Carbon sequestration and biomass production rates from agroforestry in lower rainfall zones (300-650 mm) of South Australia:

Southern Murray-Darling Basin Region

Craig R. Neumann, Trevor J. Hobbs and Merv Tucker

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Photography: Cover - Sugar gum *Eucalyptus cladocalyx* woodlot at Bondleigh, SA (C.Miles).

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Executive Summary

South Australia has the potential to sequester significant amount of carbon from revegetation in agricultural landscapes. Sustainable agroforestry can be used to store atmospheric carbon, deliver economic and environmental benefits, and provide greater resilience to climate change for our rural communities.

The influence of climate change on traditional farming businesses, expected expansion of carbon markets, and trends towards more sustainable landuse options suggest that future agricultural landscapes will contain greater diversity of landuses, including dedicated carbon crops. To evaluate the economic and potential expansion of these crops, land managers and governments require clearer information on the carbon sequestration potential of agroforestry. Stemwood production rates of a few forestry species have dominated previous studies of plantation productivity in most low-mid rainfall areas of Australia. The production rates of many of the agroforestry species suitable for lower rainfall areas are largely unquantified.

This report provides estimates of carbon sequestration rates from agroforestry activities in the low to medium rainfall (300 - 650mm) dryland agriculture zones of the Southern Murray-Darling Basin region. To improve the quality of existing allometric models used for non-destructively assessments of aboveground biomass and carbon sequestered in agroforestry plantations (Hobbs *et al.* 2010, Department of Climate Change 2009) this study undertook additional destructive samples. Results from destructively sampling of 24 individual plants (representing 8 different species) from this study were added to existing destructive datasets (total of 105 plants from 23 species) and stronger allometric relationships (stemwood volume $r^2=0.89$ or basal area $r^2=0.92$) were developed.

In this study 28 agroforestry sites were rapidly assessed using simple and non-destructive methods and results combined with previous agroforestry studies in the region (Hobbs *et al.* 2010) to allow an evaluation of total above-ground biomass and carbon accumulation rates for 121 agroforestry sites (32 species) in the Southern Murray-Darling Basin region. The average plant spacing within woodlot plantings was 945 trees per hectare (tph), 824 tph for tree-form eucalypt plantings, 1397 tph for mallee-form eucalypt plantings and 1064 tph for tree-form non-eucalypt plantings. Analysis of data from recent and past surveys provides an insight into the productive potential of a number of species being grown in the region. Preliminary assessments suggest the average above-ground carbon sequestration rate across the region is ~9.5 tonnes of carbon dioxide equivalents per hectare per year (CO_2-e t/ha/yr).

Those seeking to evaluate the feasibility of developing agroforestry crops and biomass industries in the Southern Murray-Darling Basin region may be guided by the information contained within this report. Potential productivity in the region can be highly variable and is influenced by species choices, planting designs, land management practices and climatic conditions. This research provides a valuable step towards understanding carbon sequestration rates from agroforestry activities in the region; however, further surveys are required to improve estimates for some species. Land managers, policy makers and investors should consider the potential negative impacts that agroforestry dedicated to long term carbon sequestration could have on agricultural production, rural communities and the environment. It is important that these new industries are targeted in areas where they maximise economic and environmental benefits for whole farm enterprises, regions and South Australia.

Acknowledgements

The authors would like to acknowledge that this project was supported by funding from the Australian Government Department of Agriculture, Fisheries and Forestry under its Forest Industries Climate Change Research Fund program. This project was also supported by the South Australian Government Department of Environment and Natural Resources (DENR) and by the Future Farm Industries Cooperative Research Centre – New Woody Crop Industries Program.

We are grateful to landholders in the Southern Murray-Darling Basin region for access to their agroforestry and revegetation sites.

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Introduction

Background and Rationale

To assist industry to better understand the implications of climate change, build industry capacity to adapt to predicted scenarios and capitalise on emerging mitigation opportunities the Commonwealth Department of Agriculture, Fisheries and Forestry (DAFF) established the Forest Industries Climate Change Research Fund (FICCRF). Projects funded under the scheme are focussed on generating information for industry to address specific knowledge gaps that could hamper adaptation and mitigation efforts by industry to climate change.

The South Australian Department of Environment and Natural Resources (DENR) through its Ecological Analysis and Monitoring Unit (EAMU) and Future Farm Industries Cooperative Research Centre (FFICRC) recognised the need to fill gaps in data on carbon sequestration and biomass production rates in the lower rainfall zones (300-650mm) of South Australia. In partnership with the FICCRF, DENR/FFICRC has sought the reliable agroforestry productivity data essential to improve the accuracy of models used to predict carbon sequestration rates. Confidence in the accuracy of carbon figures is essential if future investment is to be encouraged into this sector of the agroforestry industry and allow it to adjust to changing climatic conditions.

The Government of South Australia places a high priority on helping industry adapt to a changing climate for the future wellbeing of all South Australians. This is notably reflected in the State Strategic Plan's objectives of "growing prosperity, improving wellbeing, attaining sustainability, fostering creativity, building communities and expanding opportunity" (SA Government 2004a). These stated objectives are strongly connected to our ability to adapt and take advantage of the opportunities presented by a changing climate. The South Australian *Natural Resources Management Act 2004* (SA Government 2004b) provides an underlying structure to sustainably manage the natural resources on which the states industries depend. To facilitate the implementation of that Act, the *State Natural Resources Management Plan* (SA DWLBC 2006) was developed setting out a 50 year vision for, policies, milestones and strategies to achieve the Act's objectives. The goals within the NRM plans vision statement clearly indicate that landscape scale management needs to be adaptive to climate change to maintain healthy natural systems, prosperous communities and industries. The research presented here is also consistent with the State NRM plan's fundamental requirement that natural resource information should be readily available and consistent with national and international standards and protocols.

The South Australian Government also places an important emphasis on the reduction of greenhouse gas emissions and the encouragement of carbon storage methodologies as outlined in the States Greenhouse Strategy (SA DPC 2007). An objective of the strategy is to strengthen the resilience of industries reliant on natural resources in the face of a changing climate. It also aims to target commercial opportunities and develop products and services that both mitigate the release of greenhouse gasses and provide commercial opportunities for rural communities and the State.

Increasing the area of land under agroforestry has many environmental and economic benefits (Australian Greenhouse Office & Murray Darling Basin Commission 2001). New plantations can not only be used for carbon sequestration but provide other benefits such as improved biodiversity outcomes; reductions in groundwater recharge, dryland salinity, saline river discharges, wind erosion and drought risk; and increases in landscape sustainability, livestock production, economic diversification and the stability of financial returns.

The prospect of new industries based on the provision and trading of sequestered carbon to offset emissions has increased interest in agroforestry outside those areas traditionally associated with forestry and the potential of tree species not commonly used in forestry. It is also possible that some of these plantings could even provide renewable energy sources in their own right (Stucley *et al.* 2004, Zorzetto & Chudleigh 1999, Hague *et al.* 2002, Harper *et al.* 2007). Stucley *et al.* (2004) however, warns that, *"There is a general lack of information available on the growth of tree plantations in many parts of Australia."* This lack of information is particularly acute in lower rainfall areas where there has been little economic impetus toward acquiring such information in the past.

Carbon Sequestration and Biomass Production Rates

This project gathered information and tested methodologies designed to evaluate and predict woody biomass production and carbon sequestration rates in farm forestry plantings in the lower rainfall (300-650 mm) of the SA Murray Darling Basin (Figure 1). Large parts of the study area have been significantly modified since settlement and may provide opportunities to undertake economically viable revegetation in response to climate change issues (Figure 2). For this to occur, rapid and accurate estimates of biomass productivity and carbon sequestration rates are required to enable landholders to make informed decisions about the financial viability of any proposed plantings compared with traditional land usages.

The project built on the knowledge and understanding developed by DENR/FFICRC during prior research in the Murray-Darling Basin, Mid North and Upper South East regions of South Australia (Neumann *et al.* 2010, Hobbs *et al.* 2010, Hobbs *et al.* 2009) and assimilated information gathered from new surveys to increase representation, accuracy and reliability of biomass productivity data for the calibration of carbon accounting models. To assist in the improvement of carbon sequestration and biomass production estimates destructive sampling was carried out to test and further refine the allometric relationships used in the modelling. From a combination of these activities data sets on a range of native species have been compiled providing enhanced parameter information that is available for other predictive models.

Unlike most crops where the product yield is readily measured at harvest times, carbon sequestered in agroforestry and other carbon crops is more difficult to assess. There are two approaches that can be used to assess the amount of carbon stored in these situations: 1/ physical measurements supported by destructive subsamples or reliable estimation techniques (i.e. allometrics); or 2/ process or simulation models of predicted carbon yields. However the second method relies on the quality of the data upon which the models have been constructed and, as previously stated, in lower rainfall areas there is a general lack of information available.

In classical forestry simple estimates of stemwood volumes are used to determine the amount of timber that can be extracted from a plantation, however, this fails to take into account a significant amount other above-ground plant biomass (e.g. branches, twig and leaves). Carbon sequestration assessments need to fully account for the whole of plant biomass and not just stem components. By harvesting a small number of individuals of a species and exploring how their morphological parameters, individual dry biomass and the dry biomass of component fractions (leaves, bark, branches and stemwood) relate to each other, it is possible to develop useful formulas that can be applied to other similar individuals. These reliable relationships between plant measurements and biomass (allometrics) can then be used to develop a set of simple measurements (biometrics) that are able to be applied without the need for further destructive sampling, providing a rapid method of estimating site productivity. This study aimed to provide a range of these allometric equations for differing life forms and situations.

A focus of this project was to sample vegetation to test and refine the allometric equations developed within the Southern Murray-Darling Basin region during this and previous studies (Neumann *et al.* 2010, Hobbs *et al.* 2010, Hobbs *et al.* 2009, Hobbs and Bennell 2005). Assessments of productivity using these equations were applied to 28 new sites and 93 sites previously measured within the region, to provide accurate estimates of the carbon sequestered by each site and species.

A stemwood volume model was chosen because it was most comparable with the process-based stemwood models used in the FullCAM program, however, many of the other models developed in this study are equally as valid and reliable. It was intended that many of the data sets produced from this study would be used to improve the parameter sets currently available for modelling carbon sequestration and biomass production. Physical and time constraints have limited these assessments to the above ground components of plant biomass.

Predictive models of carbon sequestration and biomass production will be used to provide estimates within any proposed national carbon accounting and emission trading schemes. Species in higher rainfall regions (>650mm) are now well established within these carbon accounting schemes and models. However, this information is currently underdeveloped for species suited to planting within the medium and lower rainfall regions (<650mm). Consequently, a call for additional information collections and sampling studies has been made by a number of organisations (DCCEE, CSIRO, DENR, SA Water, Greening Australia and Canopy) to produce a more comprehensive dataset for use in carbon accounting models. Previous DENR studies have illustrated that currently available national models can misrepresent carbon sequestration rates in lower rainfall regions by 50 - 400% (Hobbs *et al.* 2009a, Hobbs *et al.* 2010).

DENR Ecological Analysis and Monitoring Unit has previously invested resources and developed collaborations with the Future Farm Industries CRC and the Rural Industry Research and Development Corporation (RIRDC) to undertake studies on carbon sequestration rates and evaluation techniques from areas within SA (Mid-North [Neumann *et al.* 2010], Southern Murray-Darling Basin [Hobbs *et al.* 2010], Upper South East [Hobbs *et al.* 2006, 2009a] & River Murray Dryland Corridor [Hobbs & Bennell 2005]). The EAMU team has collaborated extensively with CSIRO in recent years on other national studies of native plant growth rates and carbon sequestration modelling (Polglase *et al.* 2008). From these investments and collaborations DENR has developed a unique capacity to undertake scientifically rigorous evaluations of carbon sequestration rates of native plant species in lower rainfall regions.

The development of sustainability markets for carbon sequestration based on forestry activities in South Australia requires a scientifically rigorous evaluation process and an understanding of the productivity and carbon sequestration rates associated with those activities. While the ultimate objective of the State Government is to develop a comprehensive understanding of carbon sequestration rates from all plantings in South Australia, the most cost-effective approach is to develop sound methodologies and information for regions with the highest priority for investment. Landscapes currently utilised for dryland agriculture in the lower rainfall regions (300-650mm) contain areas of land that produce negative returns from cropping and are unsuitable for grazing. However, many of these unviable cropping/grazing areas have potential for investments in sustainable woody crop production with associated beneficial carbon sequestration and environmental outcomes (Figure 3).

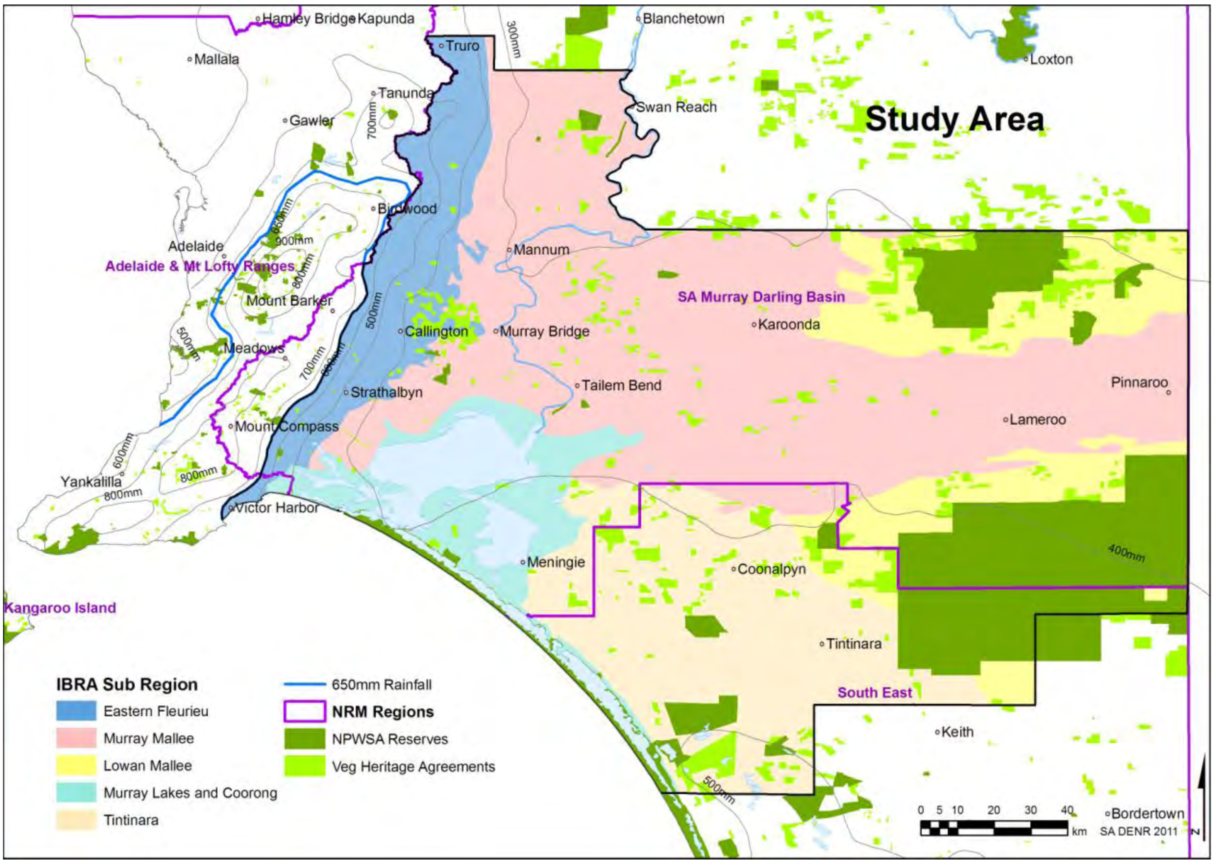
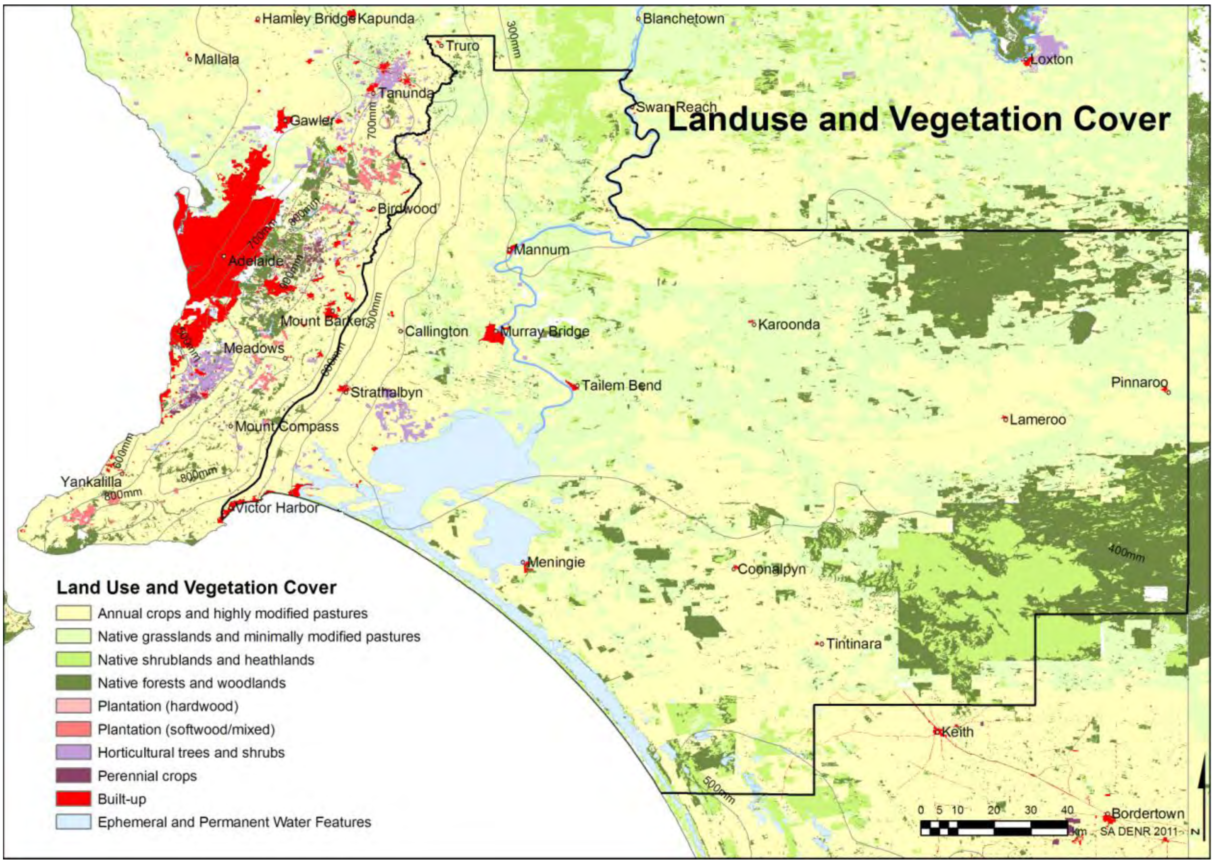


Figure 1. Carbon sequestration and biomass production rates from agroforestry project study area.



Source: BRS 2004

Figure 2. Landuse and vegetation cover types in the study region.

Photo: R. Murphy

Figure 3. A 7.5 year old, Flat Topped Yate (*Eucalyptus occidentalis*) and Sugar Gum (*Eucalyptus cladocalyx*) plantation at Callington.

Development of Carbon Assessment Methods

Assessing Above-ground Plant Biomass

The potential of agroforestry to sequester carbon in lower rainfall areas has been difficult to evaluate due to a lack of productivity data for many of the species suited to those areas. Measurements and destructive samples were taken from some of the older plantations in the study area to determine relationships (allometric models) between simple plant height by stem area measurements and above-ground plant biomass (and carbon content). Additional information was also collected from the destructive samples to determine biomass ratios (or fractions) between Stemwood : Bark : Branches : Leaves for a range of species commonly planted in the region. This data has been used to enhance the precision and reliability of non-destructive assessment methods and predictive models.

Allometric Assessment Techniques

Sampling

Individual plant measurements included height, crown width, distance to neighbouring plants, stem count and circumference at two lower section heights (basal and intermediate: 0.5m and 1.3m for trees and mallees; and 0.2m and 0.8m for shrubs), and visual ranking of leaf density using reference photographs (8 classes). The stemwood volume (outer bark) of each plant was calculated from stem height and circumferences using standard forestry formulas for tree volumes of each stemwood section (1. lower section – cylinder volume; 2. mid section - Smalian's frustum of a paraboloid volume, and 3. upper section - paraboloid volume).

The whole of each plant was destructively sampled and sorted into two biomass fractions: 1. stemwood and bark (>8mm diameter); 2. leaf, fine twig and bark (<8mm diameter) and each fraction weighed immediately.

A sub-sample of leaf material (>300g) was separated from it's associated the fine twig and bark, which was also retained to provide a ratio between the two. These two green subsamples were weighed immediately, oven dried to a steady dry-weight and reweighed to determine their moisture content.

Samples of wood and bark were taken at the basal and intermediate height of each plant with an additional sample taken half way between the intermediate height and the top of the plant. The diameter of the wood (minus bark) and bark thicknesses were measured across the north-south axis of the sample, and used to determine the bark proportion of the stemwood volume. The green weight of the wood only and bark only samples were measured immediately. The green volume of the wood only samples was determined by displacement in water, and the separate wood and bark samples were oven dried to a steady dry-weight to determine the basic wood density and the moisture content of each sample component.

The total dry biomass of each plant was determined from the green weight of each biomass fraction and the observed moisture content of oven-dried subsamples. Whole plant carbon contents were calculated from the sum of dry biomass fractions and the commonly accepted generic conversion factor of 0.5 (Snowdon *et al.* 2002).

Biometrics

Several plant species were selected and destructively sampled (24 individual plants) from dryland environments within the study area. These revegetation sites were of a known age and designed to supplement information collected during previous work in the Murray Darling basin and Upper South East regions of South Australia (105 individual plants) (see Table 1; Hobbs *et al.* 2010; Hobbs *et al.* 2006; Hobbs & Bennell 2005). Plant species were chosen to represent those species most highly ranked for agroforestry development (Hobbs *et al.* 2009a) and from the study of environmental plantings for the region. The species selected included forestry tree species, small trees and mallees. A minimum of 3 individuals of each species and location were chosen for detailed biometric measurements of plant morphology and biomass sampling.

One hundred and five individual plants have been measured and destructively sampled during these combined biometric studies. These represent 23 species (see Table 1) and include 2 generic species groupings (18 Eucalypts, 5 non-Eucalypts) and 3 lifeform types (8 eucalypt tree, 10 mallee, 5 non-eucalypt trees). Important agroforestry species were sampled more than once (e.g. Sugar gum [*Eucalyptus cladocalyx*], Swamp Yate [*E. occidentalis*], Mallee Box [*E. porosa*]) from different ages and plantations designs (e.g. blocks and windbreaks). The age of plantations sampled for this study ranged from 5.7 years old to a maximum of 42 years (overall average 20 years). Table 1 provides a summary of a number of key plant characteristics for species destructively sampled in the biometric studies. Individual plant morphological measurements were converted into a range of biometric parameters commonly used to predict above ground plant biomass. These include plant height, basal stem area (outer bark), crown area (from crown widths), stemwood volume (outer bark; from plant height and 2 stemwood area observations), wood density and foliage density. Foliage density classes were expressed as a percent of maximum density (i.e. very dense 100%, dense 86%, moderately dense 71%, moderate 57%, moderately sparse 43%, sparse 29%, very sparse 14%, no leaves 0%).

Allometric Relationships

Allometric relationships between the measured morphological parameters and individual plant dry biomass were explored using linear and non-linear regressions (Figure 4 to Figure 7). Separate analyses were conducted for total dry biomass and the dry biomass fractions: 1/ wood (>20mm diameter); 2/ stemwood bark; 3/ branch and twig (2-20mm diameter), and bark; and 4/ leaf, fine twig (<2mm diameter) and bark. Because they are often significant, the interaction of species groups and lifeform classes on biomass predictions from morphological measurements were also analysed (Hobbs *et al.* 2006).

Plots and results illustrate simple relationships between many parameters (and their interactions) and dry biomass values (Figure 4 to Figure 7). Regression relationships between stemwood volume and total above-ground dry biomass for different lifeform by species group and plant components are represented by the simple formulas presented in Table 3. The resulting generalised stemwood volume model (r^2=0.89) of total dry biomass (kg/plant) from stemwood volume (outer bark) measurements (with no species group or lifeform interactions) is presented in Figure 4. However, by including 3 lifeform by species group interactions an overall 2% greater precision can be gained for stemwood volume-based predictions of total dry biomass (1/ tree eucalypt r^2=0.96; 2/ tree non-eucalypt r^2=0.86; 3/ mallee eucalypt r^2=0.95).

Plant basal area (from stem diameter measurements) is a biometric used extensively in many individual species allometric models that attempt to predict forestry productivity and carbon sequestration rates. A generalised relationship between basal area and plant dry biomass from destructive measurements is presented in Table 2. In this case the resulting generalised basal area model (r^2=0.92) appears slightly stronger than that of stemwood volume (outer bark) measurements (with no species group or lifeform interactions) and is also presented in Figure 4. By including 3 lifeform by species group interactions an overall 2% greater precision can be gained for basal area-based predictions of total dry biomass (1/ tree eucalypt r^2=0.94; 2/ tree non-eucalypt r^2=0.89; 3/ mallee eucalypt r^2=0.95).

Figure 5 illustrates the similarity of the relationship between basal area or plant stemwood volume measurements and dry stemwood biomass (the timber component) for trees and mallees. The resulting generalised models were the same strength (r^2=0.91) and small gains (1-2%) in model fit were made in the plant stemwood volume measurement models by including the 3 lifeform by species group classes. Similarly the relationship between the above ground plant volume and total dry biomass is very strong (r^2=0.90) (Figure 6) however including foliage density with above ground plant volume weakens the resulting generalised model (r^2=0.88) (Figure 7). In this instance each of the species group class models are detrimentally affected by the addition of foliage density to above ground plant volume and its relationship with total dry biomass.

Implications of Allometric Relationships

Assessments of plantation productivity and carbon sequestrations can be achieved by one of two related methods: 1/ physical measurements supported by destructive subsamples or reliable estimation techniques (i.e. allometrics); or 2/ process or simulation models of predicted carbon yields built from observational data and refined comprehension of underlying processes. Any estimation technique or predictive model relies on the accuracy of prior data collection and as such will always have some element of inaccuracy.

This current allometric study supports the improvement of on-site physical evaluation techniques and illustrates relatively small differences in precision using fewer measurements. The question therefore is how much inaccuracy is acceptable, and when does the collection of extra measurements cease to add value?

After examining the allometric relationships presented in Figure 4 to Figure 7 and the scatter of data within these observations it can be argued that assessments of stocking rates (trees per hectare) combined with either basal area or stemwood volume (i.e. basal area, height) provide reliable estimates of biomass and carbon sequestration. Life form and species group differences significantly influence these relationships. While in some instances additional measurements such as height to calculate volume adds some level of accuracy, the extra effort required to obtain the additional data does not significantly improve estimates based on fewer measurements and effort. In some cases, such as the addition of foliage density to above ground volume in Figure 7, the added complexity can actually reduce the strength of the model fit. Unless it is required for other purpose there is little need to take extra time consuming measurements.

Table 1. Plant species measured and destructively sampled for biometric studies, including some key plant characteristics (mean values, n=3).

Species (plantation type)	Rainfall [mm]	Age [years]	Height [m]	Lifeform [Tree/Mallee]	Crown Width [m]	Crown Area [m^2]	Foliage Density [%]	Basal Area [cm^2] at 0.5m height	Stemwood Volume x 1000 [m^3]	Basic Density [kg/m^3] (n=9)	Total Dry Biomass [kg/plant]	Proportion Dry Biomass by Weight			
												Wood	Bark	Branch	Leaf
Acacia mearnsii (block)	492	12.5	9.9	T	3.3	9.7	57	180	82.4	650	73.5	0.67	0.15	0.11	0.07
Acacia pycnantha (block)	340	13.5	4.1	T	3.8	11.5	43	68	11.1	785	32.4	0.47	0.12	0.26	0.15
Allocasuarina verticillata (block)	340	12.5	5.7	T	3.3	8.4	43	184	41.4	723	48.3	0.52	0.17	0.18	0.13
Allocasuarina verticillata (block)	492	10.9	9.6	T	4.9	19.1	38	484	173.9	724	202.3	0.67	0.16	0.07	0.10
Callitris gracilis (block)	379	42.0	8.6	T	5.8	26.1	86	844	295.1	525	216.4	0.64	0.10	0.13	0.13
Corymbia maculata (block)	492	10.8	8.0	T	3.2	7.8	52	114	32.0	601	23.8	0.41	0.30	0.13	0.16
Eucalyptus calycogona (block)	379	42.0	6.9	M	9.5	52.8	43	548	159.3	906	274.3	0.75	0.10	0.07	0.09
Eucalyptus camaldulensis (windbreak)	460	10.7	11.2	T	4.9	19.1	57	450	172.4	483	92.3	0.59	0.18	0.10	0.12
Eucalyptus cladocalyx (block)	460	6.7	7.1	T	2.7	5.7	71	119	30.2	634	31.0	0.39	0.17	0.21	0.23
Eucalyptus cladocalyx (windbreak)	460	6.7	5.8	T	2.4	4.5	86	142	28.5	600	34.4	0.43	0.15	0.17	0.25
Eucalyptus cneorifolia (block)	379	42.0	5.4	M	5.1	19.2	66	450	110.7	821	159.3	0.68	0.14	0.09	0.09
Eucalyptus cyanophylla (block)	261	9.5	2.9	M	2.5	5.2	62	62	5.9	787	22.3	0.20	0.10	0.26	0.44
Eucalyptus dumosa (block)	387	12.0	3.3	M	2.7	6.5	62	63	7.8	767	20.4	0.35	0.12	0.33	0.20
Eucalyptus globulus (block)	460	10.7	13.8	T	3.5	10.1	57	224	126.1	530	90.8	0.63	0.10	0.09	0.17
Eucalyptus gracilis (block)	261	6.6	1.8	M	2.0	3.0	91	31[#1]	1.4	830	6.1	0.05	0.02	0.36	0.57
Eucalyptus gracilis (block)	357	31.2	10.0	M	7.5	48.1	71	702	318.0	908	422.1	0.75	0.14	0.06	0.05
Eucalyptus incrassata (block)	357	31.2	5.8	M	7.8	44.9	43	423	97.6	824	221.5	0.61	0.12	0.14	0.13
Eucalyptus intertexta (block)	379	42.0	12.5	T	6.1	24.6	43	1157	585.1	896	352.7	0.73	0.19	0.04	0.04
Eucalyptus largiflorens (belt)	261	10.5	3.8	M	2.6	5.4	52	95	13.0	687	19.2	0.40	0.16	0.22	0.22
Eucalyptus largiflorens (block)	379	42.0	9.5	T	6.0	34.0	43	643	237.3	920	248.6	0.79	0.15	0.04	0.03
Eucalyptus leptophylla (block)	357	31.3	6.6	M	9.2	65.2	71	666	205.7	844	388.8	0.66	0.10	0.13	0.11
Eucalyptus leptophylla (block)	379	42.0	6.9	M	7.8	47.9	57	368	99.5	919	169.1	0.66	0.13	0.13	0.09
Eucalyptus leucoxylon (block)	379	42.0	8.8	T	9.0	60.5	57	615	224.2	835	269.8	0.67	0.19	0.06	0.08
Eucalyptus leucoxylon (block)	492	10.7	9.7	T	2.9	6.6	43	172	61.1	657	42.7	0.54	0.27	0.07	0.12
Eucalyptus occidentalis (block)	379	42.0	14.6	T	8.2	53.4	43	1811	1266.3	801	1247.3	0.80	0.15	0.02	0.03

Species (plantation type)	Rainfall [mm]	Age [years]	Height [m]	Lifeform [Tree/Mallee]	Crown Width [m]	Crown Area [m²]	Foliage Density [%]	Basal Area [cm²] at 0.5m height	Stemwood Volume x 1000 [m³]	Basic Density [Kg/m³] (n=9)	Total Dry Biomass [Kg/plant]	Proportion Dry Biomass by Weight			
												Wood	Bark	Branch	Leaf
Eucalyptus occidentalis (block)	460	5.7	10.0	T	3.3	8.7	57	238	95.9	538	68.1	0.64	0.10	0.09	0.17
Eucalyptus occidentalis (windbreak)	460	6.7	8.6	T	2.3	4.5	57	134	49.7	604	39.8	0.57	0.10	0.12	0.21
Eucalyptus oleosa (block)	261	10.4	2.9	M	3.5	9.9	76	85	8.4	793	25.1	0.24	0.09	0.27	0.39
Eucalyptus oleosa (block)	357	31.2	6.4	M	9.2	57.9	57	556	158.8	841	343.2	0.61	0.12	0.12	0.15
Eucalyptus porosa (block)	261	9.5	2.4	M	3.1	7.8	76	68	4.4	668	11.6	0.19	0.06	0.39	0.35
Eucalyptus porosa (block)	340	12.4	4.5	M	3.6	17.9	71	218	34.3	663	55.4	0.43	0.13	0.18	0.26
Eucalyptus porosa (block)	387	6.7	3.9	M	3.8	11.7	71	93	11.6	577	23.3	0.29	0.08	0.26	0.37
Eucalyptus socialis (block)	261	10.5	3.3	M	4.5	16.0	71	137	16.1	757	51.5	0.25	0.09	0.30	0.36
Eucalyptus socialis (windbreak)	357	26.1	5.6	M	7.1	40.8	71	517	107.0	778	185.9	0.64	0.14	0.11	0.12
Eucalyptus viminalis (block)	460	5.7	11.1	T	3.9	12.6	52	313	129.9	487	75.4	0.55	0.15	0.09	0.21

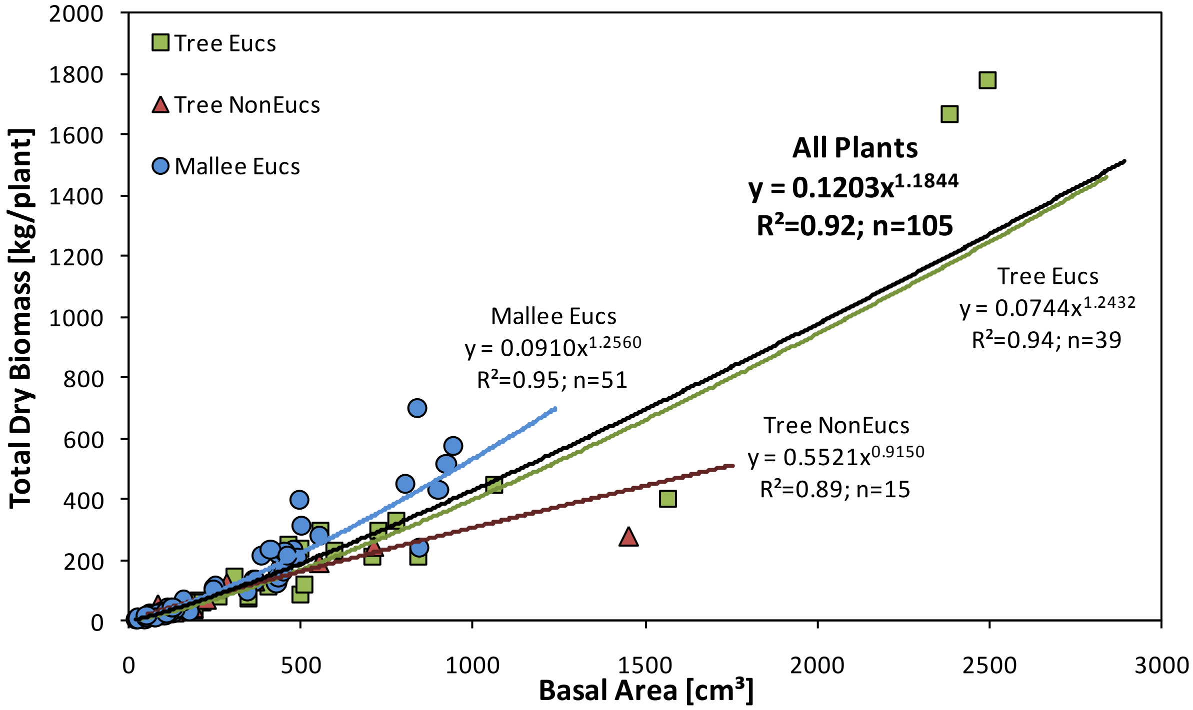
[# 1] basal area at 0.1m height

Table 2. Simple regression relationships between basal area and total above-ground dry biomass for different lifeform by species group.

Species and Lifeform Group	Obs. [n]	Model Fit [r^2]	Dry Biomass [kg/plant]
Total Above-ground Plant Biomass			
All Species (Unsorted)	105	0.92	= 0.1203 x Basal Area $[\text{cm}^2]^{1.1844}$
Tree (Eucalypt)	39	0.94	= 0.0744 x Basal Area $[\text{cm}^2]^{1.2432}$
Tree (Non-Eucalypt)	15	0.89	= 0.5521 x Basal Area $[\text{cm}^2]^{0.9150}$
Mallee (Eucalypt)	51	0.95	= 0.0910 x Basal Area $[\text{cm}^2]^{1.2560}$
Stemwood Biomass (excluding bark)			
All Species (Unsorted)	105	0.91	= 0.0060 x Basal Area $[\text{cm}^2]^{1.6034}$
Tree (Eucalypt)	39	0.94	= 0.0137 x Basal Area $[\text{cm}^2]^{1.4503}$
Tree (Non-Eucalypt)	15	0.87	= 0.1425 x Basal Area $[\text{cm}^2]^{1.0661}$
Mallee (Eucalypt)	51	0.93	= 0.0020 x Basal Area $[\text{cm}^2]^{1.8018}$
Bark Biomass			
All Species (Unsorted)	105	0.89	= 0.0051 x Basal Area $[\text{cm}^2]^{1.3545}$
Tree (Eucalypt)	39	0.91	= 0.0136 x Basal Area $[\text{cm}^2]^{1.1908}$
Tree (Non-Eucalypt)	15	0.83	= 0.0522 x Basal Area $[\text{cm}^2]^{0.9564}$
Mallee (Eucalypt)	51	0.85	= 0.0011 x Basal Area $[\text{cm}^2]^{1.6773}$
Branch and Twig Biomass			
All Species (Unsorted)	105	0.57	= 0.3020 x Basal Area $[\text{cm}^2]^{0.6312}$
Tree (Eucalypt)	39	0.72	= 0.1876 x Basal Area $[\text{cm}^2]^{0.6393}$
Tree (Non-Eucalypt)	15	0.69	= 0.5532 x Basal Area $[\text{cm}^2]^{0.5486}$
Mallee (Eucalypt)	51	0.66	= 0.0935 x Basal Area $[\text{cm}^2]^{0.9481}$
Leaf and Fine Twig Biomass			
All Species (Unsorted)	105	0.57	= 0.4012 x Basal Area $[\text{cm}^2]^{0.6076}$
Tree (Eucalypt)	39	0.53	= 0.4703 x Basal Area $[\text{cm}^2]^{0.5419}$
Tree (Non-Eucalypt)	15	0.82	= 0.1289 x Basal Area $[\text{cm}^2]^{0.7872}$
Mallee (Eucalypt)	51	0.57	= 0.1760 x Basal Area $[\text{cm}^2]^{0.8408}$

Table 3. Simple regression relationships between stemwood volume and total above-ground dry biomass for different lifeform by species group.

Species and Lifeform Group	Obs. [n]	Model Fit [r^2]	Dry Biomass [kg/plant]
Total Above-ground Plant Biomass			
All Species (Unsorted)	105	0.89	= 0.9761 x (Stemwood Volume x 1000 [m^3])
Tree (Eucalypt)	39	0.96	= 0.9268 x (Stemwood Volume x 1000 [m^3])
Tree (Non-Eucalypt)	15	0.86	= 3.0043 x (Stemwood Volume x 1000 [m^3])$^{0.7673}$
Mallee (Eucalypt)	51	0.95	= 2.2859 x (Stemwood Volume x 1000 [m^3])$^{0.9263}$
Stemwood Biomass (excluding bark)			
All Species (Unsorted)	105	0.91	= 0.3016 x (Stemwood Volume x 1000 [m^3])$^{1.1664}$
Tree (Eucalypt)	39	0.95	= 0.7584 x (Stemwood Volume x 1000 [m^3])
Tree (Non-Eucalypt)	15	0.87	= 0.9566 x (Stemwood Volume x 1000 [m^3])$^{0.9103}$
Mallee (Eucalypt)	51	0.95	= 0.2004 x (Stemwood Volume x 1000 [m^3])$^{1.3404}$
Bark Biomass			
All Species (Unsorted)	105	0.90	= 0.1161 x (Stemwood Volume x 1000 [m^3])
Tree (Eucalypt)	39	0.95	= 0.1130 x (Stemwood Volume x 1000 [m^3])
Tree (Non-Eucalypt)	15	0.85	= 0.2785 x (Stemwood Volume x 1000 [m^3])$^{0.8246}$
Mallee (Eucalypt)	51	0.86	= 0.0780 x (Stemwood Volume x 1000 [m^3])$^{1.2418}$
Branch and Twig Biomass			
All Species (Unsorted)	105	0.45	= 1.7487 x (Stemwood Volume x 1000 [m^3])$^{0.4072}$
Tree (Eucalypt)	39	0.67	= 0.7428 x (Stemwood Volume x 1000 [m^3])$^{0.4826}$
Tree (Non-Eucalypt)	15	0.56	= 1.7900 x (Stemwood Volume x 1000 [m^3])$^{0.4231}$
Mallee (Eucalypt)	51	0.62	= 1.1486 x (Stemwood Volume x 1000 [m^3])$^{0.6783}$
Leaf and Fine Twig Biomass			
All Species (Unsorted)	105	0.48	= 2.0683 x (Stemwood Volume x 1000 [m^3])$^{0.4042}$
Tree (Eucalypt)	39	0.57	= 1.2986 x (Stemwood Volume x 1000 [m^3])$^{0.4410}$
Tree (Non-Eucalypt)	15	0.66	= 0.7059 x (Stemwood Volume x 1000 [m^3])$^{0.6033}$
Mallee (Eucalypt)	51	0.53	= 1.6379 x (Stemwood Volume x 1000 [m^3])$^{0.5999}$



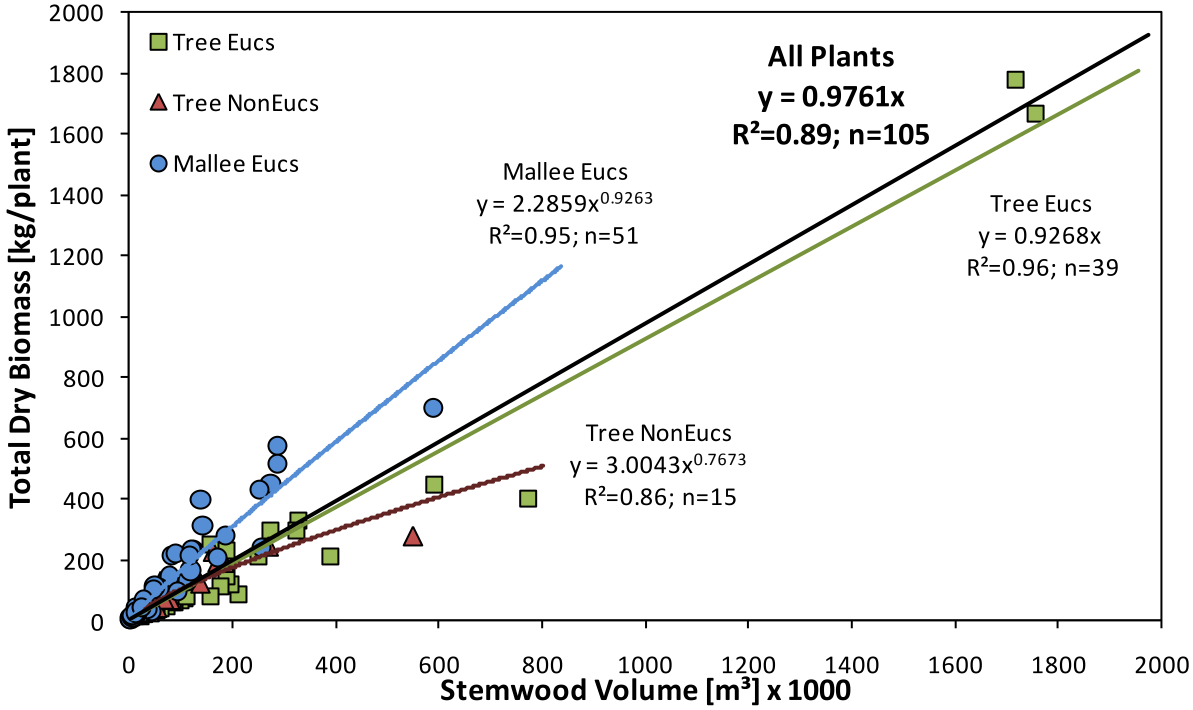


Figure 4. **Allometric relationships between basal area (at 0.5m) or plant stemwood volume measurements and total above ground dry biomass for trees and mallees.**

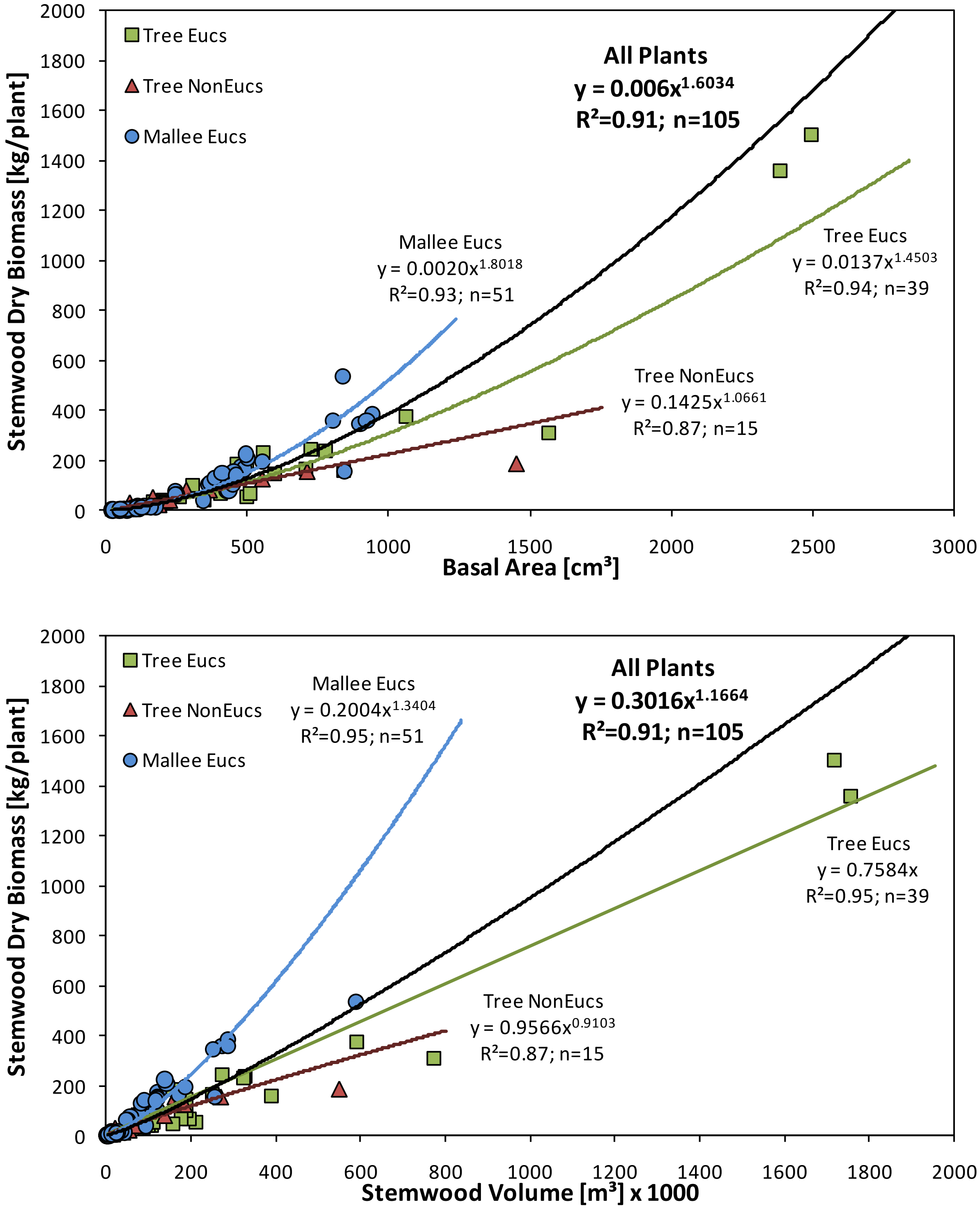


Figure 5. **Allometric relationships between basal area (at 0.5m) or plant stemwood volume measurements and dry stemwood biomass for trees and mallees.**

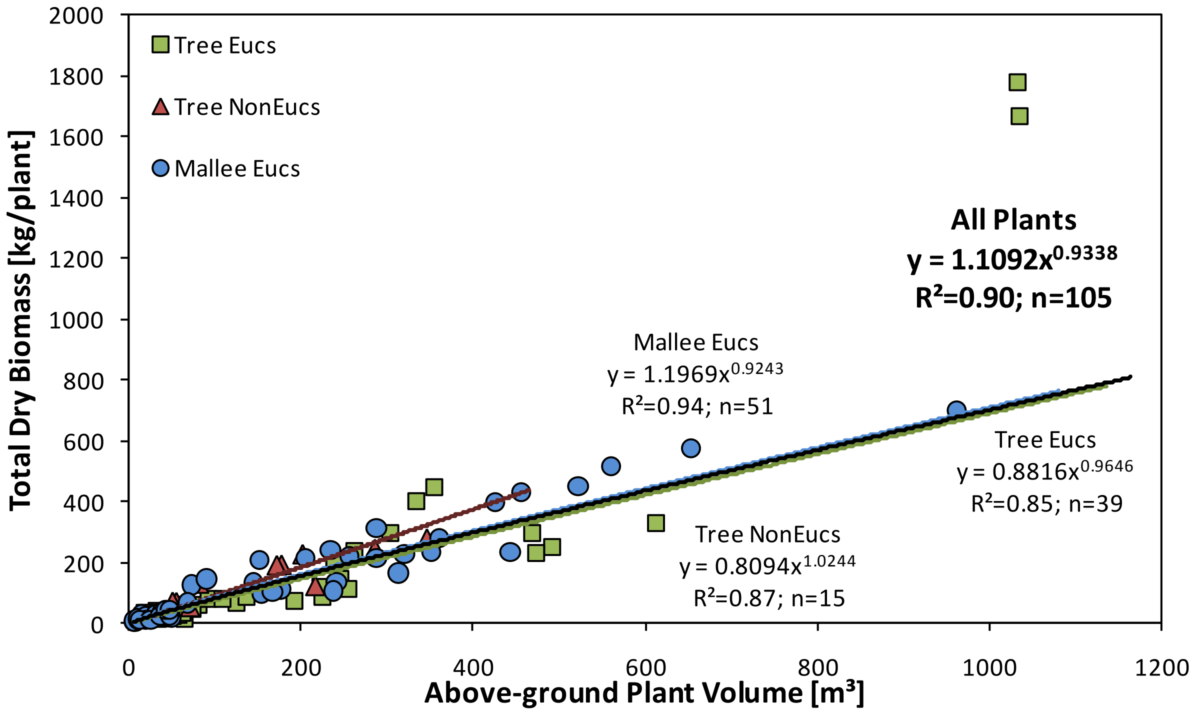


Figure 6. **The relationship between above-ground plant volume (height [m] x crown area [m²]) and total above ground dry biomass for trees and mallees.**

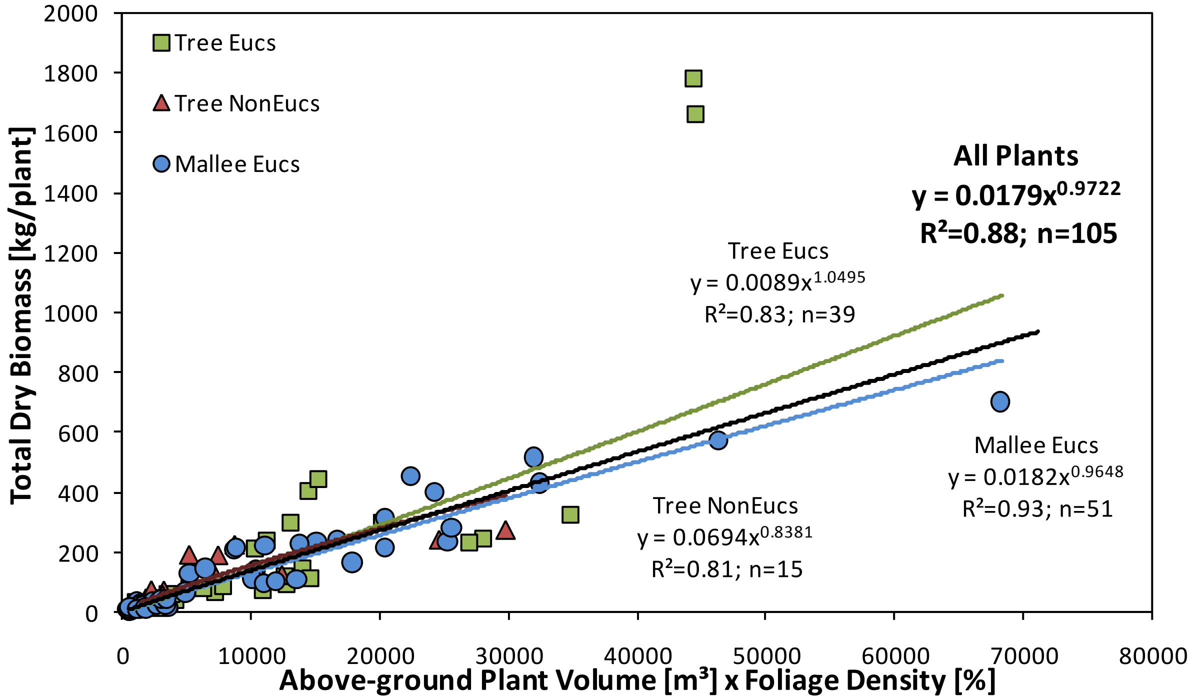


Figure 7. **The relationship between above-ground plant volume (height [m] x crown area [m²]) multiplied by foliage density [%] and total above ground dry biomass for trees and mallees.**

Productivity and Carbon Sequestration

Assessment of Plantation Productivity

Twenty eight sites of known age were chosen across the study area to be assessed for plant growth and carbon sequestration rates from Farm forestry plantings (Figure 8). The average age of plantations in this study was 16.5 years (Table 5), comprising a total of 32 different species. The information gathered from these sites was designed to bolster existing plantation information (93 plantations) collected from various sources during prior projects (Hobbs *et al.* 2009a, Hobbs *et al.* 2010); and to provide information on the individual species involved. This part of the study was conducted using non-destructive measurements in 27 monoculture blocks and one other block with two species relatively evenly dispersed across the plantation.

The productivity assessment protocols were designed for monoculture sites where a minimum of thirty six plants of the target species could be measured (Table 4). Sites were sub-sampled using 6 row segments of continuously planted individuals randomly placed through out the block (avoiding the ends of rows). The segments typically comprised of 6 individuals. Within each segment only plants two meters high and greater were measured. Data collected included height, crown width, form (tree/mallee), distance to neighbouring plants, stem count and circumference at a basal height of 0.5m and an intermediate height of 1.3m, and a visual ranking of foliage density using reference photographs (8 classes). Foliage density classes were expressed as a percent of maximum density (i.e. very dense 100%, dense 86%, moderately dense 71%, moderate 57%, moderately sparse 43%, sparse 29%, very sparse 14%, no leaves 0%).

Table 4. Generalised summary of measurement protocols used in 28 surveys of plantation productivity in the study.

Plantation	**Size**	**Total Observations (Subsites & Layout)**	**Subsite Location**
Single species block	>4 rows; >110m long	36 (6x6 plant segments)	6 segments randomly located within inside rows

The stemwood volume (outer bark) of each plant was calculated from stem height and circumferences using standard forestry formulas for tree volumes of each stemwood section (1. lower section – cylinder volume; 2. mid section - Smalian's frustum of a paraboloid volume, and 3. upper section - paraboloid volume). Robust and reliable allometric models (see preceding sections) were applied to the results gathered at the field sites to estimate stemwood volume, above-ground dry biomass productivity and carbon sequestration rates within these plantations.

Pre-existing survey data of predominantly monocultures (93 plantations; Hobbs *et al.* 2010) followed an identical methodology to that outlined above. The combined dataset and species encountered during these surveys can be found in Table 5. The average observed plant density of the sites in our study area was 945 trees per hectare (tph, n=121) is only a little lower than the 1000 tph assumed by Sheppard and Wilson (2007) in their state estimates for hectares of revegetation from nursery plant sales surveys data.

Productivity values for each revegetation site have been standardised to an annual biomass accumulation rate to account for the different ages in the plants studied. The average annual rainfall (CSIRO Land & Water 2001), BiosEquil model values (Raupach *et al.* 2001, Hobbs *et al.* 2006) and NCAT Forest Productivity Index (DCC 2009) for each sampled locality was extracted from spatial coverages using ArcGIS (ESRI 2009). NCAT Model Maximum Dry Matter values were extracted from the NCAT data server (DCC 2009) for each site. A summary of site data and observed productivity rates is presented in Table 5.

Observed Carbon Sequestration Rates

The average above-ground carbon sequestration rates across the region were 9.5 tonnes of carbon dioxide equivalents per hectare per year (CO_2-e t/ha/yr) for all measured plantations. For tree-form eucalypts the same rate was 10.6 CO2-e t/ha/yr, in mallee-form eucalypts it was 6.3 CO_2-e t/ha/yr and for non-eucalypts trees it was 6.9 (Table 5). However, rainfall has a significant influence on species selection and subsequent growth rates achieved at any site (Figure 9). Most of the species that are performing extremely well in high rainfall areas cannot be utilised in the lower rainfall areas. In those lower rainfall areas, without access to extra ground water, growth and sequestration rates are naturally slower and mallees may be the best option (Table 5 and Figure 9).

The average age of the plantings in this study was 16.5 years, with plantation ages ranging from 5.7 to 99 years since establishment. While an even distribution of plantation ages would have been desirable, 83% of the sites were less than twenty years old (38% < 10 years old) simply due to the scarcity of older plantations (Table 5). The average above-ground carbon sequestration rate across the region was 9.1 (CO_2-e t/ha/yr). Summaries of site data and observed productivity rates are presented in Table 5.

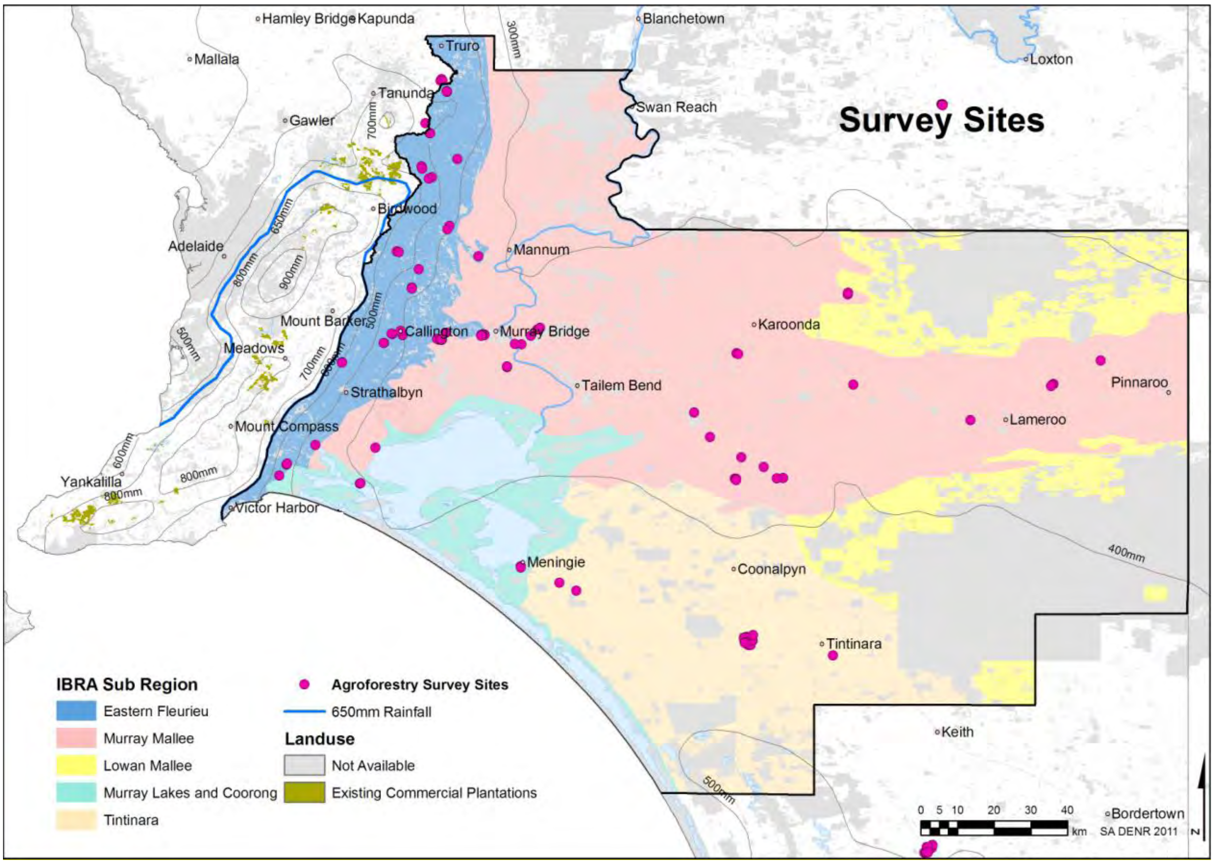


Figure 8. Location of productivity measurement survey sites in the study area.

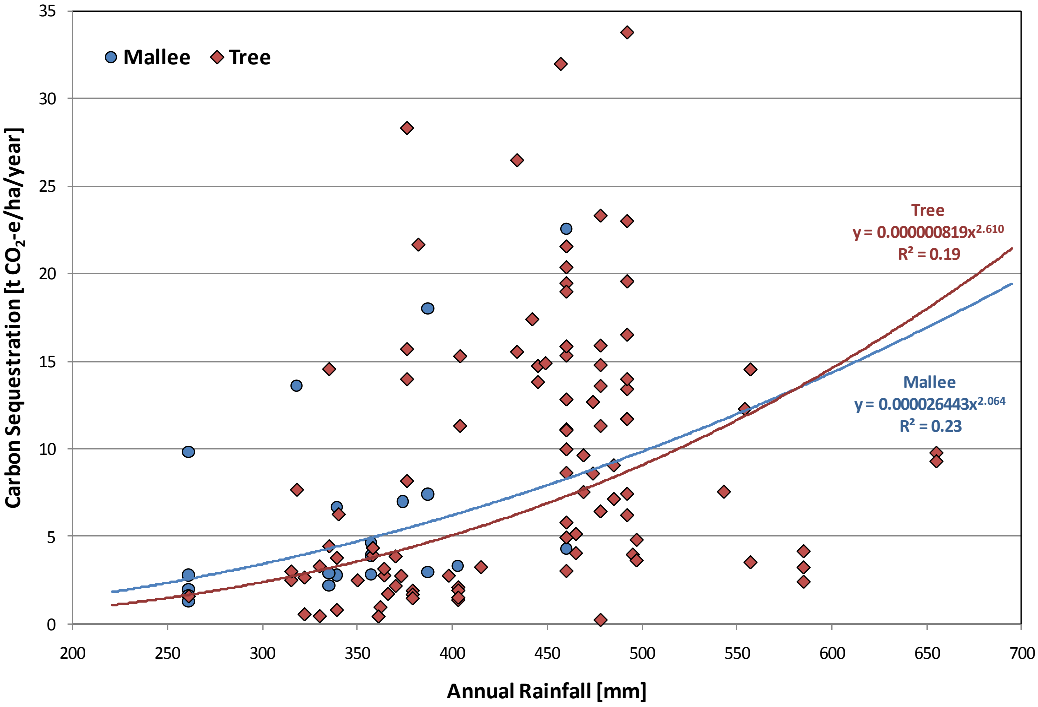


Figure 9. Observed carbon sequestration rates of woodlots and revegetation sites versus average annual rainfall in the Southern Murray-Darling Basin Region.

Table 5. Plantation growth and carbon sequestration rates from trees and mallees observed in the southern Murray-Darling Basin region of South Australia.

	Site Detail				Field Survey									Proportion of Above-ground Dry Biomass			
Species	Rain [mm]	NCAT Model – Max. Dry matter [t/ha]	NCAT Forest Productivity Index	BiosEquil Model [t C/ha/yr]	Age	TPH	Stand Type [Block, WindBreak]	Observations$^{\#}$	Height [m]	Stem Volume MAI [m^3/ha/yr]	Dry Biomass [t/ha/yr]	Carbon [t/ha/yr]	CO_2e [t/ha/yr]	Stemwood	Bark	Branches	Leaf
Trees																	
Acacia implexa	478	117.3	7.1	2.2	7.4	854	BL	36	6.0	2.77	3.78	1.88	6.89	0.60	0.13	0.11	0.16
Acacia mearnsii	492	76.9	5.4	2.3	12.5	3017	BL	32	9.9	19.41	18.58	9.22	33.83	0.67	0.13	0.07	0.12
Acacia pycnantha	340	44.9	4.0	1.6	13.8	2778	BL	30	3.7	2.70	3.81	1.89	6.93	0.57	0.13	0.12	0.18
Allocasuarina verticillata	322	77.7	5.4	1.5	17.0	720	BL	17	3.8	0.23	0.36	0.18	0.65	0.51	0.13	0.15	0.21
Allocasuarina verticillata	403	95.9	6.2	1.9	33.0	334	BL	38	5.7	0.74	0.76	0.38	1.39	0.66	0.13	0.08	0.13
Allocasuarina verticillata	492	77.1	5.4	2.3	10.9	395	BL	30	8.6	7.10	6.22	3.09	11.33	0.71	0.13	0.06	0.10
Callitris gracilis	335	90.2	5.9	1.6	18.0	757	BL	15	6.4	2.80	2.46	1.22	4.48	0.69	0.13	0.07	0.11
Callitris gracilis	478	117.7	7.1	2.2	7.4	392	BL	36	2.2	0.05	0.16	0.08	0.29	0.40	0.11	0.21	0.28
Casuarina cunninghamiana	465	116.6	7.1	2.3	14.9	848	WB	24	5.6	2.08	2.34	1.16	4.27	0.63	0.13	0.09	0.15
Casuarina cunninghamiana	585	115.3	7.0	2.4	14.9	777	WB	23	6.1	0.93	1.43	0.71	2.60	0.59	0.13	0.11	0.17
Casuarina cunninghamiana	585	121.8	7.3	2.5	14.9	828	BL	36	6.3	1.59	1.90	0.94	3.45	0.61	0.13	0.10	0.15
Corymbia maculata	492	77.4	5.4	2.3	6.9	685	BL	28	10.2	8.69	7.83	3.88	14.25	0.75	0.11	0.04	0.10
Corymbia maculata	492	77.1	5.4	2.3	10.8	432	BL	25	9.0	3.99	3.61	1.79	6.57	0.77	0.11	0.03	0.09
Corymbia maculata	495	119.2	7.2	2.2	7.4	524	BL	36	6.1	2.29	2.21	1.10	4.02	0.69	0.10	0.05	0.16
Corymbia maculata	655	87.4	5.8	2.6	8.4	824	BL	36	8.7	6.34	5.66	2.81	10.31	0.74	0.11	0.04	0.12
Eucalyptus camaldulensis	315	40.0	3.7	1.5	9.0	399	BL	28	5.4	1.55	1.39	0.69	2.54	0.70	0.10	0.05	0.16
Eucalyptus camaldulensis	362	49.1	4.1	1.7	7.6	142	BL	30	5.7	0.58	0.53	0.26	0.97	0.69	0.10	0.05	0.16
Eucalyptus camaldulensis	370	47.2	4.1	1.5	15.0	637	BL	31	7.5	2.10	2.18	1.08	3.96	0.74	0.11	0.04	0.12
Eucalyptus camaldulensis	376	48.5	4.1	1.6	15.0	1002	BL	36	15.5	16.58	16.54	8.20	30.11	0.80	0.12	0.02	0.06
Eucalyptus camaldulensis	376	48.6	4.1	1.8	24.0	367	WB	16	13.9	8.32	8.16	4.05	14.85	0.82	0.12	0.02	0.03
Eucalyptus camaldulensis	376	50.8	4.2	1.5	7.7	1027	WB	30	9.6	9.78	9.08	4.50	16.53	0.75	0.11	0.04	0.11
Eucalyptus camaldulensis	445	62.8	4.7	1.8	15.6	550	BL	18	13.4	10.72	8.06	4.00	14.68	0.80	0.12	0.02	0.05
Eucalyptus camaldulensis	460	65.4	4.9	1.9	10.7	513	WB	33	11.4	10.62	8.92	4.42	16.24	0.79	0.12	0.03	0.06
Eucalyptus camaldulensis	460	65.4	4.9	1.9	10.0	580	WB	36	13.8	31.37	27.91	13.84	50.80	0.82	0.12	0.02	0.04
Eucalyptus camaldulensis	474	68.6	5.0	2.2	12.0	3186	BL	19	6.6	5.84	4.31	2.14	7.85	0.67	0.10	0.05	0.18

Species	Site Detail				Field Survey									Proportion of Above-ground Dry Biomass			
	Rain [mm]	NCAT Model – Max. Dry matter [t/ha]	NCAT Forest Productivity Index	BiosEquil Model [t C/ha/yr]	Age	TPH	Stand Type [Block, WindBreak]	Observations#	Height [m]	Stem Volume MAI [m³/ha/yr]	Dry Biomass [t/ha/yr]	Carbon [t/ha/yr]	CO₂e [t/ha/yr]	Stemwood	Bark	Branches	Leaf
Eucalyptus camaldulensis	478	101.7	6.4	2.2	21.9	1235	BL	18	15.1	7.83	6.60	3.27	12.01	0.78	0.12	0.03	0.08
Eucalyptus camaldulensis	478	102.2	6.5	2.2	21.9	1447	BL	30	14.7	10.64	8.62	4.28	15.69	0.78	0.12	0.03	0.07
Eucalyptus camaldulensis	492	77.9	5.4	2.3	9.9	1103	BL	30	8.2	5.07	4.24	2.10	7.72	0.71	0.11	0.04	0.14
Eucalyptus camaldulensis	585	115.3	7.0	2.4	14.9	764	WB	36	6.0	2.23	2.36	1.17	4.29	0.74	0.11	0.04	0.11
Eucalyptus cladocalyx	339	39.5	3.7	1.6	98.0	281	BL	36	10.7	0.49	0.47	0.23	0.85	0.78	0.12	0.03	0.07
Eucalyptus cladocalyx	358	53.4	4.3	1.7	9.4	717	BL	36	6.1	2.25	2.15	1.07	3.91	0.70	0.10	0.04	0.15
Eucalyptus cladocalyx	366	47.9	4.1	1.9	8.4	479	BL	36	5.4	0.98	0.84	0.42	1.53	0.64	0.10	0.05	0.21
Eucalyptus cladocalyx	373	65.9	4.9	1.9	8.4	655	BL	36	6.0	1.59	1.39	0.69	2.53	0.65	0.10	0.05	0.20
Eucalyptus cladocalyx	398	45.6	4.0	1.8	8.4	774	BL	36	6.3	1.60	1.36	0.67	2.47	0.65	0.10	0.05	0.20
Eucalyptus cladocalyx	403	103.5	6.5	1.9	7.4	694	BL	36	5.3	1.02	0.92	0.46	1.68	0.60	0.09	0.06	0.26
Eucalyptus cladocalyx	404	52.2	4.3	1.7	8.4	564	BL	36	9.9	7.19	6.59	3.27	12.00	0.76	0.11	0.03	0.09
Eucalyptus cladocalyx	415	88.5	5.9	1.9	8.4	629	BL	35	6.3	1.91	1.76	0.87	3.20	0.67	0.10	0.05	0.18
Eucalyptus cladocalyx	434	76.9	5.4	1.8	10.0	591	BL	36	11.5	9.94	9.07	4.50	16.51	0.78	0.12	0.03	0.07
Eucalyptus cladocalyx	442	75.7	5.3	2.0	7.4	598	BL	36	11.9	10.74	10.16	5.04	18.50	0.77	0.11	0.03	0.08
Eucalyptus cladocalyx	460	68.6	5.0	1.9	6.7	789	WB	30	6.4	4.02	3.16	1.57	5.75	0.69	0.10	0.05	0.16
Eucalyptus cladocalyx	460	65.1	4.8	1.9	6.7	793	BL	33	5.6	2.82	2.63	1.31	4.79	0.67	0.10	0.05	0.18
Eucalyptus cladocalyx	460	64.2	4.8	1.9	14.0	793	BL	36	10.2	6.09	5.80	2.88	10.57	0.76	0.11	0.03	0.09
Eucalyptus cladocalyx	460	64.8	4.8	1.9	10.7	440	BL	30	14.9	13.44	11.37	5.64	20.69	0.80	0.12	0.02	0.05
Eucalyptus cladocalyx	460	71.9	5.1	1.9	6.7	419	WB	30	5.0	1.79	1.64	0.81	2.99	0.68	0.10	0.05	0.17
Eucalyptus cladocalyx	465	120.2	7.3	2.4	14.9	502	BL	36	12.1	3.45	3.00	1.49	5.45	0.76	0.11	0.03	0.09
Eucalyptus cladocalyx	469	110.8	6.8	2.2	8.4	984	BL	36	9.3	6.14	5.56	2.76	10.12	0.73	0.11	0.04	0.13
Eucalyptus cladocalyx	478	101.7	6.4	2.2	21.9	1185	BL	18	17.4	10.94	9.29	4.61	16.91	0.79	0.12	0.03	0.07
Eucalyptus cladocalyx	478	102.2	6.5	2.2	21.9	1088	BL	29	14.8	8.95	7.92	3.93	14.43	0.79	0.12	0.03	0.07
Eucalyptus cladocalyx	485	80.9	5.5	2.4	7.4	841	BL	36	8.7	4.44	4.09	2.03	7.44	0.70	0.10	0.05	0.15
Eucalyptus cladocalyx	497	67.0	4.9	2.1	8.3	447	BL	36	7.2	2.27	2.07	1.03	3.77	0.71	0.11	0.04	0.15
Eucalyptus cladocalyx	543	141.8	8.2	2.4	10.4	797	BL	36	9.1	4.81	4.38	2.17	7.98	0.73	0.11	0.04	0.12
Eucalyptus cladocalyx	557	131.6	7.8	2.5	17.9	2277	BL	36	13.0	15.43	8.42	4.18	15.33	0.77	0.12	0.03	0.08
Eucalyptus cladocalyx	655	85.8	5.7	2.6	8.4	851	BL	36	10.1	5.79	5.40	2.68	9.83	0.72	0.11	0.04	0.13

Species	Site Detail				Field Survey									Proportion of Above-ground Dry Biomass			
	Rain [mm]	NCAT Model – Max. Dry matter [t/ha]	NCAT Forest Productivity Index	BiosEquil Model [t C/ha/yr]	Age	TPH	Stand Type [Block, WindBreak]	Observations$^{\#}$	Height [m]	Stem Volume MAI [m^3/ha/yr]	Dry Biomass [t/ha/yr]	Carbon [t/ha/yr]	CO_2e [t/ha/yr]	Stemwood	Bark	Branches	Leaf
Eucalyptus fasciculosa	554	120.4	7.3	2.4	16.9	3618	WB	18	6.4	11.36	6.83	3.39	12.44	0.74	0.11	0.04	0.11
Eucalyptus globulus	445	62.8	4.7	1.8	15.6	389	BL	18	18.6	10.41	8.61	4.27	15.67	0.81	0.12	0.02	0.05
Eucalyptus globulus	457	64.7	4.8	1.9	14.0	369	BL	36	23.7	20.95	18.70	9.27	34.04	0.83	0.12	0.02	0.03
Eucalyptus globulus	460	65.4	4.9	1.9	10.7	898	BL	33	12.5	11.01	11.02	5.46	20.05	0.78	0.12	0.03	0.08
Eucalyptus globulus	492	77.9	5.4	2.3	6.8	1009	BL	30	11.1	14.79	13.44	6.67	24.47	0.76	0.11	0.03	0.10
Eucalyptus grandis	478	102.2	6.5	2.2	21.9	1830	BL	24	19.3	14.64	13.61	6.75	24.78	0.78	0.12	0.03	0.07
Eucalyptus grandis	492	76.6	5.3	2.3	6.8	945	BL	30	10.6	12.47	11.44	5.67	20.82	0.75	0.11	0.04	0.10
Eucalyptus largiflorens	261	22.9	3.0	1.1	14.4	398	BL	30	4.5	1.00	0.87	0.43	1.59	0.70	0.10	0.04	0.15
Eucalyptus largiflorens	322	77.7	5.4	1.5	17.0	1460	BL	31	5.2	1.67	1.31	0.65	2.39	0.65	0.10	0.05	0.20
Eucalyptus largiflorens	330	39.0	3.7	1.6	98.0	400	BL	52	7.0	0.29	0.26	0.13	0.47	0.74	0.11	0.04	0.11
Eucalyptus leucoxylon	315	40.0	3.7	1.5	9.0	374	BL	32	5.9	1.74	1.70	0.84	3.10	0.71	0.11	0.04	0.14
Eucalyptus leucoxylon	335	90.2	5.9	1.6	18.0	711	BL	27	12.7	10.95	8.47	4.20	15.42	0.80	0.12	0.02	0.05
Eucalyptus leucoxylon	339	45.1	4.0	1.4	14.0	405	WB	36	4.6	1.77	2.07	1.03	3.77	0.64	0.14	0.05	0.17
Eucalyptus leucoxylon	350	49.6	4.2	1.4	15.9	717	BL	18	6.4	1.87	1.38	0.68	2.51	0.72	0.11	0.04	0.13
Eucalyptus leucoxylon	361	43.5	3.9	1.5	99.0	235	BL	36	8.3	0.32	0.25	0.12	0.45	0.77	0.12	0.03	0.08
Eucalyptus leucoxylon	364	43.1	3.9	1.7	19.0	346	BL	22	9.9	1.77	1.61	0.80	2.93	0.76	0.11	0.03	0.09
Eucalyptus leucoxylon	370	47.2	4.1	1.5	15.0	560	BL	29	5.5	1.28	1.18	0.59	2.15	0.71	0.11	0.04	0.14
Eucalyptus leucoxylon	376	48.6	4.1	1.8	24.0	245	WB	18	10.1	7.24	4.76	2.36	8.67	0.83	0.12	0.02	0.03
Eucalyptus leucoxylon	379	54.9	4.4	1.8	32.9	568	BL	36	6.3	1.01	0.84	0.42	1.53	0.73	0.11	0.04	0.12
Eucalyptus leucoxylon	379	52.9	4.3	1.8	32.9	232	BL	47	7.7	1.18	1.11	0.55	2.02	0.79	0.12	0.03	0.07
Eucalyptus leucoxylon	379	54.4	4.4	1.8	32.9	241	BL	36	6.9	0.87	0.98	0.49	1.78	0.79	0.12	0.03	0.07
Eucalyptus leucoxylon	382	58.4	4.5	1.8	17.0	4304	BL	24	7.1	14.80	12.22	6.06	22.24	0.74	0.11	0.04	0.11
Eucalyptus leucoxylon	403	117.9	7.2	2.0	33.0	548	BL	52	5.4	0.85	0.86	0.42	1.56	0.70	0.11	0.04	0.14
Eucalyptus leucoxylon	403	95.9	6.2	1.9	33.0	215	BL	15	7.2	1.13	1.12	0.55	2.03	0.79	0.12	0.03	0.07
Eucalyptus leucoxylon	557	127.2	7.6	2.5	16.0	636	WB	31	5.4	2.41	2.00	0.99	3.65	0.74	0.11	0.04	0.11
Eucalyptus leucoxylon	492	78.0	5.4	2.3	10.7	1088	BL	33	8.6	7.34	6.76	3.35	12.30	0.74	0.11	0.04	0.11
Eucalyptus leucoxylon ssp. leucoxylon	404	53.3	4.3	1.7	8.4	768	BL	36	7.6	9.85	8.88	4.40	16.16	0.77	0.11	0.03	0.08
Eucalyptus loxophleba ssp. lissophloia	318	40.1	3.7	1.5	8.0	2094	BL	36	4.8	3.06	3.81	1.89	6.93	0.48	0.10	0.06	0.36

	Site Detail				Field Survey									Proportion of Above-ground Dry Biomass			
Species	Rain [mm]	NCAT Model – Max. Dry matter [t/ha]	NCAT Forest Productivity Index	BiosEquil Model [t C/ha/yr]	Age	TPH	Stand Type [Block, WindBreak]	Observations[#]	Height [m]	Stem Volume MAI [m³/ha/yr]	Dry Biomass [t/ha/yr]	Carbon [t/ha/yr]	CO_2e [t/ha/yr]	Stemwood	Bark	Branches	Leaf
Eucalyptus megacornuta	460	60.5	4.6	1.9	15.0	735	WB	25	7.6	7.10	6.50	3.22	11.83	0.77	0.12	0.03	0.08
Eucalyptus occidentalis	358	53.4	4.3	1.5	9.4	1094	BL	36	6.7	2.46	2.25	1.12	4.10	0.65	0.10	0.05	0.20
Eucalyptus occidentalis	364	43.1	3.9	1.7	19.0	382	BL	24	10.8	1.99	1.84	0.91	3.35	0.76	0.11	0.03	0.10
Eucalyptus occidentalis	373	67.8	5.0	1.9	8.4	655	BL	36	6.0	1.59	1.39	0.69	2.53	0.65	0.10	0.05	0.20
Eucalyptus occidentalis	434	80.3	5.5	1.8	10.0	739	BL	36	14.3	16.37	15.46	7.67	28.14	0.80	0.12	0.03	0.06
Eucalyptus occidentalis	449	67.0	4.9	1.9	12.4	593	BL	36	16.8	9.59	8.69	4.31	15.82	0.79	0.12	0.03	0.07
Eucalyptus occidentalis	460	64.2	4.8	1.9	5.7	708	BL	34	9.8	13.54	11.84	5.87	21.56	0.76	0.11	0.03	0.09
Eucalyptus occidentalis	460	68.5	5.0	1.9	6.7	603	WB	30	10.2	8.04	7.45	3.69	13.55	0.75	0.11	0.04	0.10
Eucalyptus occidentalis	460	68.6	5.0	1.9	6.7	762	WB	32	8.2	5.57	4.93	2.45	8.97	0.72	0.11	0.04	0.14
Eucalyptus occidentalis	460	60.5	4.6	1.9	15.0	755	WB	27	9.2	7.13	6.46	3.20	11.75	0.77	0.12	0.03	0.08
Eucalyptus occidentalis	469	106.6	6.7	2.2	8.4	826	BL	36	9.1	4.71	4.33	2.15	7.88	0.72	0.11	0.04	0.13
Eucalyptus occidentalis	485	77.1	5.4	2.3	7.4	675	BL	36	9.4	5.66	5.26	2.61	9.57	0.73	0.11	0.04	0.12
Eucalyptus occidentalis	492	77.9	5.4	2.3	9.9	1198	BL	30	10.5	10.85	9.59	4.76	17.46	0.75	0.11	0.04	0.10
Eucalyptus occidentalis	497	67.8	5.0	2.1	8.4	617	BL	36	7.1	3.02	2.73	1.35	4.96	0.71	0.11	0.04	0.14
Eucalyptus saligna	492	76.6	5.3	2.3	6.8	880	BL	30	9.1	8.80	8.13	4.03	14.80	0.74	0.11	0.04	0.12
Eucalyptus salmonophoia	330	39.4	3.7	1.6	95.0	942	BL	36	18.7	2.37	1.92	0.95	3.50	0.79	0.12	0.03	0.06
Eucalyptus viminalis	460	64.8	4.8	1.9	5.7	526	BL	33	10.0	10.83	9.17	4.55	16.70	0.77	0.11	0.03	0.09
Eucalyptus viminalis ssp. cygnetensis	460	64.8	4.8	1.9	9.0	561	BL	36	12.9	13.04	12.59	6.24	22.91	0.79	0.12	0.03	0.06
Eucalyptus viminalis ssp. cygnetensis	492	79.0	5.4	2.0	9.9	855	BL	30	11.1	12.85	11.44	5.67	20.82	0.77	0.12	0.03	0.08

	Site Detail				Field Survey									Proportion of Above-ground Dry Biomass			
Species	Rain [mm]	NCAT Model – Max. Dry matter [t/ha]	NCAT Forest Productivity Index	BiosEquil Model [t C/ha/yr]	Age	TPH	Stand Type [Block, WindBreak]	Observations$^{\#}$	Height [m]	Stem Volume MAI [m^3/ha/yr]	Dry Biomass [t/ha/yr]	Carbon [t/ha/yr]	CO_2e [t/ha/yr]	Stemwood	Bark	Branches	Leaf
Mallees																	
Eucalyptus brachycalyx	335	57.2	4.5	1.6	17.9	410	BL	20	4.7	0.65	1.19	0.59	2.17	0.50	0.14	0.06	0.30
Eucalyptus cyanophylla	261	22.9	3.0	1.1	13.4	555	BL	30	3.6	1.02	1.50	0.74	2.73	0.48	0.13	0.06	0.33
Eucalyptus diversifolia	460	64.8	4.8	1.9	17.0	1115	BL	35	6.2	8.67	12.31	6.11	22.41	0.68	0.16	0.04	0.12
Eucalyptus dumosa	387	46.3	4.0	1.8	12.0	836	BL	31	3.8	0.90	1.61	0.80	2.93	0.42	0.12	0.06	0.40
Eucalyptus gracilis	261	22.9	3.0	1.1	14.3	554	BL	30	3.4	0.59	1.06	0.53	1.93	0.41	0.12	0.06	0.41
Eucalyptus incrassata	357	49.9	4.2	1.7	28.9	2767	WB	37	4.0	0.93	1.44	0.71	2.61	0.44	0.10	0.06	0.40
Eucalyptus incrassata	374	47.3	4.1	1.6	8.0	1120	BL	30	3.7	1.89	3.76	1.86	6.84	0.39	0.12	0.06	0.43
Eucalyptus incrassata	460	64.8	4.8	1.9	17.0	795	BL	18	4.2	1.44	2.31	1.15	4.21	0.52	0.14	0.06	0.29
Eucalyptus leptophylla	261	22.9	3.0	1.1	13.4	1133	BL	30	2.0	0.41	0.87	0.43	1.59	0.26	0.08	0.06	0.59
Eucalyptus leucoxylon	339	45.1	4.0	1.4	12.0	304	WB	20	3.6	1.03	1.51	0.75	2.76	0.59	0.14	0.05	0.21
Eucalyptus odorata	474	68.6	5.0	2.2	12.0	2081	BL	20	8.4	8.89	7.15	3.55	13.02	0.73	0.11	0.04	0.13
Eucalyptus oleosa	261	22.9	3.0	1.1	10.4	403	BL	30	3.2	0.35	0.69	0.34	1.26	0.35	0.11	0.06	0.48
Eucalyptus oleosa	335	57.2	4.5	1.6	17.9	406	BL	21	5.0	0.98	1.56	0.78	2.85	0.57	0.15	0.05	0.23
Eucalyptus oleosa	357	49.9	4.2	1.7	28.9	1736	BL	36	5.0	1.21	2.10	1.04	3.83	0.49	0.13	0.06	0.32
Eucalyptus oleosa	357	49.9	4.2	1.7	28.9	3325	WB	36	5.0	1.41	2.44	1.21	4.44	0.43	0.12	0.06	0.39
Eucalyptus oleosa	387	47.2	4.1	1.8	6.8	1585	BL	30	3.0	2.15	3.97	1.97	7.23	0.35	0.11	0.06	0.48
Eucalyptus polybractea	318	39.3	3.7	1.5	8.0	1874	BL	36	4.2	4.29	7.32	3.63	13.33	0.44	0.12	0.06	0.38
Eucalyptus porosa	339	45.1	4.0	1.4	12.0	577	WB	30	3.1	2.30	3.62	1.79	6.59	0.56	0.15	0.05	0.24
Eucalyptus porosa	387	47.2	4.1	1.8	6.7	1522	BL	33	3.9	5.23	9.71	4.82	17.67	0.48	0.13	0.06	0.33
Eucalyptus porosa	403	117.5	7.1	2.0	33.0	4299	BL	46	3.3	1.22	1.67	0.83	3.04	0.43	0.11	0.06	0.40
Eucalyptus socialis	261	22.9	3.0	1.1	14.4	1936	BL	30	3.8	3.11	5.30	2.63	9.65	0.47	0.13	0.06	0.34
Tree Eucalypts	435	71.6	5.1	1.9	16.8	824		32	9.6	6.59	5.79	2.87	10.55	0.74	0.11	0.04	0.11
Mallee Eucalypts	351	48.2	4.1	1.6	15.9	1397		30	4.2	2.32	3.48	1.73	6.34	0.48	0.12	0.06	0.34
Tree Non-Eucalypts	452	95.6	6.2	2.1	15.0	1064		29	5.9	3.67	3.80	1.89	6.92	0.60	0.13	0.11	0.16
Tree Form Only	437	74.2	5.2	1.9	16.6	850		31	9.2	6.27	5.58	2.77	10.15	0.72	0.11	0.04	0.12
All Plants	422	69.7	5.0	1.9	16.5	945		31	8.3	5.58	5.21	2.58	9.49	0.68	0.12	0.05	0.16

Discussion

Carbon Markets, Drivers and Policies

With the Australian Federal Government's announcement of a proposed carbon tax for July 2012 and the likely emergence of a national carbon trading scheme to follow that, Governments and communities around Australia are examining the opportunities presented by participating in the carbon markets. Rather than ignoring the potential impacts of climate change on the health and prosperity of rural landscapes and communities two broad approaches are being re-examined to assist in managing the affects of climate change while exploiting any opportunities it may present. Those two broad approaches being:

1. Mitigation - reducing carbon dioxide in the atmosphere by sequestering carbon dioxide in long-term stores (e.g. woody plant biomass in forests and revegetation) or reducing atmospheric emissions from fossil fuels by encouraging the development of renewable energy sources; and
2. Adaptation - developing agricultural uses, land management practices and industries that can maintain rural prosperity by modifying current production systems to suit changed climatic conditions.

A current example that encompasses both mitigation and adaptation possibilities is the Australian Federal Government's 'Carbon Farming Initiative' which is expected to commence on 1 July 2011. Clearly focused on the rural sector the Carbon Farming Initiative will credit certain activities that reduce greenhouse emissions or increase carbon storage. The aim is to facilitate the trade and sale of these credits within existing carbon markets where those activities can be verified under the National Carbon Offset Standard. (DCCEE 2010)

Under such initiatives agroforestry industries could remove significant amounts of atmospheric carbon dioxide through sequestration. The development of forestry for bioenergy purposes could further reduce reliance on non renewable fossil fuels. Due to land prices and economic considerations it is expected that many of these new activities will focus on the low to medium rainfall zones (300-650mm/year) on dryland agricultural landscapes that are predominantly used for annual cropping and grazing. Within the Southern Murray-Darling Basin study area the amount of cleared agricultural land potentially available for forestry and carbon crops equates to 1.76 million hectares or 73% of the total land area.

The economic viability and success of any carbon sequestration plantings is highly dependent on the primary productivity of the species chosen. The growth rate, lifespan and height of plants chosen for carbon sequestration crops influence their viability as compliant carbon crops for most carbon trading schemes. The Kyoto Protocol specifies a minimum area of only 0.2 hectares, tree crown cover of 20 per cent and a tree height of two metres to qualify for carbon accounting purposes (Department of Climate Change 2008). Many woodlots and environmental plantings in South Australia currently fit these criteria and most future plantings are expected to be designed as "Kyoto-compliant" to meet the needs of carbon trading schemes.

Results from recent studies in the Mid-North, Murray-Darling Basin (Hobbs *et al.* 2010) and Upper South East (Hobbs *et al.* 2006) regions suggest that monocultures of woodlot and other commercial species are often more productive than environmental plantings at the same density (trees per hectare) particularly in higher rainfall areas. Other productivity studies within lower to medium rainfall environments (350-650mm) have identified some highly productive species which are climatically suited to large sections of the lower Murray-Darling Basin, include Sugar gum (Table 5, *Eucalyptus cladocalyx*), WA Swamp yate (*E. occidentalis*), WA York gum (*E. loxophleba)*, Blue Mallee (*E. polybractea),* WA Swamp mallet (*E. spathulata*) and WA Blue mallet (*E. gardneri*) (Bennell *et al.* 2008, Kiddle *et al.* 1987, Boardman 1992, Fairlamb & Bulman 1994). If plantation productivity and carbon prices are the primary driver for investment and monoculture woodlots are more productive than mixed species environmental plantings then economic forces will tend to push carbon plantings in that direction unless government subsidies bridge the economic gap.

Carbon Accounting, Models and Assessments

In Australia there are two key approaches used to account for the carbon being stored in agroforestry:

1. Models of plantation productivity and carbon balance
2. Assessments or inventory of carbon stores in plantations

Models provide the advantage of forward estimating carbon sequestration rates under a range of scenarios. Models generally provide rapid and low-cost estimates of carbon dynamics and stores, but their reliability for carbon accounting purposes are limited. The disadvantage of this approach is that models are highly dependent on the validity of the analytical approach taken and the quality of data used for calibrations. On-ground assessments, or inventory, typically provide more accurate estimates of carbon stores but usually incur higher costs from sites inspections, measurements and sampling.

As an example the FullCAM model (and sub-models), contained within the National Carbon Accounting Toolbox (NCAT), as been in the past been predominantly populated by parameters drawn from studies of higher rainfall commercial forestry plantations. Prior research on carbon sequestration rates from revegetation in dryland agricultural zones of South Australia (Hobbs *et al.* 2010) has clearly demonstrated that, at that time, NCAT severely under-predicted carbon sequestration rates (27% of observed above-ground carbon sequestration) in medium to lower rainfall regions.

On-site assessments or inventories of carbon sequestration in revegetation can be attained using sampling or allometric estimation techniques or a combination of both. Destructively sampling a number of representative plants within a larger population can provide an estimate of the carbon stored within a site. This approach requires a statistically valid number of samples (~30 or more) to provide accurate estimates, is labour intensive, typically high cost, and removes living plants (and carbon stores) from the plantation. Allometric estimation is a commonly used technique to non-destructively assay plantation productivity and carbon stores from a limited number of measurements at a site. This provides significant advantages in cost effectiveness over destructive sampling techniques and permits repeated measurement over time on the same site without loss of individual plants.

This current study has improved on the accuracy of allometric models developed in prior destructive sampling and measurements (Hobbs *et al.* 2010) to provide reliable estimates of biomass production and carbon sequestration rates in the Murray-Darling Basin region of South Australia. It had been found that prior models described by Hobbs *et al.* (2010) for smaller trees, mallees and shrubs were not appropriate (i.e. underestimate biomass) for very large trees, and the destructive sampling and allometric model development in this study worked toward overcoming that limitation.

Productivity and carbon sequestration in woodlots in low to medium rainfall zones of the Murray-Darling Basin (Hobbs *et al.* 2010) regions of South Australia is highly dependant on planting densities (trees per hectare) and rainfall. Generally, our surveys suggest the expected average carbon sequestration rate of mature woodlots is trending within in the range of 6.3 (Mallees) – 10.5 (Tree Eucalypts) CO_2-e t/ha/year. The maximum observed sequestration rate in this study (50.8 CO_2-e t/ha/year) was obtained from a 10 year old River Red Gum woodlot receiving ~460mm annual rainfall however this was an exceptional site with easy access to ground water. The next best observed sequestration rate (34.0 CO_2-e t/ha/year) was obtained from a 14 year old Tasmanian Blue Gum woodlot receiving ~457mm annual rainfall.

It is crucial to improve estimates of carbon sequestration in the low to medium rainfall regions of South Australia so that we can more accurately compare economic returns (and risks) of potential carbon crops with those from existing annual crops/pastures. With better information we can more readily identify the most profitable and sustainable land use options within farming enterprises and regions.

Conclusions and Recommendations

Current policies, natural resource management drivers and economic evaluations indicate there are substantial opportunities for carbon sequestration in the dryland agricultural regions of South Australia from dedicated carbon crops and extractive agroforestry/biomass industries. Recent studies (e.g. Hobbs *et al.* 2010, Hobbs 2009, Hobbs *et al.* 2009b, Polglase *et al.* 2008, Crossman *et al.* 2010, Lyle *et al.* 2009) show that the scale and profitability of carbon sequestration crops is highly dependant on market prices for carbon sequestration and opportunity costs from existing landuses. In recent years, international carbon prices have been very dynamic. Policy makers and investors should be mindful of the potential instability of carbon prices in the future and the potential investment risks associated with carbon markets. Significant pressure on the viability of existing annual crops and pastures could result from high carbon market prices in the future. If uncontrolled by policy and landuse planning, carbon crop reforestation driven by market prices alone could significantly reduce agriculture production in food and fibre industries, and reduce fresh water resources for consumptive uses in some regions.

Targeted placement of extractive agroforestry and insitu carbon crops to maximise profitability and benefits to whole farm enterprises and regions should be the goal of any investment in farm based forestry. Broad-scale evaluations of natural resource management drivers, policies, annual and woody crop productivities and farm economics provide useful tools in determining regions with greatest potential for investment in carbon crops.

To promote and develop new carbon markets and carbon sequestration activities in South Australia it is recommended that potential investors, planners and government agencies:

1. Clearly define the targeted purpose of agroforestry activities (e.g. carbon vs. biodiversity) so the correct species, scale of investment, planting designs and locations are adopted. Evaluate the influence on manipulations of plantation designs and spatial/regional priorities on financial and other intended benefits.
2. Construct a business plan for any investment in agroforestry, incorporating realistic information on expected capital, establishment and maintenance costs, carbon sequestration production rates, carbon markets, management/financial/ environmental risks, property management plans and zoning/policy restrictions.
3. Exercise caution in relying on forecasts of potential carbon sequestration from existing models, especially in low to medium rainfall regions. Current information clearly demonstrates a high degree of variation in carbon sequestration rates from plantation activities in lower rainfall regions resulting from a range of poorly studied species, management and environmental factors. Always utilise reliable

plantation assessment techniques to accurately determine quantities of carbon sequestered for carbon accounting purposes.

4. Thoroughly evaluate local site conditions, seek expert advice and select most appropriate species to maximise production rates, meet other targeted purposes, and minimise risks.
5. Support investments in further research to more accurately assess and predict carbon sequestration rates in mature revegetation plantations across the state, including a greater diversity of species, plantation types and locations. Support spatial/regional analyses of natural resource management priorities to guide future investments in revegetation and carbon sequestration within agricultural regions of the state

Glossary

ArcGIS — a geographic information system developed by ESRI that integrates hardware, software, and data for capturing, managing, analysing, and displaying all forms of spatial information.

BiosEquil (BE) — a steady state biosphere model used for the assessment of carbon, nitrogen, phosphorus and water in Australian landscapes (Raupach *et al.* 2001).

CABALA — a growth model for predicting forest growth (CArbon BALAnce; Battaglia *et al.* 2004).

CO_2e — carbon dioxide equivalent.

CRC — Cooperative Research Centre.

CSIRO — Commonwealth Scientific and Industrial Research Organisation (Australian Federal Government).

DAFF — Department of Agriculture, Fisheries and Forestry. (Australian Federal Government)

DCC — was Department of Climate Change, now Department of Climate Change and Energy Efficiency. (Australian Federal Government)

DCCEE — Department of Climate Change and Energy Efficiency. (Australian Federal Government)

DEH — Department for Environment and Heritage (Government of South Australia).

DENR — Department of Environment and Natural Resources (Government of South Australia).

DWLBC — Department of Water, Land and Biodiversity Conservation (Government of South Australia).

EAMU — Ecological Analysis and Monitoring Unit of the Department of Environment and Natural Resources (Government of South Australia).

FICCRF — Forest Industries Climate Change Research Fund of the Department of Agriculture, Fisheries and Forestry. (Australian Federal Government)

FPI — Forest Productivity Index. An index of climate and soil parameters that influence forest productivity. (Landsberg & Kesteven 2001).

FullCAM — fully integrated Carbon Accounting Model for estimating and predicting all biomass, litter and soil carbon pools in forest and agricultural systems (Department of Climate Change 2009).

FFICRC — Future Farm Industries Cooperative Research Centre.

GIS — Geographic Information System; computer software linking geographic data (for example land parcels) to textual data (soil type, land value, ownership). It allows for a range of features, from simple map production to complex data analysis.

IBRA — Interim Biogeographic Regions of Australia; regions containing similar landscapes, climates and native ecosystems (Department of the Environment, Water, Heritage and the Arts 2009).

Indigenous species — a species that occurs naturally in a region.

MAI — mean annual increment; typically used to describe growth of stemwood volumes in forestry.

Model — a conceptual or mathematical means of understanding elements of the real world that allows for predictions of outcomes given certain conditions.

NCAT — National Carbon Accounting Toolbox. A Model that estimate changes in emissions resulting from changed land management actions, such as forest establishment and harvesting, soil cultivation, fire management and fertiliser application (Richards *et al.* 2005).

NRM — Natural Resources Management; all activities that involve the use or development of natural resources and/or that impact on the state and condition of natural resources, whether positively or negatively.

PIRSA — Primary Industries and Resources South Australia (Government of South Australia).

RIRDC — Rural Industries Research and Development Corporation (Australian Federal Government).

tph — trees per hectare; average number of trees, mallees and/or shrubs planted per unit area.

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