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Regional Opportunities for Agroforestry Systems in Australia

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Foreword

Agroforestry can confer many benefits to Australia. To date development has been impeded by lack of clear identification of regions and particular agroforestry systems with the greatest opportunities for commercial investment and environmental outcomes. The combination of potential agroforestry systems, their products and regions is large and will be driven by the imagination of the diverse range of investors. As global wood shortages increase and new markets emerge for products such as forests for carbon off-sets, we can expect that large-scale expansion of agroforestry will become a viable possibility for Australia.

This project examined opportunities for different agroforestry systems across regions in Australia, including in relation to potential infrastructure and carbon markets. It assessed the profitability of various systems within a spatial framework and the potential impacts of new agroforestry developments on water interception and biodiversity. The resulting data base and spatial outputs provide a rich resource for ongoing assessment of agroforestry opportunities in Australia for investors.

Research and development has an important role to play in quantifying the expected outcomes from agroforestry. New forests, for example, may take many years or even decades before the impacts of their establishment are manifested. Australia's R&D funding is limited, including in the natural resource sectors. It is essential that a coherent and well-targeted plan is designed and implemented to maximise the efficiency and effectiveness with which these limited R&D funds are used. The results from this study can inform investors of potential opportunities for agroforestry development.

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This report is an addition to RIRDC's diverse range of over 1800 research publications. It forms part of our Agroforestry and Farm Forestry R&D program, which aims to integrate sustainable and productive agroforestry within Australian farming systems. The JVAP, under this program, is managed by RIRDC.

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Abbreviations

AER	Annual equivalent return
AFG	Australian Forest Growers
ANU	Australian National University
AG	Above ground
ASW	Available soil water
BA	Basal area
CEF	Commercial environmental forestry
CMA	Catchment Management Authority
DBH	Diameter at breast height (1.3 m)
DCC	Department of Climate Change
LAI	Leaf area index
MA	Management action
MAI	Mean annual increment
MAR	Mean annual rainfall
MAT	Management action target
NAER	Net annual equivalent return
NLWA	National Land and Water Audit
NPI	National plantation inventory
NPV	Net present value
NRM	Natural Resource Management
PFDC	Private Forest Development Committee
PFE	Profit at full equity
RCT	Resource condition target
SPH	Stems per hectare
SPIF	Scenario planning and investment framework
SV	Stem volume
WS	Mass of stem wood+branches

Contents

List of Tables

List of Figures

Executive Summary

Background and objectives

Agroforestry may confer many commercial and environmental benefits. How it is implemented is often an economic exercise, modified by community attitudes and social acceptance. A major impediment to expansion of agroforestry in the marginal regions of Australia, where the net environmental benefits are likely to be greatest, has been the inability to quantify and present the economic case. Investment in agroforestry, as with any type of investment, often comes down to risk identification and management. More recently, we have been aware of potential tradeoffs such as interception of water that otherwise would be available for consumptive or environmental use. The aim, as far as possible, is to be cognisant of all these impacts to maximise the benefits and minimise the tradeoffs.

There are a large number of potential agroforestry systems and many regions across Australia in which they could be established. There is therefore a strong argument that investment in R&D of these systems and underpinning market drivers needs to be well focussed to maximise the efficiency and effectiveness of funding. This research aims to synthesise spatial information on the productivity and economics of agroforestry systems in Australia and compare the outputs with market opportunities for agroforestry and inferred support from the regional NRM bodies and other groups. It targets a range of potential investors in agroforestry (private enterprise, governments and regional bodies) to help with decision making. It also aims to help identify future investment needs for research to assist the JVAP with planning.

Methods

Assessment of agroforestry opportunities needs to take account of many factors including the various agroforestry systems, the opportunity costs, market opportunities, regional conditions such as distances to processing mills, environmental impacts, and possible changes in economic conditions such as new processing plants and emerging markets. In many cases this assessment is best integrated within a spatial framework. This project assesses the spatial potential economic outcomes and environmental impacts across Australia at 1 km scale, comparing:

- Regions
- Agroforestry systems
- Time frames (now, future).

It is a large GIS and engagement project that includes the following components:

- *Stakeholder engagement*::
  - (i) Review of published Investment Plans for the 57 NRM Regions (mostly CMAs) for their interest in agroforestry
  - (ii) Survey of regional representatives of the AFG and the PFDCs to assess their views on community and industry attitudes to agroforestry in their region, and
  - (iii) Collating information to develop the regional silvicultural scenarios and economic costs of establishment, management, harvesting, transport and product prices

- *Scenarios for current economic and policy conditions* for 10 agroforestry systems:

Sawlog systems	**Short-rotation systems**	**Carbon plantings**
1. Hardwood sawlogs 2. Softwood sawlogs	3. Pulpwood 4. Bioenergy 5. Integrated Tree Processing 6. Fodder (in-situ)	7. Environmental plantings 8. Hardwood plantations 9. Softwood plantations 10. Mallee plantings

- *Scenarios for potential future markets*:
    - (i) Including sequestered carbon as a product, and
    - (ii) Using a fixed transport distance (100 km) to simulate the establishment of new processing mills in areas of prospective plantation expansion
- *Growth modelling* across Australia for species that typically could be grown in various geo-climatic zones and for which data were available for model calibration and validation
- *Economic modelling* to calculate spatially the profitability (at mill gate) of agroforestry systems, in terms of Net Annual Equivalent Return (NAER, \$ ha^{-1} yr^{-1}) using discounted cash flow and the opportunity costs of the preceding agricultural enterprise
- *Environmental impacts* of agroforestry on:
    - (i) Biodiversity, and
    - (ii) Rainfall interception to identify areas where profitability coincided with biodiversity need and least water impact
- *Uncertainty and sensitivity (Monte Carlo)* analyses to identify aspects of agroforestry to which profitability was sensitive.

Results and conclusions

Spatial analyses across Australia identify large areas that are potentially profitable and in total much greater than would ever be realised. Establishment of agroforestry systems is driven by many factors, community support often being a key determinant. Within any given region, the prospects for the development of new agroforestry should be considered on two fronts:

- 'Capacity' which describes the extent to which community and government drivers support establishment of new agroforestry industries, and
- 'Capability' to grow, which describes the suitability of site conditions for particular species.

Table 1 shows the summary ratings for 15 regional bodies (mostly CMAs) according to various criteria. The regions are spread across all the states but are dominated by Victoria and NSW when ranked according to the criteria in column IV. The extent to which regional bodies would help facilitate large scale establishment of agroforestry will ultimately depend on a range of policy, social, economic and environmental drivers. The intersection of broad NRM objectives with water policy represents one example of where environmental priorities may be in conflict.

In a previous report for the JVAP, URS Forestry (2008) compared market opportunities in the (mostly) NPI regions of Australia for the 'traditional' forestry systems and products. We compare their ratings with those based on the 'growing opportunity', being the total profitability for each forestry system and product within each NPI region (Table 2). There are several NPI regions identified with a High rating for the combined 'market and growing opportunity'. These are for hardwood sawlog and pulpwood/chip export systems and indicated regions that were assessed as having good market opportunity by URS Forestry and also with relatively large areas of opportunity to grow the wood resource profitably.

Table 1. Regional NRM bodies rated 'High' for capacity+capability (column IV) when considering 'capacity' (the review of NRM investment plans) and 'capability' (the area across which agroforestry might be profitable within the region). Ratings for various other criteria are also shown for comparison.

	'Capacity'	**'Capability'**		**'Capacity+Capability'**	
Region	**Review of NRM Plans**[1]	**Profitability**[2]	**Profitability+ biodiversity**[3]	**NRM plans+ profit (Mean of columns I and II)**	**NRM plans+ profit+ biodiversity (Mean of columns I and III)**
	(column I)	**(column II)**	**(column III)**	**(column IV)**	**(column V)**
Burnett Mary	**H**	**M**	**M**	**H**	**H**
Corangamite	**H**	**M**	**M**	**H**	**H**
Fitzroy	**H**	**H**	**M**	**H**	**H**
Glenelg Hopkins	**H**	**M**	**M**	**H**	**H**
Goulburn Broken	**H**	**M**	**H**	**H**	**H**
South Coast Region	**H**	**M**	**H**	**H**	**H**
Border Rivers/Gwydir	**H**	**H**	**L**	**H**	**M**
Burdekin	**H**	**H**	**L**	**H**	**M**
Central West	**H**	**H**	**L**	**H**	**M**
Hawkesbury/Nepean	**H**	**M**	**L**	**H**	**M**
Hunter/Central Rivers	**H**	**M**	**L**	**H**	**M**
North Central	**H**	**M**	**L**	**H**	**M**
North East (VIC)	**H**	**M**	**L**	**H**	**M**
Northern Rivers	**M**	**H**	**M**	**H**	**M**
South (TAS)	**H**	**M**	**L**	**H**	**M**

[1] Review of NRM plans involves rating their interest in agroforestry according to a count of relevant words

[2] Ratings for profitability involved summing the total profitable area within each region for environmental carbon plantings.

The main conclusions from this project are:

- ***Agroforestry can be competitive*** with agriculture in some regions and for some forestry systems, as demonstrated by positive values of NAER (that is, the forestry system is likely to be more profitable than the preceding agriculture phase)
- ***Pulpwood systems and hardwood sawlogs look promising*** in several regions, mainly because of the often fast rates of growth of hardwoods (and relatively short cycle time for pulpwood systems) and the relatively high price for hardwood sawn timber and pulpwood products compared to softwood
- ***Transport distances and product price are important*** in influencing profitability. This reinforces the knowledge that large-scale expansion of agroforestry systems will be constrained by distance to existing processing or handling facilities, or new ones will have to be built
- ***Northern Australia and the east coast show promise*** for expansion of agroforestry systems and industries due to the often low profitability of agriculture and potential fast rates of tree growth
- ***Dedicated bioenergy and ITP systems are not profitable at present*** unless they are very close to processing facilities. This is due to the high cost of production (harvesting and transport) relative to low product price for wood energy (market failure at present)
- ***Carbon farming looks promising*** due to the relatively low cost of production (no harvesting, transport) relative to a possibly high product price. This indicates that new forests can be grown in many locations and for multiple environmental outcomes. For example:

  - Environmental carbon plantings could be profitable and minimise the impact on water across 9 Mha. The annual rate of carbon sequestration was predicted to be 143 Mt CO_2-e yr^{-1} at an average areal rate of 16 t CO_2-e ha^{-1} yr^{-1}. This total annual increment is equivalent to about 25% of Australia's net 2005 greenhouse gas emissions
  - The profitability of longer rotation sawlog systems can be significantly improved if carbon is included as an additional, saleable, product
- ***Maximizing rates of forest growth*** remains one of the most important determinants of profitability and thus where agroforestry research can have high impact.

Table 2. Rating of NPI regions according to market opportunity, growing opportunity or both for sawlog regimes and woodchips or pulpwood exports. The market opportunity was taken from URS Forestry (2008).

Region	Market opportunity + growing opportunity[1]		
	Softwood sawlogs	Hardwood sawlogs	Wood-chip exports or pulpwood
Central & North Queensland	L	H	L
SE Queensland	L	H	H
North Coast NSW	L	H	H
Northern/Central Tablelands	M	M	M
Murray Valley	M	M	H
Southern Tablelands	L	L	H
SE NSW	L	H	L
NW Victoria	L	L	L
Central & W Vic	M	H	M
Gippsland	M	H	H
Green Triangle	M	L	M
Mt Lofty & KI	L	L	L
SW WA	M	H	H
Tasmania	M	H	H
NT	L	L	L

[1] The market opportunity+growing opportunity rating gives an overall assessment, calculated as the mean value of the market and growing ratings.

The results from this analysis should be viewed as 'prospecting' for opportunities, in which the aim is to identify regions that may meet the criteria of a particular type of investor, but which require greater ground-truthing to verify the assumptions used in the model and to assess the local social, economic and policy conditions as they pertain to agroforestry developments. The outputs from each agroforestry scenario represent only one set of assumptions within each of the broad geoclimatic regions. In reality, the assumptions used may vary greatly and thus affect the calculated profitability.

A main output from this project is the spatial data set that has been compiled and that can be used by others to run scenarios using their preferred inputs. It is underpinned by its various components such as the extensive calibration and independent validation of the growth model for a variety of species. The spatial economic model developed under this project has a user-friendly interface that enables it to rapidly interrogate the data base according to user-specified scenarios and to adjust the productivity predictions upwards or downwards if local knowledge suggests that the accuracy of the growth model predictions can be improved. The Scenario Planning and Investment Framework (SPIF) tool manages the GIS datasets and allows rapid interrogation for spatial layers of NAER, growth, carbon sequestration, water interception and Biodiversity Score. The SPIF tool is available by request with sample datasets from http://www.csiro.au/resources/SPIF.html.

Recommendations

This project has identified regions where there may be opportunities for large-scale expansion of agroforestry plantings, either for commercial benefit alone or with environmental benefits included. Many states have done their own assessments for regional targeting of plantings and the aim here is not to replicate those. On the basis of the outputs from this project we offer below some broad recommendations as to future, targeted research needs to help advance development of agroforestry systems in Australia for multiple, positive outcomes.

Research needs in prospective regions of Australia

- ***Northern Australia.*** It is predicted that, for sawlog and pulpwood regimes, high rates of growth and hence forest profitability might be possible in northern Australia (and in the high-rainfall belt of the east-coast). However, this is a region where there is a paucity of data and is outside the zone of extrapolation for many of the species to which the growth model is calibrated. We also note that the 'environmental plantings' are not predicted to perform as well in northern Australia as in southern latitudes. General experience suggests that growth of plantation species in northern climates can be greatly influenced by incursion of pests (such as termites, borers), diseases and fires. Research is needed to assess the productivity potential of agroforestry in the north and methods to manage biotic and abiotic risks
- ***Potential biodiversity plantings in south-east Qld., south-east Australia, south-west WA.*** These are large areas and warrant further investigation as to suitability of soils, availability of land, growth of existing vegetation (if any) in the region and water impact issues. To a large extent they also coincide with regions where farm forestry is supported by NRM regions (mostly CMAs).
- ***Growth prediction in a changing climate***. All scenarios performed to date use average, historical data. Given that we are interested in growth and hence economics in the years to come, it would be constructive to run production models using future climate scenarios across the various regions.

Research needs for agroforestry systems

This project identifies points for research intervention in the agroforestry value chain that can make a substantial difference.

- ***Growth data and prediction for dryland species and environmental plantings***. An emissions trading scheme that includes forests could stimulate a large expansion of the forest estate. This would include expansion into drier areas with 'environmental plantings' – regions and species where we have relatively little information. Greater confidence in prediction of growth potential is needed
- ***Carbon accounting and prediction***. Results show that a carbon market has the potential to transform the landscape. However, using trees as carbon off-sets will require robust tools for prediction and monitoring of annual rates of carbon sequestration and at relatively fine spatial scales to support an emissions trading scheme. This will require down-scaling of predictions to:
  - Hillslope level, so that carbon can be predicted and counted across the landscape, and
  - Annual time-steps, so that carbon can be estimated and therefore traded at relatively short intervals if required
- ***Breeding and silviculture to maximise growth***. The main factors influencing profitability of harvested systems are land value, growth rates, product price and transport costs. Maximising growth rates is thus one area where research in the biophysical sciences can make a difference.

Introduction

It has long been recognised that large-scale expansion of the forest estate in Australia, in the right places, can confer multiple benefits. These may include regional economic development through the expansion of existing industries or development of new ones, on-farm benefits as part of a mixed agricultural enterprise, biodiversity enhancement, carbon sequestration, and salinity mitigation. More recently, we have become aware of potential tradeoffs such as interception of water that otherwise would be available for human use. The aim, as far as possible, is to take account of all these factors to maximise the benefits and minimise the tradeoffs.

Environmental benefits would be realised mostly in the lower rainfall zones (for example, 400-700 mm mean annual rainfall) but a major impediment to expansion of agroforestry in these regions has been our inability to quantify and present the economic case. Investment in agroforestry, as with any type of investment, often comes down to risk identification and management. Because the more marginal environments are by their very nature less well tested and less certain than traditional forestry areas, they present a relatively higher risk. A key challenge is to quantify the expected economic and environmental outcomes from agroforestry plantings, but a difficulty is that trees often take many years after being established before their impacts are manifested. Impact assessment therefore needs to be based on best available knowledge and must often rely on predictive modelling to extrapolate in time and into regions for which data are presently limited.

The matrix of potential agroforestry systems, and the regions across Australia in which they could be established, is very large indeed. There is therefore a strong argument that investment in R&D for these systems and research into the underpinning market drivers needs to be well focussed to maximise the efficiency and effectiveness of investments.

Assessment of agroforestry opportunities needs to consider many factors, including the various agroforestry systems, the opportunity costs, market opportunities, regional conditions such as distances to processing mills, environmental impacts, and possible changes in economic conditions such as in new processing plants and emerging markets. In many cases this assessment is best made within an integrated spatial framework.

Various studies have been undertaken of the economic and environmental impacts of forestry and agroforestry systems in Australia. FloraSearch and the Future Farm Industries-CRC in collaboration with the Joint Venture Agroforestry Program (JVAP) used a spatial framework to examine regions of southern Australia in the wheat-sheep belt for short rotation systems (Hobbs *et al*. 2008, Bennell *et al*. 2008). Burns *et al*. (1999) examined the potential economics of forestry systems (non-spatially) within the current regions of most interest and likely profitability. Others, such as State Governments, have undertaken regional planning to target and support investment of forestry or agroforestry systems (for example, Buckton 2004 for the Forest Products Commission in Western Australia).

The project reported here assesses potential economic outcomes and environmental impacts across Australia within a spatial framework at 1 km scale. Much of the capability and data sets had been developed during the 4 years of the Commercial Environmental Forestry (CEF) study (www.ensisjv.com/cef). The project aim can be simply stated as ‘prospecting for regional opportunities and research needs for agroforestry systems in Australia’ and, in particular, to compare:

- Different agroforestry systems
- Different regions across Australia
- Time frames for the present and for the future that consider changing infrastructure or emerging markets.

Its specific objectives were to:

- Assess regional priorities for Natural Resource Management (NRM) investment in agroforestry through review of Catchment Management Authority (CMA) plans and surveys of regional Private Forest Development Committee (PFDC) and Australian Forest Growers (AFG) representatives
- Develop scenarios for 10 agroforestry systems in Australia
- Collate and compile an extensive data set on productivity and site conditions for agroforestry species across Australia
- Use the growth data to calibrate and validate the 3-PG2 model of forest growth and carbon sequestration
- Build a generic, economic model of agroforestry profitability, taking into account the opportunity costs of the agricultural enterprise
- Assess the potential impacts of agroforestry plantings on biodiversity enhancement and water interception
- Combine the data within a spatially-explicit framework for interrogation and interpretation to develop recommendations on prospective regions and systems needing further investigation. This will help inform investment decisions by the JVAP and other relevant stakeholders, and
- Provide a spatial data base and framework that can be used for further scenario development and exploration of potential agroforestry opportunities with different user-defined inputs and assumptions.

Agroforestry has many drivers and impediments; the extent to which it is implemented is largely an economic exercise and often modified by community attitudes and social acceptance. There are many different relevant investors including farmers, forestry companies, governments, fund managers and other institutional investors, each with their own financial model. The aim here is therefore not to try and replicate these various (and often confidential) investment models, but to provide a generic analysis of some of the regional opportunities, now and for the future, for various agroforestry systems. The project is companion to a report that assessed the various product and market opportunities within regions and across Australia (URS Forestry 2008).

In this report and for convenience, we use the term ‘agroforestry’ in a broad way, being any situation in which trees are planted on agricultural land. It that sense it can be trees that are planted for any combination of environmental or commercial reasons and can range in scale from woodlots to those of industrial plantation companies.

Methods

General overview

This section provides a general overview of the methodologies used in this study. Details are presented in the subsequent sections.

The study had two main components:

(i) Review of regional priorities for agroforestry investment, and
(ii) Spatial assessment of economic and environmental impacts.

The first of these has been reported elsewhere (Booth 2007) and the methods and results are only briefly described in the next section. The second comprised the main body of work, the details for which are reported below.

The spatial assessment entailed building a Geographic Information System (GIS) data base from existing information, outputs from forest productivity models and environmental impact analysis. The main outputs of interest were:

- Economic outcomes including the Annual Equivalent Return (AER) and Net Annual Equivalent Return (NAER) to the agroforestry grower or investor at mill gate. The AER is an annualised Net Present Value that 'normalises' calculated profitability to enable comparison of longer rotation crops with the annual returns derived from conventional agricultural enterprises (Hobbs *et al.* 2008). The NAER is the AER less the 'profit at full equity' of the preceding agricultural enterprise; that is, it takes into account the opportunity cost of the land
- Uncertainty and sensitivity analysis of the economic model to demonstrate the main factors controlling calculated profitability
- Potential impacts of agroforestry on biodiversity enhancement and water interception
- Data synthesis and interrogation that summarises results into quantifiable metrics.

The basic structure of the methodology and sequence was (Figure 1):

1. Development of agroforestry production systems and scenarios:
   - Ten production systems were developed and agreed to by the Project Steering Committee, covering sawlog systems, short-rotation crops for a variety of products and dedicated carbon plantings (Table 3). Each of the production systems was defined by a range of species for which it was suitable; however one species only was chosen to be modelled as being indicative of growth rates and for which a reasonable data set was available for model calibration and validation
   - Because the assessments were species specific it became necessary to divide Australia into 5 'geoclimatic' zones to enable the growth of species appropriate to each of those zones to be modelled. This included the arid interior which, because of its naturally low productivity potential, was excluded from most analyses
   - Each of the scenarios was further defined by reference to initial tree spacing, age of thinning to a prescribed stem density, time of harvest, and the split of products into its various pathways and destinations. Regional information on costs of establishment, maintenance and harvesting, and product prices were also included and was obtained in consultation with regional experts and appropriate references.

2. Construction of spatial data surfaces:
- Existing data layers were collated from various source; for example from the Bureau of Resource Sciences (BRS) and the Australian Greenhouse Office (AGO) for historical climatic parameters, existing vegetation cover, existing processing facilities, roading and transport infrastructure and 'profit at full equity' (farm profit), all mapped with 1 km spatial resolution. In addition, a new soils layer was constructed to estimate site water balance and hence as an essential input to the growth modelling.

Table 3. Agroforestry production systems and scenarios considered in the analysis. See section 'Scenario development' for further details.

No.	**Production system**	**Reference: Variable transport[1], No carbon[3]**	**Fixed transport[2], No carbon**	**Variable transport, With carbon[3]**	**Fixed transport, With carbon**
	Sawlog systems				
1	Hardwood sawlogs	✓	✓	✓	✓
2	Softwood sawlogs	✓	✓	✓	✓
	Short rotation crops				
3	Pulpwood	✓	✓	✓	✓
4	Bioenergy	✓	✓	✓	✓
5	Integrated tree processing	✓	✓	✓	✓
6	Fodder (*in situ*)	✓	n/a	n/a	n/a
	Carbon plantings	**--------------- carbon sequestration only ----------------**			
7	Environmental plantings	✓			
8	Hardwood plantations	✓			
9	Softwood plantations	✓			
10	Mallee plantings	✓			

[1] 'Variable transport' is for existing processing facilities and thus where the transport distance is thus variable depending upon location of the agroforestry system in the landscape

[2] 'Fixed transport' assumes a constant transport distance of 100 km to the nearest processing facility. It represents a hypothetical situation where new processing facilities are established close to the forest resource (Hobbs *et al.* 2008)

[3] 'No carbon' is where there is no payment for carbon sequestration. 'With carbon' is for a payment for the amount of carbon sequestered in live vegetation.

3. Growth prediction using the 3-PG2 model:
- A main first step in this exercise was the compilation of an extensive data set to be used for model calibration and validation. Sources of data included the CSIRO data base, FloraSearch and various other unpublished and published reports
- This included obtaining data on site properties (climate, soil physical attributes, management) as inputs to the model so that site water balances could be calculated
- Running of the spatial version of the 3-PG2 model for the various production systems to generate spatial outputs for volume of product at times of commercial thinning and harvest, or volumes or mass of fresh weight produced at time of harvest, or amounts of carbon sequestered.

4. Economic modelling:
- A generic economic spreadsheet model was developed and then programmed in C^{++} using Microsoft Visual C^{++} 2005 Express Edition
- For each scenario, user-defined inputs which varied across regions but which were not spatially explicit at 1 km scale, were entered for costs of establishment, maintenance and harvest, and products generated and prices. Costs of harvesting were dependent upon the volume of stems harvested

- The spatial model then read for each 1 km^2 pixel in Australia, depending of the agroforestry production system, the thinning volume, harvest volume, fresh weight produced or amount of carbon sequestered
- The model then calculated, for each product stream, actual distance to market and transport costs to derive a value for AER at mill gate
- The values for AER were then subtracted for each pixel from values of 'Profit at Full equity' (or farm profit, Hajkowicz and Young 2002) layer to determine values of NAER and which thus included the opportunity cost
- Output values were categorized and all positive values of NAER were summed to give a total value ($\$ yr^{-1}$) for each agroforestry system and scenario
- The same was done on a limited basis for select scenarios for CMA regions across Australia as a way of comparing regional outcomes with the 'capacity' determined from the regional review and stakeholder surveys
- Uncertainty and sensitivity analysis was undertaken on the spreadsheet version of the model to identify the main parameters and inputs that affected predicted economic outcomes.

5. Environmental impacts:
   - New spatial layers were developed for the impact of agroforestry plantings on water interception (decreased rates of stream flow) and on the potential biodiversity benefit.

6. Multiple impact assessment:
   - Select spatial output data were then run through the Scenario Planning and Investment Framework (SPIF) tool, developed previously under CSIRO's CEF program of research, to identify areas where profitability coincides with environmental benefit according to user-defined criteria.

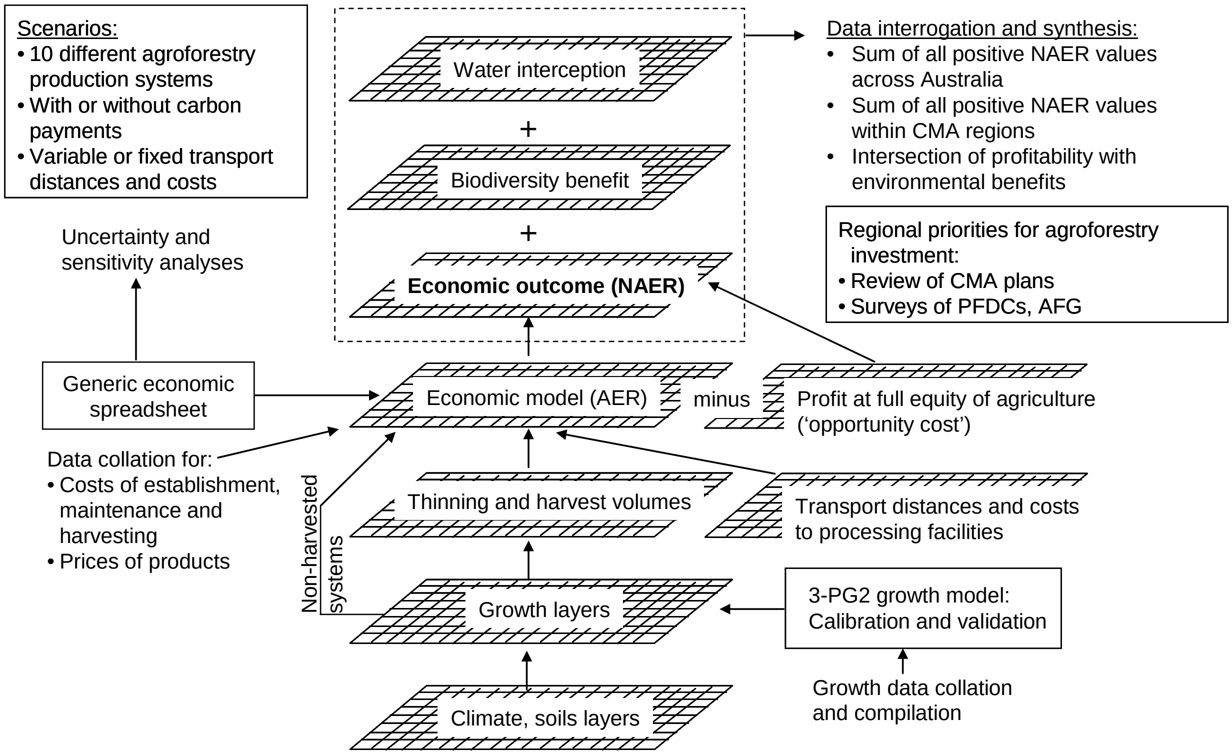


Fig. 1. Schematic flow diagram of processes followed during the study.

Regional NRM Priorities for agroforestry across Australia

Establishment of agroforestry systems can be driven by many factors. Community support is often a key determinant. Within any given region, the prospects for the development of new agroforestry systems might be thought of as being separated into:

- 'Capacity' which describes the extent to which community and government drivers support establishment of new agroforestry industries, and
- 'Capability' to grow, which describes the suitability of site conditions for particular species (biophysical capability) and the potential profitability to the grower (economic capability).

The majority of this report is concerned with the second of these, assessment of the biophysical suitability of various production systems and economic potential. However, it is possible that some regions are suitable for agroforestry developments but do not enjoy community support for any number of reasons, or vice versa, the region having active community support for agroforestry development but site conditions make it unsuitable for at least some forms of agroforestry.

The research described in this section addressed the first of the two issues above – the 'capacity' to support agroforestry.   It had two main components:

(i) Review of NRM plans for the 57 CMAs to evaluate regional priorities for vegetation establishment and potential levels of investment, and
(ii) Survey of AFG and PFDC representatives in Australia to identify opportunities for specific species and product combinations.

The results provide a useful reference point for comparison with the results from the economic spatial analyses. The methods described below and results (section) are mostly direct extracts from a previous report (Booth 2007).

Review of regional NRM plans

Access to most of these plans is available through the NRM website (www.nrm.gov.au). The NRM reports provide background information about various natural resource assets, including land, water, biodiversity, coastal, marine/estuarine, atmosphere, cultural heritage and community capacity. The current condition of natural resource assets is described, threats identified, and targets to maintain or restore their condition listed. In most cases only the NRM plans were readily available on the internet but in a few cases Investment Strategy documents were also downloadable. These provide some indication of how funds will be used to achieve the targets set in the NRM plans.

The targets are based around a hierarchy of resource condition targets (RCTs), management action targets (MATs) and management actions (MAs). The RCTs identify targets that could be addressed over 10-20 years, while MATs describe targets relevant to RCTs, but suitable for achieving within 1-5 years. MAs describe one or more actions related to a particular MAT. The targets should all be specific, time-constrained and measurable.

The NRM plans were reviewed to identify particularly MATs and MAs that concern farm forestry, agroforestry and/or the establishment of new forest plantations. Many of the plans include proposals for ecosystem restoration using native vegetation. As these activities would generally involve planting of local provenances in environmental plantings the numerous management action targets of this type were not included here. However, information was sometimes presented on the general state of forestry within a particular region, as existing infrastructure such as sawmills might assist the development of new forest industries.

The length of extracts in NRM plans was used to provide a simple index of the level of interest in agroforestry and farm forestry for each region. The regions were ranked on this word count and grouped in high, medium or low classes. Every region was contacted to check if there had been any changes with regard to agroforestry since the plans were produced. Nineteen regions replied. The self-assessment rankings of interest in agroforestry were generally similar to the rankings based on the NRM plans, though several replies indicated that the level of interest is variable between different sectors.

The NRM plans provide useful insights into the importance placed on tree planting in different regions. However, it is important to emphasize that issues such as salinity, water quality and quantity, biodiversity, soils, vegetation and communities are the main issues considered by the plans.

To check if there had been any changes since the plans were produced all NRM regions were sent an e-mail requesting updated information. This asked whether:

- There had been any changes of plan with regard to agroforestry/farm forestry/tree plantation development since the NRM plan was prepared
- Information could be provided about likely levels of future investment in agroforestry/farm forestry/tree plantation development either by the NRM body or by other organisations in their region
- They would rate the level of interest in their NRM region in agroforestry/farm forestry/tree plantation development as high, medium or low, and
- The level of interest is high or medium, and whether it was mainly in wood production, shade/shelter, dryland salinity amelioration, biodiversity, carbon sequestration or other benefits.

Survey of PFDC and AFG representatives

A questionnaire was sent to 20 AFG Branches and 23 Private Forestry Development Committees concerned with agroforestry and farm forestry. The survey had the following two paragraph introduction:

'You are invited to contribute to a national survey that will help the Joint Venture Agroforestry Program (JVAP) direct its future research funding. We seek your input to help identify particular agroforestry systems (i.e. plant species-product combinations) that have good prospects for rapid expansion in the next five years within your region. We are focusing on emerging species rather than well-established commercial plantation species such as Eucalyptus globulus spp. globulus (blue gum) or Pinus radiata (radiata pine).

Agroforestry can be defined broadly as the management of trees and shrubs integrated with agricultural systems for multiple products and benefits (JVAP R&D Plan 2004-2009). Agroforestry integrates trees or woody perennials, grown for fruits, nuts, seeds, plant extracts, timber, fodder or natural resource management, with grazing, cropping or other farm enterprises. Farm forestry is one type of agroforestry, where trees are managed in stands or woodlots for traditional wood products, but integrated into the whole-farm plan and farm business'.

The survey sought information on species likely to be planted in the next five years in 10 product categories: pulpwood, composite boards (including medium density fibreboard), bioenergy (including combustion for electricity, pyrolysis, gasification and lignocellolose for ethanol), firewood, oil only extraction, oil mallee (integrated production including electricity, charcoal, activated carbon and eucalyptus oil), fodder for grazing on site (including *Atriplex* species (saltbush), *Leucaena leucocephala*, and *Chamaecytisus palmensis* (Tagasaste)), harvested fodder for use off-site, sawlogs (including high value veneer timbers), environmental plantings and “other”.

In addition to indicating species likely to be planted in their particular region for the various product categories, respondents were asked to indicate suitable mean annual rainfall limits for the species for that product category and to estimate the likely area of new plantings in the next five years in four categories (<100ha, 100-500 ha, 500-1000 ha, >1000 ha). The areas usually refer to plantings by private landowner growers rather than commercial companies, though some estimates of large plantings included in replies obviously include estimates for commercial companies.

Questionnaires were sent to 20 AFG Branches (http://www.afg.asn.au/branches/afg_branches.html) and 23 Private Forestry Development Committees (http://www.daff.gov.au/forestry/plantation-farm-forestry/pfdcs). A follow-up call was made about three weeks later if the questionnaire had not been returned. Questionnaires to 27 of the PFDC and AFG regions were returned. Table 4 lists the agencies approached. The level of response was generally reasonable when both the AFG and PFDC sources are considered together.

Table 4. Summary table of PFDC and AFG representatives surveyed. An asterisk indicates a response.

State or Territory	PFDC	AFG
New South Wales	• Northern Inland* • Central Tablelands* • Murray Riverina* • Southern Tablelands* • South East • Northern Rivers • Lower North East	• Canberra/Monaro* • Central NSW* • Northern NSW* • South Coast NSW* • Shoalhaven • South West Slopes
Northern Territory	• Northern Territory*	
Queensland	• Private Forestry North Qld* • Central Qld Forestry Association* • Private Forestry Southern Qld	• Atherton Tablelands* • Mackay Whitsunday* • Mossman • Capricornia • Miriam Vale • Northern/Western Qld
South Australia	• Mt Lofty Ranges* • Kangaroo Island	• Green Triangle* • Mt Lofty/Kangaroo Island
Tasmania	• Private Forests Tasmania*.	• Tasmania*
Victoria	• Central* • Gippsland* • Plantations North East* • Green Triangle	• Ballarat* • North East Vic* • Gippsland • Melbourne
Western Australia	• Timber 2020* • Trees South West* • South East Forest Foundation* • Avongro wheatbelt tree cropping* • Trees Midwest*	• Tree Growers WA.

Scenario development

The development of appropriate and reasonably representative production systems and species appropriate for agroforestry across Australia was a critical first step in the spatial analysis. The production systems chosen were those considered to offer the best prospects for large-scale expansion of agroforestry and needed to include (Table 5):

- Appropriate species
- Silvicultural system such as establishment technique, initial spacing and, for harvested systems, thinning and pruning regimes, final harvest age and regeneration management (replanting or coppicing)
- Product options, and
- Costs and pricing information.

All of these factors vary on a regional basis. Furthermore, the 3-PG2 growth model, which was used to predict productivity, is sensitive to climatic, site and species-specific parameters. Therefore, the model needed to be calibrated to each species appropriate to the regional climate in which it is grown. For these reasons it was necessary to divide Australia into 5 ‘geoclimatic zones’ (Fig. 2) that would enable regional differences to be captured in species suitability, production and silvicultural system. These zones were defined on a largely arbitrary basis but sought to limit the number of zones to minimize the complexity of the growth modelling and spatial analyses while enabling sufficient capture of regional information. Zone 5 (the arid interior) was used only for a few of the scenarios because of its lack of suitability for most production systems.

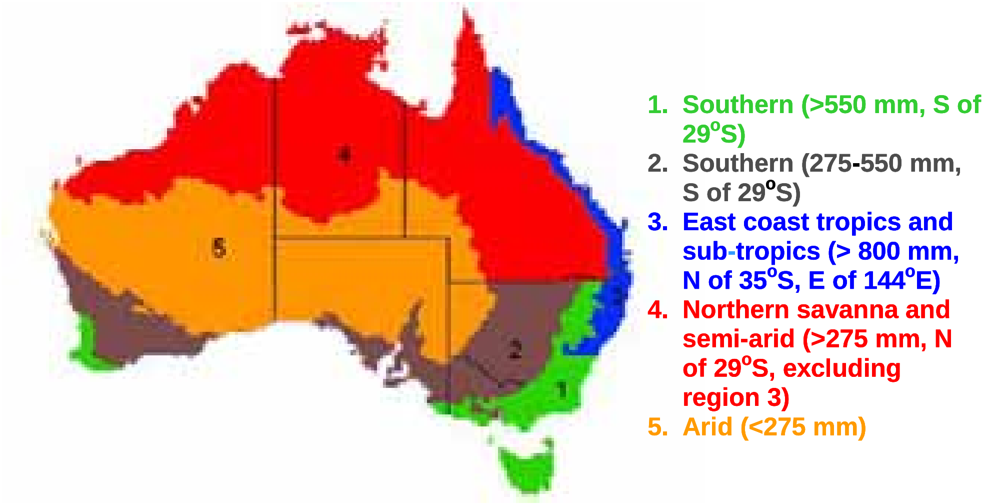


Fig. 2. The 5 geoclimatic zones of Australia used for productivity and economic modelling (Table 3).

The process for defining scenarios was:

- Extensive consultation (phone calls, e-mails) with a range of experts within regions (such as in state agencies, PFDCs) to identify suitable species and silvicultural systems. In many cases the silvicultural systems for a given species and production system, such as *P. radiata* for softwood sawlog systems, varies by State or even regionally within a State. Therefore, in such cases a production system was defined that was considered representative of the range of operational practices. For some zones, such as zone 4 (e.g. Northern savanna and semi arid) there is a limited history of agroforestry or plantation development and the appropriateness of the silvicultural systems will have less certainty.
- The possible products generated from each system were again identified through regional consultations. URS Forestry supplied regional information particularly for the conventional industrial species

- The costs associated with forestry operations (establishment, maintenance, harvesting) and pricing information were obtained from various sources including regional consultations and the published literature. Company information on some specific costs and sales contracts was often confidential and therefore could not be disclosed. Further details on costs and pricing information are given in the section ‘Economics’
- Although several species may be appropriate within regions, in some cases there were few data for purposes of growth modelling. Therefore we chose one species within each region to be modelled as an indicator of the productivity that might be expected for other species options.

Defining the sawlog production systems was particularly challenging because of the possible variations in silvicultural systems and product options from thinnings and final harvest that affect economic outcomes. The split of harvested volumes into its various product streams varies regionally with agroforestry systems, the market options available, the proximity of those markets to the agroforestry resources and product prices. It was impossible to capture the entire matrix of combinations in this exercise and as they varied by region. Rather we established for each production system within a geoclimatic zone, a single split of harvested wood into its various product streams while recognising that there would be many different markets, for any given location, for the harvested wood.

Table 5. Definition of agroforestry scenarios used.

System number and name	1. Southern wet (>550 mm, S of 29°S)	2. Southern dry (275-550 mm, S of 29°S)	3. East coast tropics and sub-tropics (> 800 mm, N of 35°S, E of 144°E)	4. Northern savanna and semi-arid (>275 mm, N of 29°S, excluding Region 3)
1. Hardwood sawlogs	**1.1**	**1.2**	**1.3**	**1.4**
Possible species	*E. globulus, E. nitens, E. saligna*	*E. cladocalyx, Corymbia. maculata, E. camaldulensis hybrids*	*Corymbia citriodora variegata* (CCV), *E. dunnii, E. pilularis, E. cloeziana, E. pellita, E. grandis*	*E. camaldulensis, E. pellita, E. longirostrata, E. tereticornis, Khaya, Tectona*
Species to be modelled as productivity indicator	*E. globulus*	*E. cladocalyx*	*E. grandis*	*E. camaldulensis*
Initial stocking (sph)	1000	1000	1000	800
First thin (years, sph)	6, 150	5, 700	3, 500	3, 500
Second thin (years, sph)	n/a	10, 500	12, 200	12, 200
Third thin (years, sph)	n/a	15, 150	n/a	n/a
Final harvest (years)	20	30	20	20
First prune (years)	3	1 (form prune), 3	3	4
Second prune (years)	5	6	6	7
Possible products	Sawlogs, appearance products, flooring, poles&posts, chip export, pulpwood, composites, LVL&plywood	Sawlogs, appearance products, flooring, poles & posts, composites, LVL&plywood	Sawlogs, poles&posts, chip export, pulpwood, composites, LVL&plywood	Sawlogs, poles&posts, chip export, pulpwood, composites, LVL&plywood
Thinning product split	Non commercial	• Thin I – non commercial • Thin II - 70% pulpwood and 30% sawlog (grade C) • Thin III = 70% sawlog (grade B) and 30% pulpwood	• Thin I – non commercial • Thin II = 70% sawlog (grade B) and 30% pulpwood	• Thin I – non commercial • Thin II – 70% sawlog (grade B) and 30% pulpwood
Harvest product split	• 40% pruned sawlog (grade A), • 26% unpruned sawlog (grade B), • 17% industrial sawlog (grade C)	• 60% pruned sawlog (grade A) • 40% pulpwood	• 10% poles, • 31% pruned sawlog (grade A) • 35% unpruned sawlog (grade B) • 8% industrial sawlog	• 10% poles • 31% pruned sawlog (grade A) • 35% unpruned sawlog (grade B) • 8% industrial sawlog

System number and name	**1. Southern wet (>550 mm, S of 29^{o}S)**	**2. Southern dry (275-550 mm, S of 29^{o}S)**	**3. East coast tropics and sub-tropics (> 800 mm, N of 35^{o}S, E of 144^{o}E)**	**4. Northern savanna and semi-arid (>275 mm, N of 29^{o}S, excluding Region 3)**
	• 17% pulpwood		(grade C) • 16% pulpwood	(grade C) • 16% pulpwood
<u>Costs and prices</u>				
Establish cost (\$ ha^{-1})	1500	1200	1800	1100
Post-establish (\$ ha^{-1})	150	75	150	75
Annual management (\$ ha^{-1})	80	30	80	30
Pruning (\$ ha^{-1})	210	210	210	210
Marking (\$ ha^{-1})	100	100	100	100
Thinning (\$ ha^{-1})	300	300	300	300
Roading (\$ ha^{-1})	400	200	400	200
Harvesting cost (\$ m^{-3})	17	17	17	17
Transport cost (\$ m^{-3} km^{-1})	0.12	0.12	0.12	0.10
Domestic pulpwood price (\$ m^{-3})	75	98	98	115
Sawlog grade A (\$ m^{-3})	95	95	95	95
Sawlog grade B (\$ m^{-3})	85	85	85	85
Sawlog grade C (\$ m^{-3})	75	75	75	75
2. Softwood sawlogs	**2.1**	**2.2**	**2.3**	**2.4**
Possible species	*P. radiata*	*P. pinaster*, *P. brutia*, *P. canariensis*	PEExPCH *(P. caribaea/ P. elliottii)*	*P. taeda*, *P. eldarica*
Species to be model as productivity indicator	*P. radiata*	*P. pinaster*, *P. brutia*	PEExPCH	PEExPCH
Initial stocking (sph)	1500	1500	833	800
First thin (years, sph)	10, 600	12, 700	17, 400	7, 400
Second thin (years, sph)	18, 250	18, 300	n/a	15, 250
Third thin (years, sph)	n/a	24, 150	n/a	20, 125
Final harvest (years)	30	30	30	35
First prune (years)	none	none	none	none

System number and name	**1. Southern wet (>550 mm, S of 29°S)**	**2. Southern dry (275-550 mm, S of 29°S)**	**3. East coast tropics and sub-tropics (> 800 mm, N of 35°S, E of 144°E)**	**4. Northern savanna and semi-arid (>275 mm, N of 29°S, excluding Region 3)**
Second prune (years)	none	none	none	none
Possible products	Sawlogs, treated poles & posts, small sawlogs, chip export, composites, LVL & plywood	Sawlogs, treated poles & posts, small sawlogs, chip export, composites, LVL & plywood	Sawlogs, treated poles & posts, small sawlogs, chip export, composites, LVL & plywood	Sawlogs, treated poles & posts
Thinning product split	• Thin I – non commercial • Thin II - 70% pulpwood and 30% sawlog (Grade C)	• Thin I – non commercial • Thin II = 70% pulpwood and 30% sawlog (grade C) • Thin III – 70% sawlog grade (B) and 30% pulpwood	• Thin I – non commercial	• Thin I – non commercial • Thin II – 70% pulpwood and 30% sawlog (grade C) • Thin III = 70% sawlog (grade B) and 30% pulpwood
Harvest log split	• 80% sawlog (grade B) • 20% pulpwood	• 80% sawlog (grade B) • 20% pulpwood	• 80% sawlog (grade B) • 20% pulpwood	• 80% sawlog (grade B) • 20% pulpwood
Costs and prices				
Establish cost (\$ ha^{-1})	1800	1500	1600	1000
Post-establish (\$ ha^{-1})	150	75	150	75
Annual management (\$ ha^{-1})	80	30	80	30
Marking (\$ ha^{-1})	100	100	100	100
Roading (\$ ha^{-1})	400	200	400	200
Harvesting cost (\$ m^{-3})	15	15	15	15
Transport cost (\$ m^{-3} km^{-1})	0.18	0.16	0.14	0.14
Pulpwood price (\$ m^{-3})	52	60	69	69
Export wood chip price (\$ m^{-3})	80	80	80	80
Sawlog grade A (\$ m^{-3})	65	65	65	65
Sawlog grade B (\$ m^{-3})	60	60	60	60
Sawlog grade C (\$ m^{-3})	55	55	55	55
3. Pulpwood	**3.1**	**3.2**	**3.3**	**3.4**
Possible species	*E. globulus, E. nitens*	*P. pinaster*	*E. grandis, E. dunnii,* *E. grandis* x *camaldulensis*	*A. mangium,* *E. camaldulensis*

System number and name	**1. Southern wet (>550 mm, S of 29°S)**	**2. Southern dry (275-550 mm, S of 29°S)**	**3. East coast tropics and sub-tropics (> 800 mm, N of 35°S, E of 144°E)**	**4. Northern savanna and semi-arid (>275 mm, N of 29°S, excluding Region 3)**
Species to be modelled as productivity indicator	*E. globulus*	*P. pinaster*	*E. grandis*	*E. camaldulensis*
Initial stocking (sph)	1000	1100	1250	1100
First harvest (years)	10	20	10	12
Return on coppice (years)	10	20	10	12
Coppice or replant	coppice	replant	coppice	coppice
<u>Costs and prices</u>				
Establish cost $(\$\ \mathrm{ha}^{-1})$	1500	1200	1800	1200
Post-establish $(\$\ \mathrm{ha}^{-1})$	150	75	150	75
Annual management $(\$\ \mathrm{ha}^{-1})$	80	30	80	30
Pruning $(\$\ \mathrm{ha}^{-1}\ \mathrm{lift}^{-1})$	n/a	n/a	n/a	n/a
Coppice management $(\$\ \mathrm{ha}^{-1})$	50	50	50	50
Marking $(\$\ \mathrm{ha}^{-1})$	n/a	n/a	n/a	n/a
Roading $(\$\ \mathrm{ha}^{-1})$	300	150	300	150
Harvesting cost $(\$\ \mathrm{m}^{-3})$	17	17	17	17
Transport cost $(\$\ \mathrm{km}^{-1}\ \mathrm{m}^{-3})$	0.16	0.16	0.12	0.10
Pulpwood price $(\$\ \mathrm{m}^{-3})$	72	72	98	115
4. Bioenergy	**4.1**	**4.2**	**4.3**	**4.4**
Possible species	*E. globulus*	*E. cladocalyx, E. tricarpa*	*E. grandis*	*A. mangium,* *E. camaldulensis*
Species to be modelled as productivity indicator	*E. globulus*	*E. cladocalyx*	*E. grandis*	*E. camaldulensis*
Initial stocking (sph)	1500	1300	1250	1500
Coppice or replant	coppice	Coppice	coppice	Coppice
First harvest (years)	10	10	10	12
Return on coppice (years)	10	10	10	12
Products (whole plant)	energy	energy	energy	energy

System number and name	**1. Southern wet (>550 mm, S of 29°S)**	**2. Southern dry (275-550 mm, S of 29°S)**	**3. East coast tropics and sub-tropics (> 800 mm, N of 35°S, E of 144°E)**	**4. Northern savanna and semi-arid (>275 mm, N of 29°S, excluding Region 3)**
<u>Costs and prices</u>				
Establish cost (\$ ha^{-1})	1500	1300	2000	1300
Post-establish (\$ ha^{-1})	150	75	150	75
Annual management (\$ ha^{-1})	80	30	80	30
Roading (\$ ha^{-1})	200	30	200	30
Harvesting cost (\$ t^{-1})	14	12	14	12
Transport cost (\$ t^{-1} km^{-1})	0.12	0.12	0.12	0.12
Delivered price (\$ t^{-1} green)	21	23	22	22

5. Integrated Tree Processing	**5.1**	**5.2**	**5.3**	**5.4**
Possible species	*E. globulus, E. cneorifolia, E. viridis_wimmerensis , E. polybractea, E. dives, E. radiata*	*E. loxophleba lissophloia, E. polybractea, E. horiste, E. viridis, E. porosa, E. oleosa, E. kocchii*	*?*	Northern mallees eg *E. bakerii*
Species to be modelled as productivity indicator	*E. globulus*	*E. polybractea*	*E. grandis*	*E. camaldulensis*
Initial stocking (sph)	1500	1500	1800	1500
Products (whole plant)	oil, charcoal, energy	oil, charcoal, energy	energy, charcoal, oil	charcoal, energy, oil
First harvest (years)	2	3	2	3
Return on coppice (years)	2	3	2	3
Coppice or replant	coppice	Coppice	coppice	Coppice
<u>Costs and prices</u>				
Establish cost (\$ ha^{-1})	1500	1300	1800	1500
Post-establish (\$ ha^{-1})	150	75	150	75
Annual management (\$ ha^{-1})	80	30	80	30
Roading (\$ ha^{-1})	200	30	200	30
Harvesting cost (\$ t^{-1})	12	10	12	10
Transport cost (\$ t^{-1} km^{-1})	0.12	0.12	0.12	0.12
Delivered price (\$ t^{-1} green)	32	36	25	28

System number and name	**1. Southern wet (>550 mm, S of 29°S)**	**2. Southern dry (275-550 mm, S of 29°S)**	**3. East coast tropics and sub-tropics (> 800 mm, N of 35°S, E of 144°E)**	**4. Northern savanna and semi-arid (>275 mm, N of 29°S, excluding Region 3)**
Carbon price (\$ t^{-1} CO_2e)	n/a	15	n/a	n/a
6. In situ fodder	**6.1**	**6.2**	**6.3**	**6.4**
Possible species	*Acacia saligna, Atriplex amnicola, Chamaecytisus palmensis*	*Atriplex nummularia, Atriplex amnicola, Acacia saligna*	*Leucaena* spp?	*Leucaena* spp?
Species to be modelled as productivity indicator	*Atriplex nummularia*	*Atriplex nummularia*	*Atriplex nummularia*	*Atriplex nummularia*
Initial stocking (sph)	2000	1500	2000	2000
First harvest (years)	1	2	1	1
Return on coppice (years)	1	2	1	1
Products (edible leaf & fine twig)	forage	forage	forage	forage
Costs and prices				
Establish cost (\$ ha^{-1})	1075	825	1075	1075
Post-establish (\$ ha^{-1})	n/a	n/a	n/a	n/a
Annual management (\$ ha^{-1})	10	10	10	10
Harvesting cost (\$ t^{-1})	n/a	n/a	n/a	n/a
In-situ price (\$ t^{-1} edible green)	65	65	65	65
7. Environmental carbon plantings	**7.1**	**7.2**	**7.3**	**7.4**
Species	Mixed species	Mixed species	Mixed species	Mixed species
Initial stocking (sph)	1500	1500	1500	1500
Type of establishment	Direct seeded	Direct seeded	Direct seeded	Direct seeded
Costs and prices				
Establish cost (\$ ha^{-1})	750	750	750	750
Post-establish (\$ ha^{-1})	150	75	150	75
Annual management (\$ ha^{-1})	40	15	40	15
Up-front legal fees etc (\$ ha^{-1})	10	10	10	10

System number and name	**1. Southern wet (>550 mm, S of 29°S)**	**2. Southern dry (275-550 mm, S of 29°S)**	**3. East coast tropics and sub-tropics (> 800 mm, N of 35°S, E of 144°E)**	**4. Northern savanna and semi-arid (>275 mm, N of 29°S, excluding Region 3)**
Annual pooling cost (\$ ha^{-1} yr^{-1})	2.5	2.5	2.5	2.5
Carbon price (\$ t^{-1} CO$_2$e)	20	20	20	20
8. Hardwood carbon plantings	**8.1**	**8.2**	**8.3**	**8.4**
Species to be model as productivity indicator	*E. globulus*	*E. cladocalyx*	*E. grandis*	*E. camaldulensis*
Initial stocking (sph)	1000	1000	1000	800
<u>Costs and prices</u>				
Establish cost (\$ ha^{-1})	1500	1200	1800	1100
Post-establish (\$ ha^{-1})	150	75	150	75
Annual management (\$ ha^{-1})	40	15	40	15
Carbon price (\$ t^{-1} CO$_2$e)	20	20	20	20
9. Softwood carbon plantings	**9.1**	**9.2**	**9.3**	**9.4**
Species to be model as productivity indicator	*P. radiata*	*P. pinaster, P. brutia*	PEExPCH	PEExPCH
Initial stocking	1500	1500	800	800
<u>Costs and prices</u>				
Establish cost (\$ ha^{-1})	1800	1500	1600	1000
Post-establish (\$ ha^{-1})	150	75	150	75
Annual management (\$ ha^{-1})	40	15	40	15
Carbon price (\$ t^{-1} CO$_2$e)	20	20	20	20
10. Mallee carbon plantings	**10.1**	**10.2**	**10.3**	**10.4**

System number and name	**1. Southern wet (>550 mm, S of 29°S)**	**2. Southern dry (275-550 mm, S of 29°S)**	**3. East coast tropics and sub-tropics (> 800 mm, N of 35°S, E of 144°E)**	**4. Northern savanna and semi-arid (>275 mm, N of 29°S, excluding Region 3)**
Species to be modelled as productivity indicator		The average of *E. loxophleba lissophloia*, *E. polybractea*, *E. kocchii*		
Initial stocking		1100		
Costs and prices				
Establish cost (\$ ha^{-1})		1500		
Post-establish (\$ ha^{-1})		75		
Annual management (\$ ha^{-1})		80		
Carbon price (\$ t^{-1} CO_2e)		20		

Spatial layers

Spatial projects can often be large and complex exercises and a key requirement is to source and manage large data sets. The definitions of data layers and their sources are given in Table 6. The data management process involved assimilating existing GIS vector (polygon, line, point) and raster or grids data and utilising them to generate new GIS layers. The spatial modelling exercise was undertaken at a resolution of 1 km, giving 7.7 million data points for Australia. In total, over 80 new raster GIS layers (more than 100 gigabytes) were produced from the modelling undertaken by 3-PG2 and the economic tool.

Ancillary datasets were purchased or available free from known sites at BRS. The process of generating new data included:

- Projecting all GIS datasets into Albers format to enable measurement of distances and area
- Resampling of raster GIS layers to 1 km grid cells as the minimum mapping unit for the project
- Back-up of data on a dedicated server
- Generation of new layers for growth, carbon sequestration, economic outputs, water interception and biodiversity
- Loading of GIS layers into the SPIF tool for visualisation and interrogation.

The SPIF tool was designed to house multiple GIS datasets for multi-criteria analysis housed on a central CSIRO data server.

Table 6. GIS layers and their derivations.

Data layer	Description	Units	Source
Ancillary data			
Regional boundaries (2006) for: • Catchment Management Authority/ NRM region • National Plantation Inventory	Boundaries of individual CMAs and NPI regions	Polygon	BRS
Integrated Vegetation Cover (2003)	Includes existing remnant vegetation, the commercial plantation estate, agriculture and urban land	Land cover type (raster)	BRS
Roads	Includes paved and unpaved roads	Line	BRS
Processing facilities and ports	Includes timber processing facilities for hardwood and softwood sawlogs, pulplogs and export ports for sawlogs and woodchips	Points	Flora-Search and BRS
Cities		Points	BRS
Profit Full Equity (PFE) (1997)	The opportunity cost of the preceding agricultural enterprise	\$ ha^{-1} yr^{-1}	NLWA
Climate surfaces.	Includes average annual rainfall records for 1970–2005.	mm yr^{-1}	ANU ANUCLIM 5.1
Frost Surface	Average number of frost days per month.	Frost days month^{-1}	DCC
Landsat Satellite Image Base Map	Includes national coverage of 25 metre resolution colour imagery.	n/a	DCC
Generated by 3-PG2		(rasters)	
Wood volumes	The volumes of commercial timber from thinning and harvest.	m^3 ha^{-1} or m^3 ha^{-1} yr^{-1}	CSIRO
Growth rate	The mass (fresh or dry) in vegetation	t ha^{-1} yr^{-1}	CSIRO
Carbon sequestration	The mass of total carbon stored in live vegetation (roots, stems, foliage,	t ha^{-1} yr^{-1}	CSIRO

Data layer	Description	Units	Source
	branches and bark).		
AER and NAER		(rasters)	
Annual Equivalent Return (AER)	The annualised Net Present Value (NPV) of an agroforestry system	$\$\ \text{ha}^{-1}\ \text{yr}^{-1}$	CSIRO
Net Annual Equivalent Return (NAER)	The net return from an agroforestry systems taking into account the opportunity cost. NAER =AER - PFE	$\$\ \text{ha}^{-1}\ \text{yr}^{-1}$	CSIRO
Other		(rasters)	
Soil Depth	Maximum soil depth derived from a soil terrain analysis technique (MRVBF) to determine soils with profiles deeper than 2 m.	metres	CSIRO
Soils AWC	Soil Available Water Capacity derived from Australian Soil Atlas polygons (McKenzie *et al*. 2000) http://www.brs.gov.au/data/datasets.	mm	CSIRO and BRS
Water Interception	The amount of water intercepted by forest compared to grasslands and based on empirical data.	mm yr^{-1}	CSIRO
Biodiversity score	A score based on proximity of new forests to existing forests. 1=most cleared and furthest from remnant area; 100 = most pristine	1-100	CSIRO

Growth modelling

The 3-PG2 version (in Excel™ VB™ script) of the 3-PG model was used to model growth. A full description of 3-PG has been provided by Landsberg and Waring (1997), Sands and Landsberg (2002), and Sands (2004). 3-PG predicts stand development and mass of stem, root and foliage components, stand water use, and available soil water.

Data required to run 3-PG include monthly climate data (air temperature, vapour pressure deficit, solar radiation, rainfall, and number of frost days), site factors (latitude, soil texture, maximum available soil water storage, and soil fertility rating), initial conditions of biomass and stocking rates, and management conditions (e.g. fertiliser application, irrigation and thinning). Parameters in 3-PG determining canopy structure and quantum efficiency, partitioning of biomass, basic wood density, litterfall and root turnover rates, and various environmental modifiers, are all likely to be species-dependent. The model runs on a monthly time-step and outputs include diameter at breast height (DBH), stem volume (SV), leaf area index (LAI) and biomass of tree components.

The 3-PG2 version has a number of improvements over the original that essentially provides a more robust method for calculating plant available water, stand water use, biomass partitioning and inclusion of understorey as opposed to modelling only a single stratum of trees (Almeida *et al*. 2007).

Data collation

The forest growth model 3-PG is widely used and has already been calibrated to *E. globulus* (Sands and Landsberg 2002, Booth *et al.* 2006, Almeida *et al.* 2007); *P. radiata* (J. Landsberg pers. comm., Rodriguez *et al*. 2002, Coops *et al*. 1999, Almeida *et al*. 2007); *Corymbia maculata* and *E. cladocalyx* (Booth *et al.* 2004, Paul *et al.* 2007, Almeida *et al*. 2007) and environmental plantings (England *et al.* 2006). However, re-calibrations were required in the present study due to the use of a newer version of the model, and datasets were extended to include a wider range of sites and species (Table 7).

Table 7. Number of locations from which growth data were collated for calibration and validation of 3-PG2. Note that some of these locations had multiple growth measurements from different times or treatments.

Species/forest type	Number of calibration sites	Number of validation sites
E. globulus	48	47
C. maculata/*E. cladocalyx*	96	57
E. camaldulensis	38	15
E. grandis	15	20
Oil mallees	24	0
Pinus radiata	28	24
P. pinaster	28	10
P. caribaea, P. elliottii and their hybrids	14	6
Environmental plantings	53	16

Across all stands, data collated included date of establishment, location (latitude and longitude), initial and final stocking, and any changes in stocking due to thinning. Most sites also had measures of stem diameter (at breast height of 1.3 m or at 10-50 cm for environmental plantings and oil mallees) and height, while some also had measures of biomass of tree components.

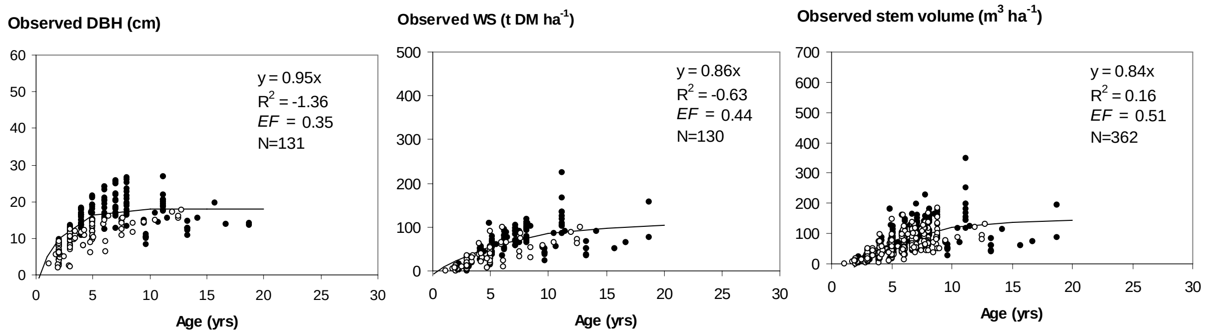
A large part of the data set and extrapolations from, for example, stem diameter to volume are based on allometric relationships that CSIRO has collated over the past few decades from destructive harvesting of stands or data collated from other sources (for example Paul *et al*. 2006a, 2006b, 2007, 2008). That is, they are based on our best available knowledge and should be a reasonable representation of expected growth rates. Moreover, the data in Fig. 3 set the constraints for expected maximum rates of growth by identifying the upper limits across all data for attributes such as stem volume.

Plantations of *E. cladocalyx* and *C. maculata* were grouped into the one dataset given that growth rates were relatively similar (Paul *et al*. 2008) as were datasets for *P. caribaea, P. elliottii* and their hybrid (Fig. 3).

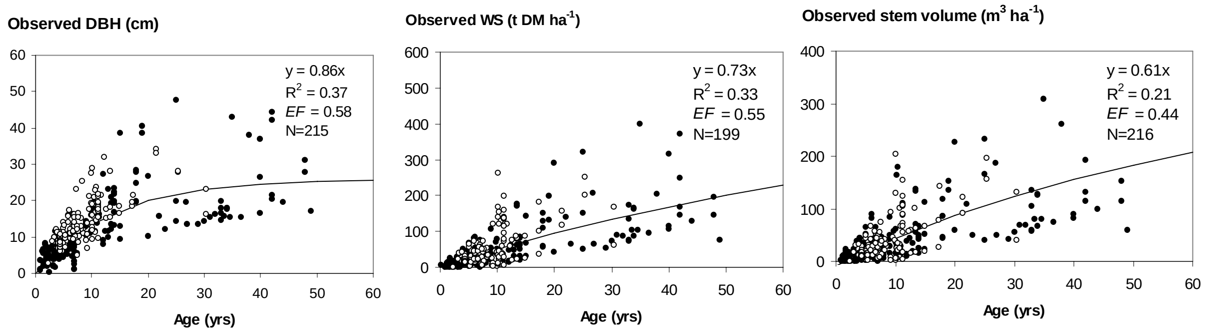
Sites were randomly divided into calibration or validation datasets with the exception of stands previously used for calibration of earlier versions of 3-PG (England *et al.* 2006, Almeida *et al*. 2007, Paul *et al.* 2007) which were again used for model calibration.

Data from sites which were known to have trees accessing a water table were not collated in the present study because the 3-PG2 model has not been tested for those conditions. Coppiced stands were also not included in the current analysis.

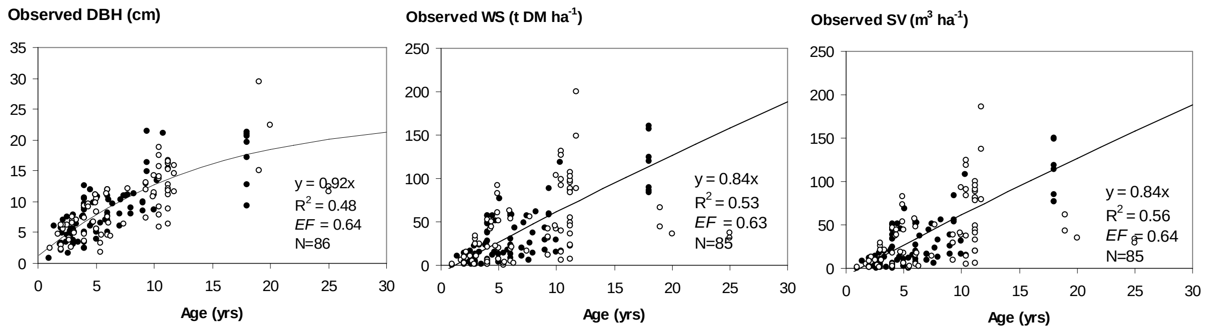
E. globulus



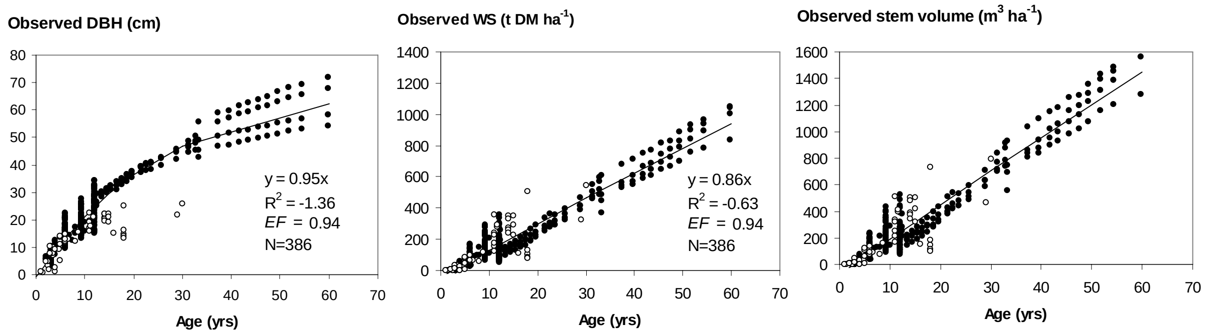
E. cladocalyx and *C. maculata*



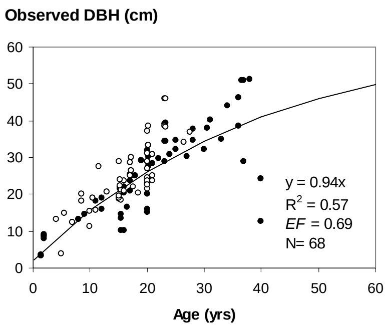
E. camaldulensis

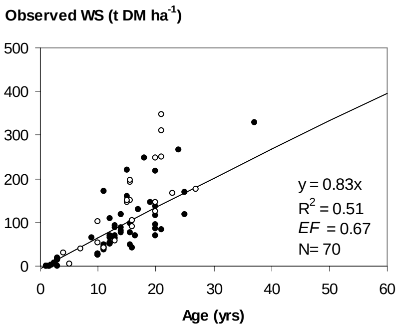


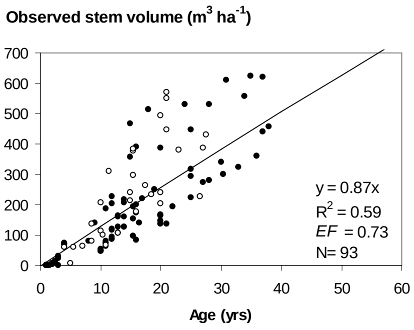
E. grandis



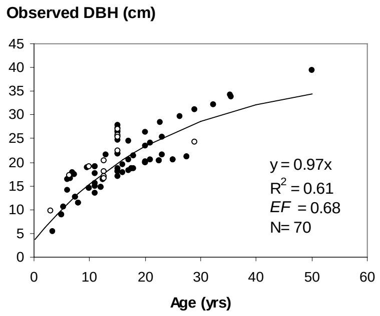
P. radiata

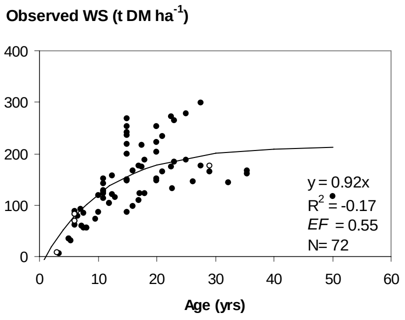


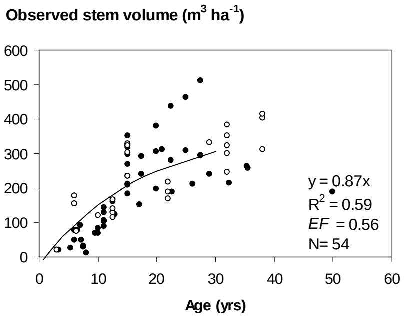




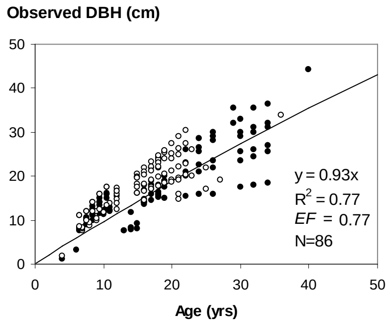
P. elliottii/caribaea

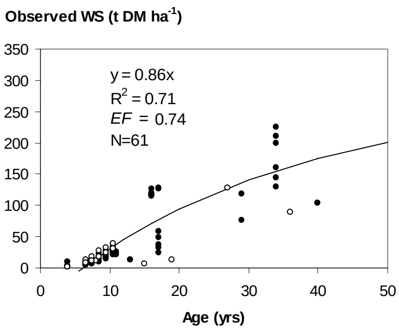


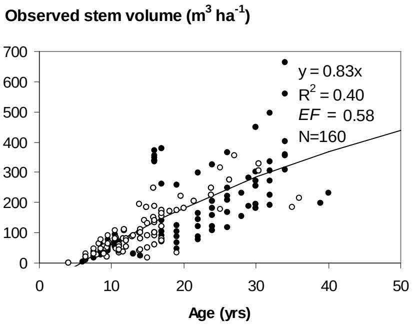




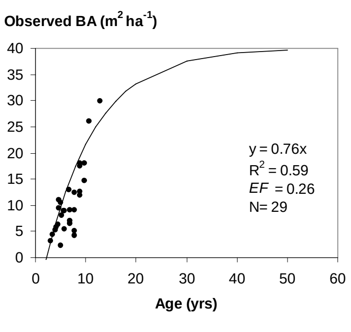
P. pinaster

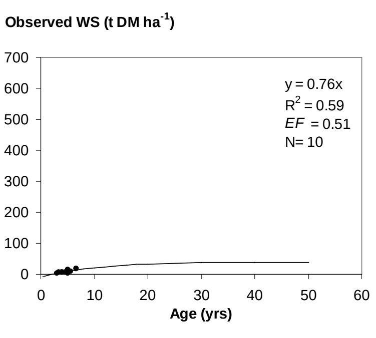






Oil mallees





Environmental plantings

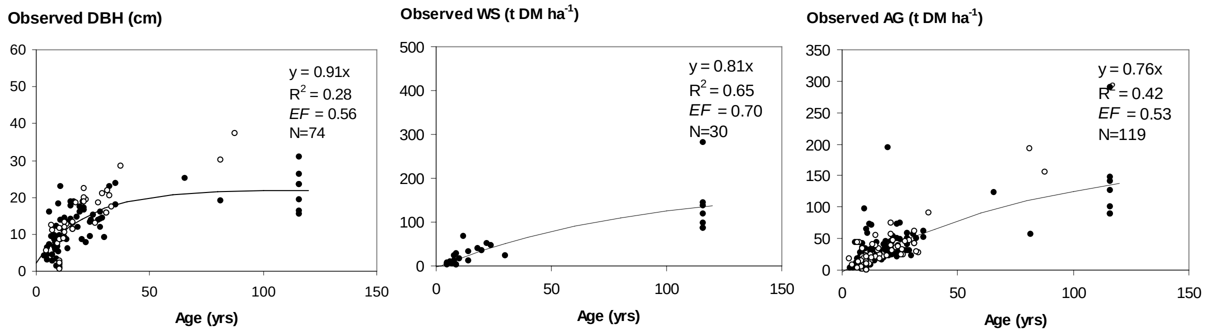


Fig. 3. Relationship across the calibration datasets (closed symbols) between stand age and DBH (or basal area for oil mallees), WS (mass of stem+branches) and stem volume (or above-ground biomass (AG) for environmental plantings). Validation datasets (open symbols) are also plotted to provide an independent test of this relationship. Note changes in scale between plots. Unlike other planting types, oil mallees were all relatively young. The curve fitted to the oil mallee growth data was not the line of best fit, but one that was considered realistic growth rates for these plantings.

Input data and assumptions

For all stands in both calibration and validation datasets, daily climatic data were obtained from SILO Data Drill for the period from time of planting up until the time of the last growth measurement at the site (Jeffrey *et al.* 2001). These daily data were converted to average monthly maximum and minimum air temperature, total monthly rainfall, number of rain days per month, average monthly solar radiation, vapour pressure deficit, and number of frost days per month (i.e. minimum air temperature < 0^{o}C).

Across most of Australia and particularly in the low-medium rainfall zones, the availability of water is the primary determinant of plant productivity. The ability to model soil water dynamics is therefore of critical importance. This is calculated in 3-PG based on the soil depth and the critical soil water contents at permanent wilting point, field capacity and saturation. These critical soil water contents are based on soil textural class in accordance with the soil attributes table in 3-PG (Almeida *et al*. 2007). Where soil depth or textural class were not known, these were derived from spatial surfaces of these properties as described below.

3-PG uses an empirical index of soil fertility (FR) to describe nutrient availability as it affects growth. Each site was assigned a fertility rating (*FR*) that was based on a decision tree. Generally, sites from which data were collated were well managed (good weed control and fertiliser applied) on land previous under improved pasture. Site *FR*s were therefore generally assumed to be between 0.7 and 0.9, or between 0.4 and 0.6 where it was known that soils were particularly infertile or growth was impeded by salinity, shallow soil depth or poor drainage.

Environmental plantings generally included a mixture or eucalypts, acacias and shrubs of various species (England *et al.* 2006). Although some environmental plantings had wide spacing with pasture between planted rows, we also assumed that forest cover was 100% and that pasture was not contributing to water-use. Often initial stocking of environmental plantings was not known, and in such cases, we assumed an initial stocking of 800 sph for sites established with tube stock or 2000 sph for sites established with direct-seeding or natural regeneration, respectively. We also assumed all species that had a measurable DBH were part of the overstorey, while all remaining multi-stemmed shrubs and small acacias formed the understorey. In contrast to calibrations of environmental plantings by Almeida *et al*. (2007), the understorey was modelled in the present study.

Oil mallee plantings had all been established in widely-spaced belts (80 to 120 m between belts) with the number of tree rows within belts varying from 2 to 10. In these circumstances there may be ‘edge effects’ such that trees on the outer rows can access more water and light and thus grow at increased rates. The percentage of ‘edge’ trees was calculated at each site based on the number of rows planted in the belt and were assumed to have a growth enhancement of 20%.

Calibration and validation

Calibrations were done manually for each planting type by adjusting parameters relating to partitioning of biomass, litterfall and root turnover, volume of soil accessed by roots, sensitivity to temperature, frost and age, stem mass at which self thinning is triggered, maximum thickness of water retained on leaves following rainfall and maximum canopy conductance. Key parameters used to calibrate the model were those to which it was most sensitive.

These calibrations were attained primarily by adjusting key parameters in 3-PG to maximise model efficiency (*EF)* for prediction of DBH (or basal area at 10 cm for oil mallee), mass of stem wood, bark and branches (WS), and the stem volume (SV) for plantations (except oil mallees), or above-ground biomass (AGB) for environmental plantings. Greatest emphasis was given to maximising accuracy of predictions for DBH or basal area because these are direct measurements. Other estimates of growth such as volumes are often calculated and therefore are subject to greater uncertainty.

We also ensured that seasonal trends and fluctuations of LAI, interception, evaporation, transpiration and soil water content were predicted accurately across all six *E. globulus* sites, and all six *P. radiata* sites where such data were available.

Once calibrated, validation datasets of each planting type were used to verify model predictions of DBH, WS and SV or AGB using the assumptions and parameter set derived from calibration.

Datasets collated were used to assess how well age alone could explain variations in growth and the improvement gained by using the 3-PG2 model. EF was calculated to determine the precision and accuracy of equations describing the relationship between stand age and measures of growth. The *EF* is a measure indicating the extent to which model predictions match that observed across each calibration dataset: $EF = 1 - [\sum(O_i - P_i)^2 / \sum(O_i - \bar{O})^2]$, where O_i are the observed values, P_i are the predicted values, and $\bar{O}$ is the mean of the observed data. Values of *EF* can be positive or negative with a maximum value of one (Soares *et al.* 1995). A positive value indicates that simulated values describe trend in measured data better than mean of observations, with a value of one indicating a perfect fit. A negative value indicates that simulated values describe data less well than a mean of observations.

Age alone can be a reasonably good predictor of growth in general terms (model efficiency of 59%), but there is considerable variation in growth between sites for a given species that is not explained by stand age. This is largely attributable to other factors such as climatic conditions, soil properties (as they affect water availability) and variations in management such as thinning regimes.

The extent to which variation in growth across all plantings was explained was increased two-fold when the 3-PG model was used compared with using age alone as an explanatory variable (R^2 value increased from 0.36 to 0.70 across all sites). Similarly, the slope of the line of best fit between observed and predicted growth averaged only 0.87 when using age alone but increased to an average of 0.92 when using 3-PG2.

The calibrated model was tested against the validation datasets (Fig. 4). Measurements of diameter were predicted with an average model efficiency of 62%. Model efficiencies were poorer (43-57%) for oil mallee and environmental plantings reflecting the diversity of species and environments simulated. In particular, the environmental plantings data are for a diverse range of forest types, ranging from eucalypt monocultures (but of local provenance) to mixed species trees and shrubs. In reality each of these would require a separate calibration to 3-PG2. Here, we have combined data to indicate the rates of growth that might be expected for these forest types.

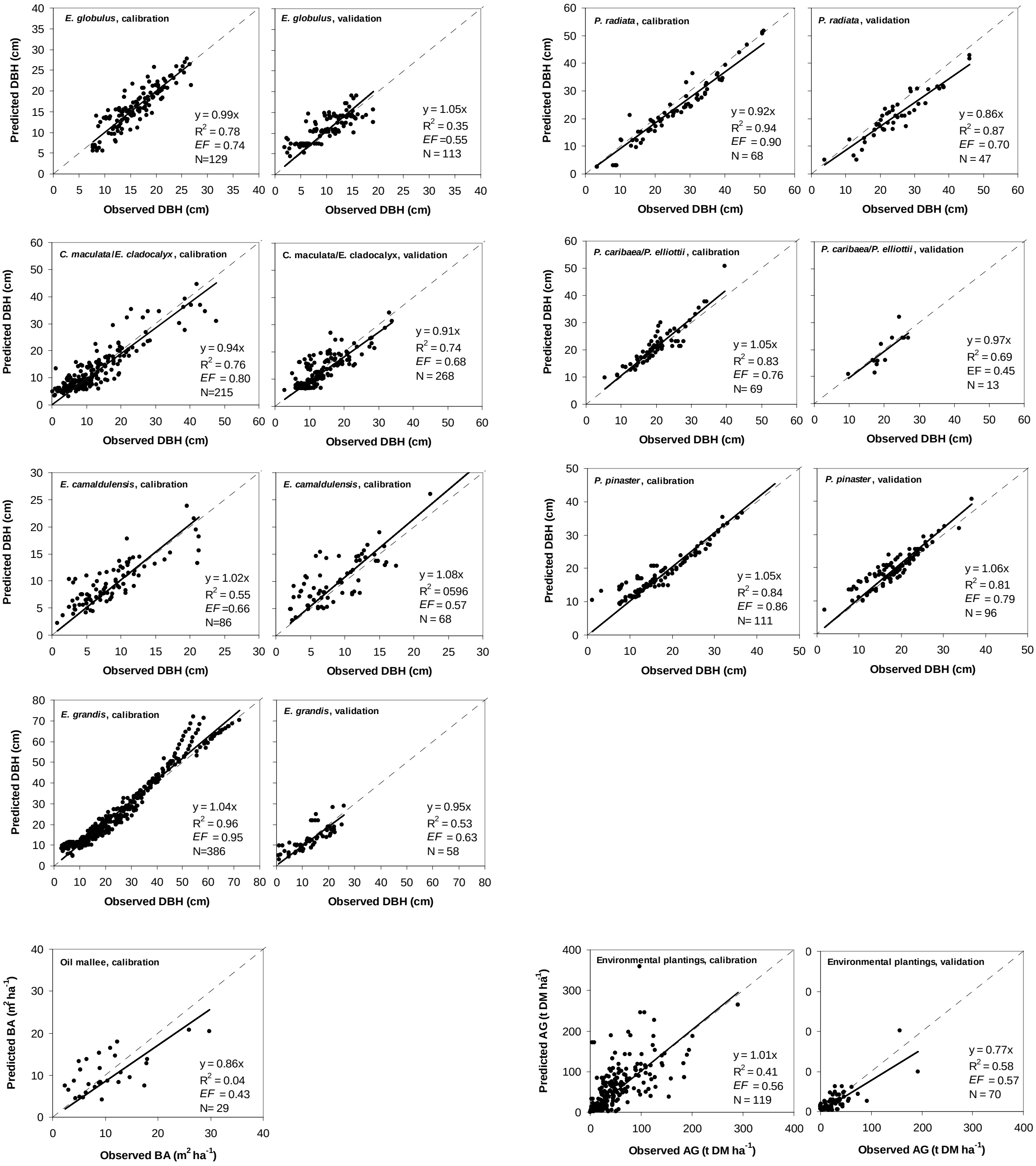


Fig. 4. Relationship between observed and predicted DBH (or BA for oil mallees, or above-ground biomass for environmental plantings), across the calibration and validation datasets.

The generally good relationships between observed and independently predicted (validated) values for tree diameter or biomass lend confidence that the results from the spatial analysis will be reasonably robust (with a few qualifications that are discussed later). In particular, the modelling is based on an extensive data set which has helped to constrain the limits of growth across the species and regions being assessed.

Spatial application of 3-PG and inputs

The 3-PG2 model, having been calibrated and validated for the various species and forest types, was run spatially across the five geoclimatic zones of Australia according to the scenarios described in Table 3. Spatial outputs included stem volumes at times of thinning or final harvest, above-ground biomass and total carbon sequestered in live vegetation. Spatial inputs required were climate, soil depth, soil texture and initial available soil water content.

Climate layers of long term monthly rainfall, maximum and minimum temperature and solar radiation were derived from the ESOCLIM (Houlder *et al.* 2000) program based on 1 km resolution of latitude, longitude and elevation (derived from the NASA Space Shuttle Terrain Mission - SRTM Digital Elevation data - DEM, acquired by CSIRO L&W) across the country (Figure 5). A 1 km Digital Elevation Model was derived from the SRTM.

Additional long term monthly climate surfaces for both frost (i.e. number of days with average minimum temperature <0^{o}C) and rain days (i.e. 0.2 mm from 9:00 am to 9:00 am next day) were obtained from J. Kesteven (pers. comm.). These had previously been created for the Australian Greenhouse Office (now the Department of Climate Change).

The soil property layers for depth, texture and water holding capacity were also used as inputs to the spatial version of 3-PG2 (Figure 6). Data for soil depth and texture for the A and B horizons were derived from the Australian Soil Atlas polygons (McKenzie *et al*. 2000) and converted to raster coverages of 1 km cell size. However, this provided information only to a maximum depth of 2 m. Therefore a soil terrain analysis technique (MRVBF, Gallant and Dowling 2003) was used to determine which soils were likely to have soil profiles deeper than 2 m (J. Gallant, pers. comm.). Based on data for soil depth of A and B horizons, a weighted average soil texture was calculated from data on the textural class of each horizon. The values for weighted average soil texture were then aligned with the texture classes used in 3-PG, based on clay content. Initial available soil water (ASW) was calculated as follows:

ASW = (volumetric water content at field capacity – volumetric water content at permanent wilting point) x soil depth.

The volumetric water contents used came from the 3-PG2 soil attributes table (Almeida *et al*. 2007).

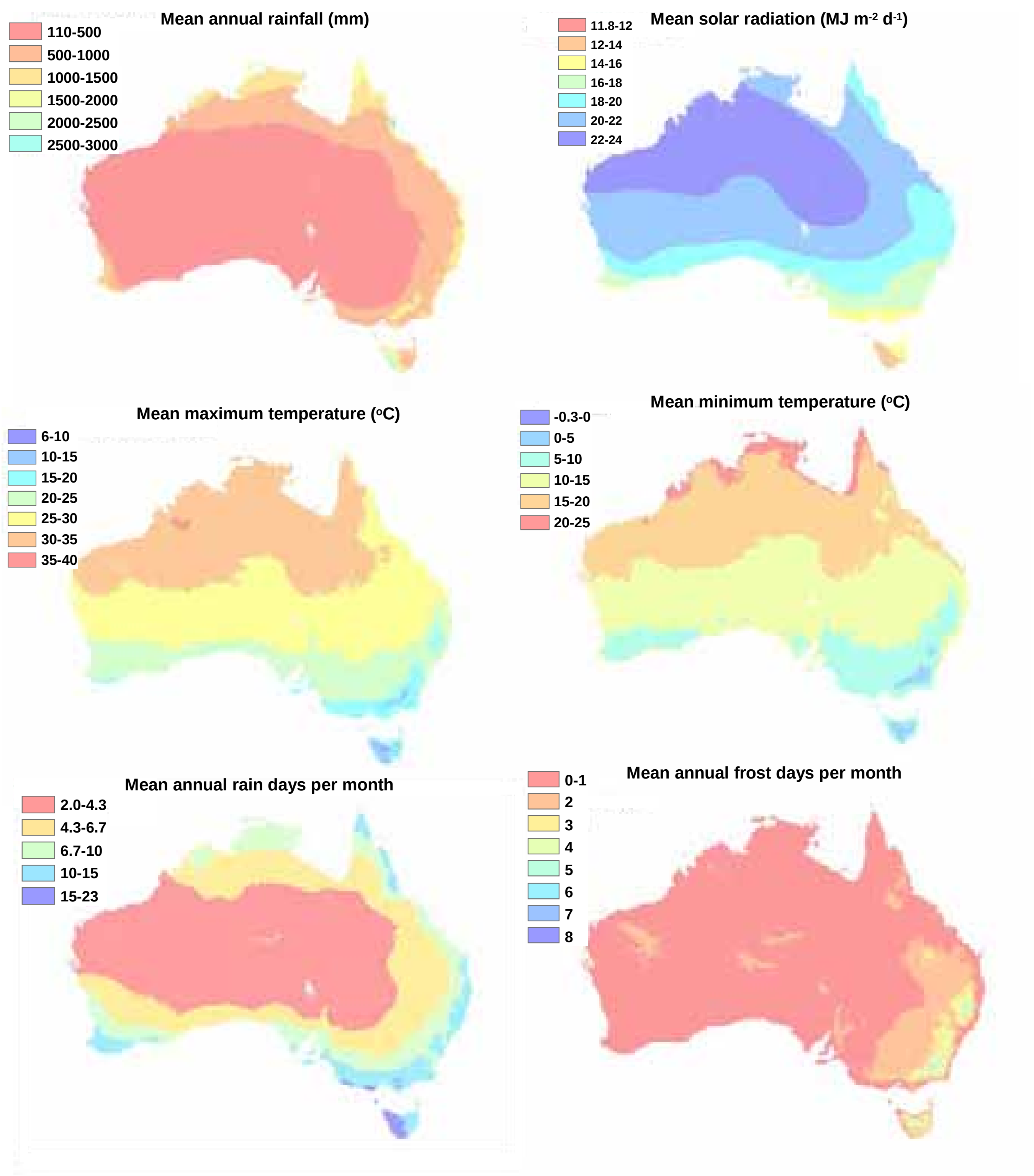


Fig. 5. Mean annual climate surfaces derived from the long-term average monthly surfaces used in 3-PG2 for climate inputs, including rainfall, solar radiation, maximum and minimum temperature.

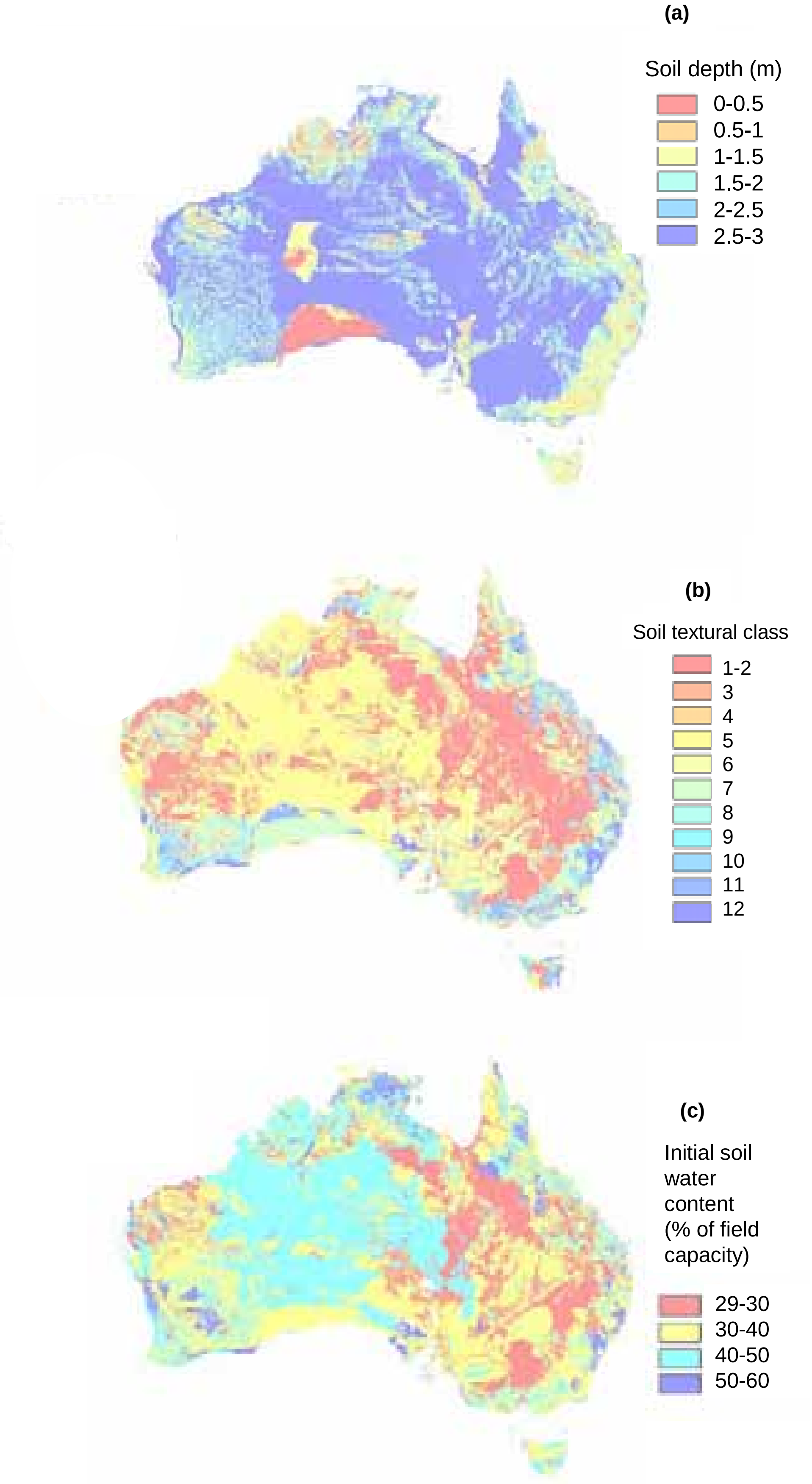


Fig. 6. Spatial layers for (a) soil depth, (b) texture and (c) initial soil water content as a percentage of field capacity.

Economics

Our general approach to the regional economic analysis follows that used by Hobbs *et al.* (2008) to identify the potential for agroforestry in southern Australia. For this study the economic analysis combined data on thinning and harvest volumes, forest growth (for non-harvest forestry systems, e.g., carbon and environmental plantings), establishment and maintenance costs, harvest and transport costs, and delivered prices of harvested products to estimate the expected cash flows and economic returns from forestry systems. To determine if investment in forestry system was more profitable than an existing farm enterprise, the returns from forestry were compared with current agricultural returns based on the Profit at Full Equity layer (Table 6). This flow of information is shown schematically in Fig. 1.

Economic model

The Appendix gives a more detailed mathematical description of the economic analysis, here a condensed version is presented. The expected cash flows and economic returns per hectare from each forestry system were estimated using discounted cash flow analysis (Boardman *et al.* 2001). This converts future costs and returns from an investment into present day values by discounting. The discount rate is the cost of financial capital required for the investment. In our analysis we used a discount rate of 6.9% per year.

The expected cash flows over a single rotation (R) from each forestry system were discounted back to the present and summed to give the net present value (NPV, \$ ha^{-1}) of the cash flow:

$$NPV_R = \sum_{t=1}^{T} \left(\frac{C_t}{(1+r)^t} - C_0 \right)$$

where t is the time of the cash flow
T is the forestry system rotation
r is the discount rate (assumed to be 6.9%)
C_t is the net cash flow at time t, and is negative if the cashflow is a cost and positive if the cashflow is a revenue.
C_0 is the initial investment in the forestry system.

Because the forestry systems studied differ greatly in their rotation length – annual for fodder to 100 years for carbon – for ease of analysis we estimated the net present value of cash flows over perpetuity:

$$NPV_\infty = NPV_R \left(1 + \frac{1}{(1+r)^T - 1} \right)$$

Calculating net present value over perpetuity is approximately equivalent to a situation where an investor purchases land or a farmer takes land out of agriculture, establishes a forest, manages that forest for some period, say 20 years, then sells the land and forest or converts the forest back to agriculture after that period.

To allow economic comparisons among the forestry systems, and with the existing land uses, the expected AER (\$ ha^{-1} yr^{-1}) for each enterprise was estimated from the net present value over perpetuity as:

$$AER = rNPV_\infty$$

The AER is an annuity where the net present value is spread equally across perpetuity. Using an annuity allows easier comparison of the returns from longer period forestry systems with those from annual crops or agricultural systems.

Because the AER from forestry was to be compared with the return from an existing farming system, the AER was calculated to be equivalent to the farm Profit at Full Equity (PFE). Hajkowicz and Young (2002) defined PFE as the economic return to land, capital and management after the value of labour provided by managers as been deducted (\$ ha^{-1} yr^{-1}).

PFE = Price x Quantity – Variable costs – fixed costs

The PFE GIS layer produced by Hajkowicz and Young (2002) was based on farm profit statistics from 1996/1997. It does not include any dept payments to financial institutions. Estimates of PFE differ from gross margins, a commonly used measure of agricultural financial performance, by including fixed costs of production (e.g. depreciation of capital assets, labour).

The profit function underlying PFE contains a yield term used to link biophysical landscape condition derived from satellite imagery to agricultural profit statistics. Hajkowicz and Young (2002) mapped the PFE at a 1x1 km grid across the more than 4,700,000 km^2 comprising Australia's farm land including broadacre grazing, cropping, horticulture and dairy. The PFE layer for this project was adjusted by the consumer price index to 2006 from 1996/97 (ABS pers. comm.) and did not take into account the variable changes in commodity prices during the last ten years.

Costs and prices

All forestry costs are based on contractor rates for establishment, silviculture, harvesting, transport, and annual management. Therefore, costs do not include direct land owner investments in capital such as machinery for site preparation, harvesting or transport. Costs were from URS (M. Kelly, pers. comm.), Burns *et al*. (1999), various web site sources and were adjusted for regional and forestry system differences through consultation with experts. All costs and prices were adjusted to 2006 dollars using the consumer price index.

Costs for all forestry systems – establishment, post-establishment treatments, pruning, thinning, and roading – varied with tree species, stocking, regime, and region (Table 5):

- Annual management costs, including road and fence maintenance, and insurance, varied from \$30 ha^{-1} yr^{-1} in dry regions to \$80 ha^{-1} yr^{-1} in wet regions
- Establishment costs, including site preparation, seedlings and planting, ranged from \$800 ha^{-1} for hardwood sawlog systems in the northern savanna to \$2000 ha^{-1} for high stocking bioenergy systems in the east coast tropics
- Post-establishment costs, including weeding and pest management, ranged from \$75 ha^{-1} in drier regions to \$150 ha^{-1} in wetter regions
- Pruning costs for hardwood and softwood sawlog regimes were assumed the same for all regions; \$210 ha^{-1}
- Costs for marking, prior to thinning, for hardwood and softwood sawlog regimes were assumed the same for all regions; \$100 ha^{-1}
- Thinning costs for hardwood and softwood sawlog regimes were assumed the same for all regions; \$300 ha^{-1}
- The pulpwood regimes included coppice management costs of \$50 ha^{-1} for all regions
- On-farm roading costs for logging trails varied from \$200 ha^{-1} in dry regions to \$400 in wet regions
- Management of forests for carbon incurred additional upfront and annual costs (see Carbon Plantings below).

Traditional forestry systems

For traditional forestry systems (hardwood sawlog, softwood sawlog, and pulpwood) stumpage prices were calculated from delivered product prices minus the cost of transport (see Transport Distance and Costs below) and harvesting (Bennell *et al.* 2008, Hobbs *et al.* 2008). Appendix I contains a detailed mathematical description of the calculation of the derivation of stumpage price.

Mill and port delivered prices vary by product, ranging from \$52 m^{-3} for pulpwood to \$75-95 m^{-3} for hardwood sawlogs. Traditional forest product delivered prices were from URS (M. Kelly, pers. comm.) and consultation with experts. Harvest costs varied with the forestry system and from region-to-region, ranging from \$10 m^{-3} for Integrated Tree Processing in the southern dry region to \$17 m^{-3} for hardwood sawlogs in the northern savanna (M. Kelly, pers. comm.).

Bioenergy

The delivered price of biomass for bioenergy was calculated from a comparison of the wood calorific value versus the coal calorific value and price (Bennell *et al.* 2008) using data for the 5-year average export value of thermal coal (\$55 per wet tonne, free on board) and the energy generation, moisture content and basic density characteristics of coal and tree species (CSIRO 2003). Delivered prices for biomass for bioenergy ranged from \$21 t^{-1} to \$23 t^{-1}.

Integrated Tree Processing

The ITP systems include bioenergy and oil mallee products. The concept is based on utilising chipped mallee (*Eucalyptus* spp.) wood, twigs and leaves to produce electricity, activated carbon, and *Eucalyptus* oil (Western Power 2006, Enecon 2001). Initial projections valued the delivered feedstock at \$30 green $tonne^{-1}$ (Enecon 2001). However, given inflation costs since 2001, the increased prices for energy (over 12% per tonne for steaming coal), wood charcoal (149% increase in gross value) and eucalypt oils (2% increase in gross value), a higher delivered feedstock value around \$36 green $tonne^{-1}$ was used.

The costs associated with Integrated Tree Processing include establishment (\$1300 ha^{-1} to \$1800 ha^{-1}), post-establishment weed control (\$75 ha^{-1} to \$150 ha^{-1}), annual management for pests, etc. (\$30 ha^{-1} to \$80 ha^{-1}), roading for harvesting (\$30 ha^{-1} in dry regions to \$200 ha^{-1} in wet regions), and harvesting (\$10 t^{-1} to \$12 t^{-1}). These costs were updated estimates from Bennell *et al.* (2008) and Hobbs *et al.* (2008).

In-situ fodder

Fodder values were based on the relative nutritional value of the fodder crop (oldman saltbush, *Atriplex nummularia*) by weight to commercial fodder species (Bennell *et al.* 2008, Hobbs *et al.* 2006, 2008). While the value of fodder is seasonally sensitive and can increase during drought conditions (Hobbs *et al.* 2008), we assumed a conservative annual price to reduce the complexity of the analysis. Allowing for moisture contents of the different products and the slight diminishing nutritional value due to salt content in *A. nummularia* we estimated an *in-situ* fodder price of \$65 t^{-1} edible green based on prices for high quality lucerne hay in 2007 (ALFA 2007). However, prices could be as low as \$45 green $tonne^{-1}$ (winter-spring) when other fodder is readily available, or as high as \$123 green $tonne^{-1}$ in drought conditions (Hobbs *et al.* 2006).

The costs associated with the fodder crop were establishment – \$1075 ha^{-1} for all regions except the Southern dry (\$825 ha^{-1}) – and annual management of \$10 ha^{-1} yr^{-1} (Hobbs *et al.* 2008).

Carbon plantings

For traditional forestry systems that include harvested products, but were also managed for carbon, we adopted the average stock approach (Schroeder 1992, Maclaren 2000, Baalman and O'Brien 2006) to estimate the value of carbon. Appendix I contains a mathematical description of the average stock approach to carbon accounting. The approach yields results equivalent to a carbon pool that is:

- Managed as a normal forest, being one that has an equal forest area in every age-class up to the rotation length. For example, a 30,000 ha forest estate with stands managed on a 30-year rotation, would have 1,000 ha stands in each age-class.
- Forest productivity across the carbon pool is the same
- The forest is managed to yield a constant sustainable harvest (non-declining yield), based on volume control, i.e., the annual forest volume harvested is equal to the annual forest volume increment from growth (Buongiorno and Gilless 2003).

For forests managed in this way the carbon stock that may be claimed for credits is half the carbon stock at harvest (Figure 7a).

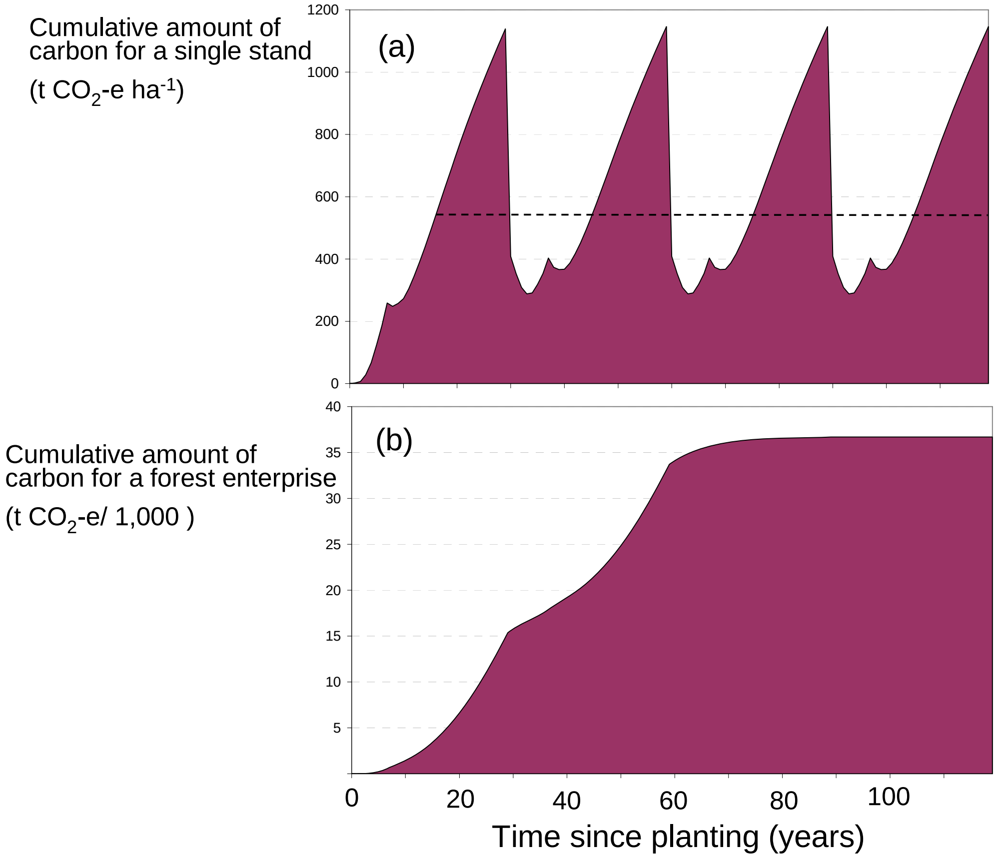


Fig. 7. (a) The long term average benefit of carbon sequestration from a harvested forests stand, and (b) from a forest estate which has an equal area of forest in every age-class up to the rotation length.

For carbon plantings, the economic analysis used information on the expected rates of carbon sequestered after 20 years to calculate an average annual increment in carbon. Returns from carbon were realised by selling carbon credits each year. Expected rates of carbon sequestration varied by tree species and region. For subsequent 20-year periods the amount of carbon sequestered was assumed to be 70% of that of the previous period, as rates of growth progressively slow, although this value can be user entered. This assumption was one of convenience because there are few data for long-term growth of the species likely to be used in carbon plantings. In any case, the longer term rates of carbon sequestration become increasingly less important to the economic outcome over time because of the effects of discounting.

Costs associated with carbon plantings were:

- Initial establishment and post-establishment weed control
- An annual management cost associated with pest control, fence maintenance, etc.
- An initial set-up cost for entering the carbon market, and
- An ongoing annual carbon pooling cost.

In the absence of a national carbon trading scheme, the costs associated with carbon farming remain to be determined. Costs considered to be a reasonable reflection of the plausible range were determined after consultations, especially with N. O'Brien (pers. comm.). It should also be recognised that like many of the agroforestry systems examined, costs will vary widely (and inversely) to the scale of the enterprise. The carbon price was assumed a constant \$20 t^{-1} CO_2-e (carbon dioxide equivalent) throughout the planning horizon. Upfront carbon management costs, which include registration and lawyers fees, were \$10 ha^{-1}. Ongoing costs of carbon forestry included monitoring and accounting costs of \$40 ha^{-1} yr^{-1} and pooling costs of \$2.50 ha^{-1} yr^{-1}. The range of values for carbon sequestration rates varied by forestry system and mean annual rainfall. For example the range of sequestration rates for softwood sawlogs in Qld including thinning volumes varied from 0 to 15 tonnes ha^{-1} yr^{-1}.

Transport distance and costs

Transportation costs are a significant influence on the economics of forestry, particularly for high volume/low value products, e.g., biomass for bioenergy, and regions that are a long distance from processing or ports. The cost of transporting products from the farmgate to a mill or port is determined by the transport distance, the weight of the product, and cost per kilometre, which in turn depends on road type and region (Fig. 8 and Table 5).

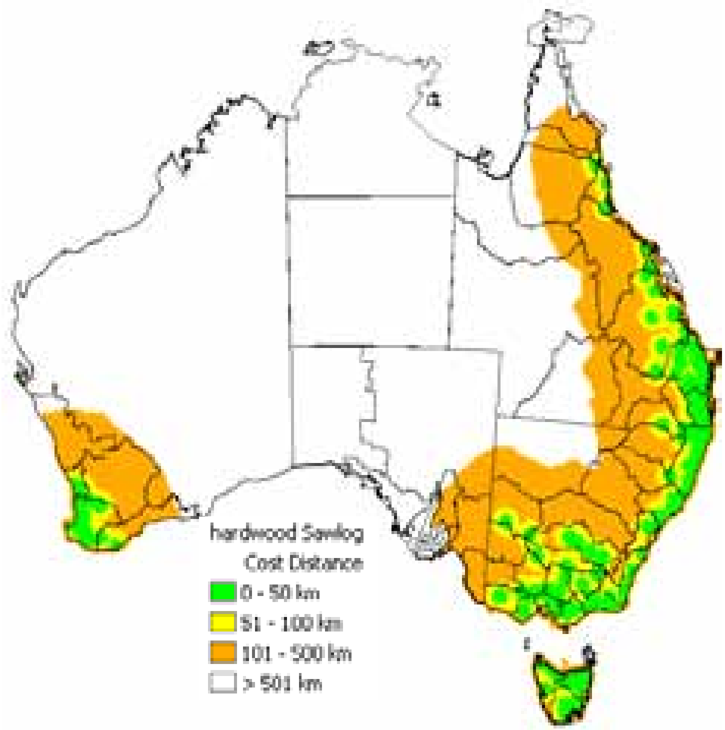


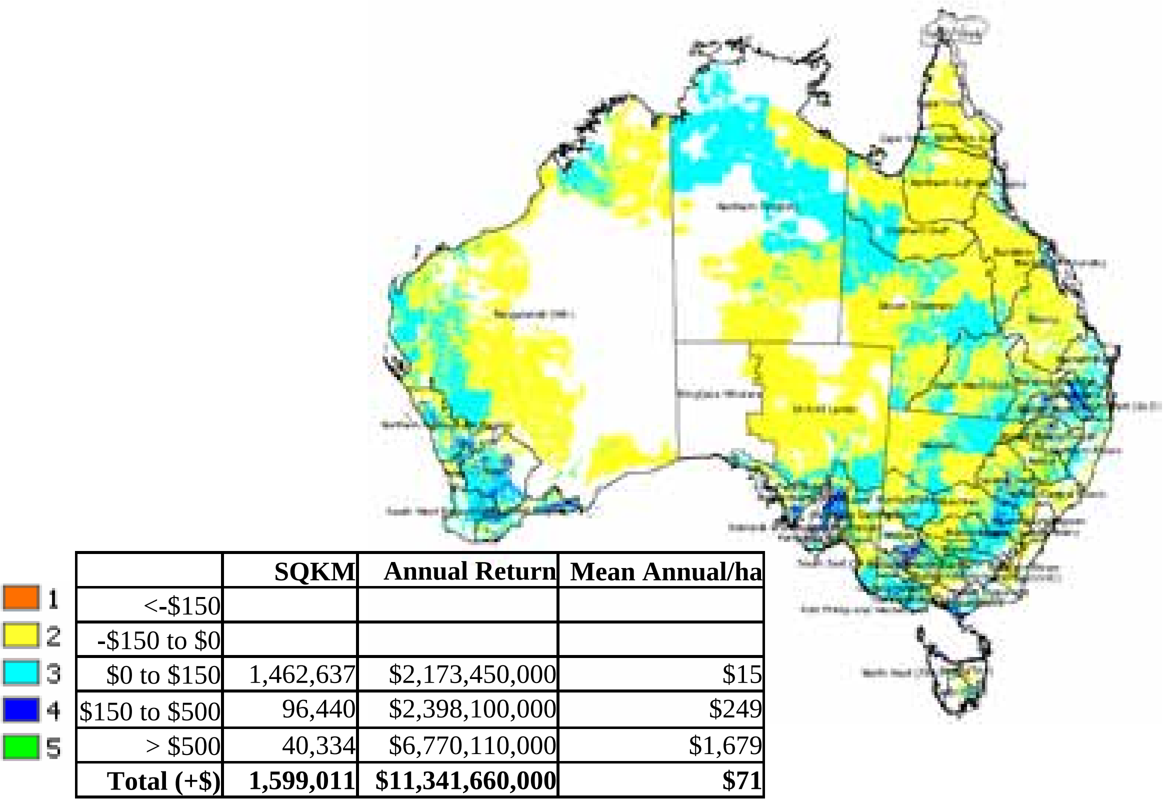
Fig. 8. Example layer for transportation distances to hardwood sawmills, adjusted by type of road surface.

This approach to representing transport cost implies that the farmgate value of the product diminishes with increasing delivery distance to the mill or port, so that high value products can be transported greater distances than low value products.

The base transport cost in southern wet regions was \$0.12 m^{-3} km^{-1} for paved roads. For unpaved roads the transport cost was 1.2 times the base cost, for minor tracks/paddocks it was 1.4 times, for transport from Tasmania to the mainland it was 5 times, and for other islands to the mainland it was 20 times.

Net Annual Equivalent Return

The return from agriculture (current land use) was measured by the profit at full equity (Fig. 9, Hajkowicz and Young 2002, ABARE 2007). This equals farm business profit, plus rent, interest and finance lease payments, less depreciation on leased items. It is the return (\$ ha^{-1} yr^{-1}) produced by all the resources used in the farm business in broadacre or dairy. Profit at full equity does not include lease costs associated with land. The 1996/97 values were adjusted to 2006 dollars using the consumer price index.



		SQKM	Annual Return	Mean Annual/ha
🟧 1	<-\$150			
🟨 2	-\$150 to \$0			
🟦 3	\$0 to \$150	1,462,637	\$2,173,450,000	\$15
🟦 4	\$150 to \$500	96,440	\$2,398,100,000	\$249
🟩 5	> \$500	40,334	\$6,770,110,000	\$1,679
	Total (+\$)	**1,599,011**	**\$11,341,660,000**	**\$71**

Fig. 9. Agricultural enterprise profit at full equity in 2006 dollars. (Hajkowicz and Young, 2002).

A comparison of the AER from forestry to the profit at full equity from agriculture is the NAER. It is a measure of the profitability of a forestry system relative to the current agricultural land use. For this comparison there are two types of forestry investor to consider:

- A farmer, who owns the land.
- An investor, who purchases or leases the land.

A farm owner should consider establishing forestry if the return from forestry (AER) exceeds the return from farming (profit at full equity). An investor should consider purchasing/leasing farm land and establishing forestry if the return from forestry (AER) exceeds the cost of purchasing/leasing the land. In this study we have assumed that the purchase/lease for the land is equal to the farm returns foregone by the farm owner, which are equal to the profit at full equity. The decision metric for the farm owner and the investor is therefore the same; however, profit at full equity is interpreted differently. For the farm owner profit at full equity is the opportunity cost of annual farm revenue foregone. For the investor the net present value of profit at full equity is the cost of purchasing/leasing the land.

Limitations

When interpreting the economic analysis presented in this report, four important caveats need to be considered:

(i) The analysis is at a national scale, therefore farm level finances are not fully represented (*cf.* Hassell & Associates 2008). The intention of the analysis is to identify broad regions within Australia that are potential opportunities for forestry investment. Findings from this study should not, therefore, be used to make investment decisions at the farm level. Financial analysis of farm level forestry investments should consider, for example:

- The proportion of the farm going into different forestry and farming systems
- Financially optimal species, rotation, silviculture and log grade mixes for the farm and local processing
- Actual costs and returns for the farming operation, including any government assistance for farming (Hajkowicz and Young 2002)
- The use of farm and contract labour to undertake forestry operations
- Specific costs associated with forestry infrastructure such as fencing, roading, skid sites, fire breaks, etc.

In addition, where an off-farm investor is purchasing the land, they should consider the sale price of comparable land in the region.

(ii) The analysis does not consider capital gain in land values. Our analysis uses the net present value of profit at full equity from farming as a proxy for land values. This simplification avoids the need for land value data and avoids having to make separate investor and farm owner economic analyses. However, it ignores capital gain in land values and the value of farming capital. Land values are likely to be higher than the proxy land value used in our analysis in areas where urban development is increasing demand for farm land.

(iii) The analysis does not consider how the forestry sector may change over time due to widespread plantings**.** If large scale forests are established in a region there are likely to be changes in land values, investment in infrastructure, and investment in processing capacity. In regions where farming is less competitive than forestry, land values would be expected to rise as investors purchase farm land for forestry. An increase in the area of forestry in a region will increase the supply of wood, potentially attracting investment in new infrastructure and processing capacity if potential supply is large enough.

(iv) Carbon economics are considerably generalised due to current uncertainty surrounding regulations affecting carbon forestry. Because schemes for investing in carbon sequestered from forests are not developed, with Australia only recently joining the Kyoto Agreement, our analysis was not able to consider the specifics of carbon forestry schemes. As such considerable caution must be exercised in interpreting the results of the carbon forestry economic analysis. In particular it should be recognised that:

- The price of carbon is uncertain
- There is no single national scheme for carbon investment
- Regional carbon sequestration schemes differ in their details
- Tax incentives for carbon sequestration are still in development, and
- Carbon liabilities at harvest are unknown.

Before investing in carbon forestry investors should carefully consider the specific requirements of schemes in their region.

Uncertainty analysis

The calculated values of AER depend on the assumptions made about product prices and costs of production (i.e. establishment, maintenance, harvesting and transport). By taking into account the uncertainty in the assumed values of each of these, we calculated the resulting uncertainty of predicted AER. This analysis was done using the spreadsheet version of the model using two case studies from geoclimatic zone 1 (southern >550m mm rainfall):

(i) Scenario 1.1, southern hardwood sawlogs (blue gum plantations), and
(ii) Scenario 7.1, southern environmental plantings.

For both case studies, the minimum and maximum input values (Tables 8 and 9) were selected by either:

- Taking the range of actual values from the spatial layers within the geoclimatic zone, such as was done for transport distances and harvest volumes, or
- Estimating the range of values based on best available knowledge at the time.

For each case study, the program @Risk for Excel® was used to calculate the range of values of calculated AER from 10,000 random combinations of parameter values. During these 10,000 iterations, values of each parameter were selected based on an assumed probability of their value being highest at their assigned 'average' and lowest at their assigned 'minimum' and 'maximum' values, Tables 8 and 9). Based on outputs from the 10,000 iterations for each case study, correlations between the value of each parameter and AER were then calculated. Graphs were then constructed to rank the relative sensitivity of AER to these parameters. Given the uncertainty assigned to the parameters used to calculate AER, a probability distribution function of AER was also constructed for both Scenario 1.1 and 7.1.

Table 8. Uncertainty assigned to the assumed costs and revenues resulting from management hardwood sawlog scenario 1.1. The average value was that assumed in the economic analysis, while the maximum and minimum values represent the expected upper and lower limits of these values.

Assumptions	Minimum	Average	Maximum
Costs			
Establishment ($ ha^{-1})	750	1500	2625
Post-establishment ($ ha^{-1})	75	150	263
Marking ($ ha^{-1})	50	100	175
Pruning 1 ($ ha^{-1})	105	210	342
Pruning 2 ($ ha^{-1})	105	210	368
Thinning ($ ha^{-1})	9	17	30
Roading ($ ha^{-1})	200	400	700
Final harvest ($ m^{-3})	9	17	30
Pruned sawlogs (A) transport ($ km^{-1} m^{-3})	0.06	0.12	0.18
Unpruned sawlogs (B) transport ($ km^{-1} m^{-3})	0.06	0.12	0.18
Industrial grade (C) transport ($ km^{-1} m^{-3})	0.06	0.12	0.18
Pulpwood transport ($ km^{-1} m^{-3})	0.06	0.12	0.18
Management ($ ha^{-1} yr^{-1})	0	80	200
Yields & transport distances			
Thinning volume (m^{3} ha^{-1})	12	72	187
Final harvest volume (m^{3} ha^{-1})	7	279	820
Pruned sawlogs (A) volume (m^{3} ha^{-1})	3	132	392
Pruned sawlogs (A) transport distance (km)	0	96	1720
Unpruned sawlogs (B) volume (m^{3} ha^{-1})	2	86	255
Unpruned sawlogs (B) transport distance (km)	0	96	1720

Assumptions	Minimum	Average	Maximum
Industrial grade (C) volume (m^3 ha^{-1})	1	56	167
Industrial grade (C) transport distance (km)	0	96	1720
Pulpwood volume (m^3 ha^{-1})	1	56	167
Pulpwood transport distance (km)	0	148	1813
Revenue			
Pruned sawlogs (A) value (\$ m^{-3})	48	95	142
Unpruned sawlogs (B) value (\$ m^{-3})	43	85	128
Industrial grade (C) value (\$ m^{-3})	38	75	113
Pulpwood value (\$ m^{-3})	38	75	113

Table 9. Uncertainty assigned to the assumed costs and revenues resulting from management environmental planting scenario 7.1. The average value was that assumed in the economic analysis, while the maximum and minimum values represent the expected upper and lower limits of these values.

Assumptions	Minimum	Average	Maximum
Costs			
Establishment (\$ ha^{-1})	100	800	3000
Post-establishment (\$ ha^{-1})	75	150	300
Management (\$ ha^{-1} yr^{-1})	0	40	200
Set up of carbon fund (\$ ha^{-1})	0	10	100
Annual pooling cost (\$ ha^{-1} yr^{-1})	0	2.5	20
Revenue			
Price of carbon (\$ $tonne^{-1}$ CO_2-e)	2	20	60
Yields			
Yield at 1st commitment period end (t CO_2-e ha^{-1})	55	338	705

Environmental impacts

Water interception

It is now well recognized that, in general, trees use more water than grasses or agricultural crops because of their deeper roots, longer-growing seasons, ability to absorb more radiation, and greater height and roughness of canopy that tends to increase evaporation. The exact impacts of forests on interception of water – here defined as the impact on stream flow as opposed to say extraction of groundwater resources – varies according to many site specific conditions (discussed briefly below). As a first approximation, the ‘Zhang curves’ can be used to estimate the amounts of water used by forests compared to grasslands and hence reductions in stream flow.

Zhang *et al*. (1999) undertook a thorough analysis of the world-wide literature on vegetation water use to derive generalised relationships between evapotranspiration (ET, or water use) and rainfall for generic ‘forest’ and ‘grass’ (Fig. 10a). The basis of their analysis is that in very dry climates, ET is limited by water availability due to low rainfall, while in very wet climates, ET is limited by available energy and that in most cases, actual ET is between these two extremes.

The curves have been derived from measurements of water use by vegetation at catchment scale that is in an average, equilibrium condition. This has a number of important implications:

- The curves represent the generalized, average condition and impact, at catchment scale. Amounts of water use at plot-scale (say in the order of several to tens of hectares) may deviate significantly from the Zhang curves depending upon prevailing circumstances.
- The impacts of forests on water yield depend upon water use by the forest relative to the baseline grass or agricultural condition. Although the focus has been very much on plantations as users of

water it is important to recognise that the agricultural condition and management (such as intensity of cropping or grazing, species of pasture) can have a profound influence.

- Amounts of water used are for average annual climates. Thus, years that are wetter or drier than the average will cause greater or lesser amounts of water use by forests compared to grasses.
- Amounts of water use by trees will depend upon many factors including tree species, age, initial spacing, position in the landscape and silvicultural practice such as initial tree spacing, thinning and harvesting. For example, trees will tend to use less water on the top of slopes where soil is shallow and water runs off easily than at the bottom of slopes and near streams where soils are deep and water accumulates. Trees in a contiguous block may use the same amount of water as trees dispersed across the landscape but the impact will be more on, for example, local creeks and tributaries.

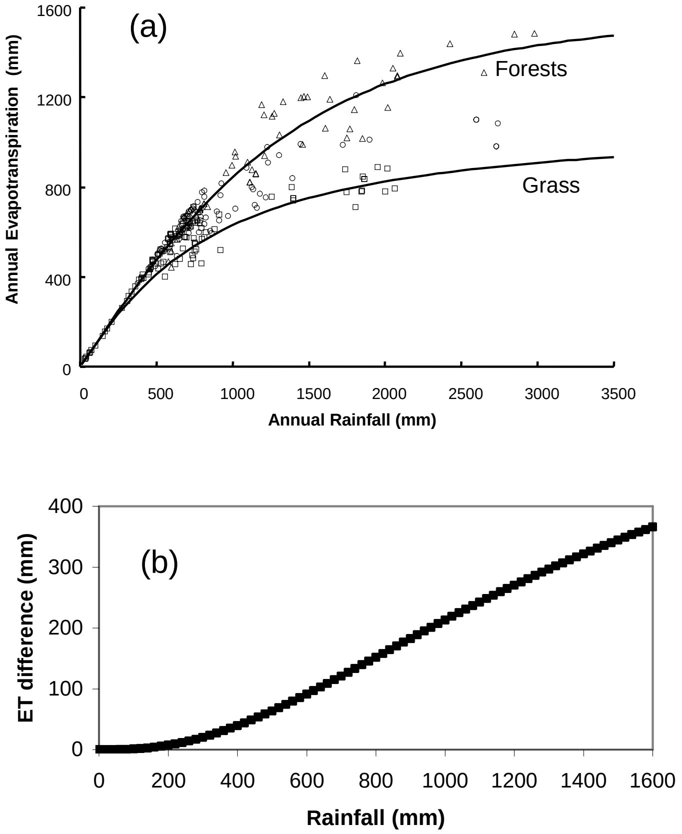


Fig 10. (a) The amounts of water use (annual evapotranspiration) by forests and grass for a global data set, and (b) the difference between the forest and grass curves, representing the total water interception (ET difference).

The difference in ET values between the two curves (grass and forest) can be calculated to give the ET difference for any given rainfall (Fig. 10b). It shows that amounts of expected water interception vary with rainfall, from about 213 mm of interception in a mean annual rainfall zone of 1000 mm to 39 mm interception in 400 mm rainfall zone. Fig. 10(a) also shows that the difference in water use data for forests and grass become increasingly variable as rainfall decreases (say below 700 mm) and thus the confidence in predictions also decreases.

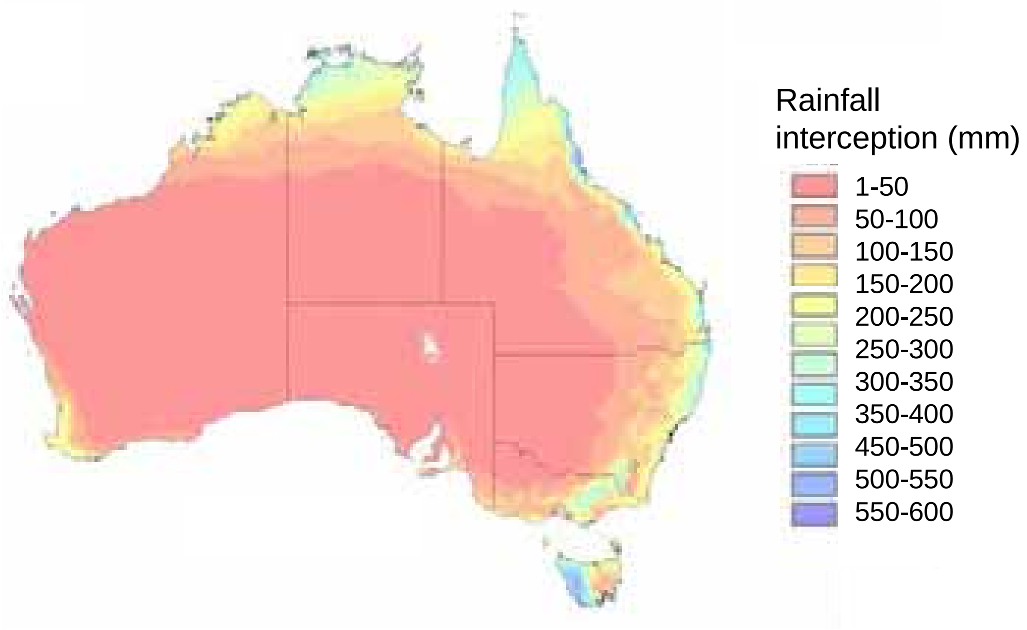


Fig. 11. Spatial layer for variation in water interception by agroforestry compared to grasslands.

We used the Zhang curves and equations that describe the differences in water use between forests and grass to derive a spatial layer for water interception (Fig. 11). As expected, it shows that greatest amounts of water interception are predicted in zones of highest rainfall and that, for much of inland Australia, the impacts are much lessened, or may even be negligible, depending upon the particular site conditions, prevailing rainfall, species and agroforestry management.

Biodiversity benefit

A biodiversity benefit layer (Fig. 12) below was derived from the Integrated Vegetation Cover layer (Thackway *et al*. 2004). It is based on the premise that remnant vegetation (forests and woodlands) provide habitat most amenable to high biodiversity and thus revegetation with forests provide more biodiversity than arable land. A score was developed, in consultation with Greening Australia (D. Freudenberger, pers. comm.), based on the connectivity between remnant forests and land previously cleared of vegetation.

The score is derived from 'neighbourhood analysis' that generates a value for biodiversity benefit, for each pixel (1 km^2) based on the mean value for condition of the existing vegetation within neighbouring pixels of a 40 km radius. The IVC 2003 layer was reclassified so that remnant vegetation was ascribed a value of 100 and everything else 0.

The neighbourhood analysis then calculates a score between 0 and 100 based on the distance to remnants or vegetation of lower class. For example, if in a given pixel the nearest remnant vegetation is more than 40 km away then a score will be in the category 0-10, indicating a large benefit from planting new forests.

In Fig. 12, areas in red are for land cleared for annual cropping in south-west Western Australia, SE South Australia and SE Queensland and indicate the greatest benefit from planting new forest.

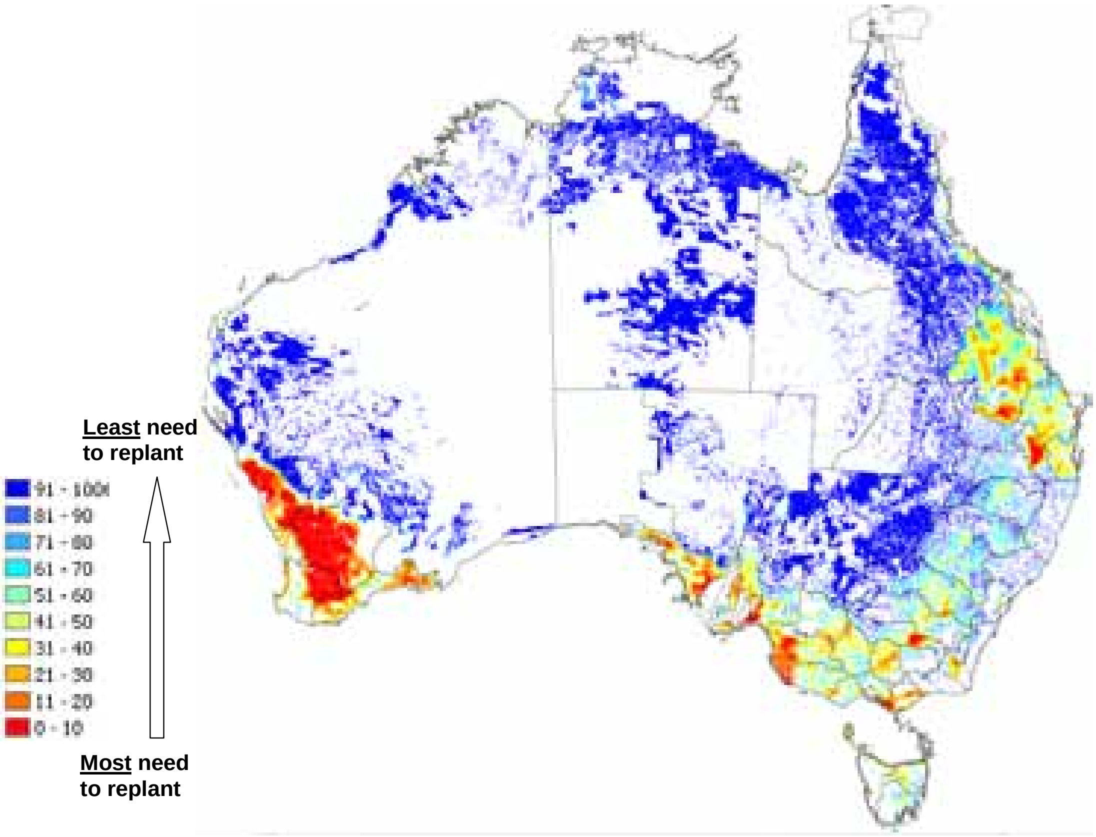


Fig 12. Biodiversity Score layer, which is the relative need for revegetation with trees based on the percentage of land cleared of vegetation for agriculture.

Results and discussion

Regional NRM Priorities for agroforestry across Australia

Results for the review of regional plans and stakeholder surveys have been documented elsewhere (Booth 2007) and are only briefly summarized here.

Review of regional NRM plans

The number of words in extracts from NRM plans relating to agroforestry, farm forestry or forestry were used as an index of their interest in these systems. The results were categorized into high, medium and low interest in agroforestry as well as a category where draft plans were not available. The results have been compiled for each NRM region in Table 10 and shown graphically in Fig. 13.

Table 10. Ranking of interest in agroforestry for NRM regions using the word count in extracts relating to farm forestry or forestry in general.

State	NRM region High interest		State	NRM region Medium interest		State	NRM region Low interest	
Qld	Wet Tropics	2129	NSW	Hunter/Central R.	199	WA	Swan	40
WA	South Coast	1201	Qld	South East Qld	162	Vic	Mallee	36
Qld	Burnett Mary	1034	WA	Avon	139	Qld	Desert Ch.	28
Tas	North West	908	Vic	East Gippsland	138	NSW	Lower M.D.	28
Vic	Corangamite	896	WA	Nth Agricultural	131	NSW	Southern R.	28
WA	South West	719	SA	South East	128	NSW	Sydney Metro	28
Qld	Mackay Whitsunday	684	NSW	Lachlan	119	SA	Arid Lands	28
Vic	Glenelg Hopkins	587	NSW	Northern Rivers	101	Qld	Northern Gulf	17
NSW	Central West	452	NSW	Murray	92	Qld	Southern Gulf	17
Vic	North Central	390	Tas	North	83	Qld	Torres Strait	17
Vic	Port Phillip & W'pt	375	ACT	ACT	78			
Vic	West Gippsland	354	WA	Rangelands	74			
Qld	Burdekin	303	Vic	Wimmera	72			
Vic	North East	292	NT	Northern Territory	70			
Vic	Goulburn Broken	285	Qld	South West	62			
Tas	South	258	SA	Kangaroo Island	51			
NSW	Hawkesbury-Nepean	240	SA	Northern & Yorke	51			
Qld	Condamine	218	NSW	Namoi	47			
Qld	Fitzroy	217	NSW	Murrumbidgee	45			
Qld	QMDC	214						

No NRM body had been created for Cape York and draft plans for four South Australian regions (Adelaide & Mt Lofty, Alinytjara Wilurara, Eyre Peninsula and Murray Darling Basin) were not available at the time of the study. All the NRM regions were asked to rate their level of interest in agroforestry but not all of the 20 regions that replied did. Generally, the self assessment ratings reflected the ratings given in Table 10 reasonably well. Two exceptions were Fitzroy (rated High in Table 8, but Low-Medium on their self assessment) and Northern Rivers (rated in the upper half of Medium in Table 8, but Very High in their self assessment). Several responses commented that the level of interest varied between different community sectors.

Updated information changes to NRM plans since publication was provided by 19 NRM bodies. Only one agency, the Avon Catchment Council, suggested significant changes which increased the length of the extracts to 697 words. This would have increased their ranking from Medium as shown in Table 10 to a High ranking and commensurate with their self assessment of Medium-High.

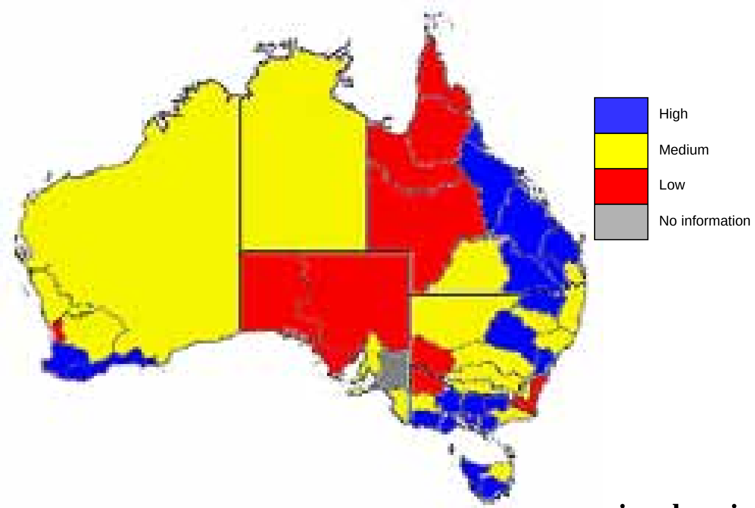


Fig 13. Spatial representation of results from Table 8 showing regional variation in interest in agroforestry.

Promotion and development of agroforestry was not the main objective of NRM plans, so the results in Table 10 need to be considered within that context and also because of the empirical way in which the rankings were developed. The results are intended to provide a general impression of relative priorities as reflected in the NRM plans and supported by regional self assessments.

The regional plans were also reviewed for their interest in *Atriplex nummularia* (old man saltbush) and tagasaste (*Chamaecytisus palmensis*) which have been identified by the FloraSearch project as promising fodder options (Bennell *et al*. 2002). Saltbush is a shrub grown on saline and non-saline soils in southern Australia as a fodder for livestock and to help rehabilitate saline land. Tagasaste (or tree lucerne) is a small tree (3-4 m high) found naturally in the Canary Islands. It is a useful fodder crop, suitable for deep, infertile sandy soils. It has naturalised in non-arid inland areas of Victoria, SA, NSW and WA.

Only a few of the NRM plans mention saltbush or tagasaste planting. In Western Australia, the Avon NRM Strategy includes an aim to develop broad-scale perennial options (woody and vegetative) for increased water use and industry diversification, including 2,500 ha tagasaste. Interestingly, the same plan mentions that the species is a considerable environmental problem in western areas of the same catchment. Also in WA the South West Regional Strategy for NRM mentions that aside from the usual weeds there are several invasive environmental weeds that have the capacity to establish in ecosystems that have not been heavily disturbed and have the potential to fundamentally change those ecosystems. These include tagasaste (though it is referred to as *Cytisus proliferus*, the species name formerly used for *C. palmensis*). This species has moved from its original plantings and become naturalized in relatively lightly disturbed jarrah forest. It will be difficult to eradicate. Tagasaste is also listed as a pest species in the Western Catchment (NSW) Plan.

Survey of PFDC and AFG representatives

Commercial plantation forestry in Australia is dominated by a relatively small number of species. *P. radiata* accounts for about 75 per cent by area of Australia's softwood plantation estate. Similarly, about 70 per cent of hardwood plantations by area are comprised of just two species, 61 per cent being *E. globulus,* and 19 per cent *E. nitens* (Parsons *et al.* 2006).

The few dominant commercial species also play an important role in farm forestry and agroforestry systems in Australia. However, the purpose here was to focus on lesser-known species of emerging importance to reduce risk for investors. Of the 43 surveys sent out to PFDC and AFG representatives and followed up with phone calls, there were a total of 27 returns. The results from the survey included a large number of species and are summarised in Fig. 14. Such variety is probably not surprising, as the regions considered include a wide range of different climatic environments. Northern rainforests are complex, so there are many potential species for planting. Many of the other species were mentioned only a small number of times and many of the future planting areas are also small. Nevertheless, some species such as *Corymbia citriodora, Eucalyptus cladocalyx* and *Khaya senegalensis* were mentioned several times and in relation to significant areas of future plantings.

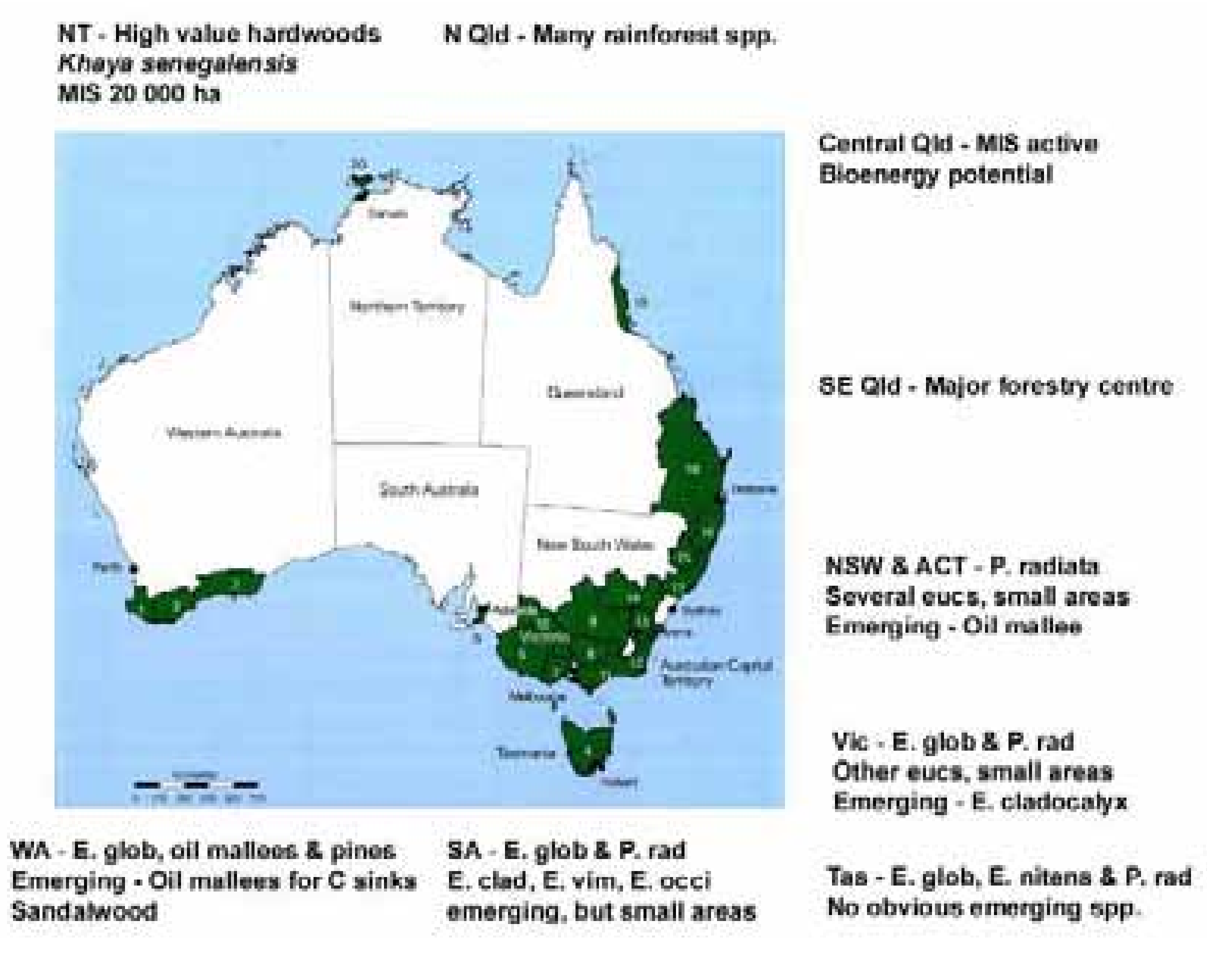


Fig 14. Summarized results from the survey of PFDC and AFG representatives highlighting the main species and products by NPI region.

Respondents were asked to estimate the possible extent of future plantings. That is obviously a difficult task and often may be more aspirational than a realistic goal. Nonetheless the data provide some impression of the relative importance of different product groups. For example, of the 27 respondents, 15 expected some planting of pulpwood plantations in the next five years, with the largest in a single region being 20,000 ha and the total 63,600 ha. The next largest area total was 37,765 ha for sawlog production with 19 areas expecting some plantings and the largest individual region anticipating 8,750 ha of plantings. Firewood plantings were expected in 14 regions with a total area of 8,285 ha and a largest area of 1,750 ha from a single region. Plantings of 9,370 ha were expected for environmental purposes from 10 regions and 6,850 ha for on–site fodder production from eight regions. Bioenergy plantings were expected in six regions, with a total area of 2,325 ha. “Other” plantings were also expected in seven regions with a total area of 2,250 ha. Production of composites was expected from a total of 5,800 ha of new plantings in only four regions. The area of anticipated oil production plantings was quite low with a total of 600 ha for oil-only production from five regions and 1,800 ha for integrated production from three regions. Harvested (i.e. off-site) fodder production was only expected in a total of 100 ha of new plantings in two regions.

Overall, the questionnaires provide a very useful summary of production systems and species being considered for agroforestry across Australia.

Growth modelling

Productivity is a key determinant of the profitability of agroforestry systems and thus the results from our economic analyses will be greatly influenced by the growth predictions reported here. The underlying assumptions and reasons for differences among productivity predictions across regions and species need to be well understood.

Rates of growth are influenced by many factors including genetic stock used, site selection, soil preparation, tree spacing, the prevailing climate, weed control and nutritional management and whether or not trees can access water stored in soil or from other sources. Some of those factors are outside the influence of the grower but many of them, such as site selection and management, can be controlled. Across forest estates it is usual to find trees growing under a wide spectrum of site and management conditions, ranging from those that promote good rates of growth to those that cause slow growth or even mortality. In calibrating the 3-PG model we chose to include all data such that an ‘average’ growth rate could be predicted. This was designed to be deliberately conservative so that expected rates of growth would not be overly inflated. However, in presenting these results it should be noted that in some locations and especially the drier areas, better growth could be achieved given optimum genetic and site selection, site preparation and forest management. Similarly, our calibrations and presentation of results were based on using the historical climatic record. It is likely that the climate in future decades will be different to the average and thus actual growth would again be lower or higher than the values presented here.

The model calibrations, validations and spatial predictions are based on extensive data sets. The graphs of volume versus age for each of the forest types (Fig. 3) can be used to determine the upper limits for growth. They also indicate the extent to which 3-PG predictions may under-predict growth compared to the maximum. Predictions for *E. cladocalyx/C. maculata*, environmental plantings, *E. camaldulensis* and *E. globulus* are likely to be most conservative with DBH at 20 years potentially being 2.05, 1.71, 1.67 and 1.66 times greater than the average, respectively (Fig. 3). Predictions of growth of *E. grandis* and softwoods are likely to be less conservative.

The great majority of our calibration and validation data sets were in the southern parts of Australia and, apart from south-east Queensland, there were very few sites that had data for the species we modelled in northern Australia. Despite this, we predicted growth in geoclimatic zone 4 for *E. camaldulensis*, *P. caribaea/P. elliottii*, environmental plantings and oil mallees, all of which were well outside the regions of calibration and validation. Mean annual rainfall and temperature are relatively high in northern Australia and this generally leads to fast rates of predicted growth. Furthermore, due to lack of data, our modelling did not account for the:

- True sensitivity of growth of these plantings to the relatively high temperature in far-northern climates

- Risks from termites and other pests and diseases as often found in the humid tropical and sub-tropical climates
- High frequency of fire, and to a lesser extent cyclones, in these landscapes, and
- Possible differences in inherent soil fertility.

The predictions for growth across northern Australia and in the east coast tropics and sub-tropics therefore have a great deal of uncertainty and need to be treated with caution. A key recommendation resulting from this study is the collection of better data and assessment of risks (and those that can be managed) in this region.

All results for MAI and carbon sequestration were normalised to a standard 20-year period because of differences in the rotation age between the various scenarios. For agroforestry systems with a rotation period less than 20 years, this involved dividing the volume or amount of carbon stored at the end of the first rotation (or harvest) by 20 years. For systems with a rotation period greater than 20 years (such as the Softwood sawlogs) we used the volume or carbon stored at the end of 20 years for calculations. This enabled a proper comparison to be made of rates of volume increment and carbon sequestration across all of the agroforestry systems.

Hardwood sawlogs

Of all the hardwood sawlog plantings, *E. globulus* was predicted to have the highest growth rates while *E .cladocalyx/C. maculata* had the lowest (Fig. 15). This reflected the greatly different rainfall in the zones in which they were growing. For example, the mean annual increment (MAI) of *E. globulus* increased from an average of about 10 m^3 ha^{-1} yr^{-1} at 600 mm mean annual rainfall (MAR) to an average of 35 m^3 ha^{-1} yr^{-1} at 2000 mm. Predicted growth averaged about 5 m^3 ha^{-1} yr^{-1} for *E. cladocalyx/C. maculata* grown at 550 mm and decreased to <2 m^3 ha^{-1} yr^{-1} at <350 mm. Growth of *E. grandis* was predicted to range from 2 to 35 m^3 ha^{-1} yr^{-1}, with highest growth rates in regions where average annual temperature was <25^{o}C.

The relationship between MAI and rates of carbon sequestration in live biomass differed among species and climatic regions because of species differences in:

- Partitioning of carbon among the various components of trees relative to the stem,
- Density of stem wood, and
- The volume of stem wood removed in thinnings. Results for MAI included volumes of stems removed to indicate productivity potential whereas results for carbon sequestration were for the standing crop only.

Despite the much greater MAI of *E. globulus* compared to *E. cladocalyx/C. maculata* or *E. camaldulensis,* predicted rates of sequestration of carbon were only slightly higher. Rates of carbon sequestration averaged 25% of the value for MAI for *E. globulus,* and were 47-48% for *E. cladocalyx/C. maculata* and *E. camaldulensis*. This large difference, for *E. globulus,* is due to the relatively lower partitioning of carbon to branch, bark and roots, and wood density is relatively low and few stems were removed in thinnings. Calculations for partitioning and hence growth and carbon sequestration were based in many cases on data collected from destructive sampling.

It was also predicted that root:shoot ratios decreased exponentially with increasing rainfall for all hardwoods, averaging 0.55 at MAR<350 mm and 0.17 at >2000 mm. Consequently, there was less variation in rates of carbon sequestration across rainfall gradients compared with MAI.

Softwood sawlogs

P. radiata (zone 1) was predicted to have the highest growth rates and *P. pinaster* (zone 2) the lowest (Fig. 16) again reflecting differences in rainfall. MAI of *P. radiata* was predicted to increase from about 8 m^3 ha^{-1} yr^{-1} at 600 mm MAR to about 39 m^3 ha^{-1} yr^{-1} at 2000 mm. Growth of *P. pinaster* was predicted to be 7 m^3 ha^{-1} yr^{-1} at 550 mm and <2 m^3 ha^{-1} yr^{-1} at <350 mm. Similarly, MAI of *P. caribaea/ P. elliottii* was 23 m^3 ha^{-1} yr^{-1} at 2000 mm and <2 m^3 ha^{-1} yr^{-1} at <350 mm.

For *P. radiata* and *P. pinaster*, predicted rates of carbon sequestration averaged 19% of the value for MAI compared with 32-33% for *P. caribaea/P. elliottii*. Consequently, differences in predicted rates of carbon sequestration between various softwoods were much less pronounced than were differences in MAI. This is mainly attributed to the higher wood density and partitioning to branches and bark for *P. caribaea/P. elliottii*.

As was the case for hardwoods, the root:shoot ratios decreased with rainfall and thus rates of carbon sequestration varied less across rainfall gradients than did MAI.

Pulpwood

Due to differences in rainfall, *E. globulus* had highest growth rates and *P. pinaster* the lowest (Fig. 17). MAI of *E. globulus* increased from an average of 6 m^3 ha^{-1} yr^{-1} at 600 mm MAR to 16 m^3 ha^{-1} yr^{-1} at 2000 mm. For *P. pinaster*, predicted growth averaged 7 m^3 ha^{-1} yr^{-1} at 550 mm and decreased to <2 m^3 ha^{-1} yr^{-1} at <350 mm. Again, these values were normalised to a 20-year time period so for the eucalypts, the values can be doubled to get the annual rate over say a 10-year rotation.

Differences in predicted rates of carbon sequestration between zones and forest types were less pronounced, particularly between *E. globulus* and *E. camaldulensis*. Rates of sequestration of carbon in live biomass were predicted to be 36% of MAI for *E. globulus,* 42% for *P. pinaster* and 82% for *E. camaldulensis*. This was largely attributable to the lower wood densities (0.44-0.48 compared to 0.60-0.70 t m^{-3}) and branch and bark fractions (0.11-0.18 compared to 0.19-0.36) of the former planting types. As noted for both hardwoods and softwoods, predicted root:shoot ratios decrease with increased MAR, thereby resulting in rates of carbon sequestration varying relatively little across gradients in rainfall when compared with MAI.

Bioenergy plantings

The scenarios were the same as for the pulpwood plantings for zones 1, 3 and 4. Predictions of growth and carbon were therefore the same as for those plantations, the exception here being that an output for bioenergy crops was total fresh weight of above-ground biomass.

The assumed carbon fraction of biomass is about 0.5 and dry:wet ratio of biomass is 0.6. Therefore, above-ground fresh weight biomass would be 3.3 times dry weight of carbon. However, given that the root:shoot ratio in 10-year-old stands was predicted to vary from an average of 0.24 to 0.42 (from *E. grandis* to *E. cladocalyx/C. maculata*, respectively), the above-ground fresh weight was predicted to average only 2.7 to 2.3 times total carbon (Fig. 18).

Integrated tree processing plantings

ITP systems are grown over short rotations of a few years and coppiced to remove biomass for processing into its various product streams (Table 5). To simplify model predictions, we used the growth predicted for the bioenergy plantations (above) over their 10 or 12 year cycles, and assumed that growth was linear up until then, and pro-rated the growth to a 2 or 3 year cycle. Because of the short rotation, the average MAI and rates of carbon sequestration are all low if considered over the 20 year time fame (Fig. 19).

These results need to be treated as illustrative only because:

- The assumption of linearity in growth between ages 0 and 10-12 years is almost certainly not true, especially when harvesting biomass on 2 or 3 year cycles. However, it may be an approximation when trees resprout under a coppicing regime and therefore do not have to start from seedlings every new cycle.
- The effect of coppicing on growth is uncertain. Evidence for mallee systems shows that rates of growth after coppicing can be substantially faster than when grown from seedling. However, there are few data for other species.

Environmental carbon plantings

Environmental plantings cover diverse forest types including tree and shrub mixtures to monocultures planted for various environmental outcomes. The model predictions presented here should be viewed as generalisations only; in reality each type of environmental planting should have its set of model calibrations to account for species-specific differences in physiological parameters. Furthermore, an output here is fresh weight of biomass and not MAI because stem diameter is usually not measured in the mixed species, high density plantings. In this case we are more interested in the use of environmental plantings for carbon sequestration.

Rates of growth of environmental plantings were predicted to range from an average of 19 t DM ha^{-1} yr^{-1} at 2000 mm MAR, decreasing with rainfall to an average of <5 t DM ha^{-1} yr^{-1} at <500 mm (Fig. 20). Like *E. grandis*, environmental plantings were calibrated to have a relatively low temperature optimum. Hence, as predicted for *E. grandis*, where average annual temperatures are >25^{o}C, environmental plantings were predicted to grow poorly, averaging only 2 t DM ha^{-1} yr^{-1} but also being consistent with the limited data set against which the model was calibrated.

For sites where average annual temperature was <25^{o}C, root:shoot ratios for environmental plantings decreased with increasing rainfall, from a value of 2 at <250 mm rainfall to 0.4 at 1500 mm. Hence, compared to variation in growth rates in above ground (AG) biomass, there is much less variation in predicted rates of carbon sequestration with rainfall gradients.

Hardwood carbon plantings

Predicted growth for hardwood carbon plantings (Fig. 21) was similar to hardwood sawlogs (Fig. 15). Hence the MAI plots in Figures 15 and 21 are similar. However, rates of carbon sequestration for carbon plantings were predicted to be 20-54% higher than that for the sawlog plantings. This is largely attributable to the fact that carbon sequestration rates in the live-biomass of sawlog scenarios do not include carbon in the trees removed at thinning.

The relationship between predicted rates of carbon sequestration and MAI were highly significant and linear. For *E. globulus*, the rate of carbon sequestration after 20 years was 32% of the predicted value for MAI. In contrast, *E. cladocalyx/C. maculata* and *E. camaldulensis* carbon plantings had rates of carbon sequestration that were 68-77% of MAI.

Compared to environmental plantings, predicted rates of sequestration of carbon are predicted to be much greater for hardwood carbon plantings for all zones. There are two main reasons for this:

(i) Unlike hardwoods, environmental plantings were calibrated to include a reasonably high level of mortality due to self thinning, as might be expected in an unmanaged native forest. Therefore, compared to managed hardwood carbon plantings, there is a much lower potential to sequester carbon in live-biomass of environmental plantings, particularly in high rainfall regions such as in zone 1 and the southern part of zone 3, and

(ii) In regions with high average annual temperatures (>25^{o} C), environmental plantings are predicted to have much lower growth rates than hardwood carbon plantings as they were calibrated to have a much lower temperature optimum. This was necessary to reproduce data from mature woodlands in northern Australia with relatively low rates of biomass production <2.4 t dry matter (DM) ha^{-1} yr^{-1} (Raison *et al*. 2004). Had this temperature limitation not been imposed, rates of carbon sequestration would have been predicted to be similar to that of hardwood carbon plantings, but this would have over-predicted growth of woodlands in northern Australia.

Softwood carbon plantings

As observed for hardwoods, predicted MAI for softwoods were similar whether grown for sawlogs (Fig. 16) or carbon (Fig. 22). However, rates of carbon sequestration for carbon plantings were predicted to be 1.3 to 2.1 times higher than for the sawlog plantings. As noted for hardwoods, this is largely attributable to the fact that in sawlog scenarios, predicted sequestration rates do not include carbon in trees removed at thinning. Differences between carbon sequestration rates between scenarios were greater for softwoods than for hardwoods because softwood plantings generally had more stems removed at thinning.

For *P. pinaster* and *P. caribaea/P. elliottii* carbon plantings, the rate of carbon sequestration after 20 years was 43 to 50% of the value for MAI, and was 31% for *P. radiata*. The difference is explained by the relatively low wood density for *P. radiata* and partitioning of carbon to components other than stem wood.

As expected, predicted rates of carbon sequestration were lower, relative to stem volume production, for softwoods than hardwoods given their lower wood densities and root:shoot ratios. However, there was no significant relationship between predicted rates of sequestration between these two planting types. This is due to the differing sensitivities to temperature, and the way in which their partitioning of biomass and wood densities vary with age.

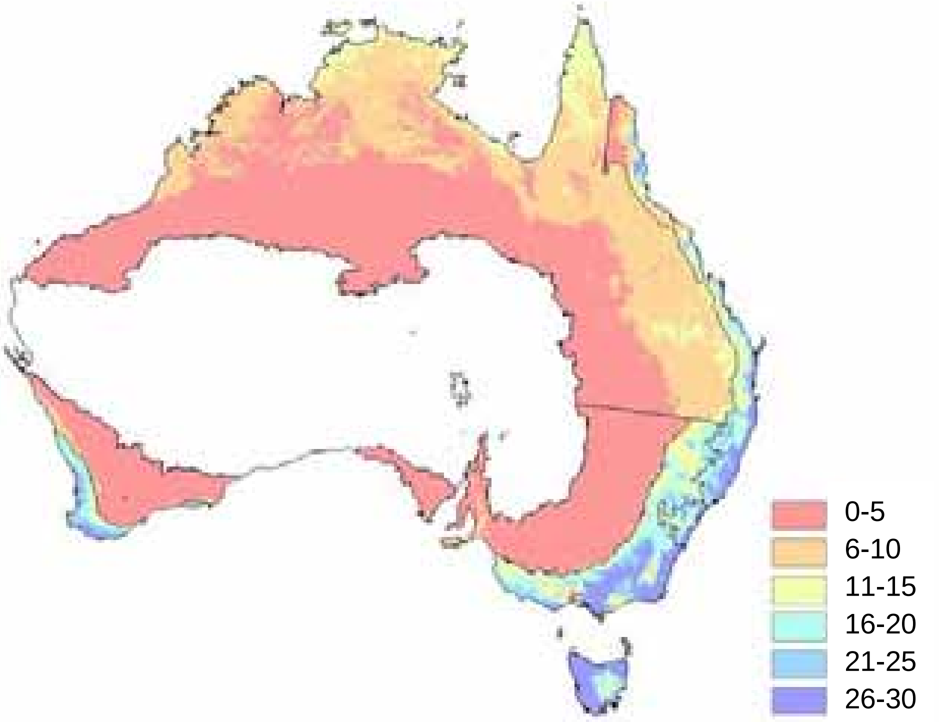
Oil mallees

Predicted rates of growth of above-ground biomass for oil mallees ranged from an average of 17 t DM ha^{-1} yr^{-1} at 2000 mm MAR to <5 t DM ha^{-1} yr^{-1} at <500 mm (Fig. 23). However, mallee species are adapted to hot environments and as a result, growth rates were predicted to be higher for oil mallee in the north of Australia than for environmental plantings or *E. grandis*. This analysis does not take into account that the northern zones are well outside the zones for which data were available and that mallee species will have differing responses to say humidity and evaporative demand. These results for mallees should therefore be treated with great caution and be seen as plausible, but highly uncertain, predictions. It is recognised that there are northern species of mallees adapted to the more humid environments but there were no data against which to test model results.

As expected, predicted root:shoot ratios of oil mallee plantings decreased exponentially with increasing MAR. At sites with MAR<250, 500, 1000 and 1500 mm, root:shoot ratios of oil mallee plantings at age 20 years were predicted to average 0.75, 0.62, 0.45 and 0.35, respectively. Consequently, at MAR<250, 500, 1000 and 1500 mm, rates of sequestration of carbon were to predicted to average about 90, 80, 70 and 67% of that of growth in AG biomass, respectively.

Hardwood sawlogs

(a) MAI (m^3 ha^{-1} yr^{-1})



(b) Total carbon (t CO_2-e ha^{-1} yr^{-1})

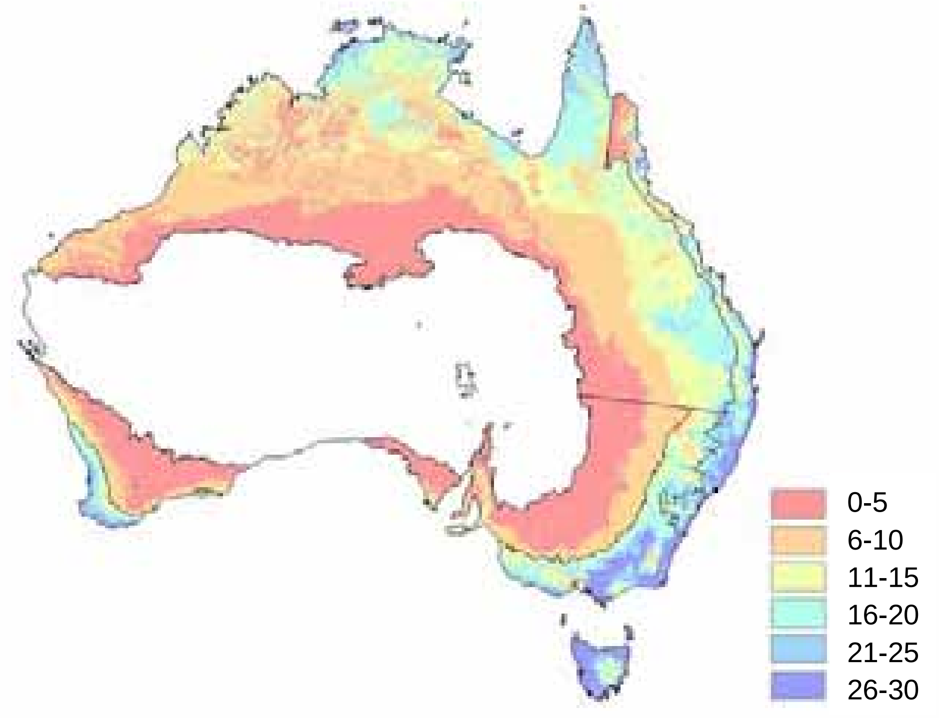
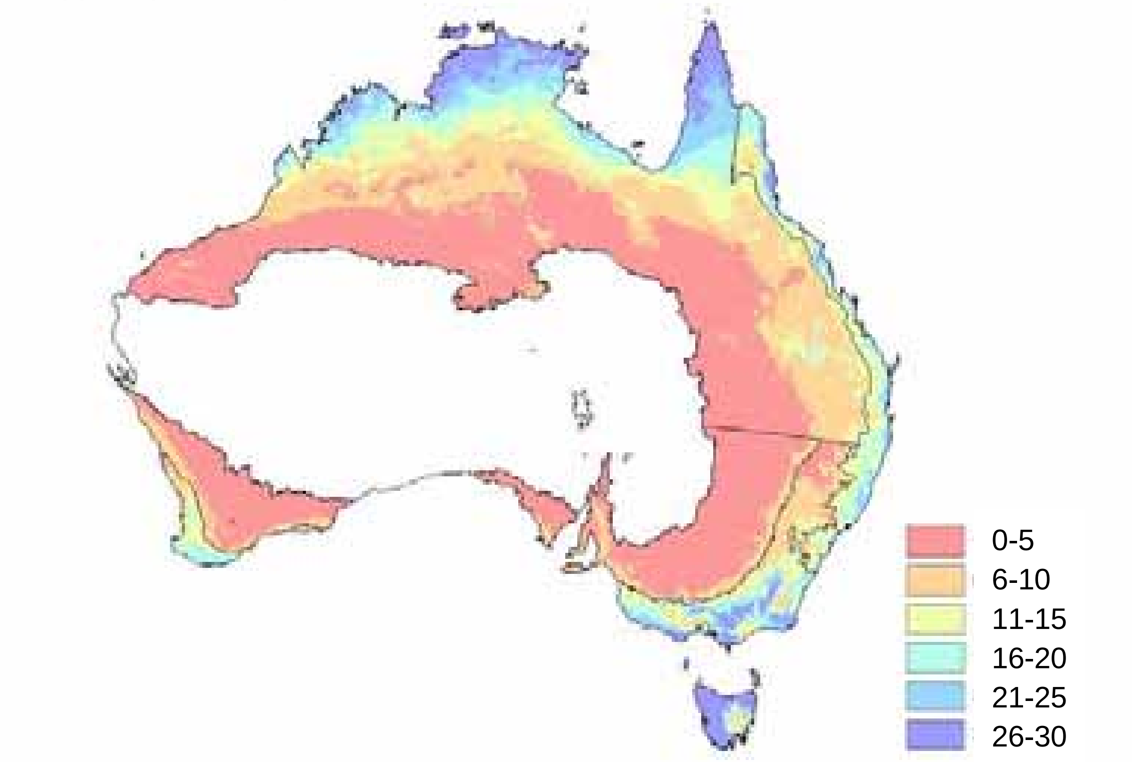
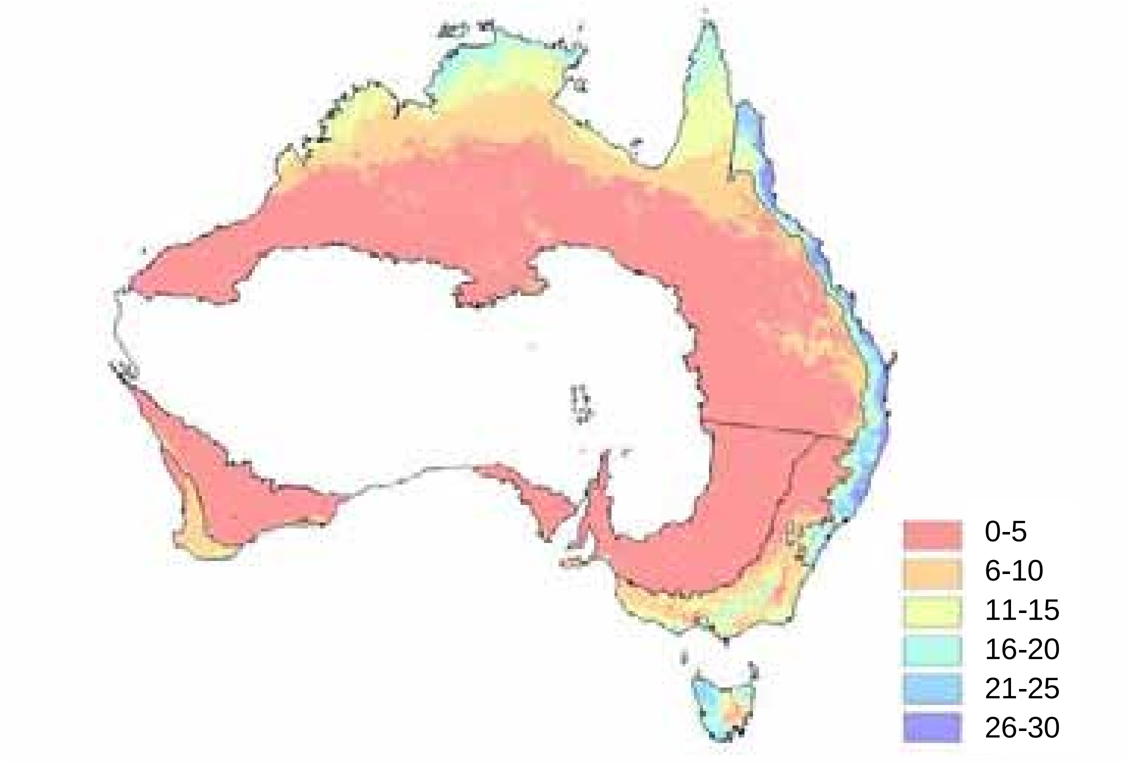


Fig. 15. Predicted (a) MAI (including material removed at thinnings) and (b) total carbon in live biomass (above- and below-ground) for a 20-year-old *E. globulus* plantation (zone 1), 30 year old *E. cladocalyx/C. maculata* plantation (zone 2), 20-year-old *E. grandis* plantation (zone 3), and 20-year-old *E. camaldulensis* plantation (zone 4). All results have been normalised to a 20-year time period.

Softwood sawlogs



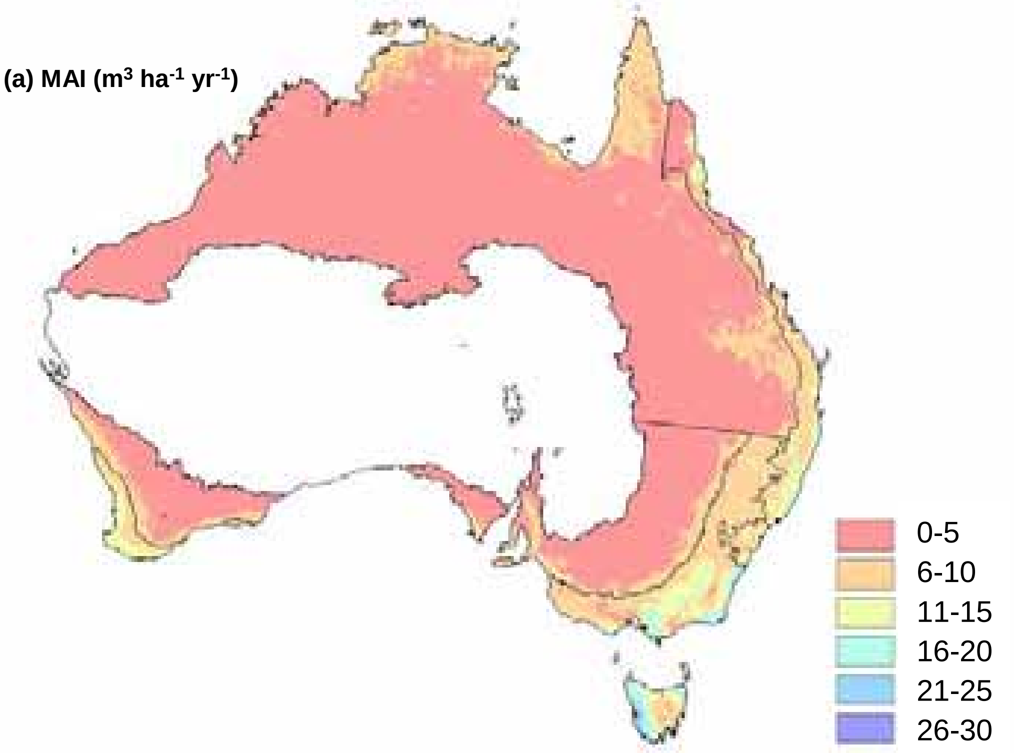
(a) MAI (m^3 ha^{-1} yr^{-1})



(b) Total carbon (t CO_2-e ha^{-1} yr^{-1})

Fig. 16. Predicted (a) MAI (including material removed at thinnings) and (b) total carbon in live biomass (above- and below-ground) for a 30-year-old *P. radiata* plantation (zone 1), 30-year-old *P. pinaster* plantation (zone 2), 30-year-old *P. caribaea/P. elliottii* plantation (zone 3), and 35-year-old *P. caribaea/P. elliottii* plantation (zone 4). All results have been normalised to a 20-year time period.

Pulpwood


(a) MAI (m^3 ha^{-1} yr^{-1})

(b) Total carbon (t CO_2-e ha^{-1} yr^{-1})

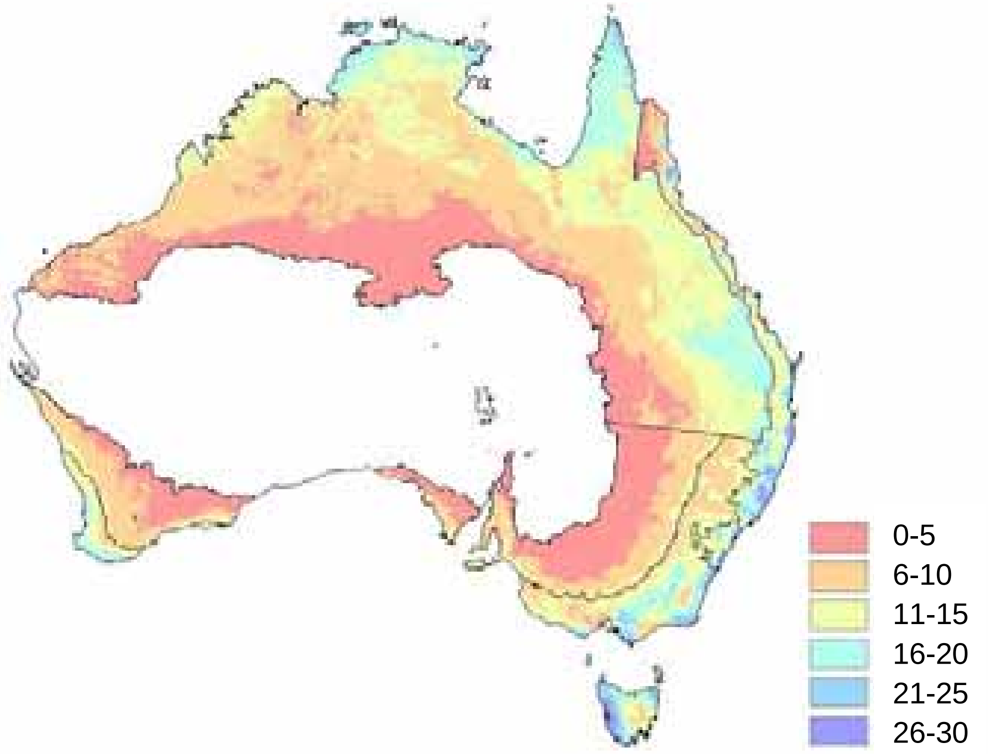
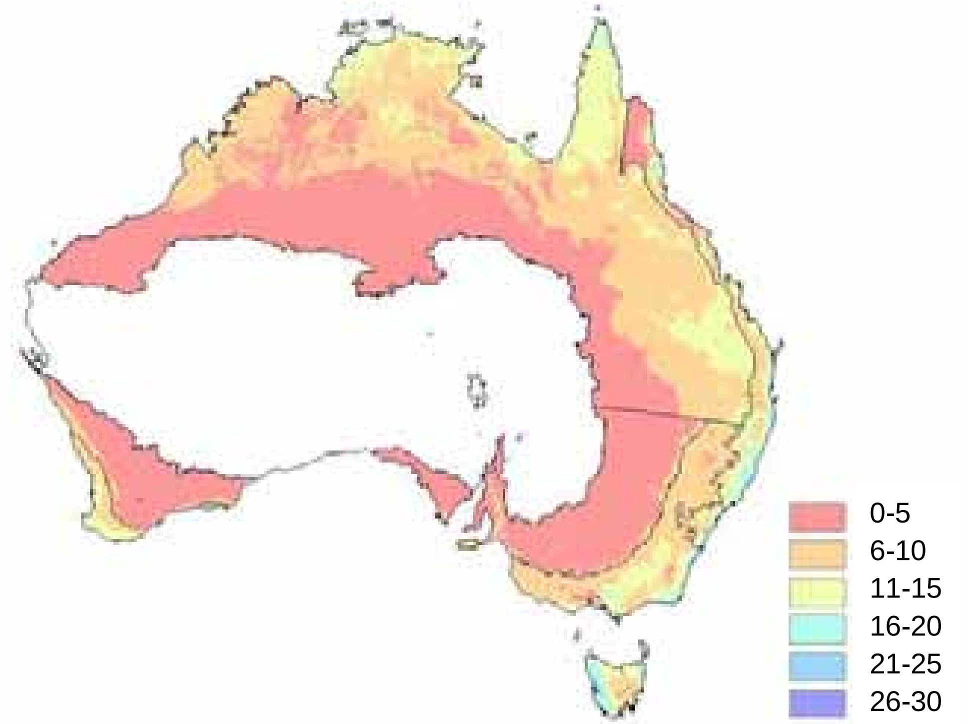


Fig. 17. Predicted (a) MAI and (b) total carbon in live biomass (above- and below-ground) for a 10-year-old *E. globulus* plantation (zone 1), 20-year-old *P. pinaster* plantation (zone 2), 10-year-old *E. grandis* plantation (zone 3), and 12-year-old *E. camaldulensis* plantation (zone 4) grown for pulpwood. All results have been normalised to a 20-year time period.

(a) Fresh weight of AG biomass (t ha^{-1} yr^{-1})



(b) Bioenergy, Total carbon (t CO$_2$-e ha^{-1} yr^{-1})

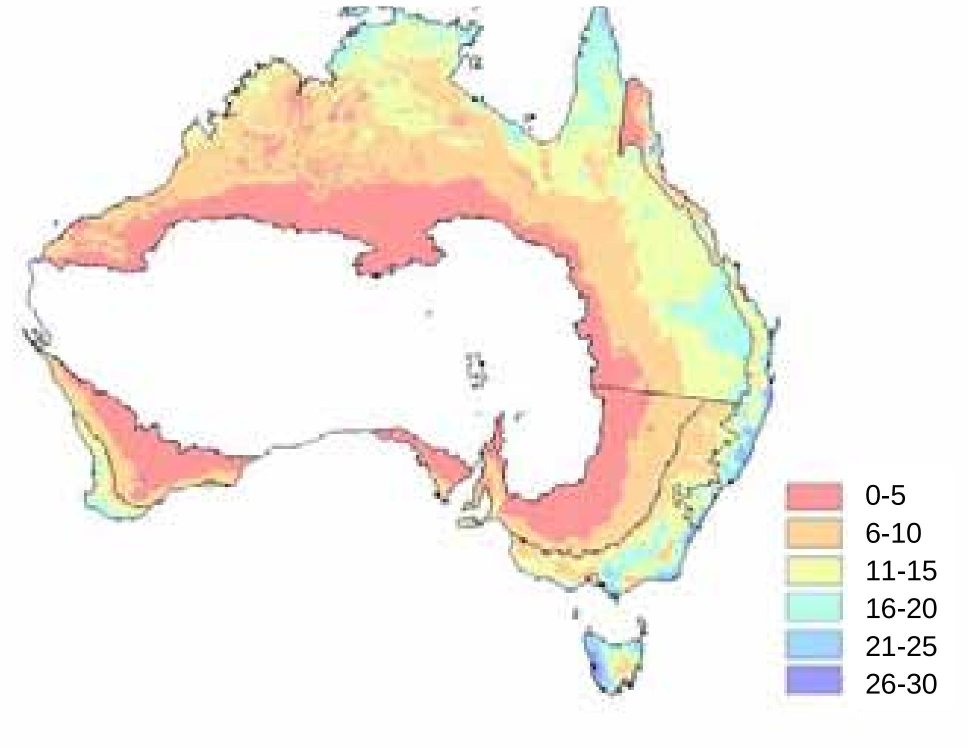
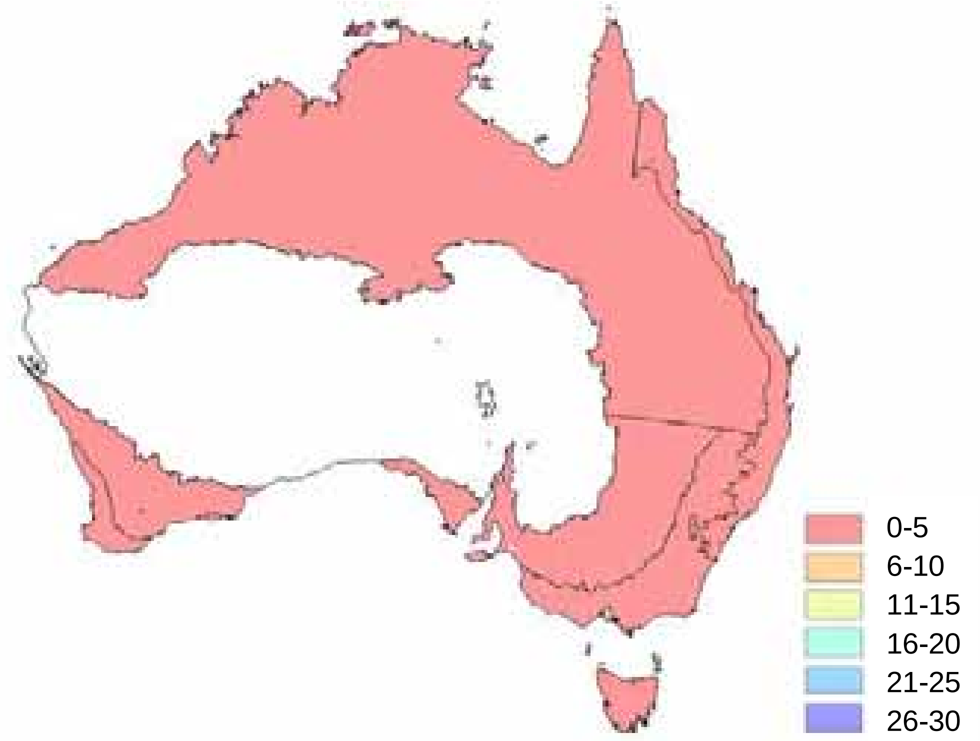


Fig. 18. Predicted (a) fresh weight of above-ground biomass and (b) total carbon in live biomass (above- and below-ground) for 10-year coppiced plantations of *E. globulus* (zone 1), *E. cladocalyx/C. maculata* (zone 2), *E. grandis* (zone 3), and *E. camaldulensis* (zone 4). All results have been normalised to a 20-year time period.

Integrated Tree Processing

(a) Fresh weight of AG biomass (t ha^{-1} yr^{-1})



(b) Integrated Tree Processing, Total carbon (t CO$_2$-e ha^{-1} yr^{-1})

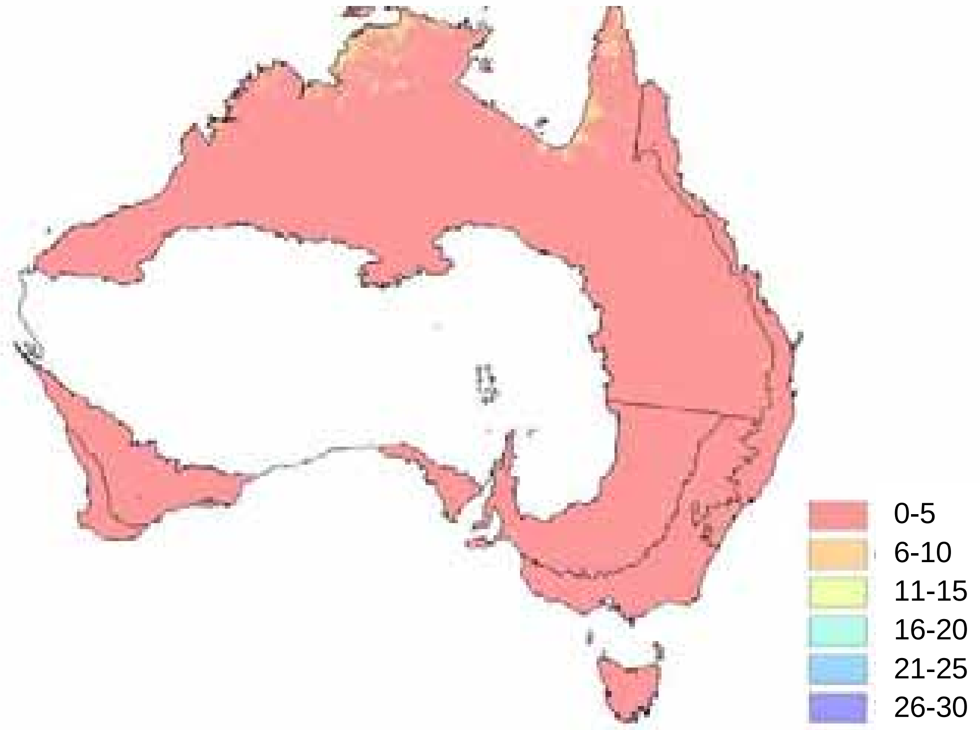
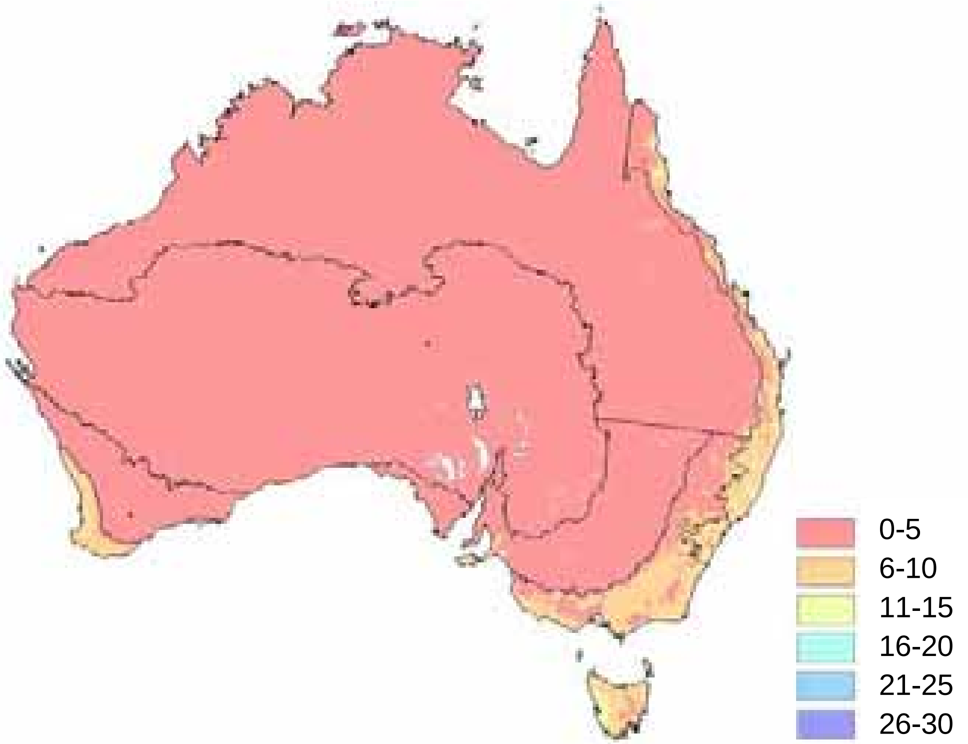


Fig. 19. Predicted (a) fresh weight of above-ground biomass and (b) total carbon in live biomass (above- and below-ground) for 2 to 3 year coppiced plantations of *E. globulus* (zone 1), oil mallee (zone 2), *E. grandis* (zone 3), and *E. camaldulensis* (zone 4). All results have been normalised to a 20-year time period.

Environmental carbon plantings

(a) AG biomass (t DM ha^{-1} yr^{-1})



(b) Total carbon (t CO_2e ha^{-1} yr^{-1})

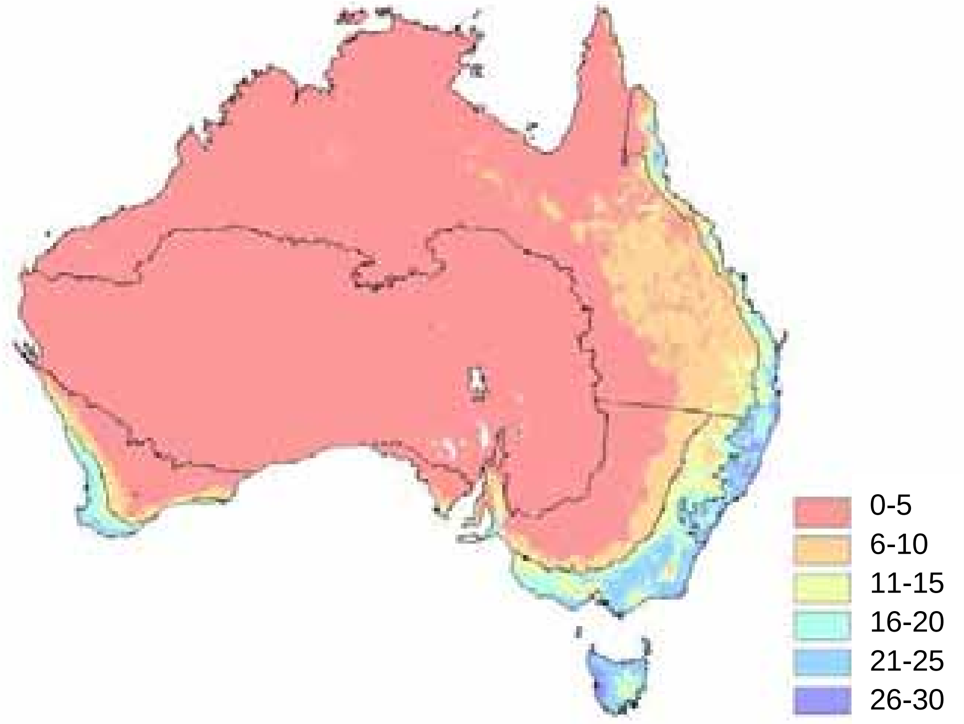
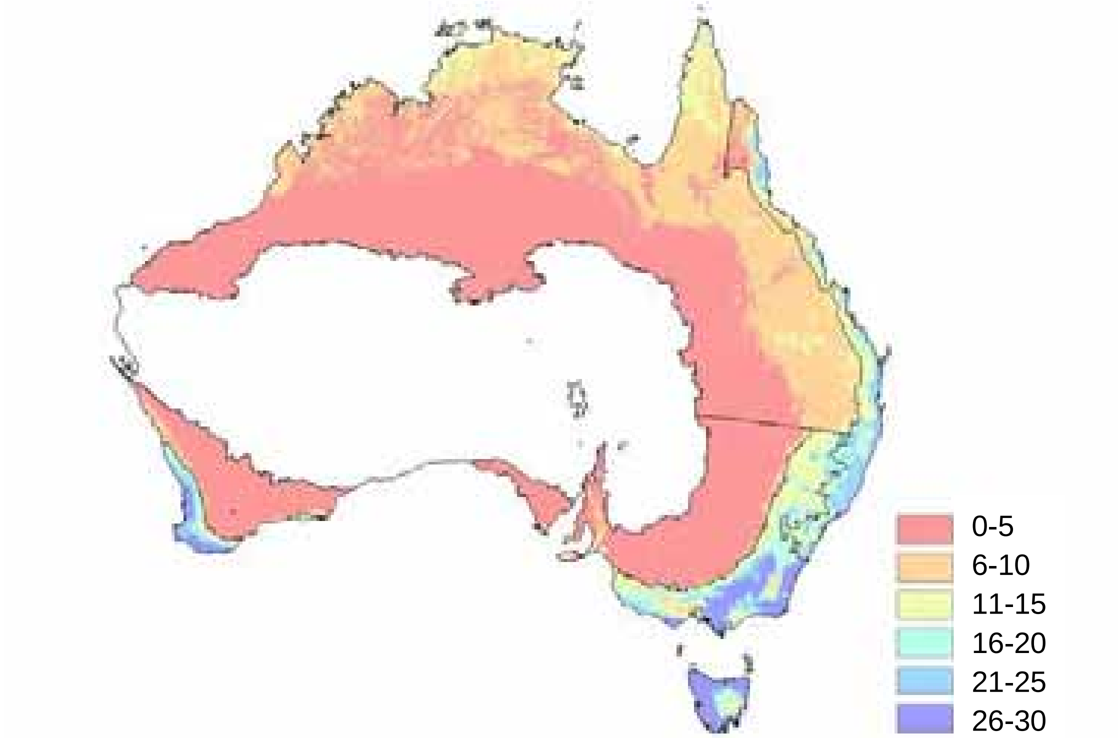


Fig. 20. Predicted (a) dry weight of above-ground biomass and (b) total carbon in live biomass (above- and below-ground) for 20-year-old environmental plantings. All results have been normalised to a 20-year time period.

Hardwood carbon plantings

(a) MAI (m^3 ha^{-1} yr^{-1})



(b) Total carbon (t CO_2-e ha^{-1} yr^{-1})

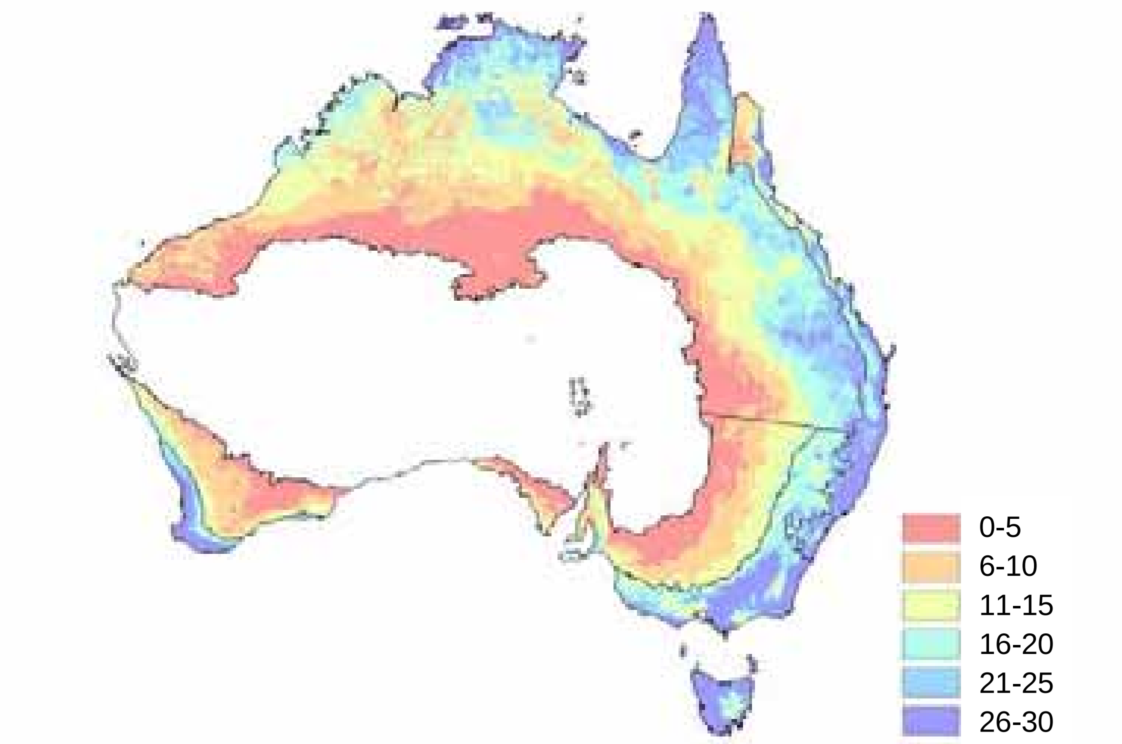
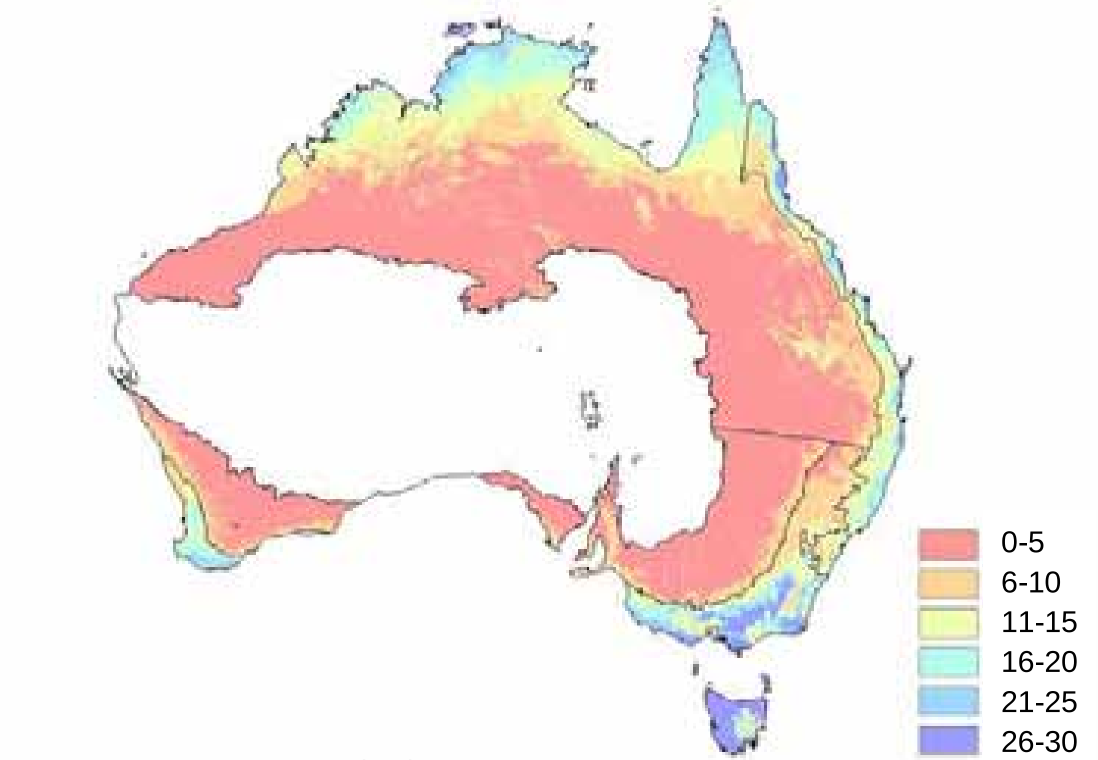


Fig. 21. Predicted (a) MAI and (b) total carbon in live biomass (above- and below-ground) at 20 years age for plantations of *E. globulus* (zone 1), *E. cladocalyx/C. maculata* (zone 2), *E. grandis* (zone 3), and *E. camaldulensis* (zone 4). All results have been normalised to a 20-year time period.

Softwood carbon plantings

(a) MAI (m^3 ha^{-1} yr^{-1})



(b) Total carbon (t CO_2-e ha^{-1} yr^{-1})

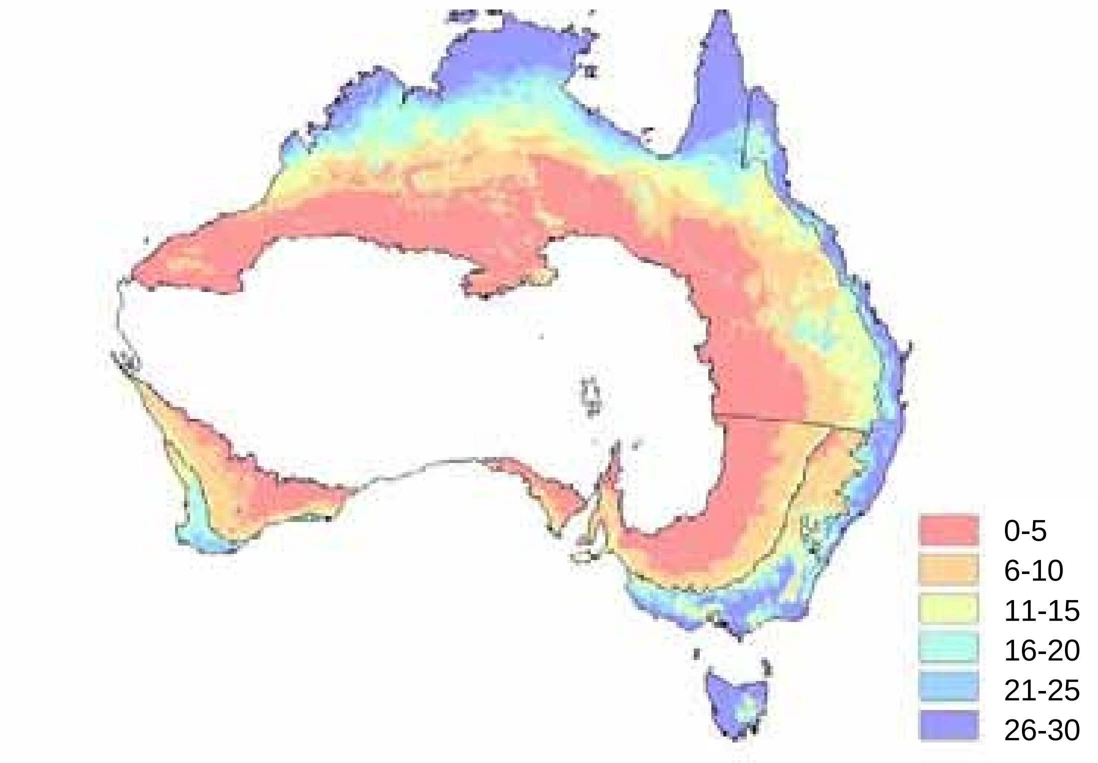
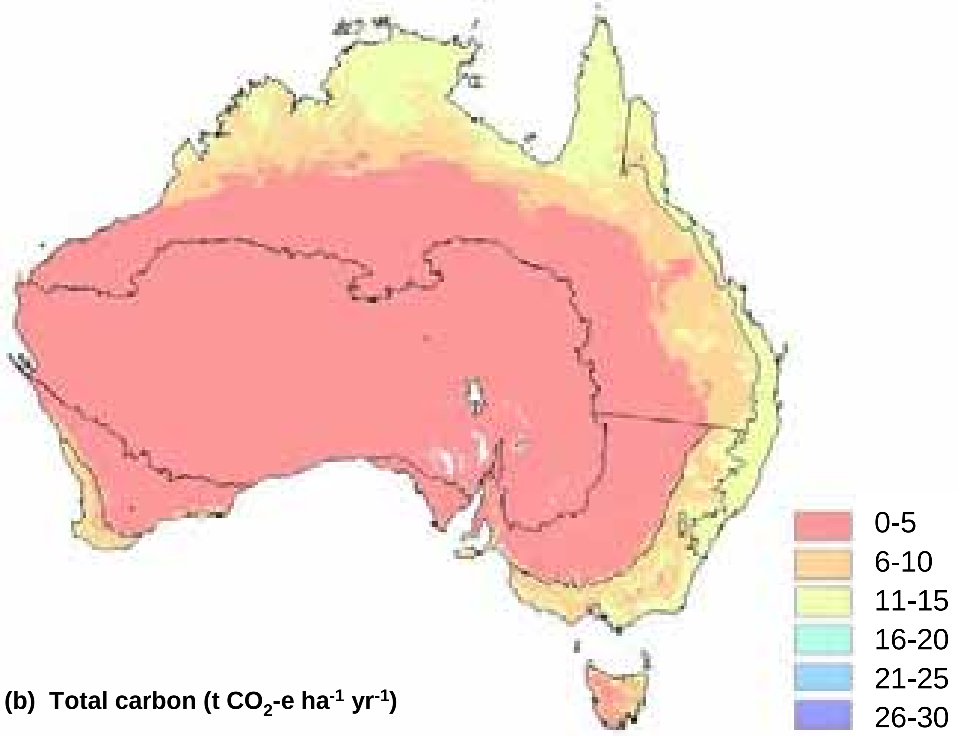


Fig. 22. Predicted (a) MAI and (b) total carbon in live biomass (above- and below-ground) at 20 years age for plantations of *P. radiata* (zone 1), *P. pinaster* plantation (zone 2), *P. caribaea/ P. elliottii* (zones 3 and 4). All results have been normalised to a 20-year time period.

Oil Mallee carbon plantings

(a) AG biomass (t DM ha^{-1} yr^{-1})



(b) Total carbon (t CO_2-e ha^{-1} yr^{-1})

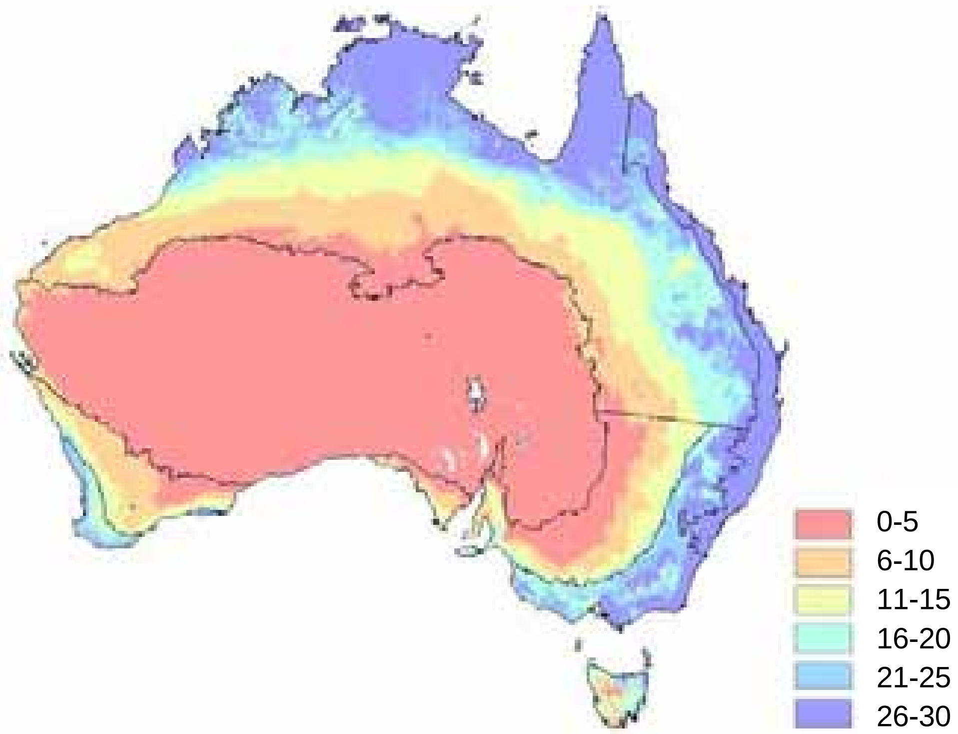


Fig. 23. Predicted (a) dry weight of above-ground biomass and (b) total carbon in live biomass (above- and below-ground) for 20-year-old oil mallee plantings. All results have been normalised to a 20-year time period.

Economic analyses

Statistics for the modelled economic outcomes for each scenario have been summarized in Figs. 25-32. We have presented results only for the NAER, which take into account the opportunity cost of the preceding agricultural enterprise, and not for the AER. In general, the trends in the NAER and AER results were very similar (Fig. 24). NAER was often greater than AER because of negative values for Profit at Full Equity.

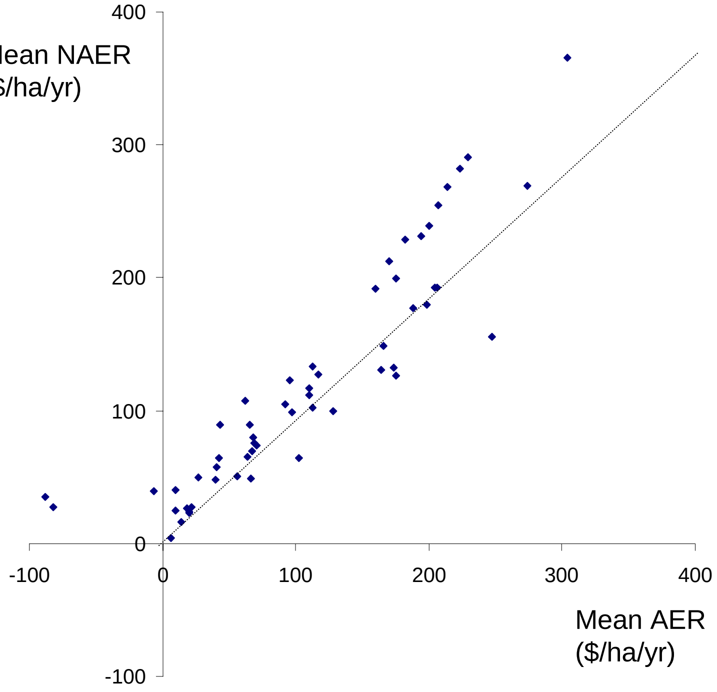


Fig. 24. Comparison of values for NAER and AER for each of the NRM regions. Each point on the graph is the mean value for NAER or AER (S ha^{-1} yr^{-1}), averaged across each NRM region for all areas of 1 km^2 where there was a positive value of NAER. Results were taken from Table 11.

The economic outputs are presented for each of the scenarios as both spatial graphical outputs showing profitability within categories (Figs. 25-32) and graphs summarizing only those areas with a positive value of NAER (Fig. 33). The statistics presented are for the total area with positive NAER (Mha), the total profitability summed across that area ($billion yr^{-1}) and the mean areal profitability ($ ha^{-1} yr^{-1}). The presentation and discussion of results are separated into sections below that represent the main differences between the agroforestry scenarios.

Sawlog and pulpwood systems

For the reference case of these harvested systems with variable transport costs to mill and no carbon trading (Figs. 25a, 26a, 27a), the potential area predicted as available and profitable was low relative to the fodder system and carbon plantings (Fig. 33). This was largely because the location of existing processing facilities constrains the areas for expansion of the harvested systems along the east coast of Australia and in south-western WA. In absolute terms however, substantial areas of high profitability were identified for the hardwood sawlog and pulpwood systems for the reference case; for example 45 Mha and 6.6 $billion yr^{-1} for the hardwood sawlog system. In contrast, softwood sawlogs were predicted to have less area available (1.2 Mha) and lower profitability (0.13 $bill/year) (Figs. 26a, 33), due almost entirely to the lower assumed price of softwood products compared with hardwoods (Table 5).

For all of these production systems, the effect of fixing the transport distance was to substantially increase the area of potential profitability, moving it progressively inland and northwards across the top end of Australia and to areas of south-western Western Australia (Figs. 25b, 26b, 27b). This effect was due to removing transport costs as a constraint on profitability when the transport distance is fixed.

For the sawlog systems, the effect of including payments for carbon sequestration was mostly to increase the profitability of areas already identified in the reference case but also to extend potential areas of profitability somewhat inland and northwards (Figs. 25b, 26b). For this scenario, the areal extent of profitability remained constrained by the location of the existing processing facilities. For pulpwood systems, including payments for carbon sequestration had very little impact on profitability (Fig. 27b) because the short rotation period of these systems (10-12 years) did not allow enough time for the forest to sequester significant amounts of carbon compared with the longer rotation sawlog systems. Pulpwood returns were predicted to be reasonably high compared with the sawlog systems, in part due to the relatively high prices assumed for wood chips and pulpwood and because the shorter rotation period provides an earlier return, thus off-setting some of the impacts of discounting.

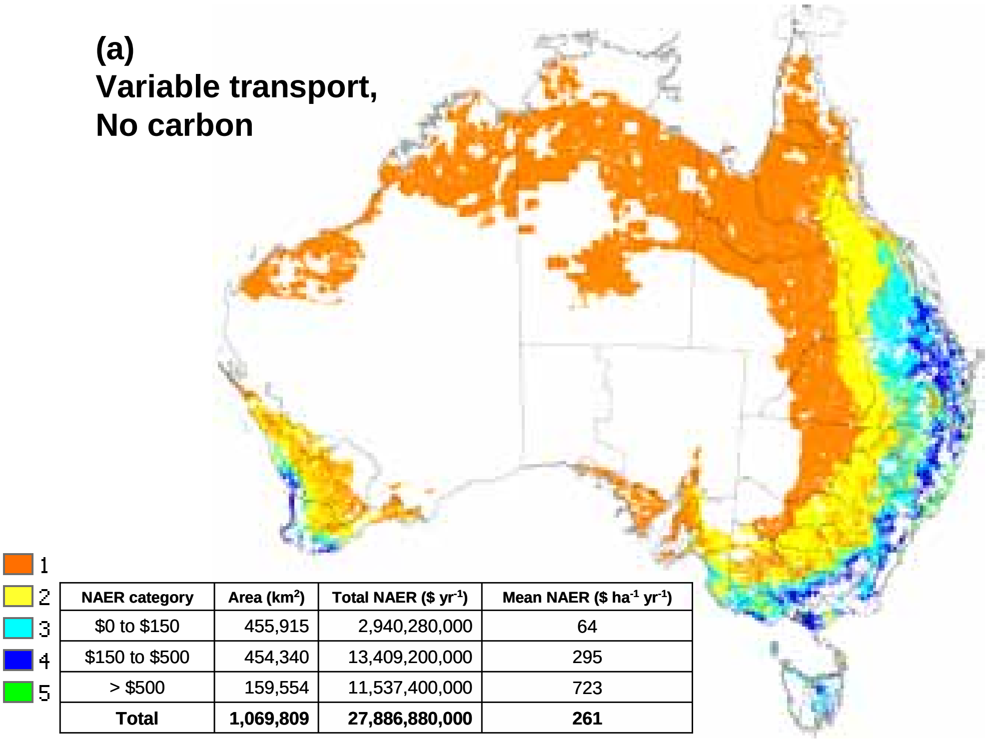
Including a fixed transport distance or carbon sequestration payments in scenarios can increase both the level of profitability within existing areas and the total extent of profitable areas. For those reasons, the patterns of change for mean areal profitability ($ ha^{-1} yr^{-1}) were sometimes different from either area or total profitability ($ yr^{-1}, Fig. 33). For hardwood sawlogs, for example, the scenario of fixed transport+carbon increased the area for which plantations could be profitable (extending inland and to the north) but also increased the profitability of land compared to the reference case. The result was to increase the mean areal profitability ($ ha^{-1} yr^{-1}) compared with other scenarios for hardwood sawlogs (Fig. 33).

Energy systems

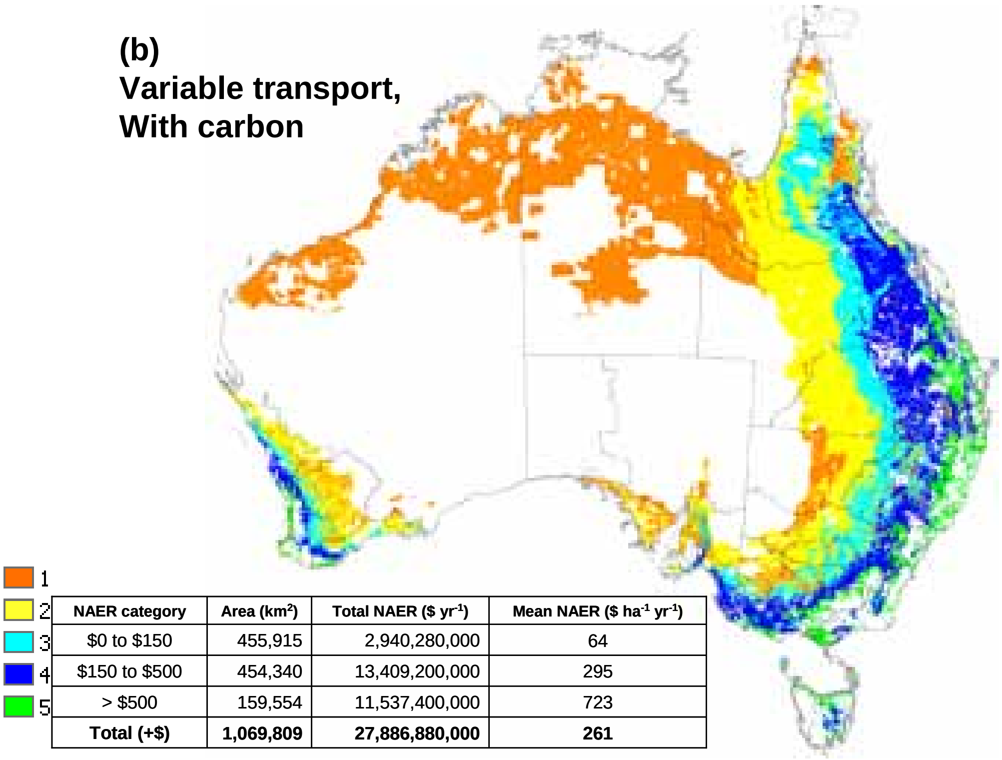
The areas of profitability for bioenergy and ITP systems were very small (Figs. 28, 29) because of the low product price of the energy feedstock relative to the high costs of growing, harvesting and transporting the product. However, Fig. 30 shows that the mean areal profitability ($ ha^{-1} yr^{-1}) can be reasonably high if the resource is grown in close proximity to the energy processing plant and so limiting transportation costs. Including carbon payments had little impact due to the short cycle time of these systems, which limited the opportunity to store significant quantities of carbon. However, we did not explicitly model the storage of carbon in the root biomass, which may add to the amounts of carbon sequestered over time.

The results here are for energy systems where the product value is assumed to remain the same and reasonably low for all the scenarios considered. We did not consider the impacts of payments for Renewable Energy Certificates, for example, nor a changing policy environment that might lead to an increased market value of the energy feedstocks.

Hardwood sawlogs


(a)
Variable transport,
No carbon

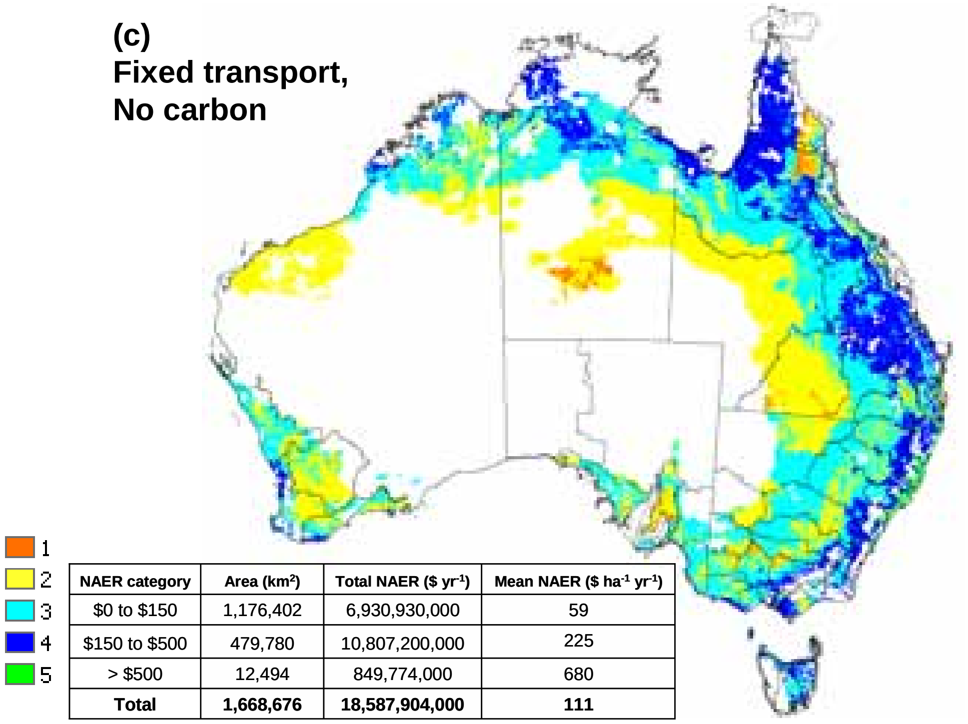
NAER category	Area (km^2)	Total NAER ($ yr^{-1})	Mean NAER ($ ha^{-1} yr^{-1})
$0 to $150	455,915	2,940,280,000	64
$150 to $500	454,340	13,409,200,000	295
> $500	159,554	11,537,400,000	723
Total	**1,069,809**	**27,886,880,000**	**261**


(b)
Variable transport,
With carbon

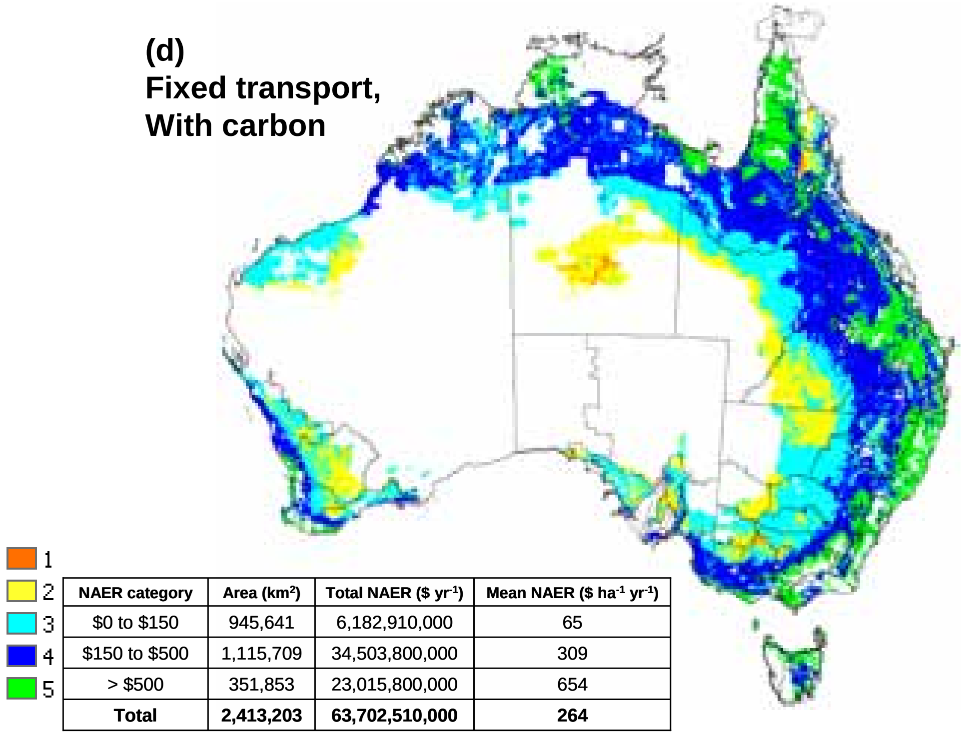
NAER category	Area (km^2)	Total NAER ($ yr^{-1})	Mean NAER ($ ha^{-1} yr^{-1})
$0 to $150	455,915	2,940,280,000	64
$150 to $500	454,340	13,409,200,000	295
> $500	159,554	11,537,400,000	723
Total (+$)	**1,069,809**	**27,886,880,000**	**261**

Fig. 25. Spatial maps for scenarios 1.1 and 1.2 (Hardwood sawlogs) summarising areas with a positive value for NAER.

Hardwood sawlogs



NAER category	Area (km²)	Total NAER ($ yr⁻¹)	Mean NAER ($ ha⁻¹ yr⁻¹)
$0 to $150	1,176,402	6,930,930,000	59
$150 to $500	479,780	10,807,200,000	225
> $500	12,494	849,774,000	680
Total	**1,668,676**	**18,587,904,000**	**111**

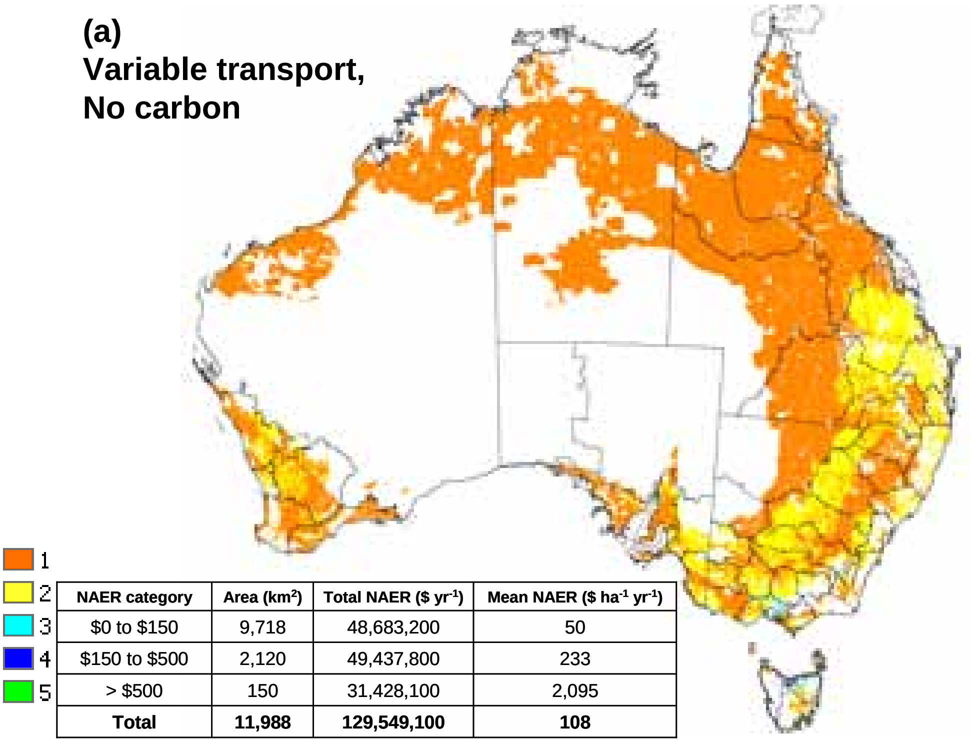


NAER category	Area (km²)	Total NAER ($ yr⁻¹)	Mean NAER ($ ha⁻¹ yr⁻¹)
$0 to $150	945,641	6,182,910,000	65
$150 to $500	1,115,709	34,503,800,000	309
> $500	351,853	23,015,800,000	654
Total	**2,413,203**	**63,702,510,000**	**264**

Fig. 25 (cont.). Spatial maps for scenarios 1.3 and 1.4 (Hardwood sawlogs) summarising areas with a positive value for NAER.

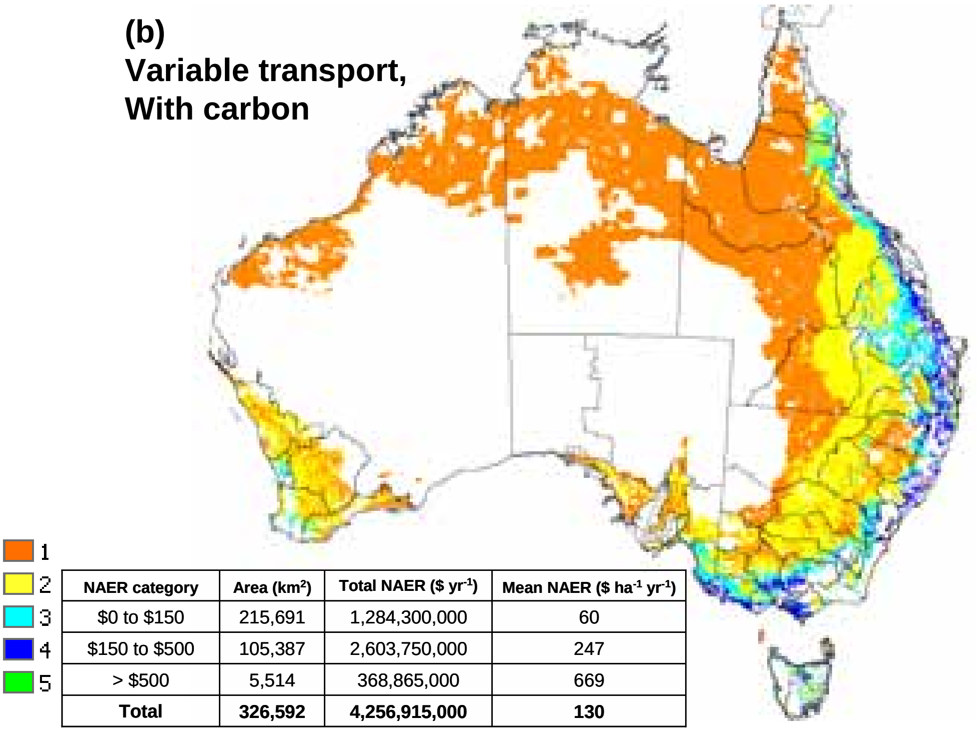
Softwood sawlogs

(a)
Variable transport,
No carbon



NAER category	Area (km^2)	Total NAER ($ yr^{-1})	Mean NAER ($ ha^{-1} yr^{-1})
$0 to $150	9,718	48,683,200	50
$150 to $500	2,120	49,437,800	233
> $500	150	31,428,100	2,095
Total	**11,988**	**129,549,100**	**108**

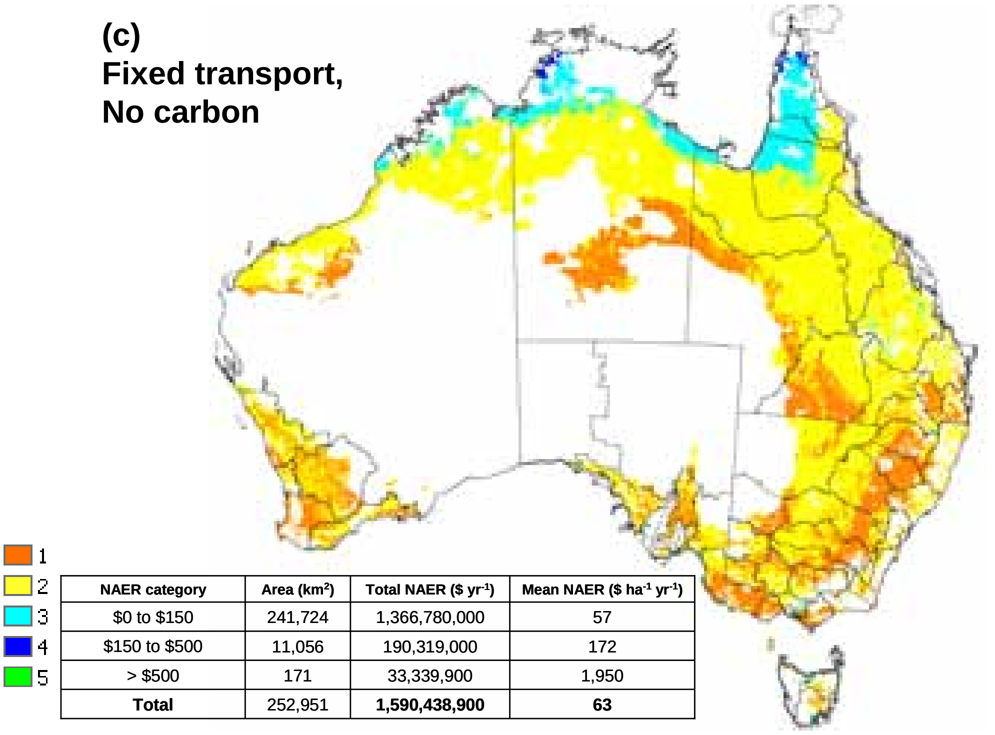
(b)
Variable transport,
With carbon



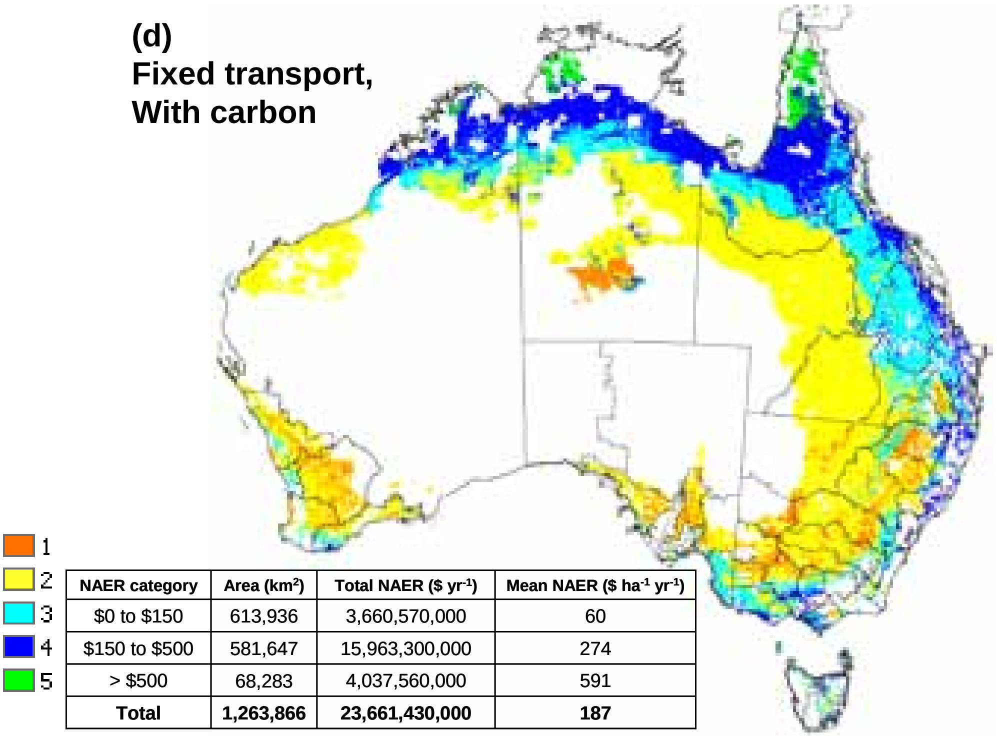
NAER category	Area (km^2)	Total NAER ($ yr^{-1})	Mean NAER ($ ha^{-1} yr^{-1})
$0 to $150	215,691	1,284,300,000	60
$150 to $500	105,387	2,603,750,000	247
> $500	5,514	368,865,000	669
Total	**326,592**	**4,256,915,000**	**130**

Fig. 26. Spatial maps for scenarios 2.1 and 2.2 (Softwood sawlogs) summarising areas with a positive value for NAER.

Softwood sawlogs



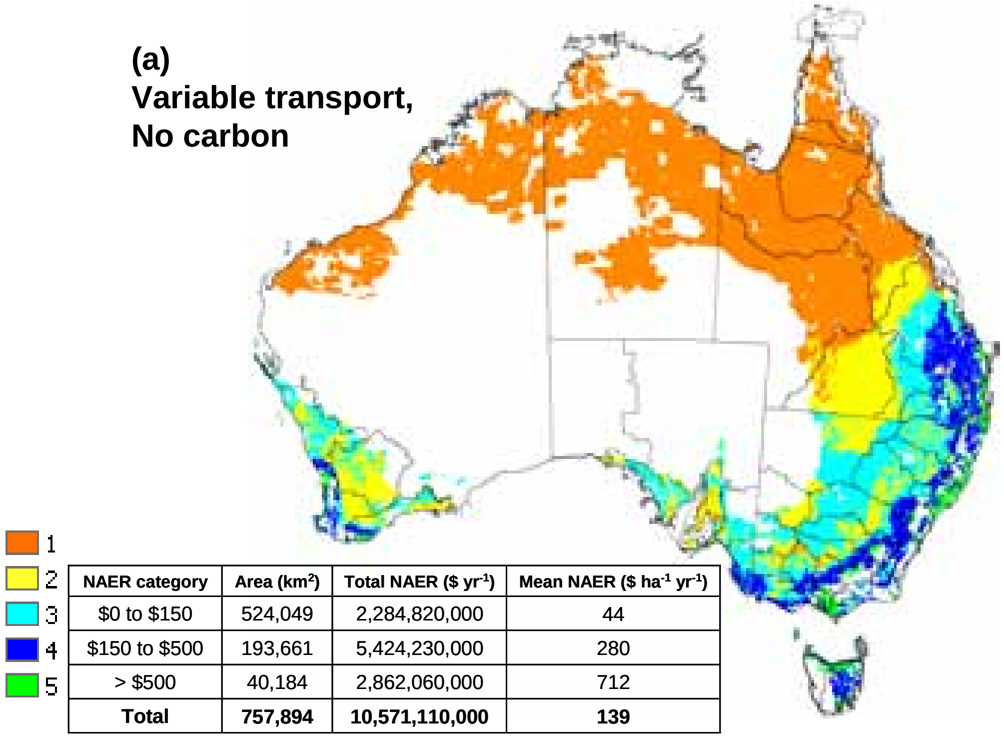
NAER category	Area (km²)	Total NAER ($ yr⁻¹)	Mean NAER ($ ha⁻¹ yr⁻¹)
$0 to $150	241,724	1,366,780,000	57
$150 to $500	11,056	190,319,000	172
> $500	171	33,339,900	1,950
Total	252,951	**1,590,438,900**	**63**



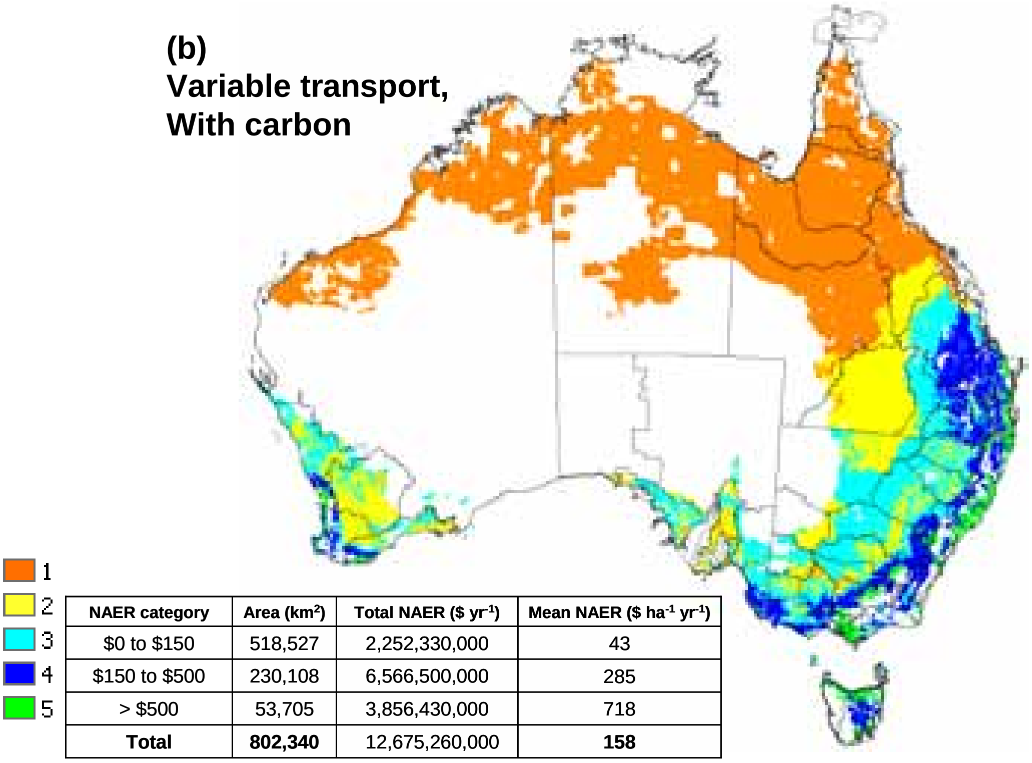
NAER category	Area (km²)	Total NAER ($ yr⁻¹)	Mean NAER ($ ha⁻¹ yr⁻¹)
$0 to $150	613,936	3,660,570,000	60
$150 to $500	581,647	15,963,300,000	274
> $500	68,283	4,037,560,000	591
Total	**1,263,866**	**23,661,430,000**	**187**

Fig. 26 (cont.). Spatial maps for scenarios 2.3 and 2.4 (Softwood sawlogs) summarising areas with a positive value for NAER.

Pulpwood


(a)
Variable transport,
No carbon

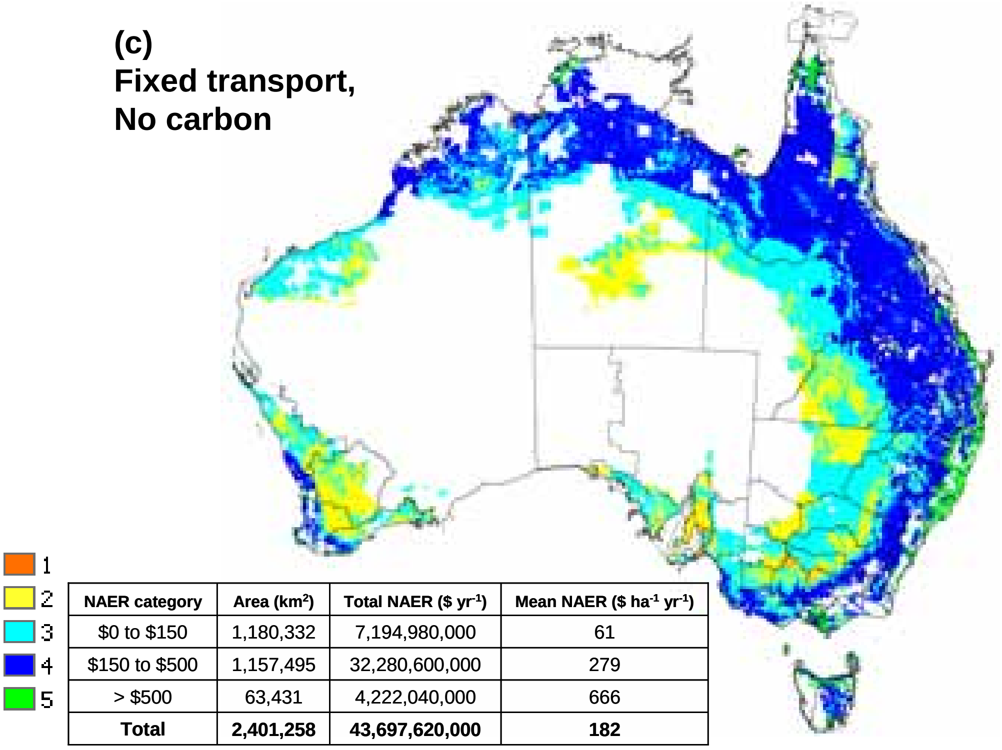
NAER category	Area (km^2)	Total NAER ($ yr^{-1})	Mean NAER ($ ha^{-1} yr^{-1})
$0 to $150	524,049	2,284,820,000	44
$150 to $500	193,661	5,424,230,000	280
> $500	40,184	2,862,060,000	712
Total	**757,894**	**10,571,110,000**	**139**


(b)
Variable transport,
With carbon

NAER category	Area (km^2)	Total NAER ($ yr^{-1})	Mean NAER ($ ha^{-1} yr^{-1})
$0 to $150	518,527	2,252,330,000	43
$150 to $500	230,108	6,566,500,000	285
> $500	53,705	3,856,430,000	718
Total	**802,340**	12,675,260,000	**158**

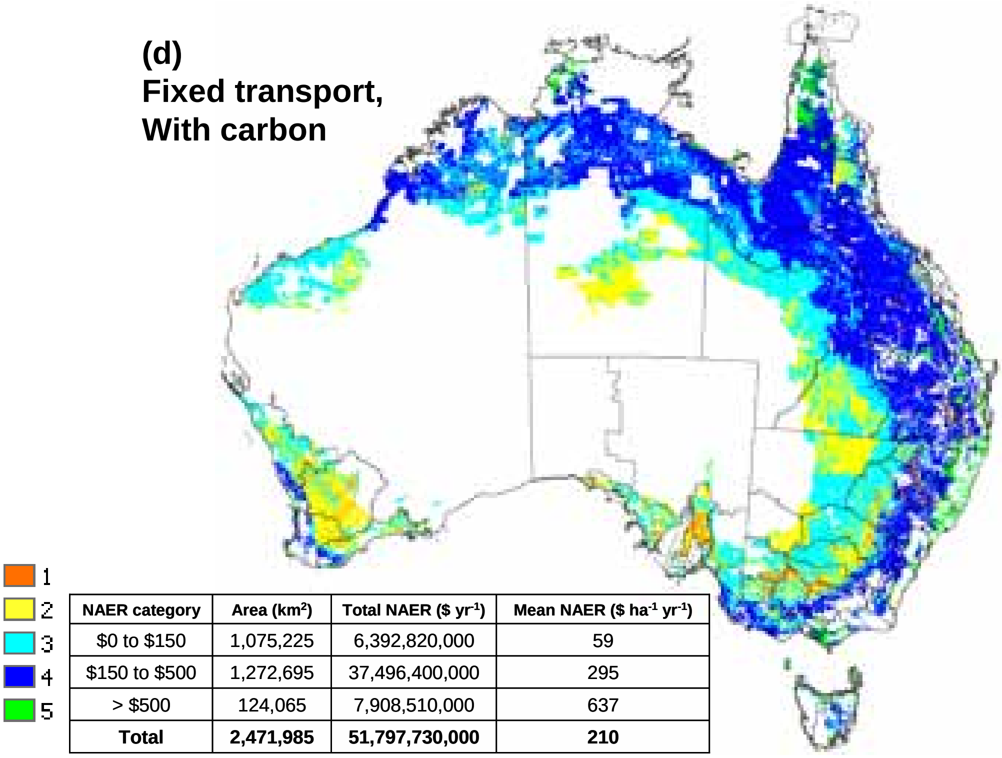
Fig. 27. Spatial maps for scenarios 3.1 and 3.2 (Pulpwood systems) summarising areas with a positive value for NAER.

Pulpwood



(c)
Fixed transport,
No carbon

NAER category	Area (km^2)	Total NAER (\$ yr^{-1})	Mean NAER (\$ ha^{-1} yr^{-1})
\$0 to \$150	1,180,332	7,194,980,000	61
\$150 to \$500	1,157,495	32,280,600,000	279
> \$500	63,431	4,222,040,000	666
Total	**2,401,258**	**43,697,620,000**	**182**



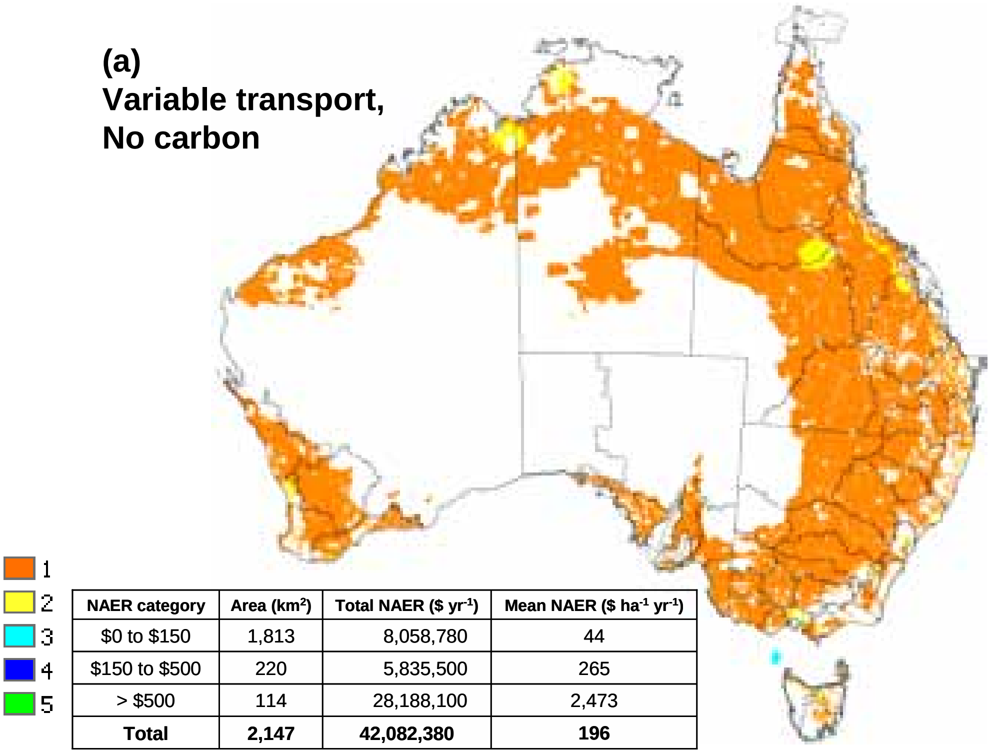
(d)
Fixed transport,
With carbon

NAER category	Area (km^2)	Total NAER (\$ yr^{-1})	Mean NAER (\$ ha^{-1} yr^{-1})
\$0 to \$150	1,075,225	6,392,820,000	59
\$150 to \$500	1,272,695	37,496,400,000	295
> \$500	124,065	7,908,510,000	637
Total	**2,471,985**	**51,797,730,000**	**210**

Fig. 27 (cont.). Spatial maps for scenarios 3.3 and 3.4 (Pulpwood systems) summarising areas with a positive value for NAER.

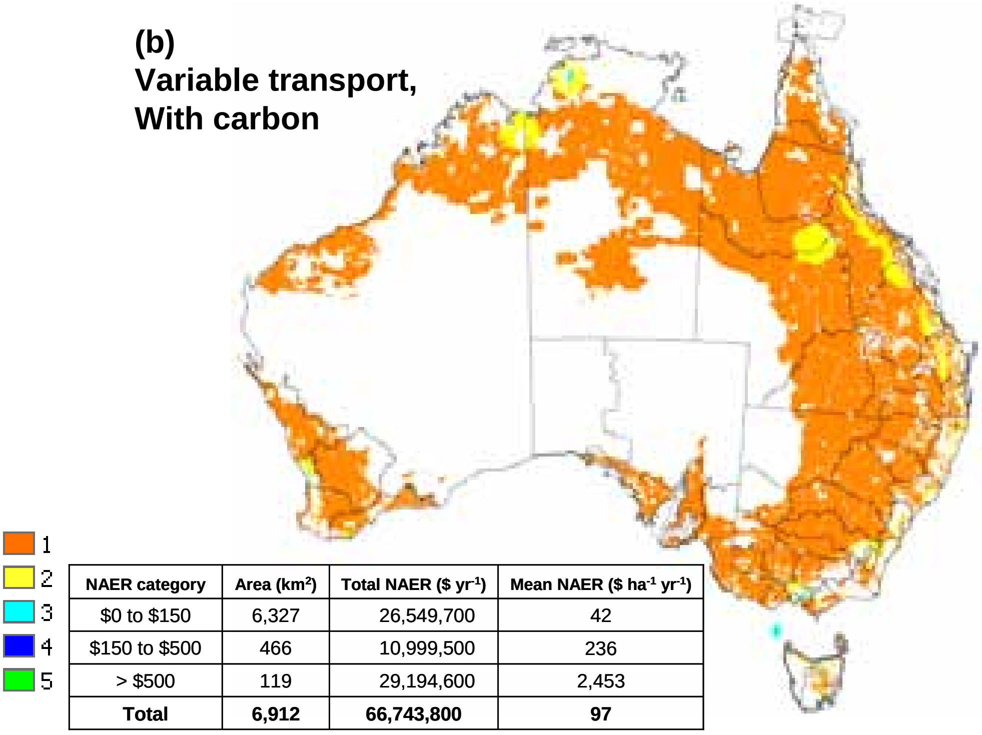
Bioenergy

(a)
Variable transport,
No carbon



NAER category	Area (km^2)	Total NAER (\$ yr^{-1})	Mean NAER (\$ ha^{-1} yr^{-1})
\$0 to \$150	1,813	8,058,780	44
\$150 to \$500	220	5,835,500	265
> \$500	114	28,188,100	2,473
Total	**2,147**	**42,082,380**	**196**

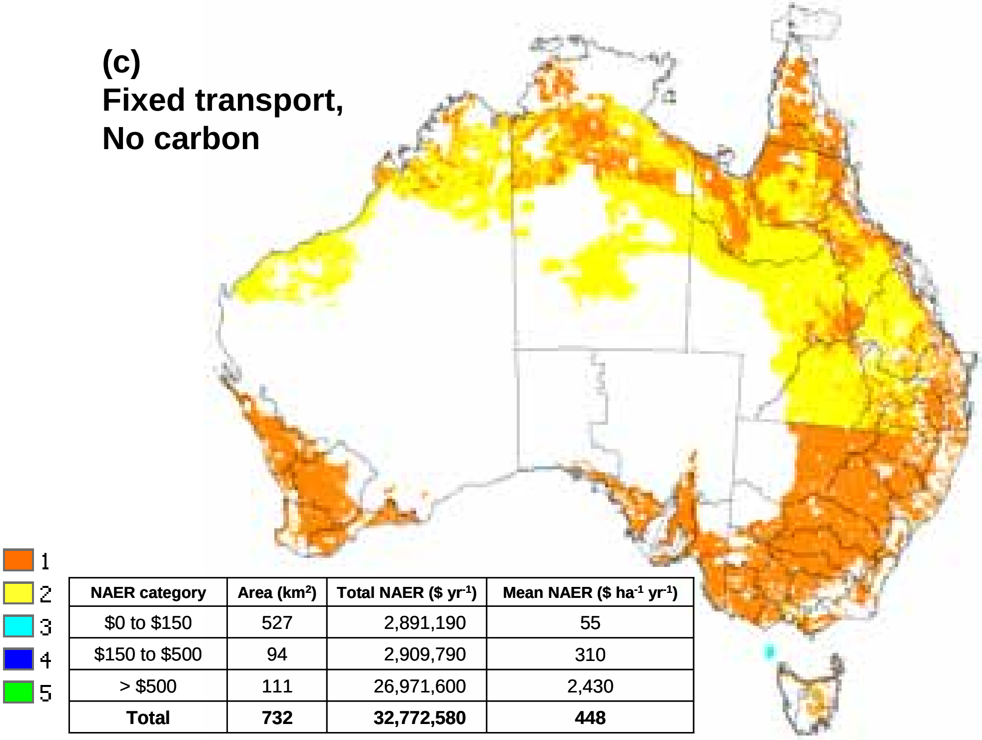
(b)
Variable transport,
With carbon



NAER category	Area (km^2)	Total NAER (\$ yr^{-1})	Mean NAER (\$ ha^{-1} yr^{-1})
\$0 to \$150	6,327	26,549,700	42
\$150 to \$500	466	10,999,500	236
> \$500	119	29,194,600	2,453
Total	**6,912**	**66,743,800**	**97**

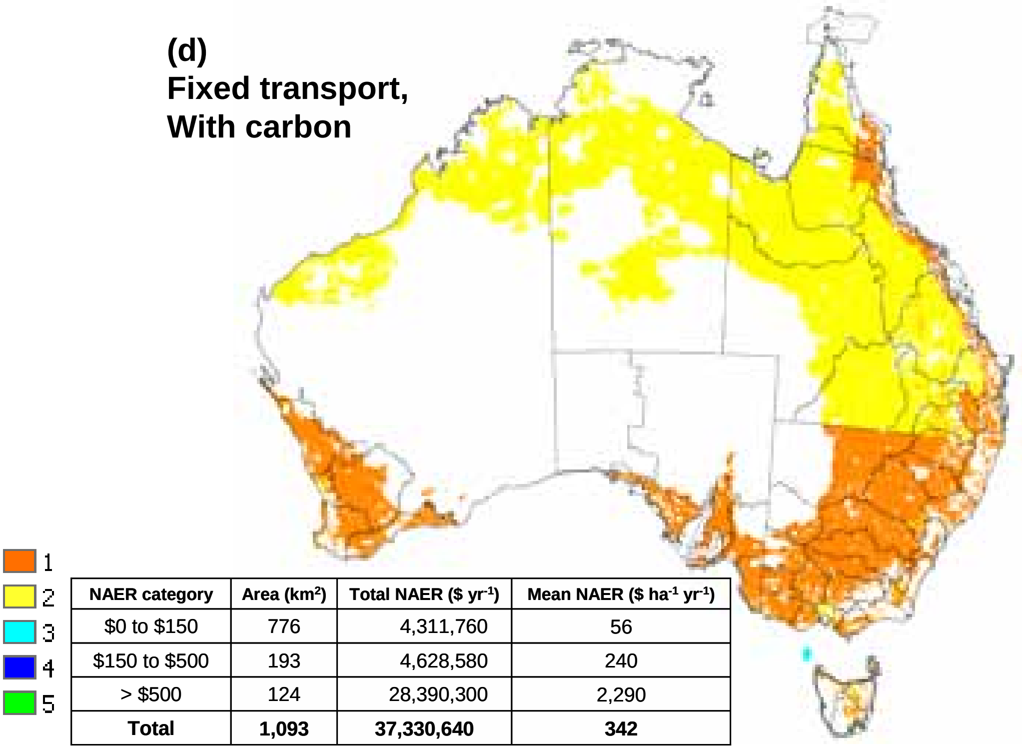
Fig. 28. Spatial maps for scenarios 4.1 and 4.2 (Bioenergy systems) summarising areas with a positive value for NAER.

Bioenergy



(c)
Fixed transport, No carbon

NAER category	Area (km^2)	Total NAER (\$ yr^{-1})	Mean NAER (\$ ha^{-1} yr^{-1})
\$0 to \$150	527	2,891,190	55
\$150 to \$500	94	2,909,790	310
> \$500	111	26,971,600	2,430
Total	**732**	**32,772,580**	**448**

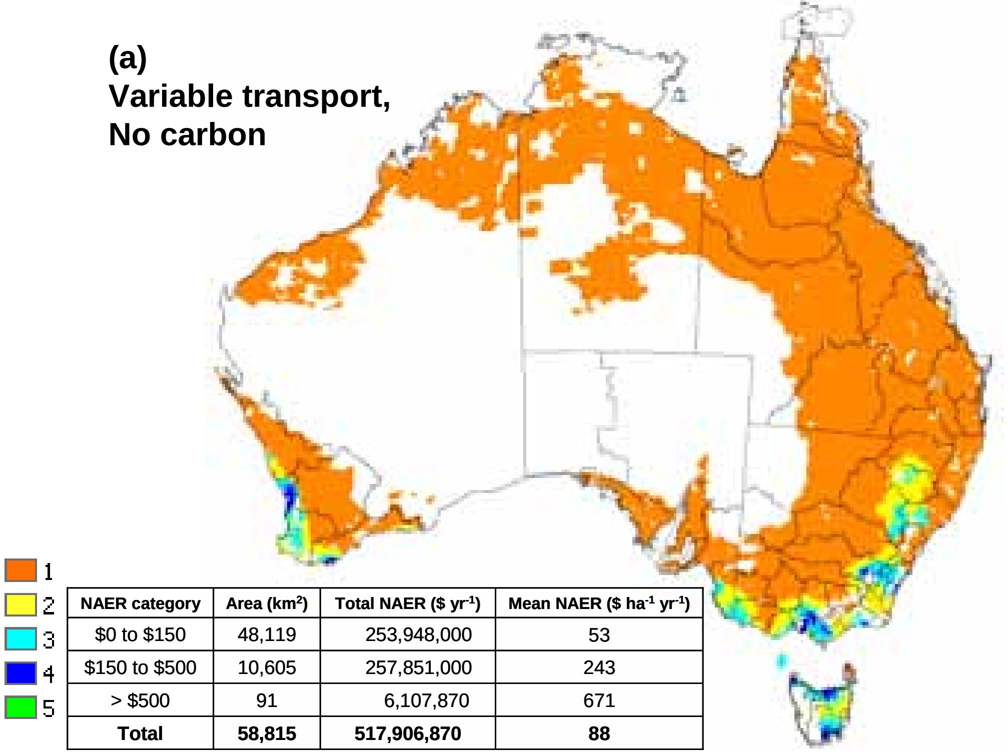


(d)
Fixed transport, With carbon

NAER category	Area (km^2)	Total NAER (\$ yr^{-1})	Mean NAER (\$ ha^{-1} yr^{-1})
\$0 to \$150	776	4,311,760	56
\$150 to \$500	193	4,628,580	240
> \$500	124	28,390,300	2,290
Total	**1,093**	**37,330,640**	**342**

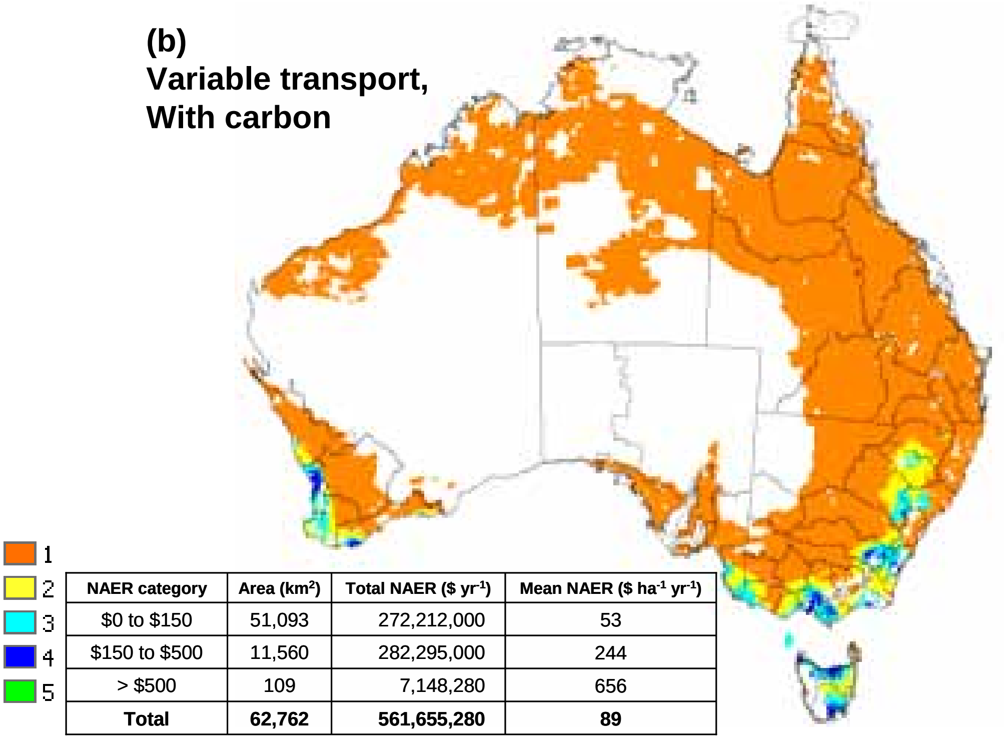
Fig. 28 (cont.). Spatial maps for scenarios 4.3 and 4.4 (Bioenergy systems) summarising areas with a positive value for NAER.

Integrated tree processing



(a)
Variable transport,
No carbon

NAER category	Area (km^2)	Total NAER (\$ yr^{-1})	Mean NAER (\$ ha^{-1} yr^{-1})
\$0 to \$150	48,119	253,948,000	53
\$150 to \$500	10,605	257,851,000	243
> \$500	91	6,107,870	671
Total	**58,815**	**517,906,870**	**88**

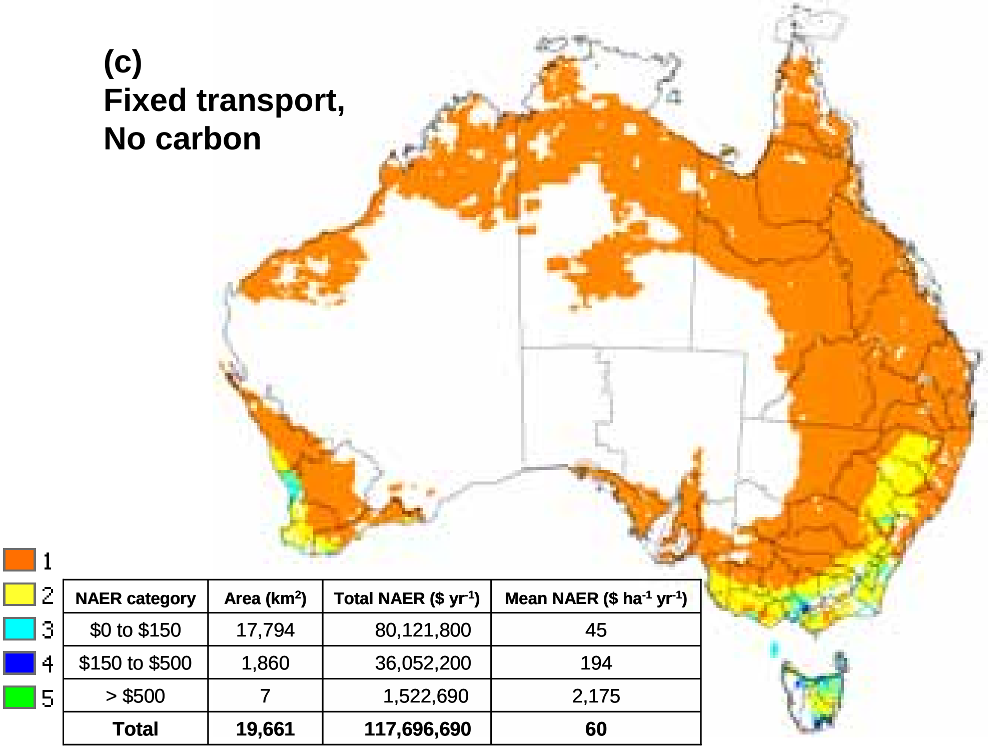


(b)
Variable transport,
With carbon

NAER category	Area (km^2)	Total NAER (\$ yr^{-1})	Mean NAER (\$ ha^{-1} yr^{-1})
\$0 to \$150	51,093	272,212,000	53
\$150 to \$500	11,560	282,295,000	244
> \$500	109	7,148,280	656
Total	**62,762**	**561,655,280**	**89**

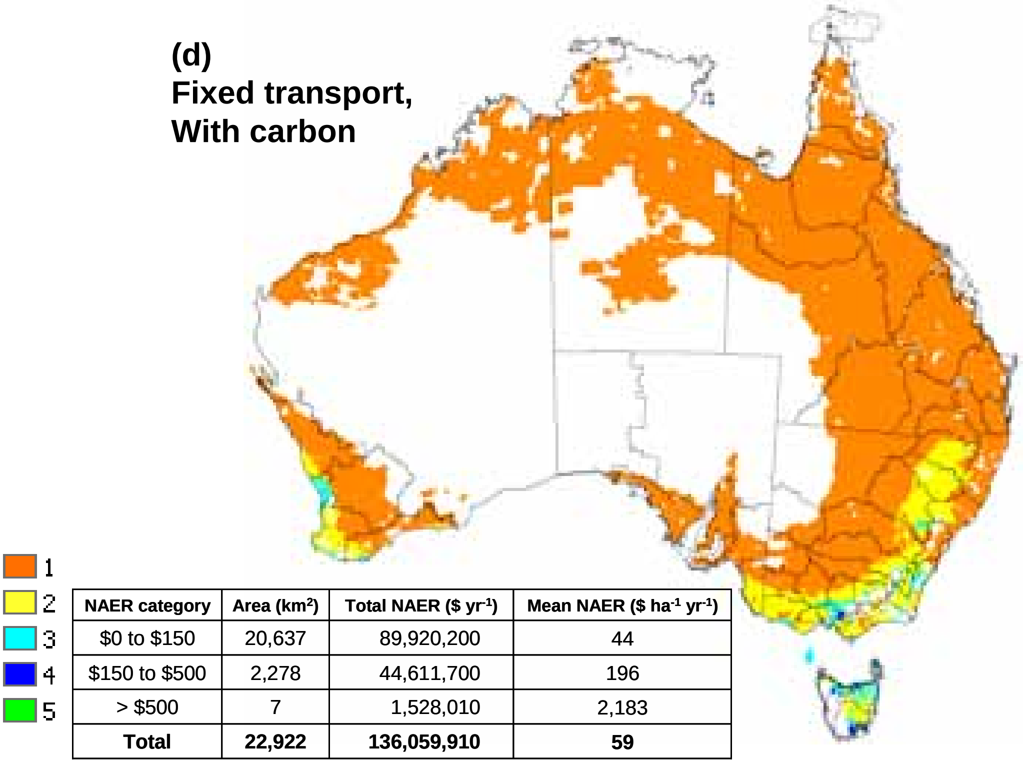
Fig. 29. Spatial maps for scenarios 5.1 and 5.2 (ITP systems) summarising areas with a positive value for NAER.

Integrated tree processing



(c)
Fixed transport,
No carbon

NAER category	Area (km^2)	Total NAER (\$ yr^{-1})	Mean NAER (\$ ha^{-1} yr^{-1})
\$0 to \$150	17,794	80,121,800	45
\$150 to \$500	1,860	36,052,200	194
> \$500	7	1,522,690	2,175
Total	**19,661**	**117,696,690**	**60**



(d)
Fixed transport,
With carbon

NAER category	Area (km^2)	Total NAER (\$ yr^{-1})	Mean NAER (\$ ha^{-1} yr^{-1})
\$0 to \$150	20,637	89,920,200	44
\$150 to \$500	2,278	44,611,700	196
> \$500	7	1,528,010	2,183
Total	**22,922**	**136,059,910**	**59**

Fig. 29 (cont.). Spatial maps for scenarios 5.3 and 5.4 (ITP systems) summarising areas with a positive value for NAER.

Fodder and carbon systems

In situ fodder and carbon plantings were predicted to be potentially profitable over extensive areas of Australia including most of the four geoclimatic zones considered, excluding the arid interior (Figs. 30-32). For the carbon plantings, the greatest profitability was generally predicted to be in the zones of highest rainfall. The predicted profitable area was greater for the hardwood and softwood carbon plantings than for the environmental plantings and in particular, zones of opportunity were predicted for plantations in northern Australia that were not predicted for environmental plantings. This is due to environmental plantings being calibrated only to those forest types that had open canopies, as opposed to more closed canopy forests that might be typical of wet native forests and plantations, and the model calibration also had a lower temperature optimum than for other calibrations. This confined the predicted extent of environmental plantings.

Of all the agroforestry systems studied, *in situ* fodder had the largest potential area of profitability, at some 450 Mha (Fig. 30a) although the mean profitability was comparable to other systems at about (\$200 ha^{-1} yr^{-1}, Fig 33).

There at least three main reasons why carbon plantings were predicted to have high profitability compared with the harvested agroforestry scenarios:

- There are no harvesting and transportation costs associated with carbon plantings, thus greatly reducing costs of production relative to the product price
- Similarly, the location of carbon plantings is not constrained by proximity to existing or future processing facilities, and thus can be established in almost any geographic region of Australia where rates of growth and carbon sequestration are deemed suitable
- The carbon payment can be an annuity, in contrast to harvested systems where the investor may have to wait years or decades before a financial return is realized. However, in this exercise we did not explicitly track the changing amount of carbon payments from the time of planting to maturity; the results presented here being for an assumed equilibrium condition.

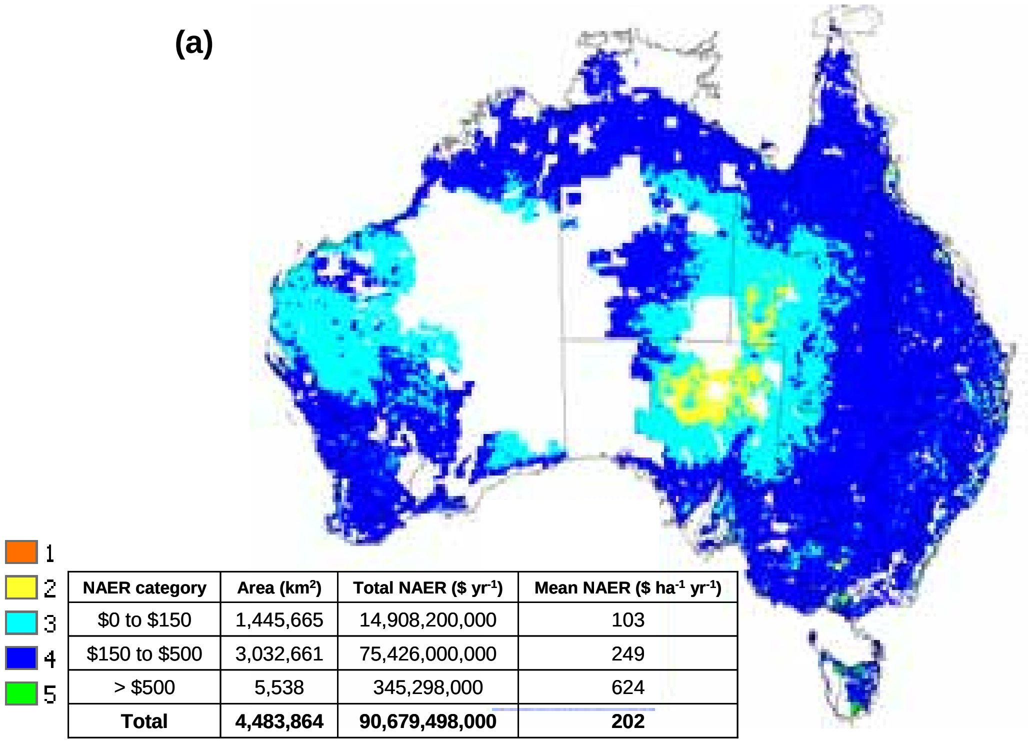
General discussion

The main points arising from the above analyses can be summarized:

- Hardwood sawlog and pulpwood systems are predicted to be reasonably profitable because of the higher assumed product value for these systems than for softwood sawlog systems.
- Transport costs are important for determining profitability
- If new processing plants or export ports were to be established within areas of significant new expansion of plantations, then new opportunities would arise at the top end of Australia and move progressively inland from the existing plantations sites
- Payments for carbon sequestration are potentially important for sawlog systems but not for the shorter rotation pulpwood systems
- Bioenergy and ITP systems are not currently profitable unless they are located within close proximity to processing plants, to decrease the costs of production associated with transport. A similar conclusion was reached by Hobbs *et al.* (2008)
- Carbon plantings may be economically attractive, compared with harvested systems, because the there are no costs associated with product (sequestered carbon) being harvested and transported and thus the location of plantings is not constrained by proximity to processing facilities.

Fodder

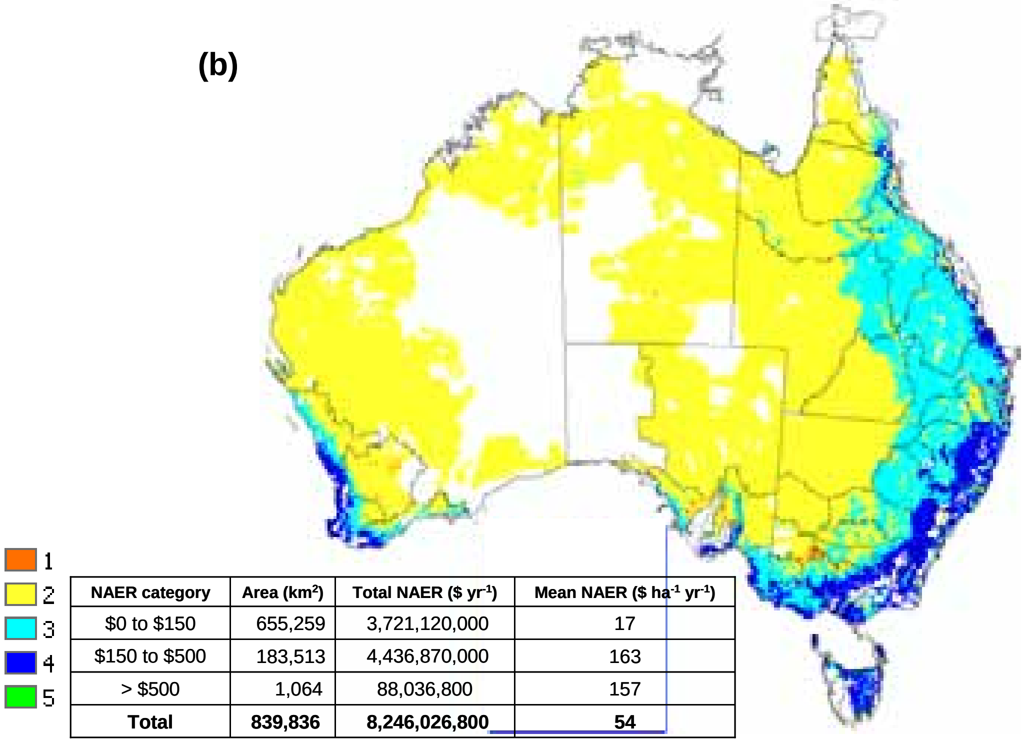
(a)



NAER category	Area (km^2)	Total NAER (\$ yr^{-1})	Mean NAER (\$ ha^{-1} yr^{-1})
\$0 to \$150	1,445,665	14,908,200,000	103
\$150 to \$500	3,032,661	75,426,000,000	249
> \$500	5,538	345,298,000	624
Total	**4,483,864**	**90,679,498,000**	**202**

Environmental plantings

(b)

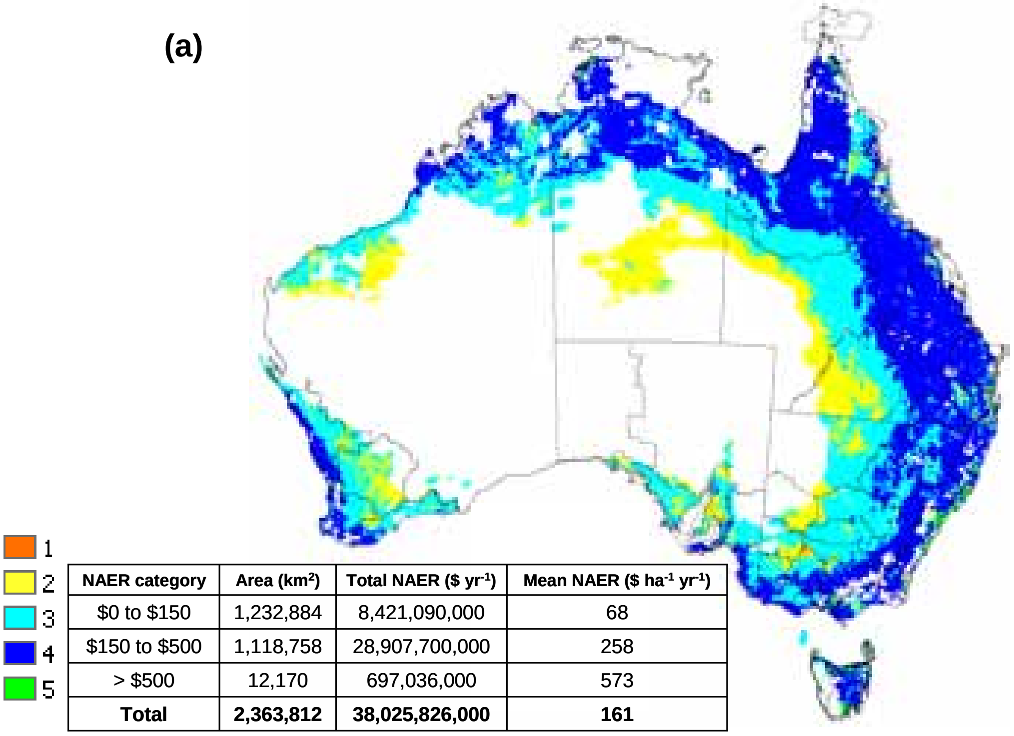


NAER category	Area (km^2)	Total NAER (\$ yr^{-1})	Mean NAER (\$ ha^{-1} yr^{-1})
\$0 to \$150	655,259	3,721,120,000	17
\$150 to \$500	183,513	4,436,870,000	163
> \$500	1,064	88,036,800	157
Total	**839,836**	**8,246,026,800**	**54**

Fig. 30. Spatial maps for scenarios 6 (Fodder systems) and 7 (Environmental carbon plantings) summarising areas with a positive value for NAER.

Hardwood carbon plantings

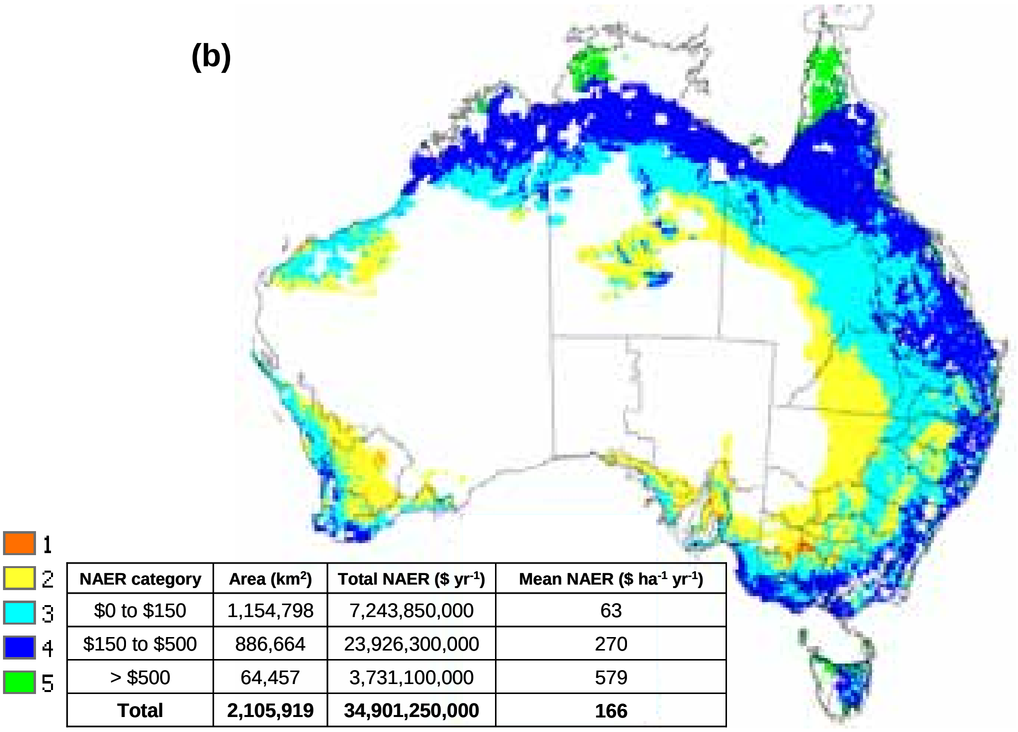
(a)



NAER category	Area (km^2)	Total NAER (\$ yr^{-1})	Mean NAER (\$ ha^{-1} yr^{-1})
\$0 to \$150	1,232,884	8,421,090,000	68
\$150 to \$500	1,118,758	28,907,700,000	258
> \$500	12,170	697,036,000	573
Total	**2,363,812**	**38,025,826,000**	**161**

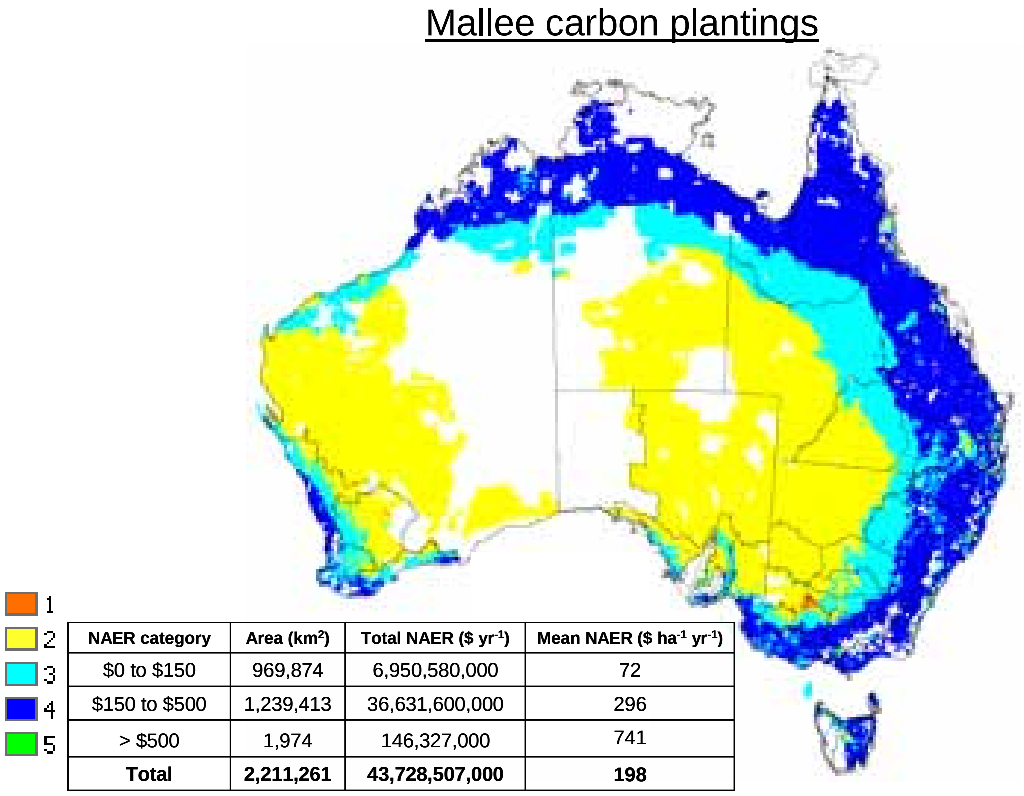
Softwood carbon plantings

(b)



NAER category	Area (km^2)	Total NAER (\$ yr^{-1})	Mean NAER (\$ ha^{-1} yr^{-1})
\$0 to \$150	1,154,798	7,243,850,000	63
\$150 to \$500	886,664	23,926,300,000	270
> \$500	64,457	3,731,100,000	579
Total	**2,105,919**	**34,901,250,000**	**166**

Fig. 31. Spatial maps for scenarios 8 (Harwood carbon plantings) and 9 (Softwood carbon plantings) summarising areas with a positive value for NAER.



NAER category	Area (km²)	Total NAER ($ yr⁻¹)	Mean NAER ($ ha⁻¹ yr⁻¹)
$0 to $150	969,874	6,950,580,000	72
$150 to $500	1,239,413	36,631,600,000	296
> $500	1,974	146,327,000	741
Total	**2,211,261**	**43,728,507,000**	**198**

Fig. 32. Spatial maps for scenario 10 (Mallee carbon plantings) summarising areas with a positive value for NAER.

All of the results and outputs need to be interpreted within the limitations imposed by modelling assumption, some of which are discussed in greater detail in the section ‘Uncertainty analysis’. The outputs for profitability for each scenario make no presumption about the potential market for any given product, for example, the ability to sell wood from sawlog systems, other than to assess the impacts of proximity to processing plants. For sawlog and pulpwood systems, the importance of the market size, current and potential, is discussed later.

The modelled outputs are highly sensitive to costs of production and product prices. The values we assumed (Table 5) should be considered as indicative values only. In reality there is also a strong interdependence between costs and scale – the smaller farm enterprises will have costs that are relatively high compared with potential returns (Hassell & Associates 2008).

For carbon plantings, the potential size of the market is not known, but it is not constrained by commodity demands in the same way as for harvested products. In our scenarios we assumed that the amounts of carbon traded for an equilibrium condition was 100% of the total amount of carbon sequestered by carbon plantings and 50% of the total pre-harvest amount for harvested systems (Baalman and O’Brien 2006). We do not know if these assumptions, including the price of $20 t^{-1} CO_2-e, will be realistic under an emissions trading scheme in Australia. However, the general conclusions will probably remain valid, regardless of the assumptions chosen, that payments for carbon sequestration can improve the profitability of sawlog systems and appear economically attractive for dedicated carbon sequestration plantings.

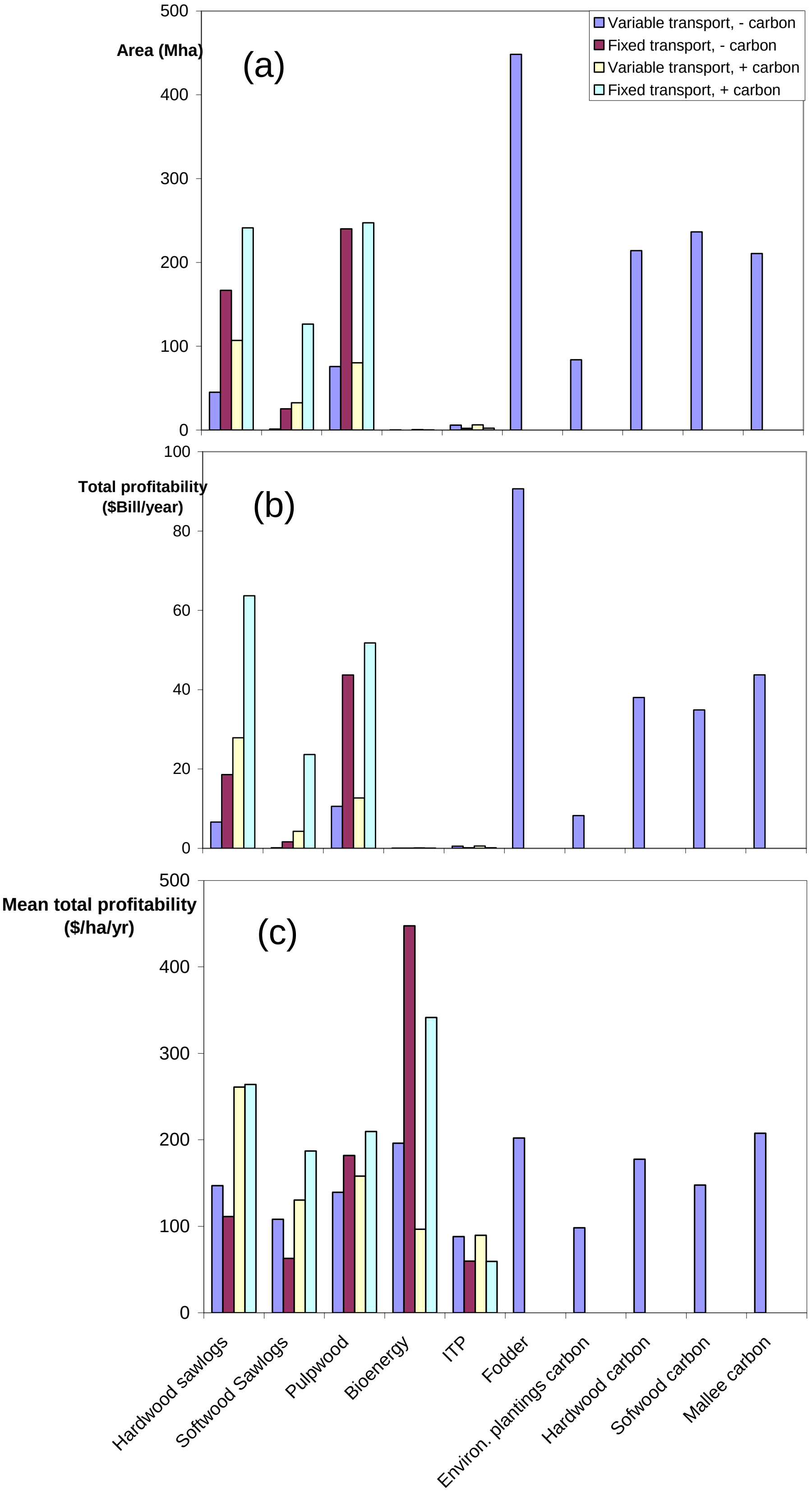


Fig. 33. Summary statistics from Figs. 24-29 for showing (a) potentially available area with positive values of NAER, (b) the total profitability (sum of all positive NAER values across those areas, and (c) the mean areal profitability.

For sawlog and pulpwood systems where fixed transport distances were assumed, the main new opportunities were predicted to be progressively inland and across the top end of Australia. The northern predictions in particular, have a reasonably high degree of uncertainty because they are dependent on productivity predictions in zones for which there were few data for either calibration or validation. Furthermore, the predicted productivity for environmental plantings identified zones of opportunity in northern zones quite different from those identified in hardwood and softwood carbon plantings. In part this represents differences in the species and forest systems calibrated (see above) and again the paucity in data sets in these northern regions. Moreover, it represents outcomes from modelling results that have not taken into account all of the risks associated with plantations in northern Australia, such as from regular fires, termites, other pests and diseases, periodic or seasonal drought and cyclones. Information on the growth potential of species in northern Australia and management of risks is very limited and this is clearly an area for future research.

Regions of greatest profitability for nearly all of the agroforestry scenarios were often predicted to be in the coastal or near coastal regions where rainfall was also highest (for example, Fig. 24). For sawlog and pulpwood systems this is mostly to be expected because the zones of current opportunity often coincided with the National Plantation inventory regions, that is, where there are existing plantation industries that are usually in reasonably high rainfall regions and not too far from the coast. This raises at least two important considerations:

- The results for NAER need to be treated with some caution along the very coastal areas on the eastern side of Australia. That is because the 'Profit at Full Equity' layer, that takes into account the opportunity cost of the preceding agricultural enterprise, was based on 1996 data which were adjusted to present day terms by applying annual values for the Consumer Price Index. That is, it did not take into account other shifts and impacts on the PFE, such as demographic shifts in 'lifestylers' and the increasing population pressures on land values along the east coast of Australia. Similarly, the impacts of the recent, wide-spread drought were not captured in the current PFE layer. The implications are that if opportunity cost is to be properly taken into account then a new and updated layer needs to be developed; land values may be a better alternative if the data are available at a scale sufficiently small for these types of analyses, and that it will be equally important to understand how the opportunity cost might shift in the years ahead under an increasingly variable and changing climate. Forests can take many years or decades before their economic or environmental benefits are realised. How the 'baseline' condition of agricultural enterprises, especially in marginal environments, will change over the coming decades will be critical as forests established in the next few years mature
- Notwithstanding the qualifications above, it appears generally true that the highest profitability of agroforestry systems will often be achieved where rates of forest growth are highest and thus in the high rainfall zones. This introduces the added complication of trade-offs of agroforestry developments with water security. The framework of the National Water Initiative is being used by various jurisdictions to consider how to treat plantations and their potential impacts on water interception. In some cases this could lead to licensing of plantations for the water they use, in other cases jurisdictions may take more of a planning and regulation approach. Whichever way policy developments evolve, the regional opportunities for agroforestry presented here may have to be modified to take into account impacts on water availability. This is discussed more in the section ('Multiple Impact Assessment'). It should also be noted that we did not assess the economic impacts of plantations on water availability in our analyses by, for example, assigning a monetary value to amounts of water intercepted.

The analyses show that dedicated energy plantations are not expected to be profitable under current economic and policy environments unless they are located within short distance to processing and energy conversion plants to keep the transportation costs to a minimum. Future policies and incentives for biomass energy systems may change the profitability of those systems, however it is worth noting that bioenergy could also be part of a mixed product system from sawlog regimes. In our analyses we did not consider the potential for bioenergy pathways from harvested sawlog systems, either from thinnings or waste at final harvest. Given a sufficiently high value of the energy feedstocks it is plausible that sawlog or other systems would be an appropriate silvicultural system to partly supply future energy demands.

Multiple impact assessment

All of the preceding analyses presented up to this point have been single impact assessments in which profitability is the sole output of interest. While economic outcomes are frequently forceful and predominant drivers, other considerations often come into play. The most obvious of these is trade-offs with water interception that has now achieved prominence under the terms of the National Water Initiative. We have not included the cost of water in our calculations of NAER although it is possible to run such scenarios. However, policies at jurisdictional level are still being framed and it is possible that there will be different regulations applying across regions and rainfall zones; for example, new plantations in high rainfall zones could be subject to regulation whereas those in the lower rainfall zones may not. The impacts of plantations also depends on local water balances that take into account all inflows and consumptive uses. The ‘Zhang curves’ used here (Fig. 10) are generalisations only of the amounts of rainfall intercepted that otherwise would result in stream flow. The impact of agroforestry on biodiversity is another main area of interest although markets are less well developed than for carbon or water interception. While establishment of native-endemic mixed environmental plantings provide the most suitable habitat for biodiversity, monoculture forestry systems for sawlogs or pulplogs still provide greater habitat for native fauna than cleared agricultural land.

Here, we apply the SPIF tool developed previously under the CEF program of research to identify regions suitable for agroforestry systems against various criteria for economic and environmental outcomes including relatively low negative water interception impact and high positive biodiversity impact. We have limited the analyses to Scenario 1.1 (Hardwood sawlog systems, variable transport and no carbon payments) and Scenario 7 (Environmental carbon plantings). The purpose here is to illustrate the methodology and types of outputs that are generated rather than attempt to provide an exhaustive set of outputs. Three sets of criteria were applied for each of the two scenarios (Figs. 34 and 35) being:

(i) NAER > $\$150$ ha^{-1} yr^{-1}, water interception < 150 mm yr^{-1}
(ii) NAER > $\$150$ ha^{-1} yr^{-1}, Biodiversity score < 50 units
(iii) NAER > $\$150$ ha^{-1} yr^{-1}, water interception < 150 mm yr^{-1}, Biodiversity score < 50 units.

Note that a low biodiversity score indicates a high need for revegetation.

The NAER was used as a common criterion for all three combinations on the assumption that profitability was a first main requirement. The results are discussed below.

Scenario 1.1. Hardwood sawlogs (Fig. 34). For criterion (i), NAER > $\$150$ ha^{-1} yr^{-1} and water interception < 150 mm yr^{-1}, the main opportunities were identified as being just west of the Great Dividing Range along the east coast of Australia and in parts of Tasmania and south-west Western Australia. The total area identified was about 6.5 Mha.

When the scenario was constrained by biodiversity benefit rather than water (criterion (ii), NAER > $\$150$ ha^{-1} yr^{-1}, and Biodiversity score < 50 units) the main regions of opportunity segregated into those in south-east Qld, central and southern Victoria, and parts of Tasmania and south-west WA. The effectiveness of planting for biodiversity enhancement in the regions identified is predicated on the fact that large areas would be required, given that it uses a ‘nearest neighbourhood’ method to determine the need for plantings. This means that a limited area of planting in the zones identified would in all likelihood do little to enhance biodiversity. The analysis here also does not exclude areas such as mid-western NSW from the biodiversity benefits of new agroforestry plantings. These areas have been cleared extensively in the past but our analysis has given them a slightly higher score than the 50 units used here as the filter (Fig. 12).

When all three constraints were imposed (criterion (iii), NAER > $\$150$ ha^{-1} yr^{-1}, water interception < 150 mm yr^{-1} and Biodiversity score < 50 units) the main region of opportunity identified was in south-east Qld. In total some 3.2 Mha were identified as meeting the criteria (Fig. 34) and notably in regions with some of the highest population growth in Australia.

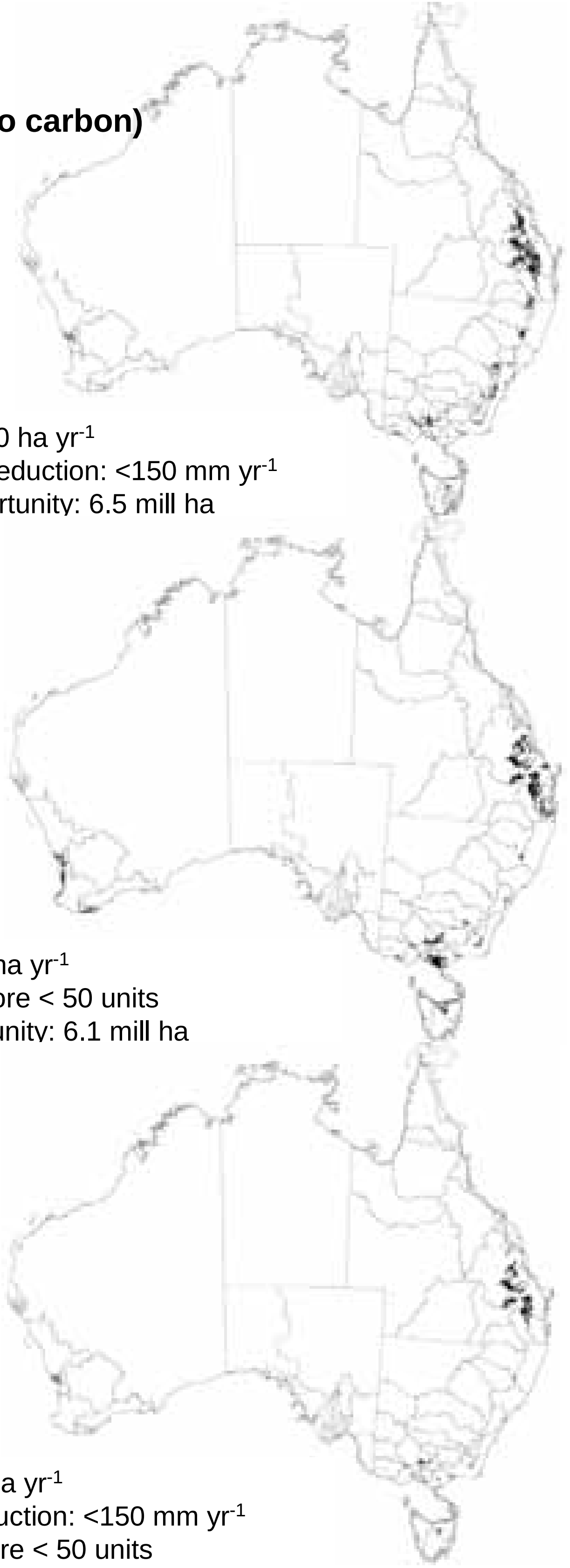
Scenario 7. Environmental carbon plantings (Fig. 35). For criterion (i), NAER > \$150 ha^{-1} yr^{-1} and water interception < 150 mm yr^{-1}, the main opportunities were confined to south-eastern Australia (west of the Great Dividing Range and extending through Victoria and NSW up to the Queensland border), southern and south-eastern South Australia and parts of Tasmania and south-west Western Australia. A total of 9.1 Mha were identified. The annual rate of carbon sequestration was predicted to be 143 Mt CO_2-e yr^{-1} at an average areal rate of 16 t CO_2-e ha^{-1} yr^{-1}. This total annual increment is equivalent to about 25% of Australia's net 2005 greenhouse gas emissions (www.greenhouse.gov.au/inventory).

Environmental plantings may often be established primarily for biodiversity benefit but would also need to be profitable to help fund the costs. For this scenario, constrained by biodiversity benefit (criterion (ii), NAER > \$150 ha^{-1} yr^{-1}, and Biodiversity score < 50 units), a very different pattern emerged from the one described above. Many of the NSW opportunities had been diminished and new opportunities were identified in south-eastern and eastern Queensland. The total area identified was about 5 Mha with an annual carbon sequestration rate of 88 Mt CO_2-e yr^{-1}. This is based solely on the extent of cleared land and does not factor in species-specific biodiversity issues.

When all three constraints were imposed (criterion (iii), NAER > \$150 ha^{-1} yr^{-1}, water interception < 150 mm yr^{-1} and Biodiversity score < 50 units), the main regions of opportunity identified were in the southern parts of Australia and had decreased to 3.2 Mha with an annual carbon sequestration rate of 44 Mt CO_2-e ha^{-1} yr^{-1}.

The examples above for both Scenarios 1.1 and 7 are illustrative only. The regions identified would change significantly if different assumptions or scenarios had been used. For example, assuming a lower or higher price of carbon than the \$20 t^{-1} CO_2-e used here led to identification of different regions and extent of opportunities. We did not consider salinity impacts in any of our analyses. This can be a difficult exercise because of the many and varying factors that control tree, water and salinity interactions Stirzaker *et al*. (2002). For example, the location, mobility and extent of salt stores is a pre-requisite for any analysis as is the location and type of groundwater flow system. A recent analysis has been completed for the Murray-Darling Basin by Gilfedder *et al*. (2006) and Davey *et al*. (2006) who attempted to map opportunities across all of Australia for planting trees for salinity mitigation.

Notwithstanding the limitations of this exercise, it is clear that there are large areas of Australia potentially available for establishment of new agroforestry enterprises for commercial and environmental benefit. The outputs in this and the preceding sections can be viewed as 'prospecting' for opportunities in which the aim is to identify regions that may meet the criteria of a particular type of investor but which require greater ground-truthing to verify the assumptions used in the model and to assess the local social, economic and policy conditions as they pertain to agroforestry developments.



Hardwood sawlogs (variable transport, no carbon)

(a)

- NAER > \$150 ha yr^{-1}
- Water yield reduction: <150 mm yr^{-1}
- Area of opportunity: 6.5 mill ha

(b)

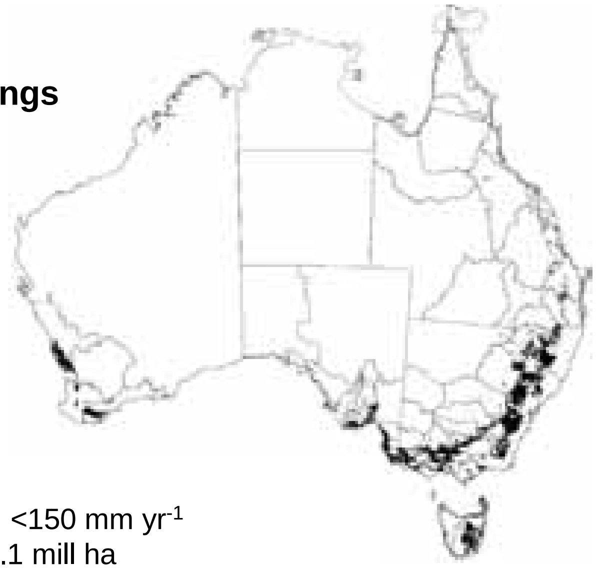
- NAER > \$150 ha yr^{-1}
- Biodiversity score < 50 units
- Area of opportunity: 6.1 mill ha

(c)

- NAER > \$150 ha yr^{-1}
- Water yield reduction: <150 mm yr^{-1}
- Biodiversity score < 50 units
- Area of opportunity: 3.2 mill ha

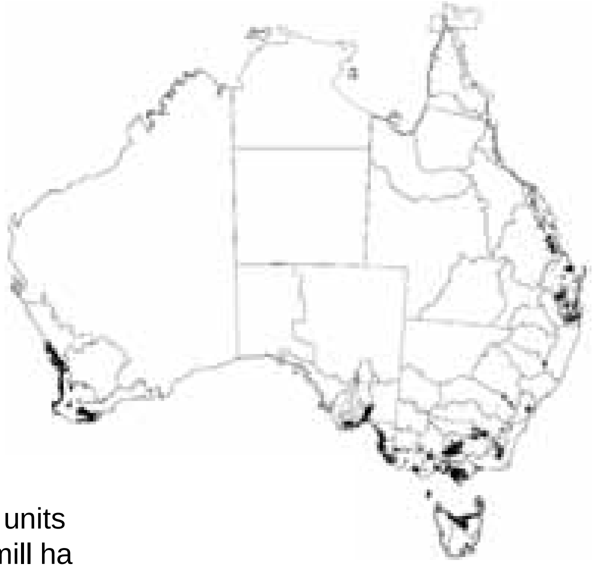
Fig. 34. The results from multiple impacts assessment against three sets of criteria for Scenario 1.1, hardwood sawlogs with variable transport and no carbon payments. Outputs were constrained by (a) profitability and water interception, (b) profitability and biodiversity enhancement , and (c) profitability, water interception and biodiversity enhancement.

Environmental plantings



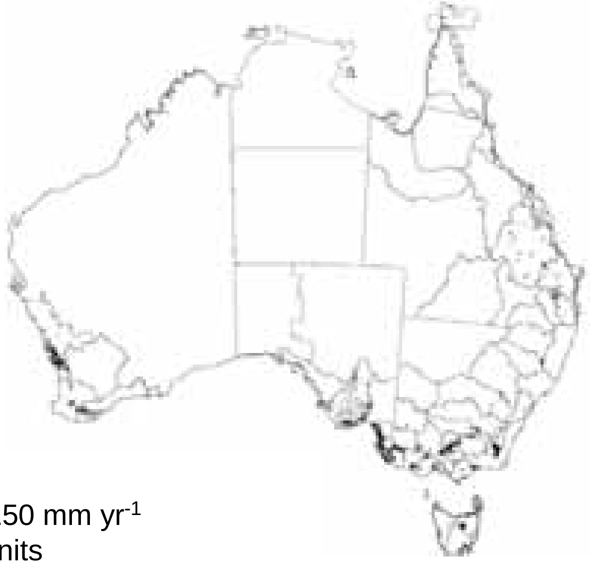
(a)

- NAER > $150 ha yr^{-1}
- Water yield reduction: <150 mm yr^{-1}
- Area of opportunity: 9.1 mill ha
- Total carbon sequestered: 143 mill t CO$_2$ yr^{-1}



(b)

- NAER > $150 ha yr^{-1}
- Biodiversity score < 50 units
- Area of opportunity: 5 mill ha
- Total carbon sequestered: 88 mill t CO$_2$ yr^{-1}



(c)

- NAER > $150 ha yr^{-1}
- Water yield reduction: <150 mm yr^{-1}
- Biodiversity score < 50 units
- Area of opportunity: 3.2 mill ha
- Total carbon sequestered: 44 mill t CO$_2$ yr^{-1}

Fig. 35. The results from multiple impacts assessment against three sets of criteria for Scenario 7, mixed environmental plantings for carbon payment. Outputs were constrained by a) profitability and water interception, (b) profitability and biodiversity enhancement, and (c) profitability, water interception and biodiversity enhancement.

Uncertainty analysis

The predominant parameters influencing calculated values of AER for hardwood sawlog production systems in geoclimatic zone 1 can be summarized (Fig. 36):

- Transport distance for the most valuable log grades (sawlog class A and B),
- The product value of those sawlogs, and
- The final harvest volume.

These results are unsurprising and in line with most previous studies of forest economics. We did not evaluate costs of land purchase or lease in this analysis, which is also known to greatly affect profitability. The potential transport distances to mill were as great at 1720 km in zone 1, yet assuming 'average' values for parameters in Table 8, this distance would need to be less than 240 km for AER to have a positive value. Transport distance and product value are controlled by forest planning and market forces and R&D can have little influence over them. In contrast, the final harvest volume is a result of all those factors known to affect the survival and growth of forests. Hence this remains a key area for intervention by R&D programs.

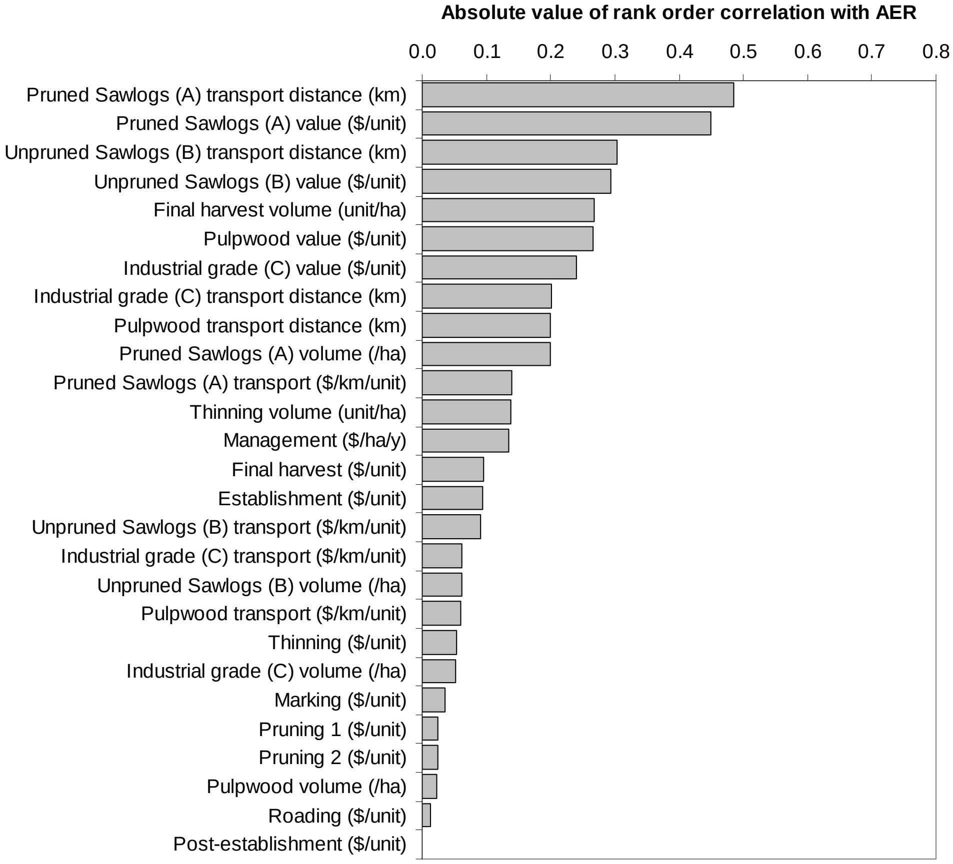


Fig. 36. Absolute value of rank order correlation between the assumed probability distribution of cost, revenue, yield and transport distances, and the resulting calculated AER for scenario 1.1, hardwood sawlogs grown in regions where MAR>550 mm.

In contrast to the sawlog scenario, environmental plantings have fewer management costs because no harvesting and transport are required. For the environmental plantings scenario 7.1, the two main factors influencing AER were (Fig. 37):

- Price of carbon, and
- Amount of carbon sequestered.

Again, it is expected that growth rate and product price would be the dominant factors. Assuming 'average' values for other parameters (Table 9), negative values of AER are attained only when the price of carbon falls below \$8 t^{-1} CO_2-e. Similarly, the carbon yield at the end of 20 years was predicted to vary between 55 and 705 t CO_2-e ha^{-1} in Zone 1, however, only yields less than 128 t CO_2-e ha^{-1} resulted in a negative AER given 'average' values for all other parameters.

Figure 38 shows the likelihood of returning a profit within zone 1 for the scenarios examined. For the hardwood sawlog system it was 75% probable that a negative value of AER would be returned. This is a direct reflection of the large area of Zone 1 and the potentially high transport distances depending upon where in the zone the plantation was established. In contrast, the profitability of environmental carbon plantings is independent of transport distances and a more normal (if skewed) distribution was predicted for profitability, the most likely returns being \$100-300 ha^{-1} for AER.

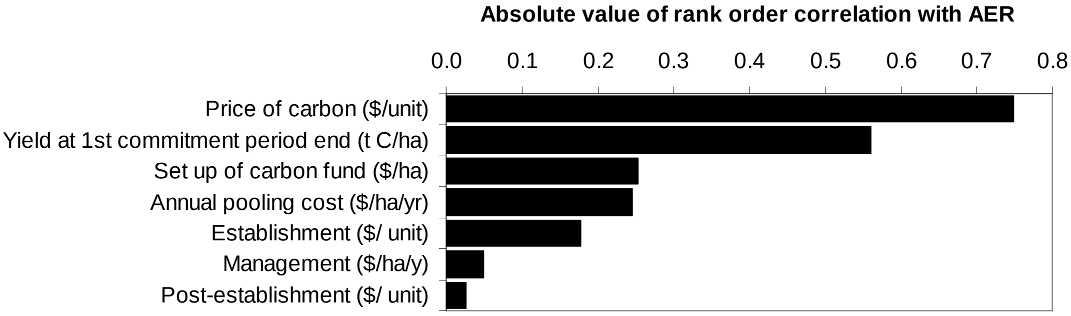


Fig. 37. Absolute value of rank order correlation between the assumed probability distribution of cost, revenue, yield and transport distances, and the resulting calculated AER for scenario 7.1, environmental plantings grown in regions where MAR>550 mm.

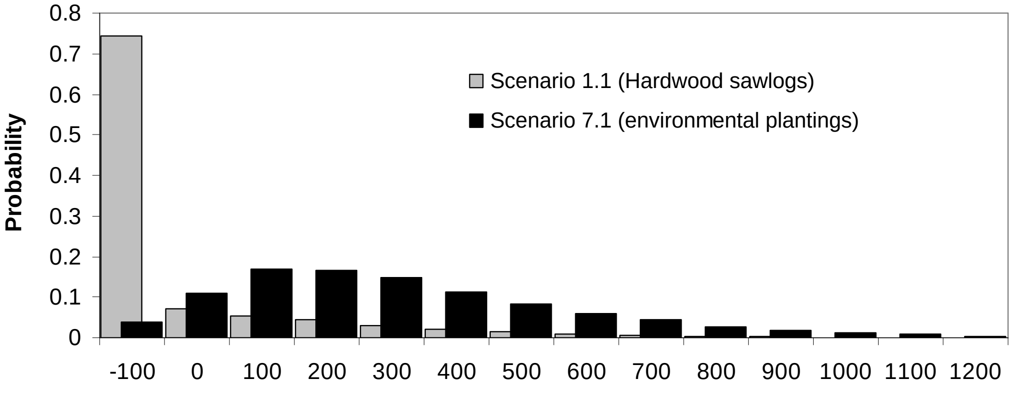


Fig. 38. Probability distribution function of calculated AER for scenarios 1.1 (Hardwood sawlogs) and 7.1 (Environmental carbon plantings) given the assumed uncertainty in assumptions of cost, revenue, yield and transport distances as shown in Tables 8 and 9.

Regional prioritisation

A key objective of this study was to identify regions that offered the greatest opportunities for large-scale agroforestry investments and thus where investment of R&D and related funds might be directed. The preceding section and discussion of results makes it clear that those opportunities will depend on a range of factors including the type of agroforestry system and current and future policy, market and climatic environments. This makes identification of particular regions for focus somewhat problematic. In the end, all the analyses undertaken here are indeed scenarios and represent only a few of the possible combinations. Furthermore, the results are for broad economic outputs only. They do not represent, nor were they intended to be, financial outputs. There are many kinds of investors in agroforestry, from the farmer, governments and private industries covering traditional forestry companies, to fund managers and NGOs. Each of these will have their own specific requirements and financial investment models, many of them undisclosed. Farmers will have their own set of criteria for investment which will be within the context of overall farm management plans.

Given that background, the intent here is to present summary statistics for NAER from representative agroforestry systems, discuss possible implications for future expansion of agroforestry and let the reader draw their own conclusions as to where the greatest opportunities might lie. In essence this exercise can be viewed as one of 'prospecting' – identifying where opportunities might lie but which will require further assessment and ground truthing at regional or local scales to test the assumptions contained in our scenarios, and to re-run models using locally calibrated and verified data.

Results are presented for:

- NRM regions, which are mostly CMAs, and the outputs compared against the assessment of Regional Investment Plans where we ranked their levels of interest in agroforestry (see previous sections), and
- National Plantation Inventory (NPI) regions that were used in the recent report 'Market opportunities for farm forestry in Australia' (URS Forestry 2008). The URS report had an explicit link to our analyses and helped guide interpretations.

NRM regions

For each NRM region results are presented only for Environmental carbon plantings to help prioritise regional assessments. This was done because most regional bodies have targets for various types of revegetation but for the most part they include new forests for environmental remediation. The Environmental plantings scenario is used here to be indicative only; different results may be obtained if other scenarios are used.

Statistics are summarised for all those areas that have a positive value for NAER and results are given for the total profitability summed across the area ($million yr^{-1}) and the mean areal value of profitability ($ ha^{-1} yr^{-1}). The results show that there are many regions with high values for either or both mean areal profitability or the total summed across the region (Table 11). The latter is probably the better metric because it integrates across the whole area.

Table 12 (columns II) assigns ratings for the results from Table 11 according to the values for total NAER ($million yr^{-1}), being: <$100 million yr^{-1} (Low), $100-$400 million yr^{-1} (Medium) and >$400 million yr^{-1} (High). This categorisation is arbitrary, as were the rankings derived from assessment of the NRM Investment Plans. Nonetheless, they serve as a useful basis for comparison. Similar trends would have been evident if the mean areal NAER ($ ha^{-1} yr^{-1}) had been used instead, with a few exceptions.

We then took the results from the multiple impact assessment (Fig. 35b) in which areas were identified with profitability (NAER) greater than $150 ha^{-1} yr^{-1} and the need for biodiversity was in the top 50 percentile (Biodoiversity score less than 50 units). This served to indicate those areas that would meet multiple commercial and environmental objectives. The areas identified in Fig 34b were then separated into NRM regions and the total profitability summed across each region ($million yr^{-1}). Ratings were then assigned (Table 12, column III) as described above.

The review of NRM plans represents the ‘capacity’ of regions to support agroforestry whereas the analyses in columns II and III in Table 12 are a measure of the biophysical ‘capability’ to grow forests. Finally, the last two columns in Table 12 are mean ratings for the combined ‘capacity+capability’ for each NRM region and for considering: (i) NRM plans and profitability, or (ii) NRM plans and profitability and biodiversity enhancement.

Table 12 shows that there are many NRM regions (14 or 15) where the capacity and capability intersect to give a high rating. When considering review of NRM plans and profitability only, the opportunities rated as high covered all states and were dominated by Victoria and NSW. When biodiversity was also considered then, the high ratings covered all states except NSW, this being assessed as not having as much biodiversity benefit from new forests compared with some regions in the other states.

The analyses also serve to indicate those regions with a relatively low combined ‘capacity and capability’ (Table 12). These were mostly urban regions, those in low rainfall areas and thus which were constrained by low rates of growth, and some regions in parts of the tropics. For this latter group (the tropics) more data are required to properly assess the growth potential of forest plantations. In some areas, rainfall is clearly not a limitation, but other constraints may be imposed by pests, diseases, hurricanes and fire. Some of the northern regions also were rated low for their interest in agroforestry, but it is possible this may change with emerging policy drivers such as carbon markets and an increasing presence by forest industries.

Table 11. Summary statistics by NRM Region for environmental plantings for all areas with a positive value of NAER.

Region	Area (M ha)	Total profitability ($Mill yr^{-1})	Mean total profitability ($ ha^{-1} yr^{-1})
Burnett Mary	2.60	289.7	111
Corangamite	0.93	121.2	130
Fitzroy	8.39	542.7	65
Glenelg Hopkins	2.02	267.1	132
Goulburn Broken	1.12	215.5	192
South Coast Region	1.45	148.8	103
Border Rivers/Gwydir	3.13	415.3	133
Burdekin	7.71	440.3	57
Central West	6.15	551.5	90
Hawkesbury/Nepean	0.71	191.8	268
Hunter/Central Rivers	1.60	370.2	232
North Central	1.32	141.8	107
North East (VIC)	0.63	120.3	192
Northern Rivers	1.88	506.4	269
South (TAS)	0.58	124.3	213
North (TAS)	0.66	187.3	282
North West (TAS)	0.23	85.8	366
Northern Agricultural	1.69	134.6	80
Port Phillip and Westernport	0.68	173.6	254
South West (QLD)	2.15	52.9	25
South West Region	1.41	178.1	126
West Gippsland	0.64	99.9	155
Condamine	0.77	50.0	65

Region	Area (M ha)	Total profitability ($Mill yr^{-1})	Mean total profitability ($ ha^{-1} yr^{-1})
Mackay Whitsunday	0.26	26.3	100
Murrumbidgee	2.42	283.9	117
SA Murray Darling Basin	0.49	43.2	89
South East (QLD)	1.03	152.5	149
Wet Tropics	0.68	85.9	127
Border Rivers	2.02	131.1	65
Lachlan	3.16	312.9	99
Maranoa Balonne	3.74	185.2	49
Namoi	2.82	346.1	123
NT Nth	0.07	0.3	4
South East (SA)	1.96	206.2	105
Adelaide, Mt. Lofty Ranges	0.22	43.2	199
Kangaroo Island	0.22	38.8	179
Murray	1.11	84.0	76
Southern Rivers	0.89	213.7	239
Swan	0.70	160.9	229
ACT	0.03	6.3	192
Alinytjara Wilurara		0	
Avon	0.38	18.5	49
Cape York	0.54	37.9	70
Cape York - Northern Gulf	0.17	12.3	74
Desert Channels	6.78	155.0	23
East Gippsland	0.27	48.4	177
Eyre Peninsula	0.56	22.4	40
Lower Murray/Darling	0.02	0.8	35
Mallee	0.09	2.4	28
Northern and Yorke	0.50	25.6	51
Northern Gulf	0.97	46.4	48
Rangelands (WA)	0.07	1.8	27
SA Arid Lands	0.01	0.3	27
Southern Gulf	1.05	17.3	16
Sydney Metro	0.02	5.1	291
Torres Strait	0.01	0.2	24
Western	1.14	44.7	39
Wimmera	1.10	77.2	70

Table 12. Rating of regional bodies for capacity, capability or their combination, according to various criteria. The regions are ranked in descending order according to column IV.

	‘Capacity’	‘Capability’		‘Capacity+Capability’	
Region	**[1]Review of NRM Plans[1]**	**[2]Profitability**	**[3]Profitability + biodiversity**	**NRM plans+ profit (Mean of columns I and II)**	**NRM plans+ profit+ biodiversity (Mean of columns I and III)**
	(column I)	**(column II)**	**(column III)**	**(column IV)**	**(column V)**
Burnett Mary	**H**	**M**	**M**	**H**	**H**
Corangamite	**H**	**M**	**M**	**H**	**H**
Fitzroy	**H**	**H**	**M**	**H**	**H**
Glenelg Hopkins	**H**	**M**	**M**	**H**	**H**
Goulburn Broken	**H**	**M**	**H**	**H**	**H**
South Coast Region	**H**	**M**	**H**	**H**	**H**
Border Rivers/Gwydir	**H**	**H**	**L**	**H**	**M**
Burdekin	**H**	**H**	**L**	**H**	**M**
Central West	**H**	**H**	**L**	**H**	**M**
Hawkesbury/Nepean	**H**	**M**	**L**	**H**	**M**
Hunter/Central Rivers	**H**	**M**	**L**	**H**	**M**
North Central	**H**	**M**	**L**	**H**	**M**
North East (VIC)	**H**	**M**	**L**	**H**	**M**
Northern Rivers	**M**	**H**	**M**	**H**	**M**
South (TAS)	**H**	**M**	**L**	**H**	**M**
North (TAS)	**M**	**M**	**H**	**M**	**H**
North West (TAS)	**H**	**L**	**M**	**M**	**H**
Northern Agricultural	**M**	**M**	**H**	**M**	**H**
Port Phillip and Westernport	**H**	**L**	**H**	**M**	**H**
South West (QLD)	**M**	**M**	**H**	**M**	**H**
South West Region	**H**	**L**	**H**	**M**	**H**
West Gippsland	**H**	**L**	**H**	**M**	**H**
Condamine	**H**	**L**	**L**	**M**	**M**
Mackay Whitsunday	**H**	**L**	**L**	**M**	**M**
Murrumbidgee	**M**	**M**	**M**	**M**	**M**
SA Murray Darling Basin	**M**	**M**	**M**	**M**	**M**
South East (QLD)	**M**	**M**	**M**	**M**	**M**
Wet Tropics	**H**	**L**	**L**	**M**	**M**
Border Rivers	**M**	**M**	**L**	**M**	**L**
Lachlan	**M**	**M**	**L**	**M**	**L**
Maranoa Balonne	**M**	**M**	**L**	**M**	**L**
Namoi	**M**	**M**	**L**	**M**	**L**
NT Nth	**M**	**M**	**L**	**M**	**L**
South East (SA)	**M**	**L**	**H**	**L**	**H**
Adelaide, Mt Lofty Ranges	**M**	**L**	**M**	**L**	**M**
Kangaroo Island	**M**	**L**	**M**	**L**	**M**
Murray	**M**	**L**	**M**	**L**	**M**
Southern Rivers	**L**	**M**	**H**	**L**	**M**
Swan	**L**	**L**	**H**	**L**	**M**
ACT	**M**	**L**	**L**	**L**	**L**
Alinytjara Wilurara			**L**	**L**	**L**
Avon	**M**	**L**	**L**	**L**	**L**
Cape York	**L**	**L**	**L**	**L**	**L**
Cape York - Northern Gulf	**L**	**L**	**L**	**L**	**L**
Desert Channels	**L**	**M**	**L**	**L**	**L**

	'Capacity'	'Capability'		'Capacity+Capability'	
Region	[1]Review of NRM Plans[1]	[2]Profitability	[3]Profitability + biodiversity	NRM plans+ profit (Mean of columns I and II)	NRM plans+ profit+ biodiversity (Mean of columns I and III)
	(column I)	(column II)	(column III)	(column IV)	(column V)
East Gippsland	M	L	L	L	L
Eyre Peninsula	L	L	L	L	L
Lower Murray/Darling	L	L	L	L	L
Mallee	L	L	L	L	L
Northern and Yorke	M	L	L	L	L
Northern Gulf	L	L	L	L	L
Rangelands (WA)	M	L	L	L	L
SA Arid Lands	L	L	L	L	L
Southern Gulf	L	M	L	L	L
Sydney Metro	L	L	L	L	L
Torres Strait	L	L	L	L	L
Western		L	L	L	L
Wimmera	M	L	L	L	L

[1] Ratings are derived from Table 10.

[2] Ratings are based on the sum profitability (\$ yr^{-1}) across all areas with a positive value of NAER.

[3] Ratings are based on the results from Fig. 35; areas where NAER> \$150 ha^{-1} yr^{-1} and the biodiversity score is less than 50 units.

NPI regions and market potential

Market analysis is an essential first step before entering new business enterprises. For that reason the project 'Market opportunities for farm forestry in Australia' was commissioned by the JVAP (URS Forestry 2008). That study looked primarily at NPI regions and ranked their suitability for a range of product options for conventional, industrial plantations based on market demand and opportunity.

Results of our analyses were influenced by proximity to processing sites and hence the suitability of a product within any particular region. It did not take into account the size of product markets. For example, the areas of land identified for many of the harvested forestry systems were far in excess of market demand, particularly for some of the scenarios that include future changes such as new processing facilities or payments for carbon sequestration (Fig. 33). Here, we compare the results from our assessments of economic opportunities for forest growers with the market-based assessments of the URS report. Again, we considered only the scenarios relevant to the present infrastructure and policy conditions (that is, variable transport distances, no carbon payments) to ensure closest consistency with the assumptions of the URS assessments.

Table 13 compares the rankings for the 'market opportunity' (URS Forestry 2008) and the 'growing opportunity' for softwood sawlogs, hardwood sawlogs and wood chips export or pulpwood. The growing opportunity rankings followed the same methodology as for Table 12, according to a relative scale for the total NAER within each NPI region (\$ million yr^{-1}), being: <\$100 million yr^{-1} (Low), \$100-\$400 million yr^{1} (Medium) and >\$400 million yr^{-1} (High).

In this assessment, we deliberately defined the objective as identification of opportunities for large-scale expansion of agroforestry. Thus, a 'Low' rating implies that either the suitable area is limited or that the average profitability per unit land area is small. It does not indicate that any scenario with a 'Low' rating for the assessment of growing opportunity would not be profitable. For example, the SE Queensland region was rated as 'Low' for softwood sawlogs but in fact there were 115,000 ha indentified as potentially profitable and where the mean NAER was \$157 ha^{-1} yr^{-1} (data not shown). Thus, there may be a significant area available, of the order of tens of thousands of hectares, where forests could be established profitably, especially where they are in reasonably close proximity to existing processing facilities or where growth rates or product prices are greater than those assumed in our analyses. Once transport distance to processing facility exceeds a certain distance, the profitability decreases rapidly. It is also worth noting that the results are for NAER where the profitability of the agroforestry enterprise is over and above that of the agricultural enterprise.

For the analyses of growing opportunity, the predicted profitability of hardwood sawlogs and wood chips export/ pulpwood was closely aligned with NPI regions when considered across all of Australia (Figs. 25a, 27a). This simply reflects the fact that the main processing facilities are located in NPI regions and which also support reasonable rates of growth. For the softwood sawlog systems, all regions were rated as being ‘Low’ (Table 13). Compared to hardwood sawlogs, which had higher ratings, this mainly reflects the lower assumed price for softwood products (Table 5). However, the total area of opportunity identified for all sawlog systems across Australia was still large at 1.2 Mha (Fig. 33). Furthermore, the results indicate that softwoods can be profitable and especially if grown close to processing or export facilities so that transport costs are minimised.

The ratings for market opportunity and growing opportunity were combined to give an overall, relative rating (the last three columns in Table 13). For Harwood sawlog systems there was a high degree of correlation between regions rated high for the combined market and growing opportunity and those rated as high for the market opportunity alone. This identifies regions where there is a reasonably high level of concurrence between market opportunity and the biophysical and economic opportunities to grow the resource. The level of agreement remained good for the wood chips export/ pulpwood systems but was less than for the Harwood sawlog systems.

There were a few discrepancies in the regional assessments of market opportunity and growing opportunity. For example, Hardwood sawlogs for the Murray Valley were assed by URS as being of ‘Low’ potential on the basis that there is only a small hardwood sawmilling capacity in the region. Our analysis, in contrast, resulted in a ‘High’ rating on the basis of adequate predicted rates of growth, product prices and distance to mill. However, if the processing capacity is limited then the market assessment of URS Forestry should be used as the primary filter in identifying suitable NPI regions because it captures the main factors influencing regional capacity.

We also note that URS Forestry report assessed regional opportunities for other products such as veneer, plywood, laminated veneer lumber and composite wood products. However, assessing the growing opportunity for those products was beyond the scope of this study.

Table 13. Rating of forestry regions according to market opportunity, growing opportunity or both for sawlog regimes and woodchips or pulpwood exports.

Region	Market opportunity [1]	Growing opportunity [2]	Market opportunity	Growing opportunity	Market opportunity	Growing opportunity	Market opportunity + growing opportunity[3]		
	Softwood sawlogs		Hardwood sawlogs		Wood-chip exports or pulpwood		Softwood sawlogs	Hardwood sawlogs	Wood-chip exports or pulpwood
Central & North Queensland	L	L	M/H	M	M	L	L	H	L
SE Queensland	M	L	H	H	M	H	L	H	H
North Coast NSW	L	L	H	H	M	H	L	H	H
Northern/Central Tablelands	M/H	L	M	M	L	H	M	M	M
Murray Valley	H	L	L	H	H	H	M	M	H
Southern Tablelands	M	L	L	M	M/H	M	L	L	H
SE NSW	M	L	M/H	M	M	L	L	H	L
NW Victoria	L	L	L	L	L	L	L	L	L
Central & W Vic	H	L	H	M	M	M	M	H	M
Gippsland	H	L	H	M	H	H	M	H	H
Green Triangle	H	L	L	M	M	M	M	L	M
Mt Lofty & KI	M	L	L	L	L	L	L	L	L
SW WA	H	L	H	H	M	H	M	H	H
Tasmania	H	L	H	M	M	H	M	H	H
NT	L	L	M	L	L	L	L	L	L

[1] Market opportunity ratings are from the report ‘Market opportunities for farm forestry in Australia’ (URS Forestry 2008)

[2] Growing opportunity ratings are derived from the sum of positive values of NAER within each region (see text for details

[3] The ‘market opportunity+growing opportunity’ rating gives an overall assessment, calculated as the mean value of the market and growing ratings (see text for details).

Conclusions

The aims of this project were to prospect for regional opportunities and research needs for agroforestry systems in Australia and, in particular, to compare:

- Different agroforestry systems
- Different regions, and
- Time frames for the present and the future that consider changing infrastructure or emerging markets.

It was a large data generation and management exercise that collated and combined relevant information from a variety of sources and integrated them into a spatial framework. The main conclusions from this project are summarized within broad categories.

Sawlog and pulpwood systems

A general conclusion from this analysis is that agroforestry can be competitive with agriculture in some regions and for some systems, as demonstrated by positive values of NAER (that is, the agroforestry system is more profitable than the preceding agriculture phase). This is true of the current economic and policy environment and even more so if new markets or processing facilities were to be established. For the reference case for hardwood sawlog systems (variable transport distance to existing processing facilities, no carbon payments) it was estimated that there were 39 Mha of land available where the value of NAER was positive; that is it exceeded the profitability of the preceding agricultural enterprise (Fig. 33). This also equated to \$6.6 billion year^{-1} when summed across all those areas with a positive NAER across Australia. The values were higher for pulpwood systems, having a potential area of 76 Mha for a total profitability of \$11 billion year^{-1}. For softwood sawlogs systems, the values were lower; the reference case having a potentially available area of 1.2 Mha at a total profitability of \$0.13 billion year^{-1}. The main difference between these systems results from the assumed, relatively high price for hardwood sawn timber and pulpwood products compared to those from softwood (Table 5). For pulpwood systems, the shorter rotation period improves profitability through partly negating the impacts of discounting.

Transport distances and product price are important in influencing profitability. This reinforces the conclusion that large-scale expansion of agroforestry systems that are harvested and have transported products will be constrained by distance to existing processing or handling facilities, or new ones will have to be built. Assuming a fixed transport distance to processing facilities across of Australia (to reproduce the impact of new processing facilities being established) greatly increased the potential area of profitable, available land northwards across the top end of Australia (Figs. 25b, 26b, 27b). This was especially so for pulpwood systems for which fixing the transport distance created 214 Mha of potentially available land with a total profitability of \$45 billion year^{-1}. In general, the east coast of Australia and northern Australia show promise for expansion of agroforestry systems due to the potential fast rates of growth, often low profitability of agriculture (in northern regions) and the location of existing processing facilities (along the east coast in the mostly NPI regions).

Results from the uncertainty analysis (Fig. 36) showed that the factors most affecting profitability of these systems were transport distance, product price, and harvest volumes. Maximizing rates of forest growth thus remains one of the most important determinants of profitability where research can have high impact.

Including carbon payments (at \$20 t^{-1} CO_2-e) in these harvested systems significantly increased the profitability of hardwood and softwood sawlog systems, but not of pulpwood (Fig. 30). In contrast to the effect of constraining transport distances it extended the zones of profitability inland from existing areas (Figs. 25a, 26a). The carbon payment had little impact on pulpwood because of their relatively short rotation and thus these systems had less opportunity to store carbon compared to the longer rotation sawlog systems.

We assumed that 50% of the final crop of carbon (pre-harvest amount) could be traded according to an average stocks approach (for example, Baalman and O'Brien 2006). Until the eligibility of forestry in a National Emissions Trading System and mechanisms are decided, this remains an assumption. Nonetheless, at this stage it would be a pragmatic approach and serves to indicate the impact.

Energy systems

Dedicated bioenergy and ITP systems are not profitable at present unless they are very close to processing facilities. This is due to the high cost of production (harvesting and transport) relative to low product price for wood energy (market failure). We calculated a price for feedstock based on calorific value, as a substitute for power generation. Including carbon payments in these systems made little difference to the economics because of their short rotation times. We also did not account for other payments incentives such as Renewable Energy Certificates that may affect profitability. Furthermore, if the price for energy feedstock was sufficiently high, such as for an export market, then it may compete for other products such as chip for pulpwood.

Feedstock for bioenergy can come from many sources and not just the dedicated energy systems that we analysed here. It may be that feedstock is better sourced from residues from conventional plantations as part of a mixed product, sawlog regime for example.

Fodder

Of all the agroforestry systems studied, *in situ* fodder had the largest potential area of profitability, at some 450 Mha (Figs. 30a, 33). It was predicted to be potentially profitable over extensive areas of Australia including most of the four geoclimatic zones considered. Fodder shrubs are resilient and will grow in a wide range of climates including arid and salt-affected zones. The price of *in situ* fodder often makes it competitive with other agricultural enterprises.

Carbon plantings

Carbon plantings had a high potential area, up to 240 Mha, and total profitability of up to \$43 billion year^{-1} (Figs. 30b, 31-32). There at least three main reasons why carbon plantings were predicted to have high profitability compared with the harvested agroforestry scenarios:

- There are no harvesting and transportation costs associated with carbon plantings, thus greatly reducing costs of production relative to the product price.
- The location of carbon plantings is not constrained by proximity to processing facilities and thus can be established in almost any geographic region of Australia where rates of growth and carbon sequestration are deemed suitable.
- The carbon payment can be an annuity, in contrast to harvested systems where the investor may have to wait years or decades before a financial return is realized.

The values for NAER depended upon the type of carbon planting system modelled (Figs. 30b, 31-32). Environmental plantings have the least carbon storage potential because we explicitly modelled them as an open woodland structure in the long term, as opposed to plantations of hardwoods or softwoods that use genetically improved stock and that are managed for maximum growth. The potential area available and profitability of mallee systems was predicted be comparable to that of hardwood and softwood plantings, but this may well be an artefact of the limited mallee data set on which the growth model was calibrated. Many of the regions identified as being suitable were outside the climatic range of calibration for the dryland species that we used. Nonetheless, there are northern species of mallees growing in more humid and wet climates that could provide opportunities for a range of agroforestry systems.

Multiple impact assessments

All of the preceding spatial assessments were based on a single criterion; the economic profitability of the agroforestry system (value of NAER). Although profitability is a powerful driver other considerations may be important in decision making at either policy or investor level; impacts on water interception and biodiversity are two of the more obvious ones. We interrogated the spatial data set for scenarios (Hardwood sawlog systems and Environmental carbon plantings) to illustrate the types of outputs that can be generated for specific targeting of agroforestry against pre-determined sets of criteria. Three sets of criteria were applied for each of the two scenarios (Figs. 34 and 35) being:

(i) NAER > \$150 ha^{-1} yr^{-1}, water interception < 150 mm yr^{-1}
(ii) NAER > \$150 ha^{-1} yr^{-1}, Biodiversity score < 50 units
(iii) NAER > \$150 ha^{-1} yr^{-1}, water interception < 150 mm yr^{-1}, Biodiversity score < 50 units.

As one example, it was shown that for environmental carbon plantings constrained by NAER > \$150 ha^{-1} yr^{-1} and water interception < 150 mm yr^{-1}, there was a total of 9.1 Mha of land potentially available with a combined NAER of \$1.9 billion yr^{-1} (assuming a carbon payment of \$20 t^{-1} CO_2-e). The main opportunities were confined to south-eastern Australia (west of the Great Dividing Range and extending through Victoria and NSW up to the Queensland border), southern and south-eastern South Australia and parts of Tasmania and south-west Western Australia. The annual rate of carbon sequestration was predicted to be 143 Mt CO_2-e yr^{-1} at an average areal rate of 16 t CO_2-e ha^{-1} yr^{-1}. This total annual increment is equivalent to about 25% of Australia's net 2005 greenhouse gas emissions.

Regional analyses

In this study we reviewed the investment plans of the 57 regional NRM bodies (mostly CMAs) for their interest in agroforestry and surveyed PFDC and the AFG representatives. A companion report to this (URS Forestry 2008), assessed the market opportunities for various agroforestry systems and products in Australia. For the more conventional plantation systems, URS rated the opportunities within NPI regions for each of the likely product markets. In our spatial analysis of scenarios we further summarised statistics for profitability within each of the 57 NRM regions and for the NPI regions used by URS. This enabled a qualitative comparison of our spatial assessments against the interest in agroforestry for NRM regions (Table 12) and against the NPI regions assessed by URS (Table 13).

There were 14 or 15 NRM regions that were rated high for both 'capacity' (support for agroforestry) and 'capability' (the biophysical and economic opportunity). It was shown that additional categorisation was possible if the analyses were further constrained by the regional biodiversity benefit of forest establishment.

The profitability of Hardwood sawlogs and pulpwood/ chip export was generally greatest in the NPI regions. This is expected and simply reflects the location of current processing and export facilities and where land is suitable to grow trees profitability. In terms of opportunities for future expansion, several NPI regions rated High for the combined 'market and growing opportunity'. These were for hardwood sawlogs and pulpwood/ chip export products and indicated regions that were assessed as having good market opportunity by URS Forestry and also with relatively large areas of opportunity to grow the wood resource profitably.

Recommendations

This project has identified (mostly) broad regions where there may be opportunities for large-scale expansion of agroforestry plantings, either for commercial benefit alone or with environmental benefits included. Many states have done their own assessments for regional targeting of plantings and the aim here is not to replicate those assessments. On the basis of the outputs from this project we offer below some broad recommendations as to future, targeted research needs to help advance development of agroforestry systems in Australia for multiple, positive outcomes.

Research needs in prospective regions of Australia

- ***Northern Australia.*** It was predicted that, for sawlog and pulpwood regimes, high rates of growth and hence forest profitability could be achieved in northern Australia (and in the high-rainfall belt of the east-coast). However, northern Australia is a region where there is a paucity of data and to some extent was outside the zone of extrapolation for many of the species to which the growth model was calibrated. We also note that the ‘environmental plantings’ were not predicted to perform as well in Northern Australia as in southern latitudes. General experience suggests that growth of plantation species in northern climates can be greatly influenced by incursion of pests (such as termites, borers), diseases and fires. Research is needed to asses the productivity potential of agroforestry in the north and methods to manage biotic and abiotic risks
- ***Biodiversity plantings in south-east Qld., south-east Australia, south-west WA.*** These are potentially large areas and warrant further investigation as to suitability of soils, availability of land, growth of existing vegetation (if any) in the region and water impact issues. To a large extent they also coincide with regions where farm forestry is supported by Regional Bodies (mostly CMAs) and the farm forestry industry
- ***Growth prediction in a changing climate***. All scenarios performed to date use average, historical data. Given that we are interested in growth and hence economics in the years to come, it would be constructive to run production models using future climates across the various regions.

Research needs for agroforestry systems

This project has identified points for research intervention in the agroforestry value chain that can make a substantial difference.

- ***Growth data and prediction for dryland species and environmental plantings***. An emissions trading scheme that includes forests could stimulate a large expansion of the forest estate. This would include expansion in drier areas with ‘environmental plantings’ – regions and species where we have relatively little information. Greater confidence in prediction of growth potential is needed
- ***Carbon accounting and prediction***. Results show that a carbon market has the potential to transform the landscape. However, using trees as carbon off-sets will require robust tools for prediction and monitoring of annual rates of carbon sequestration and at relatively fine scales to support and emissions trading scheme. This will require down-scaling of predictions to:
  - Hillslope level, so that carbon can be predicted and counted across the landscape, and
  - Annual time-steps, so that carbon can be estimated and therefore traded at short intervals
- ***Breeding and silviculture to maximise growth***. The main factors influencing profitability of harvested systems are land value, growth rates, product price and transport costs. Maximizing growth is thus one area where research can make a difference.

References

ALFA. (2007). Industry information. (Australian Lot Feeders' Association, http://www.feedlots.com.au)

Almeida A., Paul, K.I., Siggins, A., Sands, P., Jovanovic, T., Theiveyanathan, T., Crawford, D.F., Marcar, N.E., Polglase, P., England, J.R., Falkiner, R., Hawkins, C. and White, DE. (2007). *Development, Calibration and Validation of the Forest Growth Model 3-PG with an Improved Water Balance*. Report to the Australian Department of Agriculture, Fisheries and Forestry on the Commercial Environmental Forestry Project. CSIRO Sustainable Ecosystems, Canberra.

Annandale, M., Bristow, M., Storey, R. and Williams, K. (2003). *Land Suitability for Plantation Establishment within 200 kilometers of Cairns*. Department of Primary Industries (Agency for Food and Fibre Sciences, Queensland Forestry Research Institute), Natural Heritage Trust and Department of Natural Resources and Mines.

Australian Bureau of Agricultural and Resource Economics. (2007). *Australian Farm Survey Results 2004-05 to 2006-07*. ABARE, Canberra.

Baalman, P. and O'Brien, N.D. (2006). Crediting of carbon storage in reforestation projects under timber management. *Australian Forestry* 69, 90-94.

Bennell, M., Hobbs, T.J. and Ellis, M. (2008). *Evaluating Agroforestry Species and Industries for Lower Rainfall Regions of southeastern Australia. FloraSearch1a.* Report to the Joint Venture Agroforestry Program (JVAP) and CRC for Plant-based Management of Dryland Salinity. RIRDC, Canberra.

Boardman, A.E., Greenberg, D.H. Vining, A.R. and Weimer, D.L. (2001). *Cost-Benefit Analysis: Concepts and Practice*. 2nd Edition. Prentice Hall, Upper Saddle River, NJ. 526 p.

Booth, T.H. (2007). Regional NRM priorities for Agroforestry across Australia. Report to the Joint Venture Agroforestry Program (JVAP). RIRDC, Canberra.

Booth, T.H., Jovanovic, T. and Paul, K.I (2004). *Growth Estimation Using the 'Intensive' Approach for the Commercial Environmental Forestry Theme: Year 1*. Report to the Australian Department of Agriculture, Fisheries and Forestry on the Commercial Environmental Forestry Project. CSIRO Sustainable Ecosystems, Canberra.

Booth, T.H., Paul, K.I and Jovanovic, T. (2006). *Predicting Potential Plantation Growth in the South West Goulburn Broken*. Report to the Australian Department of Agriculture, Fisheries and Forestry on the Commercial Environmental Forestry Project. CSIRO Sustainable Ecosystems, Canberra.

Buckton, M. (2004). *Western Australian Forestry Cell Planning and Marketing Process*. (2004). Australian Forestry Summit, Melbourne. 29 p.

Buongiorno, J., and Gilless, J.K. (2003). *Decision Methods for Forest Resource Management*. Academic Press, San Diego.

Burns, K., Walker, D. and Hansard, A. (1999). *Forest Plantations on Cleared Agricultural Land in Australia. A Regional Economic Analysis. ABARE Research Report 99.11*. ABARE, Canberra.

Coops, N.C. (1999). Improvement in predicting stand growth of *Pinus radiata* (D.Don) across landscapes using NOAA AVHRR and Landsat MSS imagery combined with a forest growth process model (3-PGS). *Photogrammetric Engineering and Remote Sensing* 65, 1149-1156.

CSIRO (2003). *Biofuel Database*. www.det.csiro.au/science/energysources/biomass.htm. Accessed 11 October, 2007.

Davey, S.M., Baker, P., Frakes, I and Mullen, I. (2006). *Opportunities for Commercial Environmental Forestry in Australia*. Report to the Australian Department of Agriculture, Fisheries and Forestry on the Commercial Environmental Forestry Project. Bureau of Rural Sciences, Canberra.

Enecon Pty Ltd. (2001). *Integrated Tree Processing of Mallee Eucalypts*. Report to the Joint Venture Agroforestry Program (JVAP). RIRDC, Canberra.

England J.R., Theiveyanathan S., Falkiner R.A., Paul K.I., Polglase P.J., Koul V., Larmour J., Smith J. and Stewart L. (2006). *Water Use, Growth and Carbon Sequestration of Environmental Plantings*.

Report to the Australian Department of Agriculture, Fisheries and Forestry on the Commercial Environmental Forestry Project. CSIRO Sustainable Ecosystems, Melbourne.

Gallant J.C, and Dowling T.I. (2003). A multiresolution index of valley bottom flatness for mapping depositional areas. *Water Resources Research* 39, 1347.

Gilfedder, M., Stenson, M., Dowling, T., van Dijk, A.I.J.M. and Walker, G. (2006). *Impacts of Afforestation and Climate Change on Water and Salt Generation from Upland Areas in the Murray- Darling Basin: BC2C Modelling Results*. Water for a Healthy Country Report to the Australian Department of Agriculture, Fisheries and Forestry on the Commercial Environmental Forestry Project. CSIRO Land and Water, Canberra. 40p.

Hajkowicz, S.A. and Young, M.D. (Eds.) (2002). *Value of Returns to Land and Water and Costs of Degradation. A consultancy report to the National Land & Water Resources Audit.* CSIRO Land and Water, Canberra. Canberra.http://environment.gov.au/atlas.

Hassell & Associates (2008). *Whole Farm Financial and Environmental Returns under Farm Forestry – Six Case Studies.* Report to the Joint Venture Agroforestry Program (JVAP). RIRDC, Canberra.

Hobbs, T.J, Georgaras, P.A., Tucker, M., Neumann, C., and Bennell M. (2008). *Woody Biomass Productivity and Potential Biomass Industries in the Upper South East*. Report for the SA Centre for Natural Resource Management. FloraSearch Series. SA Water, Land and Biodiversity Conservation, Adelaide.

Hobbs, T.J., Bennell, M., Huxtable, D., Bartle, J. Neumann, C., George, N., O'Sullivan, W. and McKenna, D. (2007). *Potential Agroforestry Species and Regional Industries for Lower Rainfall Southern Australia. FloraSearch 2*. Report to the Joint Venture Agroforestry Program (JVAP) and CRC for Plant-based Management of Dryland Salinity. RIRDC, Canberra.

Houlder, D., Hutchinson, M.F., Nix, H.A. and McMahon, J.P. (2000). *ANUCLIM 5.0.* Centre for Resource and Environmental Studies, Australian National University. Canberra.

Jeffrey, S.J., Carter, J.O., Moodie, K.M. and Beswick, A.R. (2001). Using spatial interpolation to construct a comprehensive archive of Australian climate data. *Environmental Modelling and Software* 16, 309-330.

Landsberg, J.J. and Waring, R.H. (1997). A generalised model of forest productivity using simplified concepts of radiation-use efficiency, carbon balance and partitioning. *Forest Ecology and Management* 95, 209-228.

Maclaren, J.P. (2000). *Trees in the Greenhouse: The Role of Forestry in Mitigating the Enhanced Greenhouse Effect. Forest Research Bulletin No. 219.* Scion, Rotorua, NZ.

McKenzie, N.J., Jacquier, D.W., Ashton, L.J. and Cresswell, H.P. (2000). *Estimation of Soil Properties using the Atlas of Australian Soil*. CSIRO Land and Water Technical Report 11/00.

Parsons, M., Gavran, M., and Davidson, J. (2006). *Australia's Plantations 2006*. Bureau of Rural Sciences, Canberra. 56 p.

Paul, K.I, Polglase, P.J., Snowdon, P., Theiveyanathan, S., Raison, J., Grove, T., and Rance, S. (2006a). Calibration and uncertainty analysis of a carbon accounting model to stem wood density and partitioning of biomass for *Eucalyptus globulus* and *Pinus radiata*. *New Forests* 31, 513-533.

Paul, K.I., Booth, T.H., Jovanovic, T., Sands, P.J. and Morris, J.D. (2007). Calibration of the forest growth model 3-PG to eucalypt plantations growing in low rainfall regions of Australia. *Forest Ecology and Management* 243, 237-247.

Paul, K.I., Jacobsen, K., Koul, V., Leppert, P. and Smith, J. (2008). Predicting growth and sequestration of carbon by plantations growing in regions of low-rainfall in southern Australia. *Forest Ecology and Management* 254, 205-216.

Paul, K.I., Jovanovic, T., Theiveyanathan, S., Hawkins, C., England, J.R., Booth, T., Marcar, N. and Polglase, P. (2006b). *Prediction of Growth and Carbon Sequestration of Plantations and Environmental Plantings using 3-PG+*. Report to the Australian Department of Agriculture, Fisheries and Forestry on the Commercial Environmental Forestry Project. CSIRO Sustainable Ecosystems, Canberra.

Raison. J, Keith, H., Barrett, D., Burrows, B. and Grierson, P. (2004). *Spatial Estimates of Biomass in 'Mature' Native Vegetation*. National Carbon Accounting System, Technical Report No. 44. Australian Greenhouse Office, Canberra.

Rodriguez, R., Espinosa, M., Real, P. and Inzunza, J. (2002). Analysis of productivity of radiata pine plantations under different silvicultural regimes using 3-PG process-based model. *Australian Forestry* 65, 165-172.

Sands, P.J. (2004). 3PGpjs vsn 2.4 - a User-Friendly Interface to 3-PG, the Landsberg and Waring Model of Forest Productivity. Technical Report. No. 140, CRC Sustainable Production Forestry, Hobart.

Sands, P.J. and Landsberg, J.J. (2002). Parameterisation of 3-PG for plantation grown *Eucalyptus globulus*. *Forest Ecology and Management* 163, 273-292.

Schroeder, P. (1992). Carbon storage potential of short rotation tropical tree plantations. *Forest Ecology and Management* 50, 31-41.

Soares, P., Tome, M., Skovsgaard, J.P., and Vanclay, J.K. (1995). Evaluating a growth model for forest management using continuous forest inventory data. *Forest Ecology and Management* 71, 251-265.

Stirzaker, R.J., Vertessey, R. A. and Sarre, A. (2002). Trees, Water and Salt: An Australian Guide to using Trees for Healthy Catchments. Report to the Joint Venture Agroforestry Program (JVAP). RIRDC, Canberra.

Thackway, R., Donohue, R. and Smart, R. (2004). *Integrated Regional Vegetation Information - A Compilation of Vegetation Types for National Action Plan and Natural Heritage Trust regions*. Bureau of Rural Sciences, Canberra.

URS Forestry (2008). Market opportunities for farm forestry in Australia. Report to the Joint Venture Agroforestry Program (JVAP). RIRDC, Canberra.

Western Power (2006). *Bioenergy*. http://www.westernpower.com.au/about_us/environment/renewable_energy/renewable_bioenergy.html)

Zhang L, Dawes W.R and Walker GR (1999). *Predicting the Effect of Vegetation Changes on Catchment Average Water Balance*. Technical Report 99/12. Cooperative Research Centre for Catchment Hydrology, Canberra.

Appendix. Mathematics for Economic Analysis

Annual Equivalent Return

The **net present value** ($\mathrm{NPV_R}$) for a single rotation of a forestry system is the difference between the present value of annual and intermittent costs, and revenue from forestry:

$$\mathrm{NPV_R} = \mathrm{PV_R} + \mathrm{PV_{AR}} - \mathrm{PV_C} - \mathrm{PV_{AC}} \qquad [1]$$

The formulas to calculate each of these are described below.

The **present value of forestry system costs** (PV_C) is calculated from the cost incurred with each operation (C_t), e.g., establishment, thinning, pruning, harvest, etc., at time *t*, discounted using the discount factor, $\frac{1}{(1+r)^t}$, where *r* is the discount rate:

$$PV_C = \sum_t \left(\frac{C_t}{(1+r)^t} \right) \qquad [2]$$

The number of terms in the brackets is equal to the number of operations for the forestry system. For example, a pulp log system may only have two operations, establishment and harvests, while a sawlog system may have six, establishment, two pruning, two thinnings and harvest.

The **present value of forestry system annual costs** (PV_{AC}) is calculated from the annual cost (AC_t), discounted using the discount factor for an annuity:

$$PV_{AC} = AC_t \left(\frac{1}{r} - \frac{1}{r(1+r)^T} \right) \qquad [3]$$

Annual costs include fertilizer, weed control, pest control, etc.

The **present value of forestry system revenue** (PV_R) is calculated from the revenue received from harvest, thinning and/or coppicing (R_t), discounted using the discount factor:

$$PV_R = \sum_t \left(\frac{R_t}{(1+r)^t} \right) \qquad [4]$$

Revenue is a function of product yield and stumpage price (see Stumpage Price below). The number of terms in the brackets of Equation (4) is equal to the number of thinnings, coppicings and harvest in a system rotation. For example, a pulp log system will only have one revenue; at harvest.

The **present value of forestry system annual revenue** (PV_{AR}) is calculated from the annual revenue (AR_t), discounted using the discount factor for an annuity:

$$PV_{AR} = AR_t \left(\frac{1}{r} - \frac{1}{r(1+r)^T} \right) \qquad [5]$$

Annual revenue in forestry may be derived from carbon. To calculate this it was assumed that the forest is managed to yield a constant sustainable harvest (non-declining yield, *NDY*) (Maclaren 2000), based on volume control (Buongiorno and Gilless 2003). This is equal to the annual volume increment across the area. The non-declining yield for the stand is defined as:

$$NDY = \frac{\overline{S}}{T} \qquad [6]$$

where $\overline{S}$ = the average expected carbon stock (t ha^{-1}) of the stand, which is assumed to be half the total carbon stock at rotation end, i.e., $\overline{S} = 0.5S_T$. The annual carbon revenue *AR* (\$ ha^{-1} yr^{-1}) is then:

$$AR = NDY \times P_c \qquad [7]$$

This annual carbon revenue is therefore a constant periodic revenue stream over the forestry system rotation.

To calculate the **net present value of the forestry system over perpetuity**, NPV_∞, the net present value for a rotation, NPV_R, is treated as a constant periodic income that is received each rotation:

$$NPV_\infty = NPV_R\left(1 + \frac{1}{(1+r)^T - 1}\right) \qquad [8]$$

The **Annual Equivalent Return**, AER, is then calculated from the net present value over perpetuity, NPV_∞, as:

$$AER = rNPV_\infty \qquad [9]$$

This Annual Equivalent Return from forestry can be compared with the profit at full equity from agriculture to determine the profitability of the forestry system relative to the current agricultural land use.

Stumpage Price

The **stumpage price** for forest products was calculated from mill/port delivered product prices minus transportation and harvest costs (Bennell *et al.* 2008):

$$P_s = \left(\frac{\theta}{1000}\right)[P_m - c_t t] - c_h \qquad [10]$$

where: P_s = product stumpage price (\$ m^{-3} green)
P_m = product mill-gate/ port delivered price (\$ m^{-3} green)
c_t = transport cost (\$ t^{-1} km^{-1} green)
t = transport distance from forest to mill/port (km)
c_h = harvest cost (\$ m^{-3})
θ = wood basic density (reported in Hobbs *et al.* 2008).

To reflect differences in transport cost on sealed and unsealed roads the transportation cost included the different **cost of transport** on these road types:

$$c_t t = c_u t_u + c_s t_s \qquad [11]$$

where c_u = transport cost on unsealed roads (\$ t^{-1} km^{-1} green)
t_u = transport distance on unsealed roads (km)
c_s = transport cost on sealed roads (\$ t^{-1} km^{-1} green)
t_s = transport distance on sealed roads (km).