship program. Management may be for production or aesthetic benefits or as part of lifestyle and other values, including valuing conservation (Ecker *et al.* 2011; Hogan *et al.* 2011). Nationally, farmers have set aside around two per cent of total agricultural holdings for conservation and protection purposes, or nearly eight million hectares of land (ABS 2011).

2.3 Public policy environment

The private provision of environmental benefits through native vegetation is likely to be sub-optimal from society's viewpoint as a result of insufficient incentives to supply these benefits. Governments have a role in implementing measures that protect native vegetation or encourage its management where there is a net public benefit.

Community concern over the decline of native vegetation has grown, particularly over the past 15 years, and has driven demand for stronger legal protection of native vegetation. The states and territories have primary responsibility for these issues and all have introduced regulations to prevent clearing of native vegetation. The definition of native vegetation varies by jurisdiction, but generally includes remnant trees, grasses and shrubs and some native regrowth vegetation where it is of a certain age. Plantation forests grown for harvest are not included in the definition. Some clearing of native vegetation may be allowed through an exemption provision or a formal permit. Frequently, the legislation relating to native vegetation is complex and has terms that can be open to interpretation. It is also perceived to have insufficient flexibility to take into account regional and local issues (Senate Inquiry 2010).

In addition to legal limitation on clearing, governments at all levels have invested in a range of stewardship programs, extension support, and research and development to support and reward land managers and enhance the public benefits of native vegetation on agricultural land. Some programs offer funding tied to particular management actions, while others offer rate rebates, in-kind assistance or co-funding arrangements. However, the location and recurrence of programs change according to government priorities and funding availability. This can affect the engagement and participation of land managers and inhibit achievement of a program's objectives. Greater certainty for future program funding can support more effective program outcomes and help maintain land manager engagement (Binney *et al.* 2010). In addition, short timeframes are unlikely to match the long-term nature of native vegetation management.

Along with regulation and programs, government can also support private activities through research and development, extension, and indirect policy (such as taxation). There are a range of private-sector initiatives where non-government organisations work with land managers to protect and manage native vegetation. Farmers also take private action to enhance the extent and condition of native vegetation on their land and the environmental services it provides. Government policy supports this private action to varying degrees.

A challenge to developing government policy is how to give material support for actions additional to what farmers are already doing or likely to do, to avoid crowding out private action. This can be difficult because of information asymmetry problems where the land manager is better placed than government to judge the profitability of the activity and has little incentive to share this information. One approach is to use common practice assessment to test for additionality, as is legislated under the Australian Government's Carbon Farming Initiative. Common practice assessments measure adoption of particular activities or actions and compare this to a set threshold; activities or actions where adoption is found to be below this threshold are then considered to be additional (Woodhams *et al.* 2012). This threshold can be difficult to determine (Woodhams *et al.* 2012).

Another approach is to use market-based programs, although particular programs may not require additionality. Environmental incentive programs based on market-based instruments are increasingly popular in Australia, and are designed to avoid crowding out private action and to address information asymmetry problems between government and land managers. Under a market-based program, land managers submit a bid for funding based on undertaking particular land management actions over a specified area and time. The expected environmental benefits of these management actions are linked to the bid price, and the bids generating the highest estimated environmental benefits per dollar invested are funded until total funds are allocated or a particular price is reached. Governments are usually the only buyer or broker in these programs and the amount of price or quantity information available to participants is often limited. However, price and quantity information from previous or current market-based programs are useful for farmers to calculate an appropriate bid price. This information is also essential if a market for environmental services is to develop outside program parameters.

3. Survey method

In 2011 ABARES ran a national survey of farmers to collect information on the area of native vegetation on farmland, how and why it was being managed, and farmers' involvement in and perceptions of regulation and environmental stewardship programs. The survey was a structured telephone survey supplementary to the ABARES annual broadacre (Australian Agricultural and Grazing Industries) and dairy (Australian Dairy Industry) surveys. Respondents were selected on the basis of a stratified random sample of establishments with an estimated value of agricultural operations of $40 000 or more. The survey targeted 1017 farmers and there were 985 responses.

Results were calculated by weighting the data collected from each sample farm. Sample weights were calculated so that estimates of numbers of farms, areas of crops and numbers of livestock in various geographic regions and industries corresponded as closely as possible to the most recently available Australian Bureau of Statistics data, as collected in the agricultural censuses and updated annually with data collected in agricultural commodity surveys. For further information on survey design and weighting see ABARES (2011).

4. Results

4.1 Native vegetation extent

The extent of native vegetation varies across the landscape and is a function of current and historical land uses. The extent and distribution of native vegetation also varies within a farm. Native vegetation can occur on farmland used for grazing or cropping, as well as on parts of a farm not used directly for agricultural production (but which may be used for sheds, roads, dams and conservation).

Farms in Queensland and the Northern Territory had the highest median proportion of native vegetation on farmland overall and on farmland allocated to grazing (Table 1).This reflects the prevalence of pastoral production in these jurisdictions and use of native vegetation as an input to agricultural production.

On some farms, native vegetation exists in patches on land that is largely unused. On farms in South Australia, Western Australia and the Northern Territory, most of the farmland not directly used for agriculture had native vegetation.

Native vegetation, in the form of scattered paddock trees, also occurs on land allocated to cropping. While paddock trees can have an important ecological function, their location in the agricultural environment means they are declining as a result of natural attrition and lack of recruitment (Fischer *et al.* 2009; Manning *et al.* 2006). Cropping or mixed-enterprise (cropping–grazing) farms in Queensland and Victoria were least likely to have native vegetation on their cropping land. Thirty-nine per cent of cropping or mixed-enterprise farms in Queensland and 47 per cent in Victoria had native vegetation on their cropland.

Table 1. Native vegetation on farms

Jurisdiction	Native vegetation on farm overall (median % of farm area)	Native vegetation on farm grazing land (median % of farm grazing land)	Native vegetation on farm unused land (median % of farm unused land)	Farms with native vegetation on cropping land (% of farms)
New South Wales	13	40	5	66
Victoria	6	7	20	47
Queensland	40	65	1	39
South Australia	10	20	70	77
Western Australia	10	5	80	74
Tasmania	9	5	1	57
Northern Territory	99	100	100	100
Australia	12	30	25	59

Note: Areas refer to the median percentage of native vegetation on a farm, on land used for grazing and on land that is unused for grazing or cropping on a surveyed farm. The final column refers to the proportion of cropping and mixed-enterprise farms reporting native vegetation, including paddock trees, on cropping land.

4.2 Native vegetation management goals

Eighty-five per cent of farmers were managing their native vegetation for production and/or environmental benefits on-farm (Table 2). Many farmers were also looking beyond their farm: 30 per cent took into account how their native vegetation management contributed to regional or landscape outcomes (such as contribution to a catchment plan). Nearly one-quarter were considering the connection between their native vegetation and the vegetation on neighbouring properties or Crown land. About 15 per cent were managing for both connectivity and landscape outcomes concurrently.

Table 2. Focus of farmers' native vegetation management

Objective	Fraction of farmers (%)
On-farm benefits	85
Connectivity	22
Regional/landscape outcomes	30

Note: Column adds to more than 100 per cent as farmers could choose more than one response.

4.3 Future management intentions

At a national level, more farmers were interested in improving the condition or increasing the extent of native vegetation than they were in clearing native vegetation (Table 3). Thirty-one per cent of farmers intended to improve the condition of their native vegetation while 20 per cent intended to increase its extent. Around 12 per cent intended to do both. This provides some indication of the types of program and extension support that interest farmers.

Table 3. Future management intentions for native vegetation

Management intention	Fraction of farmers (%)
Clear	10
Increase area	20
Improve condition	31
No change	56

Note: In order to encompass the different terminologies across jurisdictions, farmers were asked whether they intended to 'clear, develop or modify' their native vegetation, increase the area or improve the condition of their native vegetation to achieve environmental outcomes, or make no change. Column adds to more than 100 per cent as farmers could choose more than one response.

Slightly fewer than 10 per cent of farmers intended to clear native vegetation, including clearing of patches of native vegetation or scattered paddock trees. Of these, most intended clearing 10 per cent or less of their native vegetation. A small number were interested in clearing more than 90 per cent of on-farm native vegetation. While, nationally, interest in clearing was small relative to farmers' other intentions for native vegetation management, there were strong regional differences, often reflecting historical patterns (see Harris-Adams *et al.* 2012).

4.4 Management arrangements

Most native vegetation management was undertaken informally through private action, but about 13 per cent of farmers managed their native vegetation through formal agreements where they had a contract with a third party (such as government or a private organisation) (Table 4). Most farmers managing their native vegetation formally were managing 30 per cent or less of the native vegetation on their properties under these agreements. In contrast, most farmers managing their native vegetation informally managed more than 80 per cent of their native vegetation.

Table 4. Native vegetation management arrangements

Arrangement	Fraction of farmers (%)	Fraction of native vegetation managed (%)				
		≤5	6–15	16–30	31–80	>80
Formal agreement	13	25	13	14	40	8
Private action	54	3	5	10	19	64

Note**:** About 9 per cent of respondents were managing their native vegetation through both formal and informal arrangements concurrently.

While the timeframes for formal agreements varied, more than half (59 per cent) were for 10 years or less (Table 5). Nearly one-third were 'in perpetuity' or permanent agreements.

Table 5. Duration of formal agreements

Duration	Fraction of farmers (%)
Less than 10 years	59
11 to 20 years	4
More than 20 years	6
In perpetuity	31

4.5 Role of government programs and regulation

Over the period 2005 to 2011, 27 per cent of farmers had applied for funding from a government program to help manage native vegetation for environmental benefits (Table 6). Most of these (86 per cent) were successful. For those that did not apply for funding, more than one-third considered the transaction costs of participation to be too great; either the process was too complex (22 per cent) or too time-consuming (13 per cent). Twenty-three per cent were not aware there were any programs available, and, indeed, there may not have been any appropriate programs available to some farmers. For the 39 per cent of farmers that gave ‘other’ reasons, these reasons included farmers not wanting government involvement in their management activities, and farmers assuming they would not qualify for funding.

Slightly more than half of farmers considered government programs for native vegetation to be fully or partly effective, though only 14 per cent thought them fully effective (Table 7).

Table 6. Applications for government funding

Funding history and details	Fraction of farmers (%)
Applied for funding	27
For those who applied for funding:	
Started application process but did not complete it	3
Applied for funding but did not receive funding	12
Applied for and received funding	86
Did not apply for funding	73
Reasons for not applying:	
Not aware of programs	23
Application process too complex	22
Application process too time-consuming	13
Other	39

Note**:** Farmers were asked whether, since 1 January 2005, they had applied to a government program that provided funding to help manage native vegetation to deliver environmental outcomes. Figures may not add to 100 per cent because of rounding.

Table 7. Attitudes to government programs and regulations

Entity and attitude	Fraction of farmers (%)
Government programs	
Fully effective	14
Partly effective	38
Ineffective	29
Do not know	19
Government regulations	
Lack flexibility and/or are unclear	42
Are acceptable	21
Could be more stringent	2
Need more information to comment	34
Other	5

Note**:** Farmers were asked specifically about their views of the effectiveness of government programs to protect native vegetation. Native vegetation regulation refers to the local, state and federal legislation and regulations controlling use of native vegetation on farmland, such as vegetation or planning acts. Lower column adds to more than 100 per cent as respondents could select more than one response.

Twenty-nine per cent thought the programs were ineffective. Farmers were also asked their views of native vegetation regulation, as it applied to their farm. Many thought the regulations lacked flexibility and/or clarity. Twenty-one per cent considered the regulations to be acceptable and only 2 per cent thought the regulations could be more stringent. Just over one-third needed more information to comment, suggesting farmer awareness of native vegetation regulations and the outcomes governments seek to achieve may be limited.

4.6 Future business intentions

Farmers manage their native vegetation alongside or in conjunction with their production systems, so farm business decisions can be significant constraints to or drivers for native vegetation management. Nearly one-third of farmers intended to increase production and another 20 per cent intended to improve profitability or reduce input costs (Table 8). Twenty-nine per cent did not intend to change their production. A very small proportion of farmers intended to change enterprise and no farmers intended to change industry, suggesting options for farmers to respond to changes in policy may be limited.

Table 8. Future business intentions

Intention	Fraction of farmers across all enterprises (%)	Fraction of farmers in individual enterprises (%)					
		Cropping	Mixed cropping–livestock	Sheep	Beef	Sheep–beef	Dairy
No change	29	20	40	17	35	36	27
Increase production	31	40	27	38	22	37	34
Decrease production	1	2	0	2	2	<1	<1
Reduce inputs/ increase profitability	20	17	20	27	19	12	19
Cease farming	11	9	5	7	20	0	13
Change enterprise	2	0	2	1	2	15	4
Change industries	0	0	0	0	0	0	0
Unsure	5	13	6	9	<1	0	2

Note**:** Columns may add to more than 100 per cent as respondents could select more than one response.

5. Discussion

Farmers work within a framework of multiple regulations and programs. The ease of understanding and working within this framework affects farmer engagement and what environmental outcomes can actually be achieved by government policy. Twenty-nine per cent of farmers thought native vegetation programs were ineffective, and 42 per cent thought native vegetation regulations lacked flexibility or were unclear. Farmers are uncertain about what government policy aims to achieve and how the regulation and programs interact. Farmers need greater certainty in order to participate in these processes and to have the time to plan any changes on their farms.

Farmers' intentions for the farm business also need to be considered alongside policy, particularly given that only a very small proportion of farmers intended to change enterprise and no farmers intended to change industry. This suggests policy needs to work within the existing enterprise structures.

6. Conclusion

Farmers already manage a substantial proportion of Australia's native woodlands, forests and other native vegetation to deliver environmental and agricultural production benefits. Greater benefits could be delivered if farmers are given sufficient information, support and, in some cases, other incentives.

Governments have taken a range of approaches to address society's opinions about how private native vegetation should be used and its role in achieving nature conservation objectives. The challenge is providing an operating environment that is flexible, transparent and conducive to achieving stated goals. This suggests a more nuanced approach to public policy development through:

1. support of private action
2. smart regulation
3. increased use of market-based instruments
4. better targeting of incentives to capture public goods.

More than half the farmers surveyed had taken private action to manage their native vegetation, without participating in a formal program. This suggests native vegetation has value to them, such as production, environmental or personal value. It is important to recognise and support these management actions where there is a net public good. Extension support, from public or private organisations, can be particularly important to developing skills and understanding the effects of certain management practices on the environment and on production.

Smart regulation needs to be flexible to allow for individual circumstances and to work in combination with programs and market-based instruments. At the same time it needs to be transparent so that land managers can be clear on what the requirements and options are for native vegetation management. Greater transparency of program design and outcomes could also assist land managers, particularly in market-based programs.

Native vegetation management requires a range of flexible policy approaches as well as recognition of the wider benefits of native vegetation. As part of the package of approaches, market-based instruments and markets for environmental services will play an increasingly important role alongside government programs, regulation and private action in supporting delivery of more environmental services from agricultural land.

Given the range of policy instruments available to government to steer native vegetation management, it is necessary to understand how these instruments engage land managers to deliver good outcomes. The choice of instruments will have important implications for how woodlands and forests and other vegetation on farmland are used, managed and conserved. It is also important to ensure these instruments function at a scale relevant to protect and improve native vegetation while delivering better environmental and, potentially, better production outcomes.

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Hardwood plantation forestry in the cyclone zone: post-Yasi assessment of long-term growth plots

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Abstract

The coastal region of northern Queensland experiences a climate conducive to rapid tree growth, but is also prone to the destructive forces of tropical cyclones (TCs). DAFF assessed growth plots and trials to examine differences in cyclone resilience after the impact of severe TC 'Yasi' in 2011. The results were incorporated into a *Best Practice Guide for Timber Plantations in Cyclonic Areas*, produced by Timber Queensland. This paper expands on key points from the guide, using additional data. Damage was most strongly correlated with wind speed, tree age and species. Damage varied dramatically over short distances. The largest trees were the most prone to damage within each stand. Silver quandong (*Elaeocarpus angustifolius)* fared best of the species assessed, although the resilience of all species was affected by the suitability of the site and the mixture of species. Most coastal lowland woodlots were destroyed or severely degraded, but losses were considerably less inland.

Introduction

The coast and ranges of north-eastern Queensland receive very high rainfall and warm temperatures for much of the year. The natural vegetation of the area included rainforest and tall wet sclerophyll forest, which supported a timber harvesting industry for almost a century until logging was prohibited in 1988 when crown lands were listed for World Heritage (Vise *et al.* 2005). Several afforestation schemes were initiated in the 1990s, the largest of which was the Community Rainforest Reforestation Program (CRRP), which had a stated goal of establishing a plantation resource of native hardwoods for the local timber industry. Around 1780 ha of predominantly small-scale, mixed-species stands were planted between Cooktown and Sarina under the CRRP before it concluded in 1998 (Vise *et al.* 2005). Since 2000 most forestry plantings have been monocultures of the species that performed best in the CRRP, namely *Eucalyptus pellita* (red mahogany) in the wet tropics, and *Khaya senegalensis* (African mahogany) in the dry tropics. A third species, *Tectona grandis* (teak), was not planted widely in the CRRP, but was planted by MIS companies using clonal germplasm from south-east Asia. A eucalypt hybrid (*E. grandis* × *E. camaldulensis*) that had been grown in coastal central Queensland was also planted in some parts of the Mackay region, but planting ceased when the trees succumbed to drought and disease. The total area of hardwood plantation in tropical Queensland was estimated to be around 11 000 ha at the end of 2010.

Tropical cyclones (also called typhoons or hurricanes) are rotating low-pressure systems on a synoptic scale, which form in tropical waters in many parts of the world (BOM 2012). They typically reach maximum intensity over water, but then degenerate after crossing land, or over the ocean if they encounter less favourable water conditions. Tropical cyclones are remarkable for the contrast in wind speed between the calm central 'eye' region, and the very intense wind of the 'eye wall' or destructive core, which can approach the maximum wind speed recorded anywhere in the world. In Australia tropical cyclones are classified according to the intensity of the strongest sustained wind speed, on a scale from 1 (weakest) to 5 (strongest) (BOM 2012). In the 20 years between 1992 and 2011, ten tropical cyclones crossed the coast between Cooktown and Townsville. In 2006 TC Larry (Category 3) caused destructive winds between Cairns and Tully, including parts of the Atherton Tablelands. Five years later TC Yasi (Category 4) caused catastrophic damage between Tully and Ingham, with less severe damage extending for several hundred kilometres north, south and west.

The area of greatest damage from TC Yasi was also the focus of forestry investment in North Queensland. Most pine, eucalypt and teak plantations were located in this area, and most of the stands were destroyed. In the wake of TC Yasi the Queensland Government provided disaster relief funding to industry groups to assist in economic recovery. Timber Queensland received funding to produce a *Best Practice Guide for Forestry Plantations in Cyclonic Areas* (Timber Queensland (TQ) 2012). Part of the funding was made available to the Queensland Department of Agriculture, Fisheries and Forestry (DAFF) Forestry Research to produce a Technical Report (Lindsay and Dickinson 2012) to inform the guide. This paper outlines the key aspects of the DAFF Technical Report, supplemented by further assessments conducted after the TQ Guide was published.

Methods

Plot location

The core of the study involved 87 growth plots established in the CRRP estate in 1998, and remeasured until 2002 (DAFF experiment 799ATH). The areas had been planted between 1993 and 1995, between Mossman (16°30′S 145°23′E) and Bambaroo (18°51′S 146°7′E). The plots represented the variety of the site types planted, but no attempt was made to weight the distribution of plots in proportion to the planted area (Bristow *et al.* 2005). Most plots were six rows wide by ten trees long. Stand density varied between 667 and 1100 stems per hectare. Most plots were polycultures, often comprising alternate rows of a ‘pioneer’ type species and rainforest species. The variety of species planted in the polycultures was very large. The CRRP data were supplemented by observations of seven growth plots in small-scale African mahogany woodlots planted between 2000 and 2007, and 18 experimental trials examining mixed-species and monoculture stands established by DAFF between 1991 and 2010 (Lindsay and Dickinson 2012).

Assessment criteria

Cyclone damage was assessed using three criteria: stem breakage, lean and crown damage. The height above ground of stem breakage was estimated visually. Stems were deemed to be ‘degraded’ if a break was visible above 6.0 m, and ‘destroyed’ if the break was below 6.0 m. Assessment of lean was made visually and somewhat subjectively, since some stems may have had a pre-existing lean related to light competition. The criteria for ‘degraded’ was 10% (about 6°) to 20% (about11°) off vertical, beyond which stems were ‘destroyed’. Crown damage was the most difficult damage type to assess, because there was no pre-cyclone data for comparison. The criteria for ‘degraded’ stems was those that had lost major branches, and were reshooting from the stem; the criteria for ‘destroyed’ stems aligned with the stem breakage criteria, so was not used based on crown damage.

Wind speed estimates

Wind speed estimates for TC Yasi were determined by the Cyclone Testing Station of James Cook University, as part of the Timber Queensland project, using on-ground assessments after the cyclone, and interpolation through modelling. For TC Larry, contemporary media articles and local knowledge were combined with details from the Bureau of Meteorology (BOM). The BOM details were generally the only available source for other cyclones, and inferences were drawn about likely wind speeds at each location.

Analysis

Data were analysed on a species and stand basis. For each species the individual-tree results were combined, and stratified according to modelled wind speed (cyclone category). Stand resilience was determined by the percentage of trees with minor or no evidence of cyclone damage. In many instances the plot could not be located precisely. In these cases a stand resilience assessment was made visually, aided by photographs and ‘proxy plots’ established in the approximate location of the original plot. Four categories of stand resilience were determined:

1. High resilience—minimal wind damage affecting less than 10% of trees
2. Moderate resilience—modest wind damage affecting 11–25% of trees
3. Low resilience—major wind damage affecting 26–50% of trees
4. Very low resilience—severe destruction affecting more than 51% of trees

Results and discussion

General patterns

Stand resilience was strongly related to maximum wind speed since 2002 (either TC Yasi or TC Larry). The destructive force of wind increases exponentially with speed (Timber Queensland 2012) (the power is proportional to the third power of the wind velocity), and most plots located in the area subjected to Category-3 strength winds were totally destroyed. The greatest variations in stand resilience were observed in areas that experienced Category-2 strength winds (gusts of 125–164 km per hour), and these areas became the focus of DAFF investigations. Plots that experienced Category 1 strength winds in TC Yasi had minor damage; perhaps this was unsurprising, as the trees would have probably experienced similar (or stronger) winds in the past.

Peak wind speeds decreased rapidly with distance from the coast, so most inland stands received only Category-2 or -1 strength winds during TC Yasi and TC Larry. The proportion of plots that suffered minimal or modest damage (high or medium resilience) was much higher for plots located 50–100 km inland (72%) compared with coastal plots (28%), as shown in Table 1. It should be noted that TC Yasi continued to generate cyclonic winds for around 1000 km inland. These far-inland areas had not experienced gales for many decades, and large tracts of woodland suffered major damage.

It was notable, however, that some stands modelled to have had Category-3 strength winds suffered only modest damage. It is thought likely that these stands were sheltered from the strongest winds by local topography or good fortune, since cyclones are notoriously capricious, and peak wind speeds vary greatly over short distances (Timber Queensland 2012). No differences were apparent in relation to aspect, slope position or soil type.

Table 1. Stand resilience by location (shires* arranged north to south within region)

Region and shire	Resilience class (fraction of plots in class, %)				No. of plots
	High	Medium	Low	Very low	
Coastal					
Douglas	100				1
Mulgrave		25	25	50	4
Johnstone			25	75	12
Cardwell			67	33	6
Hinchinbrook	6	53	24	18	17
Inland					
Mareeba	67	25	8		12
Atherton	40	20	40		10
Eacham	19	44	38		16
Herberton	44	33	22		9
Average coastal	3	25	33	40	40
Average inland	40	32	28	0	47

* Shire boundaries changed in 2008. The names shown were those in use in 1998.

Tree age was also strongly related to cyclone resilience. Trees younger than five years were typically more affected by lower-strength winds than were older trees. A notable exception was the exotic species *Tectona grandis* (teak). Trees that were damaged at a young age had short bole lengths, and the tree was prone to degrade and further damage during subsequent events.

Stands that had been recently thinned were subject to much greater damage than stands that had not been thinned. To some extent there was a trend that well-managed stands (as recorded in field notes in 2002) suffered less damage than poorly-managed stands; but again, the capriciousness of the cyclone meant that many well-managed stands were destroyed.

Sources of variation

Within a given stand, the greatest damage occurred near the edges, or where there was significant variation in tree height between adjacent trees. The largest trees in the stand were more likely to be damaged than trees of average height, presumably because they had the greatest surface area and offered the greatest wind resistance. Thus the effect of the cyclone was to reduce the mean tree size, as well as per-hectare stocking and basal area. Amongst the plots inspected, there was less damage amongst monocultures than polycultures. In some stands large trees had broken off or blown over, causing substantial damage to surrounding trees as they fell. There appeared to be less damage in stands that had been planted at wider spacings, but this was difficult to analyse given the variation in species composition and growth between sites.

There were clear differences in cyclone resilience between species within polyculture stands. Stand composition varied too greatly to allow statistical analysis, but in general species had differing resilience depending on whether they were at or below general canopy level. For a given species there were often marked differences between plots, related to (a) differences in site type; or (b) the other species in the stand. Site–species matching is very important: the resilience of a species on a suitable site was far superior to that of the same species on an unsuitable site.

Several species were regarded as ‘above average’ for cyclone resilience, notably *Elaeocarpus angustifolius* (85% of mature trees not severely damaged by Category-2 strength winds), *Flindersia brayleana* (73%), *Eucalyptus cloeziana* (72%), *E. grandis* (61%) and *E. pellita* (58%). Numerous qualifying statements apply to this list, and growers should not rely on the results of this study alone when making investment decisions. The two rainforest species, *E. angustifolius* (silver quandong) and *F. brayleana* (Queensland maple) tended to withstand the effects of the cyclone initially, but a proportion of trees died in the year following the cyclone. *Eucalyptus cloeziana* (Gympie messmate) and *E. grandis* (rose gum) tended to be planted on inland sites, and may not have experienced winds of the same intensity as species in coastal plantings. *Eucalyptus pellita* (red mahogany) was considered to be ‘above average’ in mixed species stands aged older than ten years; but young *E. pellita* are considered to have ‘very poor’ cyclone resilience, as evidenced by the thousands of hectares of commercial plantation aged less than five years that were destroyed by TC Yasi. The older *E. pellita* stands tended to be small-scale woodlots, often located near mature native forest, whereas the young *E. pellita* stands were broad-scale plantings in an otherwise cleared landscape; this difference may have affected the results also. Readers should refer to the DAFF report prepared for Timber Queensland (Lindsay and Dickinson 2012) for more details.

The young plantations of *Khaya senegalensis* were more resilient than expected (98%), but they were largely located outside the zone of the strongest winds; a large trial located in the Category-3 wind area had very low resilience, with 60% of stems destroyed. Most species were regarded as ‘average’, meaning that resilience was quite variable. Several species were regarded as consistently ‘below average’. These included two exotic species that were initially considered promising (*Cedrela odorata* and *Tectona grandis*). As noted earlier, young teak trees in the Tully area endured extremely strong winds with little sign of damage, but trees older than five years that had developed a full canopy were decimated. The species with the poorest resilience was the fast-growing native species *Acacia mangium*. These trees had large canopies and were predisposed to breaking or leaning; moreover, in doing so they caused damage to neighbouring stems and understorey trees. Readers are referred to Lindsay and Dickinson (2012) for a full listing of species and their characteristics.

There was some evidence of variation within a species, but the results were not definitive, and were generally correlated with tree size: the trees which grew better (taller) suffered more wind damage. Provenance trials of *E. pellita* and *K. senegalensis* were located in areas that received Category-3 strength winds, and most trees were destroyed, irrespective of provenance. Within the CRRP plots there were few records of which provenance had been planted on each site, but in general local northern Queensland provenances were used (Kitchener, pers. comm. 2012).

Sampling issues

The methods used to assess damage were similar to other studies of cyclone damage (for example Luo *et al.* 2006), but deliberately simplified for the purposes of rapid survey. It was clear, however, that the time elapsed since the cyclone provided an extra dimension of variation. Many species lost a substantial proportion of their crown during the cyclone, but grew new leaves the following summer. Others survived the cyclone with minimal apparent damage, but died in the following year.

The criteria chosen in this study dictated the outcome, but other approaches may have drawn alternative conclusions. For instance, many silver quandong trees had branches broken off near the top of the tree; in our study they were not scored as damaged, but other researchers could argue that the species was prone to damage (albeit minor). The existence of pre-cyclone damage assessments and measurement data permitted a more detailed analysis than post-hoc damage descriptions. However, it is likely that our study over-estimated the damage due to TC Yasi, as it is unknown how many stems died, for reasons unrelated to the cyclone, since the plots were last measured. For instance, most silver quandong trees in the CRRP plantings in the Herbert Valley died during a major drought in 2002–03. Some interpretation was therefore required to improve the estimate of cyclone resilience.

Management implications

A recurrent theme during the assessments was that many of the woodlots had not been managed silviculturally for over a decade, and stems that had been damaged in earlier cyclones were still standing. It seemed likely that the stems that had not suffered significant damage could have grown faster if the damaged stems were removed. The reasons for not removing the damaged stems were varied, but included (a) lack of knowledge on the part of the landowner (b) lack of skilled labour to perform the work; (c) the expense of the operation; and (d) the absence of any market for small logs removed in thinning.

The lack of market opportunities is a significant issue affecting any decisions to invest in forestry in this region. The total extant area of plantation forest managed for hardwood timber production as at January 2013 is probably less than 2000 ha, and it is likely that the overall mean annual increment (allowing for damaged stems, sub-optimal silviculture, poor site matching and non-harvestable areas) is probably less than 5 cubic metres per hectare per year. This volume, spread over a large geographic area, may be too low to justify investment in a processing plant, particularly for small wood, let alone damaged stems.

During this study we have reviewed previous publications about hardwood plantation forestry in north-eastern Queensland, and discovered that the risk posed by cyclones was rarely considered. Economic modelling of tree growing in this region did not seem to account for the risk of cyclone damage, or the cost of post-cyclone clean up (Harrison *et al*. 2005; Herbohn 2006). We suggest that future economic analysis give consideration to discounting yield related to reduction in merchantable stems per hectare and average log length, reduction in growth rate (due to reduced leaf area, root damage and disease), and removal of genetically superior individuals because of their greater height and thus susceptibility to damage. Cyclone-related costs include felling broken stems and hang-ups, re-establishing access tracks and managing increased fire danger from fallen branches. There may also be expenses related to controlling coppice regrowth and also weeds that, although unlikely to affect the growth of the trees, might spread to surrounding farmland, and increase the fire hazard in the plantation.

Consideration should also be given to the economic impact of total loss of plantation viability. Statistically, all parts of tropical Australia have the same likelihood of being impacted by a tropical cyclone. A wind risk matrix model is shown on page 11 of the TQ report. This shows that the likelihood of a Category-1 cyclone occurring in any one year at a nominated location is about 17%. From our survey we have observed that winds of Category-1 strength can cause major destruction to young stands, so the risk of major loss is quite high. Category-3 strength winds may cause major destruction to stands of any age; from the same table, the probability of a Category-3 impact at least once in 25 years is 14%.

Areas for further investigation

There is limited information available to growers and wood purchasers about the impact of strong winds on timber quality. Given the observation that some silver quandong and Queensland maple trees stood upright during the cyclone, but died in the following months, it would be useful to know whether key wood properties deteriorated as a result of the cyclone or not. It would also be useful to have some information about the rate of decay in stems that had fallen over or snapped off, and guidance for storage of stems that had been salvaged. Any information regarding interspecific variation in decay would also be useful for species selection and stand management; for instance it appeared that *Agathis robusta* stems damaged in TC Larry recovered better than *E. pellita* stems: the forest manager may therefore be inclined to retain damaged kauri pines but remove damaged *E. pellita* trees.

This project has highlighted the value of the long-term forestry research activities of the Queensland Government. It is hoped that the growth plots and trials will continue to be monitored, in order to maximise their value to future forest growers.

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Options for managing Australia's forests for greenhouse gas mitigation

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1. Background

Forests play an important role in the exchange of greenhouse gases (GHGs) between the terrestrial biosphere and the atmosphere both in Australia (e.g. Raison and Squire 2010; Page et al. 2012) and globally. Over time-scales of decades to centuries, significant amounts of carbon (C) derived from the atmosphere can be stored in above-ground biomass, roots, dead organic matter and soils. The processes controlling C accumulation are reasonably well understood, as are the patterns of GHG emissions associated with disturbances such as fire, harvesting, conversion to plantations, or deforestation (IPCC 2006). Creation of new forests (afforestation/reforestation) on agricultural land in Australia results in quite variable rates of increase in C storage, depending on species planted, management inputs and site growing conditions. These new forests may be established for a range of reasons: commercial wood production (including biomass for bioenergy), as 'environmental plantings' or as 'C forests'.

When examining the potential contributions of forests to GHG mitigation, it is important to examine both changes occurring on the land within the forest estate as well as the effects of the substitution of wood for fossil energy use or other C-intensive products.

McHenry (2012) has comprehensively reviewed the range of policy initiatives implemented over the last two decades aimed at achieving GHG mitigation from biosequestration and bioenergy from the Australian land sector. He concluded that these efforts have been largely ineffective, and argues that in future '... policy mechanisms that provide administrative simplicity, project longevity and market certainty are needed…'. I conclude this paper with a discussion of the likely opportunities and impediments for forestry under the Federal Government's most recent scheme (the Carbon Farming Initiative) aimed at generating carbon credits from the land sector including forests.

2. GHG balance of forests

The GHG balance of a forest depends on the change in C stocks in biomass, soils and dead organic matter (litter and harvest residues), and on non-CO2 GHG emissions (mainly from fire). C changes are the generally the most important, with biomass being the key and most dynamic C pool. Net change in biomass carbon is the difference between sequestration in new growth and the losses of biomass C caused by decay or disturbance. Changes over time can be expressed as C accumulation or loss curves such as the simple example shown in Figure1.

Biomass contains ~ 50% C by mass. Thus a cubic metre of wood (with a density of 500 kg m^{-3}) contains about 0.25 t C. So as a rule of thumb, a cubic metre of wood contains the equivalent of about 1 t CO2. Whilst most biomass C is stored above-ground, the root:shoot ratios in Australian forests typically range between about 0.3 and 0.7 (Snowdon et. al. 2000) meaning that 20–40% of total biomass C can be stored in roots.

3. Current contribution of Australian forests to the national GHG balance

The following is a summary of the GHG balance of Australia's forests as reported in the national inventory report in 2010 (DCCEE 2012). Units are millions of tonnes of carbon dioxide equivalent.

- Total national net GHG emissions including those from the Land Use Land Use Change and Forestry (LULUCF) sector were 580
- Deforestation ('land clearing') was a source of 56 (~10% of total)
- Managed forests were a net sink of 53 (9%) with native regrowth contributing 36 (6%), plantations 17 (3%) and harvested wood products 4.4 (0.7%)

Both emissions from deforestation and removals from managed forests are significant in the national context, and effectively cancel each other out. As discussed below there are opportunities to manage Australia's forests for better GHG outcomes.

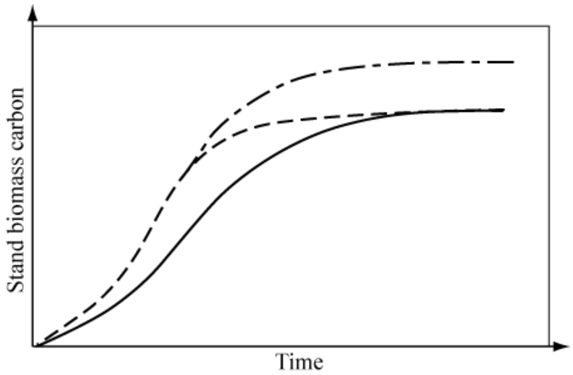

Figure 1. Example of some differing patterns of accumulation of biomass C in forests. Biomass C dynamics reflect rates of forest growth (including rates of regrowth following disturbance) and removals of C during disturbances such as harvesting or fire. The C accumulation curves are 'reset' by disturbances which often result in rapid and large losses of biomass C from a forest.

4. Options for increasing the positive contribution of forests to national GHG balance

The following actions enable forests to make a positive contribution to GHG balances:

- **Protecting the large stocks of C in existing forests.** Internationally, evolving mechanisms are focusing on avoiding deforestation and forest degradation (REDD+) in tropical countries. In Australia, legislation now strongly limits further deforestation. Deforestation rates (millions ha y^{-1}) have declined from about 1.0 in 1974, to 0.6 in 1990 to 0.25 in 2010 (DCCEE 2012). The conversion of 'mature' (high C) forests to regrowth forest or to plantations has almost ceased. Emissions from wildfires have increased during the last decade (DCCEE 2012), and may be hard to constrain under a warming/drying climate in SE Australia.

  Large areas of Australia's native forests are in conservation reserves, and some of these forests are still re-accumulating C after prior disturbance by fire or logging (SOFR 2008). Some groups are currently arguing for cessation of harvest as a means of preserving existing C stocks in native forests used for wood production. As discussed below this is unlikely to result in the most effective GHG or climate mitigation outcomes. Protection of conservation forests and other forests from fire is critical both to prevent direct GHG emissions and to avoid damage to stands which can lower C uptake during forest recovery. Fire protection is likely to be more challenging in the future under a warming and drying climate, and because of a decline in resourcing for fire management and suppression activities.

- **Creating new forests** that sequester C from the atmosphere for varying lengths of time. Rates of C sequestration (range ~ 1–10 t C ha^{-1} y^{-1}), and site carrying (storage) capacity vary markedly with species mix, planting geometry, site growing conditions and management (e.g. CSIRO 2013). Such forests do not have to be 'permanent' to provide a GHG mitigation benefit. The concept of time-averaged (e.g. over the life of a forest rotation) C stock is important in this context but is often not well understood or reflected in C accounting methods, or in greenhouse policy. This concept is illustrated in Figure 2. The average C stocks (ACS) approach gives credit for C sequestration in systems such as harvested forests where biomass C stocks are highly dynamic over time. Once calibrated, this approach would be relatively easy to apply.

There is a limited land base in Australia for the establishment of new plantings (perhaps a maximum of 10% of currently cleared land) which sets a ceiling on C sequestration by permanent ‘C forests‘. As an illustration, permanent planting will result in average total C sequestration (at maturity) of about 300 t CO2-equivalent ha^{-1}. Thus if ~ 5% of cleared farmland (2.5 M ha) was progressively planted, total sequestration would be ~ 750 Mt CO2 equivalent. This equates to only slightly more than one year of Australia’s total GHG emissions, whilst removing 2.5 M ha of land from other uses.

Whilst total C storage will be less in forests which are harvested and regrown, the cumulative benefits for GHG mitigation will be greater and on-going. This is because in sustainably managed forests, harvested wood products (HWP) can be used to substitute for fossil energy and other C-intensive materials. HWP can have long residence times both in service and in landfill, and can be used for energy generation at end of life. In general, the harvest and regrowing of forests results in greater GHG mitigation benefit than the non-harvest option. This has been well demonstrated by both Australian (Ximenes et al. 2012) and international (Peckham et al. 2012; Klein et al. 2013) studies.

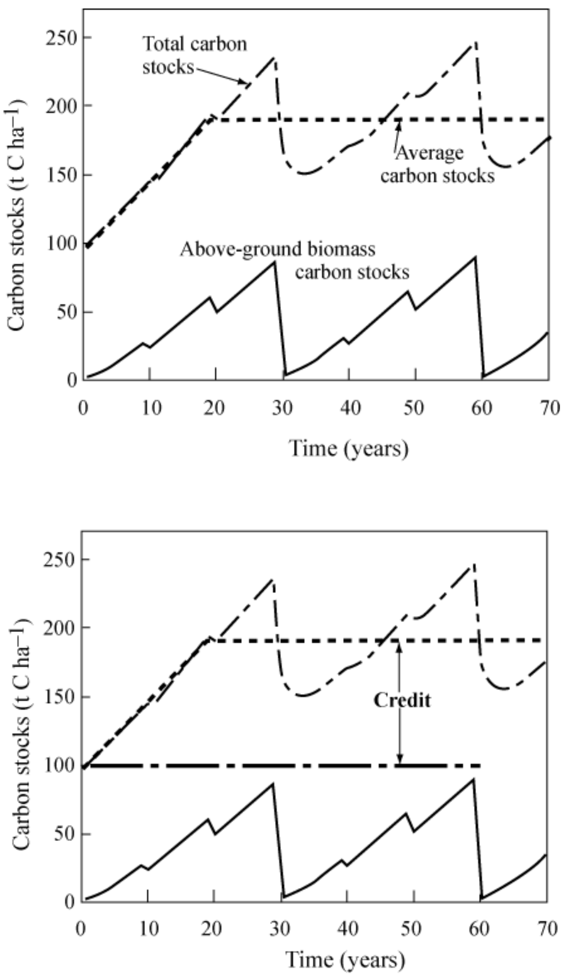

Figure 2. Schematic diagram illustrating the average carbon stocks (ACS) approach to estimating the change in the amount of carbon stored in a forest ecosystem (after Kirschbaum et al. 2001). The upper panel shows the change over time in biomass carbon and total carbon when forests are established and grow, and the effects of harvesting over a rotation of 30 years. The ACS in the harvested forest is shown by the horizontal line. The lower panel shows the average long-term benefits (C ‘credit’) derived from the managed forest.

- **Use of forest biomass for production of bioenergy** (bio-electricity or biofuels) that can result in the substitution for fossil energy use on an on-going basis. In general it is currently not economic to harvest and transport wood specifically for electricity production in Australia (e.g. Rodrigues et al. 2011) – an exception may be when there is also an opportunity to capture the excess heat produced (combined heat and power systems), but these are very limited in Australia. There are better prospects for the conversion of wood to liquid fuels (ethanol or aviation fuel), and technologies are approaching commerciality. At meaningful scale they require large amounts of biomass (millions of tonnes annually), and thus represent significant opportunities for biomass suppliers (CSIRO 2011).

Key considerations for bioenergy are that biomass feedstocks must be sourced from sustainably managed forests, and that GHG savings must be estimated across the full life cycle of biomass production and bioenergy production. Bioenergy can never lead to 100% reduction in GHG emissions because there are emissions associated with the growing, harvest and transport of biomass (May et. al. 2012), but can still result in significant benefits (IEA Bioenergy 2011). Overall, in Australia forest bioenergy may result in useful but moderate GHG mitigation (see Farine et al. 2012)

5. Discussion

For several reasons the potentially significant contribution of Australian managed forests to climate change mitigation has not been realised (McHenry 2012). Current government policies and programs (e.g. the Carbon Farming Initiative (CFI 2011), and the Renewable Energy Target (RET)) provide only limited opportunities for forestry. Under the CFI, a range of land-based activities can be undertaken to create C credits (called Australian Carbon Credit Units, with each unit being equivalent to 1 t CO2) that can then be traded to offset liability for C emissions elsewhere in the economy. The Federal Government estimated that, if effectively implemented, the CFI might result in mitigation of 5–15 Mt CO2-e from Kyoto Protocol Article 3.3 activities by 2020 (DCCEE 2011). Agriculture and forestry is not a covered sector under the CFI, meaning that they currently have no liability for emissions, but are eligible to create credits from specific activities. The CFI currently excludes many forest activities because:

- Only credits created after January 2010 are eligible, but these can be from existing eligible plantings.
- Activities must be additional to ‘business as usual’ (i.e. not be common practice), and must result in permanent (for 100 years, with a maximum reporting interval of 5 years) storage of C. This excludes most traditional forest activities.
- Plantings in the >600 mm y^{-1} rainfall zone are excluded to avoid perceived threat to water resources (such plantings are on what is known as a ‘negative’ list).
- Harvested forests are currently ineligible, for example mallee plantings established for environmental care as well as the production of biomass for bioenergy. However, ways of including harvested forests are currently being explored.

Obtaining reliable estimates of the amount of C sequestration in forest plantings is a considerable challenge given the high spatial and temporal variability in the biological processes involved. Credit is given for the increment in C over a specified period, not the accumulated C stock; and increments are more difficult to accurately estimate than total C stocks at a single point in time. In order to simplify and to reduce the cost of estimation and verification of C credits, some (e.g. McHenry 2012) have proposed a simple ‘deeming’ approach where conservative C credits are allocated according to rules related to specific management practices applied in different regions. However, such approaches are not favoured by many project proponents who believe that estimation of credits for their individual circumstances will provide them with greater benefit.

There is on-going debate about the utility and practicality of modelling approaches versus the use of direct inventories for estimating C increments. In reality, neither approach is very reliabile at specific locations (CSIRO 2013), but over and under-estimates balance out across landscapes and regions. Under the CFI, project proponents can submit a new methodology for estimating C credits, and if approved it can be used by both the proponent or anyone else implementing similar projects. The flexibility provided by such an approach can clearly result in delays in approval of methods, complexity of implementation and uncertainties in C estimates resulting from the application of different methods. A Reafforestation Modelling Tool (RMT) is available from the Department of Industry, Innovation, Climate Change, Science, Research and Tertiary Education for estimating C increments in environmental plantings, but the current version is very conservative, thus limiting benefits to growers. A re-calibrated version of the RMT based on extensive research and synthesis that predicts much greater rates of C gain by environmental plantings and mallee eucalypt plantings (CSIRO 2013) will be available by late 2013.

Environmental plantings comprised of mixtures of local tree and shrub species generally have lower rates of C sequestration than tree monocultures or other tree-dominated systems (CSIRO 2013). Thus incentives are likely to be needed to encourage the establishment of environmental plantings rather than monocultures such as mallee. The ‘biodiversity fund’ established by the Federal Government as part of the Clean Energy Futures package may help address this issue.

Whilst the current CFI rules are not favourable to forestry, the system continues to evolve via revision of the ‘positive and negative list’, the consideration for approval of more methodologies applicable to forestry projects (including those involving harvest regimes), and the availability of more reliable modelling tools. A major review of the CFI is proposed for 2014.

Forestry, along with many other land uses, requires relatively long-term planning horizons. These are generally not compatible with the volatile GHG mitigation policy and carbon prices experienced during the last decade, and which are on-going. Lack of stability in the price of carbon (e.g. that caused by the decision to accelerate transition from a C tax to a 'floating' C price announced in July 2013) remains a major impediment to investment in forest biosequestration and bioenergy projects.

6. Conclusions

- Forests play a significant role in Australia's net GHG balance, with emissions and C uptake currently being of similar magnitude.
- Protection of the large C stock in native forests and plantations from fire is very important.
- There are emerging opportunities both to increase forest C stocks, and to expand forest bioenergy, especially production of biofuels, for on-going GHG mitigation.
- In general, a strategy of sustainable forest harvest followed by regrowing will produce greater long-term GHG mitigation benefit than a no-harvest option
- Policy settings that provide simplicity of project implementation including clear and consistent 'rules' for estimating and reporting C credits, and long-term market certainty, are required to encourage investment in forest biosequestration and bioenergy projects.

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A pilot study of the cost of plantation biomass removal underpinning potential biomass sales price[1]

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Abstract

Plants store solar energy and CO_2 and it is possible to utilise that stored energy to generate electricity. Managers may see the potential to sell harvest residues into the bioenergy market—but at what price? Prospective purchasers will work back from electricity price to determine capacity to pay for the biomass; prospective suppliers need a clear idea of their cost of production.

Sustained cropping requires continuing availability of nutrients for the crop. This availability is particularly threatened by nutrient losses through burning, leaching and other processes in the inter-rotation period, and by the removal of nutrient-rich produce from the site. What is the cost of maintaining supply?

A pilot project (on Kangaroo Island, KI) determined the cost of biomass sales based on nutrient removal, and replacement costs via the addition of fertiliser. Single trees of *Eucalyptus globulus*, *E. nitens* and *Pinus radiata* were segmented into stem-wood, stem-bark, stem and branch materials (above merchantable stem small-end diameter—SED) and leaves/needles, mimicking potential recovery scenarios. Samples were tested for elemental and energy content to inform a scenario model estimating nutrients removed via harvest and the cost of replacement. The analysis assumed direct replacement by fertiliser of nutrients removed, which in reality is likely to under-estimate the quantity of fertiliser needed.

Leaves and needles had the highest nutrient replacement costs per unit of mass ($25.30 to $28.85 / t_{GREEN}), and stem-wood the lowest ($1.86 to $3.49/$t_{GREEN}$). On a per-hectare basis, stem-wood nutrient replacement costs ($535 to $635/ha) were greater than leaf / needle nutrient replacement costs ($436 to $560/ha). The cost of replacing nutrients in the 'non-merchantable' (but potentially saleable) biomass remaining after conventional harvesting ranged from $702 to $1732/ha.

The analysis indicated great variation in the cost of nutrient replacement between biomass components, and also variation between the species sampled. It is unlikely that leaves/needles will be separated from twigs/branches at harvest, and thus recovery would either include fine branches and leaves/needles or such material would remain on the plantation site. This analysis, based on a small sample, reveals a need for caution in any full biomass recovery (harvesting) and removal from a site, and a requirement for further research.

Introduction

Interest in renewable energy has resulted in a range of studies of the use of biomass to inform that interest and associated debate. Some studies are geographically specific, for example Hamilton (2009) reported on issues associated with biomass use in North America, and SED Consulting (2009) reported more broadly on bioenergy considering the Scandinavian and Australian situation. Brawner (2009) considered the financial impact of biomass sales on the development of longer-rotation eucalypt plantations for solid-wood products, and Goble and Jarvis (2007) reported on the potential of sawmill residues as a biomass resource. Stucley *et al.* (2004) presents a comprehensive review of the

[1] This work will be reported in more detail in a paper to be submitted to *Australian Forestry*

Australian bioenergy sector. Geddes (2010) reported on bioenergy potential in the Green Triangle / Limestone Coast region of South Australia. A key issue in considering any opportunity to use biomass is to understand the full impact of its utilisation.

RuralAus Investments Limited (RuralAus) purchased an integrated plantation forestry asset on Kangaroo Island (KI) comprising 2200 ha of *Pinus radiata* (radiata pine) plantations and a timber processing centre. The current electricity grid on KI is unable to supply adequate power to the processing centre, and analysis indicates that in the past onsite (diesel generator) electricity costs placed significant pressure on profitability. RuralAus has considered the development of biomass-based electricity generation for the processing centre and, supported by RenewablesSA, they completed a study into a 10 $MW_{e\ GROSS}$ biomass-based plant. As part of that study an analysis was conducted of the biomass resource, and in particular of the cost of nutrient replacement as a proxy to estimate the value and therefore cost of biomass as a feedstock. This paper presents the findings of that analysis.

Project methods

Biomass sampling strategy and analysis

The objective of biomass sampling was to provide representative samples to an analytical laboratory to determine the elemental and energy content of that material. Biomass samples can be collected from harvest and mill residues piles, but such a strategy reduces the ability to understand the relative contribution of the different tree components to the overall biomass attributes. Therefore the samples were collected from individual trees. A modified disc sampling strategy was adopted with sub-sampling within each disc to maximise the capture of within-tree variation while minimising sample weight: the proposed laboratory analysis required a minimum of 100 g per sample. Individual-tree component samples were collected to allow scenario analysis of the contribution of each biomass component to an overall biomass mixture based on likely biomass streams and harvesting options: merchantable-bole wood, merchantable-bole bark, stem-wood and bark above the tree small-end diameter (SED; i.e. the limit of the merchantable bole) with branches, leaves (eucalypts) and needles (*P. radiata*). Representative sample trees were selected in plantations managed by RuralAus on KI: *P. radiata* samples were collected from an area harvested the previous week and *Eucalyptus globulus* and *E. nitens* sample trees were felled and biomass samples recovered.

Plantation biomass allocations

The objective of developing biomass allocation functions was to understand the quantity (contribution) of each biomass component per hectare of plantation for each species. Detailed growth plot data are not available for the *P. radiata* estate on KI. In the absence of robust and defendable yield data, an MAI of 18 m^3/ha/y at age 30 years for the total stem-wood was applied. Plots across three age classes of *E. globulus* plantations on KI indicate MAIs of 15–24 m^3/ha/y at age 10 years; an MAI of 18 m^3/ha/y at age 12 years for total stem-wood was assumed.

P. radiata stem volume (m^3/stem) was converted into dry weight assuming a wood basic density of 450 kg/m^3. Biomass allocation was based on Borough *et al.* (2001: p. 54) and others. Allocation of *E. globulus* and *E. nitens* biomass to tree components was based on Mendham *et al.* (2003: p. 359); basics densities of 530 kg/m^3 and 480 kg/m^3 for *E. globulus* and *E. nitens* respectively were assumed.

Laboratory analysis

Individual elemental content of each biomass sample for each species was determined in the Melbourne laboratory of HRL Technologies Pty Ltd.

Nutrient replacement cost model

The nutrient content determined per unit of each biomass component was combined with the estimated biomass per hectare to generate a profile of the nutrients removed under a range of biomass harvesting scenarios. Nutrient replacement costs were estimated using the cost of applied fertiliser (product plus application) for each of the individual biomass components on a per-tonne of each component, and on per-hectare basis.

Results

- ***Key elements:*** The main elemental components (by weight) of the biomass are nitrogen (N), calcium (Ca), potassium (K), magnesium (Mg), chlorine (Cl), sulphur (S), sodium (Na) and phosphorous (P)
- ***Location:*** In general, most of the elemental content is within the biomass components typically not removed during routine harvesting, viz. needles / leaves, branches and the non-merchantable stem-wood and bark (eucalypts)
- ***Species:*** There are differences between *P. radiata* and the two eucalypts, in particular the nutrient content of the needle / leaf materials and an overall greater quantity of the elements assessed for *P. radiata* due to the greater quantities of biomass per hectare. The aluminium content of *P. radiata* is 30 to 40 times as much as for the eucalypts.

Replacement of removed elements

N is the major cost at over $1400/ha for *P. radiata* (100% compensation) and close to $600/ha for *E. globulus* (100% compensation). The total nutrient replacement cost is close to $2500/ha for *P. radiata* and around $1300 /ha for the eucalypts if 100% of the above-ground biomass is removed. If the increase in nutrient loss due to biomass removal in excess of routine harvesting is considered, the nutrient replacement costs are as follows:

- ***P. radiata***: $1583/ha to replace the nutrient content in traditionally un-merchantable stem-wood, branches and needles (62% of the total cost of $2572/ha)
- ***E. nitens***: $702/ha to replace the nutrient content in bark, traditionally un-merchantable stem-wood, branches and leaves (52% of the total cost of $1336/ha)
- ***E. globulus***: $853/ha to replace the nutrient content in bark, traditionally un-merchantable stem-wood, branches and leaves (61% of the total cost of $1388/ha).

Conclusions

The impact of complete removal of biomass from plantations is well recognised. The Australian example of second-rotation decline of *P. radiata* growing in South Australia, indentified in the 1960s, led to changed management practices including the retention of harvest residues onsite. Similar practices have been adopted across most plantation estates in Australia. The effect of harvest residue management in eucalypt plantations has been quantified; the impact is greatest on inherently low-nutrient sites. If plantation managers seek to increase revenues, after the sale of the routine products, by the sale of harvest residues to the energy sector, any increase in biomass recovery must be informed by the impact on plantation sites and recognition that retained biomass is not a nil-value waste but rather a valuable source of nutrients.

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The role of insurance in carbon forestry

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The frequency and severity of weather-related catastrophe losses is the main driver of insurer action on carbon insurance. 2012 saw economic losses of US$160 billion from natural catastrophes and man-made disasters. This was significantly lower than 2011's unprecedented US$370 billion. At that point, eight of the top 10 significant natural catastrophes worldwide were weather-related, and cost a total $95.3 billion; less than 40% ($36.4 billion) were insured.

Put into context with past years, there is an obvious upward trend in losses. Katrina remains the largest single event at US$75 billion. Katrina, along with hurricanes Wilma and Rita, all in the US, contributed the lion's share of that year's total global catastrophe claims of US$123 billion. Thailand's loss in the 2011 flood, at US$12 billion, is the highest ever recorded for a river-water flood event.

The upward trend in natural catastrophe losses, both insured and economic, for the past 30 years is creating enormous economic hardship. They cost the global insurance industry roughly $226 billion in 2010, $370 billion in 2011 and $65 billion in 2012.

The trend of increasing loss cannot be denied and, along with most climate models' 'most likely' outcomes, means insurers have had little choice but to take action at many levels. There is now an array of public/private insurance partnership programs, alternative risk transfer mechanisms, and performance guarantees around the climate industry and green technologies in particular.

Insurance Facilitators has been involved in the latter and is now at the forefront of forest-sequestered carbon insurance. We are the benchmark in the Australian market and are looking to extending our contribution to other markets.

Insurance Facilitators insurer is Catlin, the largest insurance syndicate at Lloyds. The Catlin Group has a market capitalisation of US$148 billion and Standard & Poors Rating of A+ (Strong).

Catlin is proactive in gathering information about our climate.

Catlin funded the Catlin Arctic Survey to help project how long before the perennial sea-ice cover would cease to be a year-round surface feature of the planet. By 2030–40, there is a significant probability that the Arctic Ocean's sea ice cover will be transformed into ice-free open ocean in summer times. When this happens, everything changes—including global weather patterns reliant upon there being a body of ice at the North Pole. The implications for a global weather catastrophe insurer are obvious.

Catlin also funded the Catlin Seaview Survey, the first comprehensive study to document the composition and health of coral reefs and addressing a series of important questions regarding the changes associated with the rapidly-warming and acidifying oceans. The health of this carbon sink should concern all of us.

Catlin is also supporting those who embrace photosynthesis because it remains the most cost-effective, immediate and tangible means by which we can sequester CO_2, a root cause of our collective ill. In so doing Insurance Facilitators is supported in the delivery of the first and foremost forest-sequestered carbon product in Australia.

Insurance Facilitators insures:

- permanent carbon forest sinks both in the Voluntary Market and Carbon Farming Initiative (CFI)
- on an agreed value basis Australian Carbon Credit Units (ACCUs) and Voluntary Emission Reductions (VERs)
- on an annual basis the option of future carbon to five years ahead, which means the underpinning new forest carbon projects when at their most vulnerable and protection for carbon off-take agreements with emitters.

This is a major step for insurers who have effectively set aside moral hazard and insured something not yet grown. Insurance Facilitators now has the broadest policy coverage of any insurer of forestry and forest carbon in the Australian market and its product base will continue to grow and evolve to meet the needs of the market.

Topically, it has allowed many to permanently transfer the risk of their CFI emission obligations because the Risk of Reversal Buffer does not do this. Whether a 1% or 100% emission, no participating CFI carbon farmer can apply for new credits until they have re-grown all that was lost.

IF transfers this risk, depositing credits equal to their emission obligation into their Australian National Registry of Emissions (ANREU) Account.

The underpinning of Australian forest-sequestered carbon is a drop in the ocean of global carbon emissions, and even less when considering the premium it generates. It is, however, a proving ground, and a very important one, in the drive to securitize REDD—Reduced Emissions from Deforestation and Degradation.

Global deforestation and forest degradation accounts for nearly 20% or 5½ billion tonnes of carbon dioxide emissions every year, almost all in the tropical regions. This is second only to emissions from the energy sector.

The projected global forest carbon market from REDD projects (this excludes any planting projects) is expected to grow from US$30 million per year in 2010 to over US$45 million per year in 2015. Having factored in the current financial uncertainty, the UN REDD program has predicted that financial flows for greenhouse gas emission reductions from REDD could reach US$30 billion a year. It will take a long time to get that high, but this significant North–South flow of funds would reward a meaningful reduction in carbon emissions and stabilise global average temperatures within the target range of two degrees Celsius.

So if Catlin's support for Insurance Facilitators Australian forest-sequestered carbon insurance program is successful, we will not only set the scene to securitize REDD and share in a wholly new US$30 billion industry, but have done something even more valuable: we will have forever tied Catlin's financial protection of our carbon forests to a reversal in insurers' ever-increasing and multi-billion dollar, global weather-related catastrophe loss trend.