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Testing carbon farming opportunities for salinity management

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TESTING CARBON FARMING OPPORTUNITIES FOR SALINITY MANAGEMENT

A Scientific Report on the

'Pilot to Test Carbon Driven Solutions to Salinity Project'

Supporting people to support the natural environment

NACC
Managing Natural Resources

THE GOVERNMENT OF WESTERN AUSTRALIA

Department of Agriculture and Food
GOVERNMENT OF WESTERN AUSTRALIA

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GLOSSARY AND CODES AND ABBREVIATIONS

Glossary	
Allometric equation	A mathematical equation that relates the growth of one part of an organism to another part or the whole organism, e.g. height to weight; stem diameter of a tree to total tree biomass.
Biomass Sample Trees (BSTs)	Trees selected for destructive sampling to develop allometric equations.
Carbon Farming Initiative	An Australian Government scheme that allows farmers and land managers to earn carbon credits by storing carbon or reducing greenhouse gas emissions on the land. These credits can then be sold to people and businesses wishing to offset their emissions.
Carbon sequestration	The removal of carbon dioxide (CO_2) from the atmosphere and storage of the carbon (C), e.g. in plants.
Carbon stocks	The amount of carbon in something, e.g. the amount of carbon in a tree may be measured in kg, the amount of carbon in a planting may be measured in t/ha.
Diameter equivalent	For multi-stem trees, the diameter equivalent at the measurement height is calculated as the diameter of a circle with area equal to the sum of cross-section areas of all stems at that height.
Emissions Reduction Fund	A proposed Australian Government scheme that will allow applicants to bid to provide offsets (emission reductions) in an auction process.
Mallee	Typically short (2 to 5 m tall at maturity) woody plant, with many stems originating from a lignotuber.
Sample plots	A small area of land in which measurements are made on trees.
Shrub	Typically very short (less than 2 m tall) woody plants. May have one, a few, or many stems.
Tree	A tall (more than 2 m height at maturity) woody plant. In this study both tree form and mallee form were classed as trees.
Tree form	Typically tall (more than 5 m height at maturity) woody plant with one or few stems.

Codes and Abbreviations	
BST	Biomass Sample Tree
C	Centigrade. (°C indicates degrees centigrade.)
CEA	Carbon Estimation Area
CFI	Carbon Farming Initiative
cm	Centimetre
CO_2-e	Carbon dioxide equivalent
CVI	Crown Volume Index
DAFWA	Department of Agriculture and Food, Western Australia
DAH	Diameter at Ankle Height
DAHe	Diameter at Ankle Height equivalent
DBH	Diameter at Breast Height
DBHe	Diameter at Breast Height equivalent
DKH	Diameter at Knee Height
DKHe	Diameter at Knee Height equivalent
DPAW	Department of Parks and Wildlife
ECa	Apparent soil electrical conductivity
ECe	Electrical conductivity of a saturated soil extract
EM	Electromagnetic Induction
ERF	Emissions Reduction Fund
FPC	Forest Products Commission
FullCAM	Full Carbon Accounting Model
G	Parameter in the FullCAM TYF that defines the age of peak growth rate.
g	gram
ha	Hectare
Kg	Kilogram
Lat.	Latitude
Long.	Longitude
m	Metre
MCC	Moore Catchment Council
MSEP	Mixed species environmental planting
MSEPT	Mixed species environmental planting temperate
mm	Millimetre
mS/m	Millie Siemens per metre
NA	Not available
NACC	Northern Agricultural Catchments Council
NAR	Northern Agricultural Region
NLR	NonLinear Regression
PSP	Permanent Sample Plot
R^2	Coefficient of determination
R:S	Root to shoot ratio
TC	Tree Carbon stock
TYF	Tree Yield Formula
TSP	Temporary Sample Plot
t	Tonne
YYCMG	Yarra Yarra Catchment Management Group

SUMMARY

An emerging prospect for farm revenue from revegetation of saline and other lands that are marginal or non-productive for agriculture is the sale of carbon credits. Australian Government schemes for carbon credits include the Carbon Farming Initiative (CFI) and the proposed Emissions Reduction Fund (ERF).

Therefore, this study aimed to assess the potential for woody vegetation (trees and shrubs) established on and around salt-affected lands in the Northern Agricultural Region (NAR) to remove carbon dioxide from the atmosphere and store (sequester) the carbon in new growth.

Revegetation plantings on six farms were selected for study after the landowners expressed an interest in participating in the study. Criteria for selection included: a minimum of 5 ha planted on and around salt-affected land; a variety of native tree and shrub species planted; and that the planting be at least 10 years old. Across the six farms a total of nine sites were selected for study.

Objectives of the study were:

1. Obtain estimates of the average amount of carbon accumulated (carbon stocks) in each of the nine sites, and each of the 50 native species that were recorded across the sites.
2. Relate the carbon stock estimates for sites and species to salinity levels.

To those ends, a carbon inventory and salinity measurements were carried out on the study sites in 2013. Some key steps were as follows.

1. A network of 237 sample plots was established across the sites.
2. To indicate salinity level at each sample plot, apparent electrical conductivity (ECa) was measured with the GEONICS EM38 instrument.
3. All trees and shrubs in the sample plots were measured (total 5,170 trees and shrubs). For trees, stem diameter(s) were measured and, for shrubs, crown width and height was measured to calculate Crown Volume Index (CVI).
4. A sample of 313 trees and shrubs were also measured, then harvested (destructive sampling) to measure the biomass (and, therefore, carbon stock) of those Biomass Sample Trees (BSTs).
5. From the destructive sampling data, biomass prediction equations (allometric equations) were calculated for each species to estimate carbon stock from the non-destructive measurements (stem diameter or CVI).
6. These carbon inventory data were processed to calculate estimates of the carbon stock (kg) of each tree/shrub in the sample plots, then carbon stocks (t/ha) for each sample plot and the average and total carbon stocks for each site.

The estimates of carbon stocks in species and sites were projected forwards or backwards from the measurement ages (11 – 22 years) to age 15 years to 'age standardise' the results and facilitate comparisons between species and sites. This was done using the national carbon accounting model, FullCAM.

Some key results and conclusions were as follows.

- *Effect of salinity on carbon stocks*

Across all sites, carbon stocks in the revegetation decreased with increasing salinity beyond ECa 200 mS/m. There was no statistically significant difference between salinity categories of ECa < 100 mS/m and ECa 100 – 199 mS/m. For these categories the average Tree Carbon stocks at age 15 years (TC_{15}) was 42 t CO_2-e/ha. However, TC_{15} declined to 29 t CO_2-e/ha (68%) for sample plots with ECa 200 – 299 mS/m, and to 12 t CO_2-e/ha (29%) for sample plots with ECa > 300 mS/m.

These levels of carbon stocks indicate modest carbon credit returns from plantings with a similar mix of species. For example, if carbon credits are worth $20 per t CO_2-e, then, after 15 years, the returns from planting on non-saline (ECa < 200 mS/m) land would be $8,400 per ha. These returns could be increased by planting the more productive species identified in this study

Planting on saline lands (e.g. ECa > 200 mS/m) would provide lower returns from carbon credits. However, if degraded land with little or no commercial value for agriculture, then carbon credits may provide some financial returns from the land.

- *Species*

There were substantial differences between species in the growth (carbon sequestration) rates. Therefore, if tree planting is done for a carbon purpose, large gains can be achieved by selecting the more productive species.

Tree form *Eucalyptus* species such as *E. sargentii* and *E. spathulata*, had clearly superior carbon sequestration rates. These species accumulated at least double the carbon stocks compared to the best performing mallee or shrub species in any of the salinity categories.

However, other species may be of more value for other benefits besides carbon revenue. Thus, mallee species such as *E. kochii* subsp *borealis* and *E. loxophleba* subsp *lissophloia* were originally selected for leaf oil production. Tree form species can provide fence posts and other farm timbers, and *Melaleuca* species can provide material for brushwood fences in residential areas. All local native tree and shrub species will provide biodiversity value with some, such as *Melaleuca* shrub species that are often prolific producers of flowers and nectar, having particular biodiversity value. The saltbush (*Atriplex*) species provide fodder for sheep and other livestock, and other salt-tolerant species, such as *Casuarina obesa* may also have fodder value. All revegetation will provide multiple other benefits such as reducing soil erosion and the spread of secondary salinity and the aesthetic value of putting a green belt around ugly salt scalds.

- *FullCAM*

Of the two versions of FullCAM used to predict carbon stocks at the nine study sites at the ages they were measured, FullCAM 3.40 under-predicted carbon stocks, except for two sites. They were the Eva site that had the highest salinity level (average ECa 245 mS/m) and the Butcher saltbush site that had a moderate salinity level (average ECa 153 mS/m) but the planting had few trees and mostly saltbush (*Atriplex* species) that were grazed annually.

The more recent version of the model (FullCAM 3.55) gave substantially higher predictions of carbon stocks (average 280% higher). Hence, FullCAM 3.55 over-predicted carbon stocks in all but one site. At the Eva and Butcher saltbush sites the over-prediction exceeded 500%.

- *Methods*

The strategy of studying existing revegetation projects established by landowners in the NAR was an effective way of evaluating carbon farming opportunities for salinity management. An alternative would have been to establish new plantings, e.g. demonstration sites and/or field trials. However, apart from the cost of establishing new plantings, a considerable disadvantage of such an approach would be that it is necessary to wait for around 10 years, or more, before meaningful results could be obtained.

Of course longer-term monitoring is desirable. To this end all sample plots were permanently marked and every second sample plot on the study site was left undisturbed as a Permanent Sample Plot (PSP), available for re-measurement. One of the recommendations for future study, if funding can be obtained, is to re-measure the PSPs around three to five years after the first measurements. This will indicate which species are still healthy and growing vigorously, and which species are declining, e.g. growth rates have slowed or high mortality rates.

INTRODUCTION

Secondary salinity caused by rising saline water tables is a major problem in the Northern Agricultural Region (NAR) of Western Australia and elsewhere throughout the Wheatbelt of Western Australia.

Options for reducing or reversing the spread of salinity include the establishment of trees and shrubs such as salt tolerant *Casuarina*, *Melaleuca*, and *Eucalyptus* species on or around saline lands. Such revegetation can provide additional multiple benefits.

Community benefits include the protection and enhancement of biodiversity values and contribution to global efforts to mitigate climate change. In the NAR there may be considerable scope for corridor revegetation projects, e.g. planting along salinized drainage lines.

Direct on-farm benefits, besides managing the spread of salinity, include reducing soil erosion. For grazing enterprises, benefits may include providing shade and shelter for livestock, and fodder production if salt tolerant fodder shrubs, such as saltbush (*Atriplex*) species, are planted. Depending on the species planted, farm timbers, such as posts and rails may be obtained. For commercial harvest a prospective species may be the Western Australian native sandalwood (*Santalum spicatum*). Suitable host species for sandalwood include a wide range of other native species. Sandalwood may be planted around saline areas and on other degraded or non-productive soils such as acid wodjil soils. There is also interest in commercial harvest of multiple products from mallee eucalypts (*Eucalyptus* species), including eucalypt oils and bioenergy products, but this is dependent on markets being developed.

However, an emerging prospect for farm revenue from revegetation of saline and other lands that are non-productive for agriculture is the sale of carbon credits. Australian Government schemes for carbon credits include the Carbon Farming Initiative (CFI) and the proposed Emissions Reduction Fund (ERF).

Hence, this study aimed to assess the potential for carbon farming to be an economic driver for revegetation to provide multiple benefits, including managing salinity on farms. In particular the aim was to investigate the potential for trees and shrubs established on and around saline lands in the NAR to remove carbon dioxide from the atmosphere and store (sequester) the carbon in new growth.

On saline lands the growth rates and, therefore carbon sequestration rates, may be slow. However, if the land has no economic value for cropping, then revegetation and sale of carbon credits (carbon farming) may be economically worthwhile.

Of particular interest in this study was how carbon sequestration rates vary according to the species planted and the severity of soil salinity. The knowledge gained and information products developed will aid landholders, government and industry to make informed decisions on carbon farming on and around saline lands.

METHODS

SITE SELECTION

Six farms where cleared agricultural land had been planted with woody vegetation were selected for study. Criteria for selection were:

1. Located in the Northern Agricultural Region of Western Australia.
2. Valley floor or lower slope planting;
3. Affected by salinity;
4. A variety of native species planted, preferably including tree and shrub species;
5. Minimum 5 ha planted; and
6. Minimum 10 years since planting.

Potential sites were identified through a call for expressions-of-interest from farmers and through referral from NACC and DAFWA staff. All nominated sites were inspected, resulting in the final selection of nine sites on six farms (Table 1, Figures 1, 2). Long term average annual rainfall at all sites was around 300 mm.

Table 1. Sites selected for study.

Landowner /farm	Site	Year Planted	Age when measured (years)	Description
Andrew	Andrew	1996	17	Perimeter planted around a saline flat. Main species were mallee eucalypts (*Eucalyptus*) with Melaleuca (*Melaleuca*) shrubs on more saline land.
Butcher	Butcher saltbush	2002	11	Mainly saltbush (*Atriplex)* fodder shrubs with scattered *Eucalyptus* on a saline flat.
Butcher	Butcher waterway	1996	17	Mixture of trees (*Eucalyptus*) and shrubs (mainly *Melaleuca* and *Atriplex* species) planted along a waterway.
Eva	Eva	2000	13	Salt tolerant shrubs and trees (mainly *Melaleuca*, *Atriplex*, and *Eucalyptus* species and *Casuarina obesa*) planted as a wildlife corridor along a saline valley floor with tree species (mainly *Eucalyptus*) planted on the adjoining lower slopes.
Falconer	Falconer	2002	11	A variety of shrubs (mostly *Melaleuca* species) planted on three waterlogged and salt-affected flats with trees (mainly *Eucalyptus*) and shrubs (mainly *Melaleuca*) on the adjoining lower slopes.
McFarlane	McFarlane E	1990	23	The east paddock had 3-5 row belts with salt tolerant *Eucalyptus* trees planted on a waterlogging and salt-affected flat. Approximately 40 m cropping alleys between the belts
McFarlane	McFarlane W	1995	18	The west paddock had 6-9 row belts (mostly 6 rows) with salt tolerant *Eucalyptus* trees and some salt tolerant shrubs (mostly *Melaleuca* and *Acacia* species) planted on waterlogged and salt affected flats and gentle slopes. Approximately 150 m cropping alleys between the belts.
McGlew	McGlew mallee	1998	15	2-4 row belts of mallees, either *E. loxophleba* subsp *lissophloia* or *E. kochii* subsp *borealis*. Narrow (approximately 10 m wide) unplanted alleys between the belts.
McGlew	McGlew Melaleuca	1994	19	Small block planting alongside a saline flat planted with salt tolerant trees and shrubs (*Eucalyptus* and *Melaleuca* species and *Casuarina obesa*).

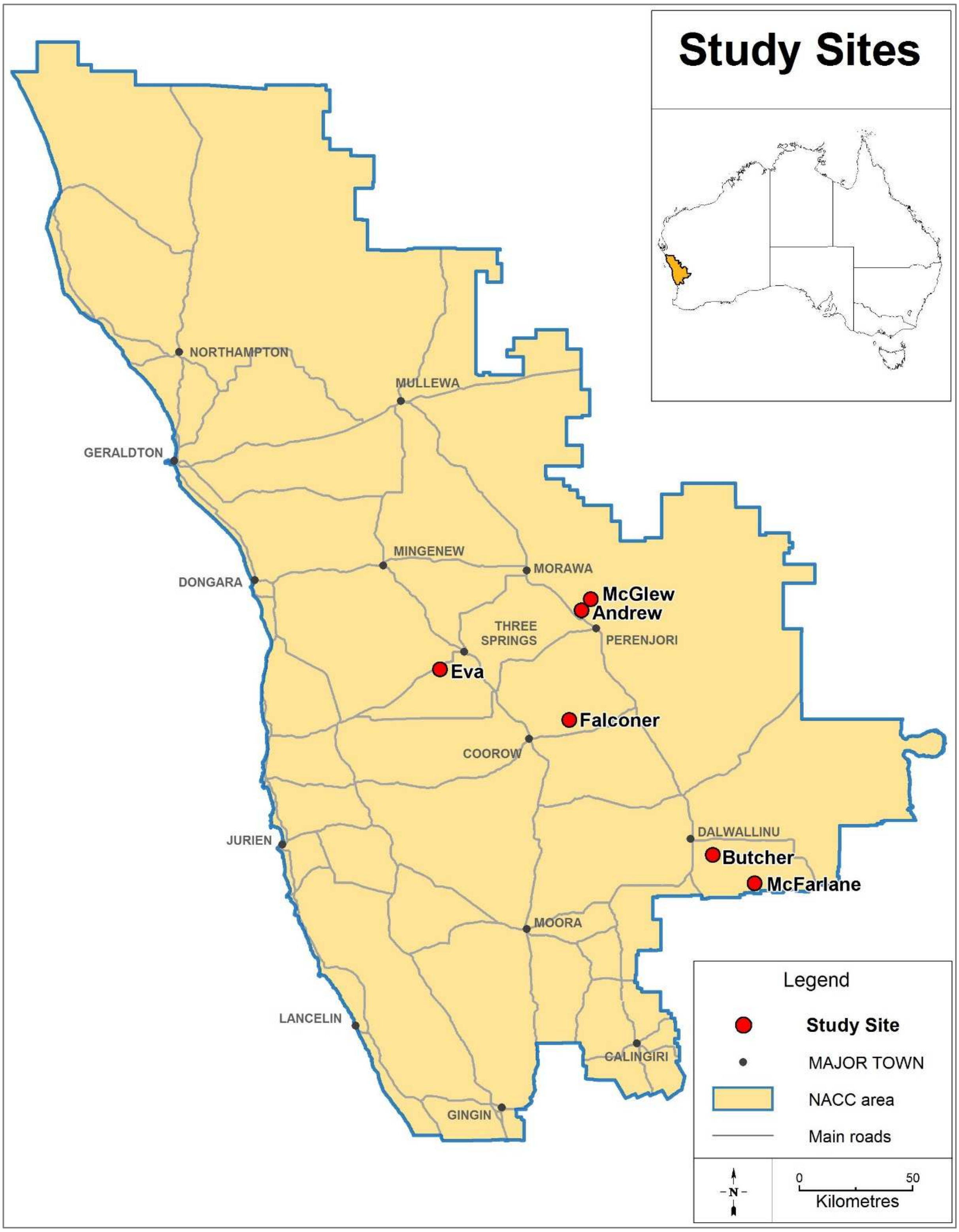


Figure 1. Location of the six farms in the Northern Agricultural Region of Western Australia. Road centre line dataset Copyright © Western Australian Land Information Authority, trading as Landgate (2014).


Figure 2a. ‘Andrew’ site


Figure 2b. ‘Butcher saltbush’ site


Figure 2c. ‘Butcher waterway’ site


Figure 2d. ‘Eva’ site


Figure 2e. ‘Falconer’ site


Figure 2f. ‘McFarlane E’ site


Figure 2g. ‘McFarlane W’ site


Figure 2h. ‘McGlew mallee’ site


Figure 2i. ‘McGlew Melaleuca’ site

Figure 2. The study sites

CARBON INVENTORY

A carbon inventory of all sites was carried out in April to June, 2013. Generally the methods followed the Carbon Farming Initiative (CFI) 'Farm Forestry' methodology (Department of the Environment, 2014a, c). Key steps in the process were:

1. Establish a network of 'sample plots' throughout all sites.
2. Measure stem diameters or crown dimensions of each tree or shrub in the sample plots.
3. Harvest a sample of the trees and shrubs to determine the amount of biomass and, therefore, carbon in each of those Biomass Sample Trees (BSTs).
4. Calculate regression equations for each species that relate the 'carbon stock' in a tree or shrub to the easily measured stem diameter or crown dimensions.
5. Process the inventory measurements to calculate estimates of the carbon stock (kg) in each tree or shrub in the sample plots, then carbon stocks (t/ha) for each sample plot and the average and total carbon stocks for each site.

These steps are described in more detail in the following sections.

Sample plot location

The sample plots on a farm planting were located at the grid intersections of a randomly placed and oriented square grid. This is known as 'systematic sampling with a random start' (Schreuder et al., 1993, pages 53-56).

Figure 3. Sample plot location at the Eva site. Aerial photography Copyright © Western Australian Land Information Authority, trading as Landgate (2014).

For example, Figure 3 indicates the sample plot network at the Eva site. In that case the grid size (selected to achieve 30 – 40 sample plots) was a square 1.35 ha (116 m x 116 m) grid. The location of one plot (the anchor point) was determined from random Easting and Northing coordinates from the range for the site, i.e. the 'random start'. The randomly selected orientation for the grid was 11 degrees from true north.

The Excel spreadsheet used for the sample plot location is suitable for application to other sites and is available from NACC (contact Sarah Jeffery, Sarah.Jeffery@nacc.com.au) or FarmWoods (contact Peter Ritson, peter@farmwoods.com.au).

For the belt plantings at the McFarlane East and West sites 'systematic sampling with a random start' was also used but this involved sampling at regular intervals along the length of the belts (Figure 4). From the southern end of the far eastern belt, a path running up and down the belts was determined. Then, from a random start along the length of the first belt, plots were located every 1500 m of planting line. For example, where the plots were four rows wide the plots were located every 1500/4 = 375 m of belt, or where the plots were six rows wide the plots were located every 1500/6 = 250 m of belt. The first plot was located at a randomly selected distance along the first 1500 m of planting line.

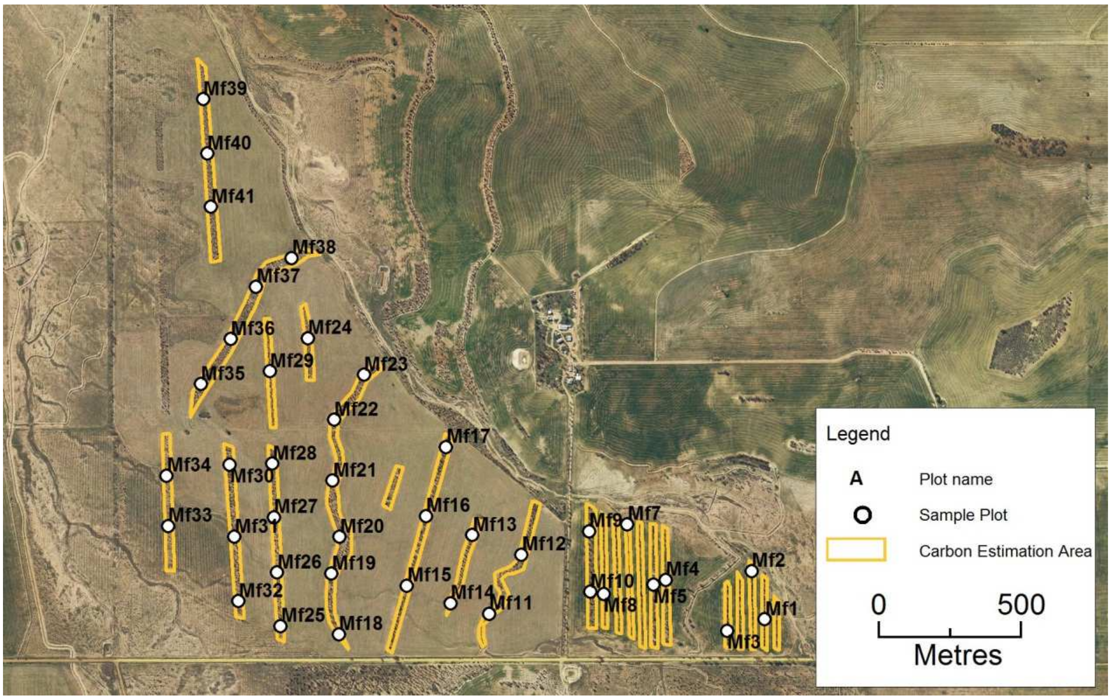


Figure 4. Sample plot location at the McFarlane site. Aerial photography Copyright © Western Australian Land Information Authority, trading as Landgate (2014).

The target was to establish at least 30 sample plots on each farm planting and the actual number varied from 30 (Andrew) to 46 (Falconer).

Sample plots

Circular sample plots (Figure 5) were established in block plantings and in the McGlew mallee belt plantings. As the McGlew mallee belt plantings had narrow unplanted alleys between the belts the circular plots covered both belts and pasture alleys at that site.

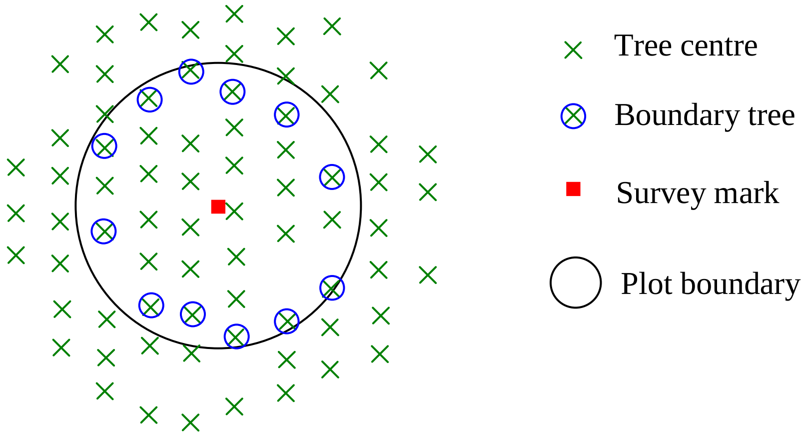


Figure 5. Example of a circular plot in a block planting. Boundary trees (at ends of rows in the plot) were marked with flagging tape to indicate which trees were in the plot. The survey marks were retained as permanent markers for the plot centres.

Belt plots (Figure 6) were established on the McFarlane belt plantings. Plot length was calculated so that the area covered by each belt plot was 0.04 ha (400 m^2).

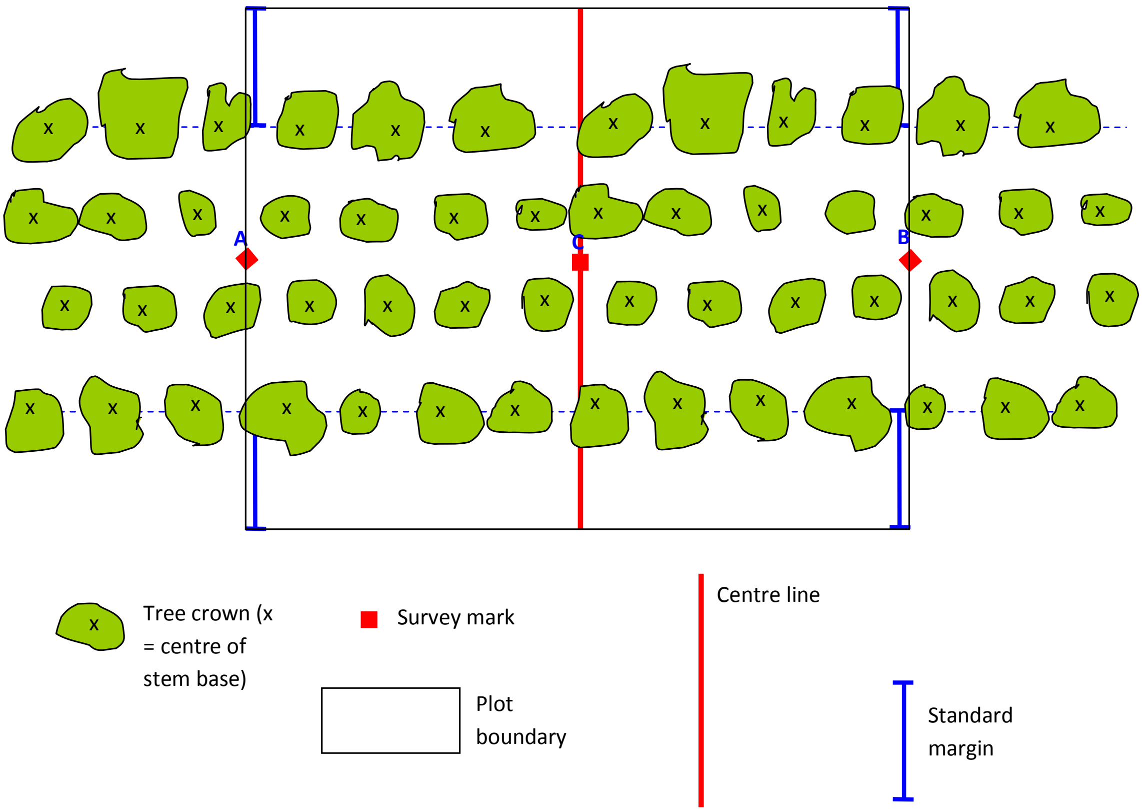


Figure 6. Example of a belt plot in a 4-row belt planting. Distance AC = Distance BC = half plot length. The standard margin distance was 2 m. Plot length (AB) was calculated to give the required plot area.

Table 2 has some details of all sample plots. Plot areas were determined for each planting so that there were at least 20 planting positions in each plot, i.e. at least 20 'trees' if 100% survival.

Table 2. Sample plot designs

Site	Plot type	Plot area (ha)	Comments
Andrew	Circular	0.03	
Butcher Saltbush	Circular	0.02, 0.04	Nested plots, inner (0.02 ha) and outer (0.04 ha).
Butcher Waterway	Circular	0.04	
Eva	Circular	0.03	
Falconer	Circular	0.02	
McFarlane E Paddock	Belt	0.04	
McFarlane W Paddock	Belt	0.04	
McGlew Mallee	Circular	0.04, 0.06	Plot areas were 0.04 ha in *E. kochii* belts and 0.06 ha in *E. loxophleba* belts. All plots included belts and pasture alleys.
McGlew Melaleuca	Circular	0.03	

Nested circular plots were established at the Butcher Saltbush site as the site had a high density of saltbush (*Atriplex* species) shrubs (planted and regeneration from seed) and a low density of tree form Eucalypts. The saltbushes were measured in the inner 0.02 ha plots while the Eucalypts were measured in the 0.04 ha plots.

Some plots were edge plots, i.e. the centre point for the plot was in the planted area (including the 2 m standard margin) but some of the plot was outside. Usually for edge plots there was only one straight edge. In these cases the mirror (mirage) method was applied. The mirage method was first proposed by a German (Schmid-Haas) in 1969. For English language descriptions and discussions of the method see Loetsch *et al*. (1973), Beers (1977), Gregoire (1982), AGO (2002), or Mason (2005).

However, two of the edge plots (both in belts) were corner plots, i.e. at least two straight edges in the plot. In those cases the area weighted method was applied as the mirage method was not practical to apply. If there is more than one edge in a sample plot, the area weighting method (also known as the direct weighting method), although not bias free, is the least biased of alternative methods (Beers, 1977; Loetsch et al., 1973).

Tree measurements

As discussed below, stem diameter was measured on trees (tree form and mallee form) and Crown Volume Index (CVI) measured on shrubs. The objective was to establish a simple measurement for each species that could be used to indicate the biomass (carbon stock) of a tree or shrub. See Carbon Stocks, pages 32-37 for more descriptions of the allometrics methods.

<u>Stem diameter measurements</u>

See Appendix 1 for the detailed protocol for stem diameter measurements.

Stem diameters were measured at one of three heights (Table 3, Figure 7). Generally, stems were measured at the greatest height possible where there was at least one stem with a diameter greater or equal to 10 mm.

Table 3. Stem diameter measurement heights.

Measurement	Measurement Height
Diameter at Breast Height (DBH)	1.3 m
Diameter at Knee Height (DKH)	0.5 m
Diameter at Ankle Height (DAH)	0.1 m

Figure 7. Stem diameter measurement with a diameter tape.

On tree form species live stems only at the measurement height were measured.

On mallees the diameters of all live stems and branches at the measurement height were measured. This was because it is often difficult to distinguish between stem and branches in mallees. The following species were defined to be mallees: *E. comitae-valis*, *E. horistes*, *E. kochii*, *E. loxophleba* and *E. subangusta*. All other tree species (see list in Table 4) were measured as tree form species. Note that the *E. loxophleba* planted on the study sites were *E. loxophleba* subsp *lissophloia*.   These were classed as mallees but, on the study sites, usually had only two or three stems, i.e. not the many stems typical of the mallee form.

Where there were multiple stems (or multiple stems and branches on mallees) to be measured all stem diameters were measured and a diameter equivalent calculated as the diameter of a circle of area equal to the sum of cross-section areas of all stems and branches measured at that height

$$D_e = \sqrt{\frac{4\sum_{i=1}^{n} A_i}{\pi}}$$

i.e., diameter equivalent can be conveniently calculated as

$$D_e = \sqrt{\sum_{i=1}^{n} D_i^2} \qquad \text{Equation 1}$$

where

D_e = diameter equivalent at the measurement height

A_i = cross sectional area of the i^{th} stem (i^{th} stem or branch if a mallee) at the measurement height

D_i = diameter of the i^{th} stem (i^{th} stem or branch if a mallee) at the measurement height

π = pi

Crown volume index measurements

It was not practical to measure stem diameters on shrub species (Table 4) so Crown Volume Index (CVI) (Ritson and Pettit, 1992) was measured instead.

$$CVI = (h - h_c)w_1w_2 \qquad \text{Equation 2}$$

where:

h = tree height,

h_c = height to crown base,

$(h - h_c)$ = crown depth,

w_1, w_2 = crown width measured along and across the rows (planting lines).

Tree height (h) was measured as the vertical height of the highest live leaf, or other living tissue, above the stem base (Figure 8).

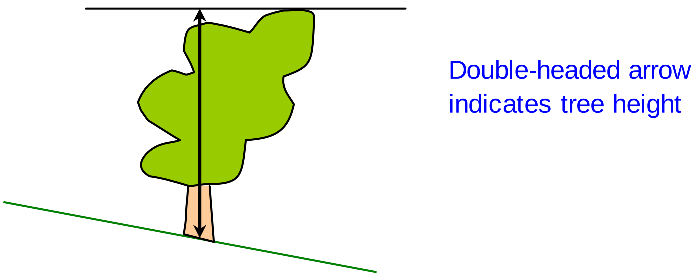
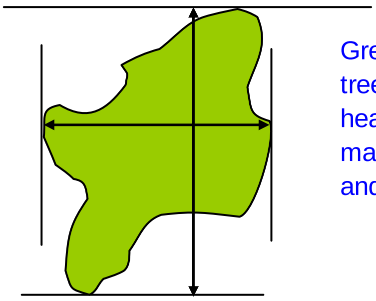


Figure 8. Measurement of tree height.

Height to crown base (h_c) was measured as the vertical height above the stem base of the lowest green leaf.

Crown width is the maximum extent of the crown measured along (w_1) and across (w_2) the rows. (Figures 9, 10).



Green shape represents a tree crown. Double-headed arrows indicate max. crown extents along and across rows

Figure 9. Measurement of crown width along and across the rows.

Figure 10. Crown width measurement for CVI calculation

ALLOMETRICS

Biomass Sample Trees

<u>Selection</u>

All sample plots on the sites were listed and every second sample plot retained as a Permanent Sample Plot (PSP). No destructive sampling or other disturbance was allowed in the PSPs. The intention is that the PSPs can be re-measured, e.g. in three to five years, to indicate survival and growth rates of all species.

All other sample plots were classed as Temporary Sample Plots (TSPs), i.e. no intention to re-measure these plots. Hence, all trees selected for destructive sampling for allometrics development were in the TSPs.

The objective was to select 10 Biomass Sampling Trees (BSTs) for destructive sampling from each species where there were at least 10 trees measured in the TSPs. If less than 10 trees were measured in the TSPs then all measured trees were selected as BSTs. Steps were as follows.

1. Rank all trees (or shrubs) of a species measured in TSPs by the size of the predictor variable, i.e. either stem diameter (tree form and mallees) or CVI (shrubs).
2. Divide the data set into five classes of equal width.
3. Apply a systematic selection of trees in a size class. Initially four BSPs were selected from each size class where they were available, i.e. the 12.5th, 37.5th, 62.5th, and 87.5th tree by rank size in a size class.
4. If four trees not available in a size class, then attempt to make up the shortfall from the next size class, e.g. if only two trees measured in the top size class, attempt to find six BSTs in the next size class.
5. However the above steps resulted in up to 20 BSTs selected for each species. As this appeared to be too many BSTs to handle logistically the number was reduced to a maximum 10 BSTs per species for the first round of sampling. For example, if 20 BSTs for a species, every second BST was selected.
6. Subsequently, more of the initial 20 BSTs from key species (i.e. species occurring frequently in the plantings and/or having high biomass growth) were sampled.

<u>Measurements</u>

Tree measurements on the BSTs were the same as for trees measured in the sample plots (see Generic allometrics pages 30-32), i.e. stem diameters measured on tree form and mallee species and CVI measured on shrub species. However, a difference was that stem diameter was measured at all three heights (0.1 m, 0.5 m and 1.3 m). This was to allow calculation of allometric equations to predict tree biomass (and carbon stocks) from all three measurement heights.

<u>Destructive sampling for above ground biomass</u>

Destructive sampling generally followed procedures in the biomass sampling protocol developed for the National Carbon Accounting System (now the National Inventory) (Snowdon et al., 2002) and the CFI Farm Forestry methodology. In summary, steps were as follows.

1. Each BST was cut at ground level. This was achieved by removing any litter or other loose material from around the base of the stem and spray painting the stem base to indicate ground (mineral earth) level. Then sufficient soil from below the stem base was removed (Figure 11) to allow felling of the tree at ground level with a chainsaw or pruning shears if a very small tree.
2. The Above Ground Biomass (AGB) of each BST was divided into components of:
    a. Stem,
    b. Crown (branches and foliage), and
    c. Dead material, e.g. dead branches attached to the tree. This component only included if sufficient material present.
3. Each component was weighed in the field (Figure 12). This was known as the Fresh Weight (FW).
4. Representative sub-samples (around 200 – 800 g) of each component were taken in the field and weighed on a portable digital balance to get the FW of the samples.
5. All sub-samples were dried to constant weight at 70° C in a fan forced oven, then weighed to get the dry weight (DW) of the samples.

Figure 11. Removing soil from the base of a *Melaleuca* shrub to allow cutting at mineral earth level.

Figure 12. Weighing crown material in the field

Then, the dry weight of a component was calculated as

$$DW_c = \frac{DW_{ss}}{FW_{ss}} FW_c$$

where

DW_c = dry weight of the component

DW_{ss} = dry weight of the sub-sample

FW_{ss} = fresh weight of the sub-sample

FW_c = fresh weight of the component.

The total Above Ground Biomass (AGB) of a BST was calculated as the sum the dry weights of the components

$$AGB = \sum_{i=1}^{n} DW_{c,i}$$

where

AGB = above ground biomass of a BST

n = number of components in the BST

DW_c = dry weight of the *i*th component

Root biomass estimation

Estimates of root biomass were obtained by running the national carbon accounting model (FullCAM) for each site to estimate the Root:Shoot ratio for the site at the measurement age. Thus, the Root:Shoot ratio was calculated as

$$R:S = \frac{B_R}{B_{AGB}} \qquad \text{Equation 3}$$

where

R:S = root to shoot ratio

B_R = root biomass

B_{AGB} = above ground biomass (AGB)

In FullCAM, R:S was calculated as the ratio of 'carbon mass of below ground tree components' to 'carbon mass of above ground tree components'.

Allometrics development

All allometric equations were of the form

$$B_{AGB} = b_1 M^{b_2} \qquad \text{Equation 4}$$

where

B_{AGB} = above ground biomass of the BST

M = predictor variable, either DAH_e, DKH_e, DBH_e, or CVI

b_1, b_2 = parameters to be estimated

All allometric equations were fitted by nonlinear regression (NLR) in the Systat statistical analysis package. Transforming variables (e.g. log transformations or weighting to achieve constant variance (Clutter et al., 1983, pp 3-29; Parresol, 1999) was not followed. The reason is that this gives less weight to the larger trees in the regression fit, i.e. less weight to the more important trees for the carbon stock calculations.

Species allometric equations were developed for 37 species, comprising 22 tree (tree form or mallee) and 15 shrub species. These species accounted for a little over 98% of the 5,170 individual trees and shrubs measured.

The remaining trees and shrubs measured comprised 0.6% trees (five species and some unidentified *Acacia* species) and 1.3% shrubs (eight species). It was necessary to develop generic allometric equations from the pooled data for the other tree and shrubs species to estimate the carbon stocks of these uncommon species.

CARBON CALCULATIONS

Tree carbon stocks of plots

Estimates of carbon stocks in the sample plots (PSPs and TSPs) at all sites were calculated as follows.

1. The AGB of each tree or shrub was calculated from the relevant allometric equation (Equation 4). Note that biomass (including AGB) is the same as the dry weight.
2. AGB values were converted to Tree Carbon stocks from expansion factors, i.e.

$$TC_{TS} = AGB * (1 + R{:}S) * 0.5 * \frac{44}{12} \qquad \text{Equation 5}$$

where

TC_{TS} = Tree Carbon stock in an individual Tree or Shrub (kg CO_2-e)

AGB = Above Ground Biomass of an individual tree or shrub (kg)

R:S = Root:Shoot ratio for the site, estimate from FullCAM.

0.5 = estimate of the carbon fraction, i.e. the proportion of biomass that is carbon. Commonly a carbon fraction of 0.5 is assumed, e.g. (DCCEE, 2012; IPCC, 2003)

44/12 = the ratio of the molecular weights of carbon dioxide (CO_2) to carbon (C).

3. The Tree Carbon stocks (t CO_2-e/ha) for a sample plot were calculated as the sum of the Tree Carbon Stocks of each tree or shrub, divided by the area of the sample plot:

$$TC_{Plot,h} = \frac{\sum_{i=1}^{n} TC_{TS,i}}{1000 * A_h} \qquad \text{Equation 6}$$

where

$TC_{Plot,h}$ = Tree Carbon stock in the h^{th} plot (t CO-e/ha)

$TC_{TC,i}$ = Tree Carbon stock in the i^{th} of *n* trees and shrubs in the plot (kg CO_2-e)

A_h = Area of the h^{th} plot (ha)

Tree carbon stocks of sites

Estimates of Tree Carbon stocks for a site were calculated as the average of the estimates of tree carbon stocks for all sample plot in the site:

$$TC_{Site} = \frac{\sum_{h=1}^{n} TC_{Plot,h}}{n} \qquad \text{Equation 7}$$

where

TC_{Site} = Average Tree Carbon stock in a site (t CO-e/ha)

$TC_{Plot,h}$ = Tree Carbon stock in the h^{th} of n plots in the site (kg CO_2-e)

n = number of plots

Projection of tree carbon stock estimates

All estimates of carbon stocks, i.e. estimates for tree or shrub species (kg CO_2-e) and sites (t CO_2-e/ha), were projected forwards or backwards to age 15 years, and forwards to age 30 years. The reason was to 'age standardise' the estimates. As the sites were measured in 2013 at ages ranging from 11 – 23 years this gave a means of comparing carbon sequestration rates between species and sites without having to consider the measurement age.

Growth of trees and forests is typically not linear. Therefore, it is necessary to project along a growth curve. This was done using the Tree Yield Formula (TYF) in FullCAM (Waterworth et al., 2007) in projection form, i.e.

$$TC_2 = TC_1 * \mathrm{e}^{(-2\mathrm{G}+1.25)\left(1/A_2 - 1/A_1\right)} \qquad \text{Equation 8}$$

where

y_1 & y_2 = the response variable (tree carbon stocks) at ages A_1 and A_2

e = exponential (base of natural logarithms)

G = tree (stand) age of maximum growth rate, i.e. approximately the age of crown closure;

A = tree age.

For the projections it was assumed that G = 10 years, hence the growth curves in Figure 13. See Appendix 3 for further discussion of the projection methods and estimation of the G parameter value.

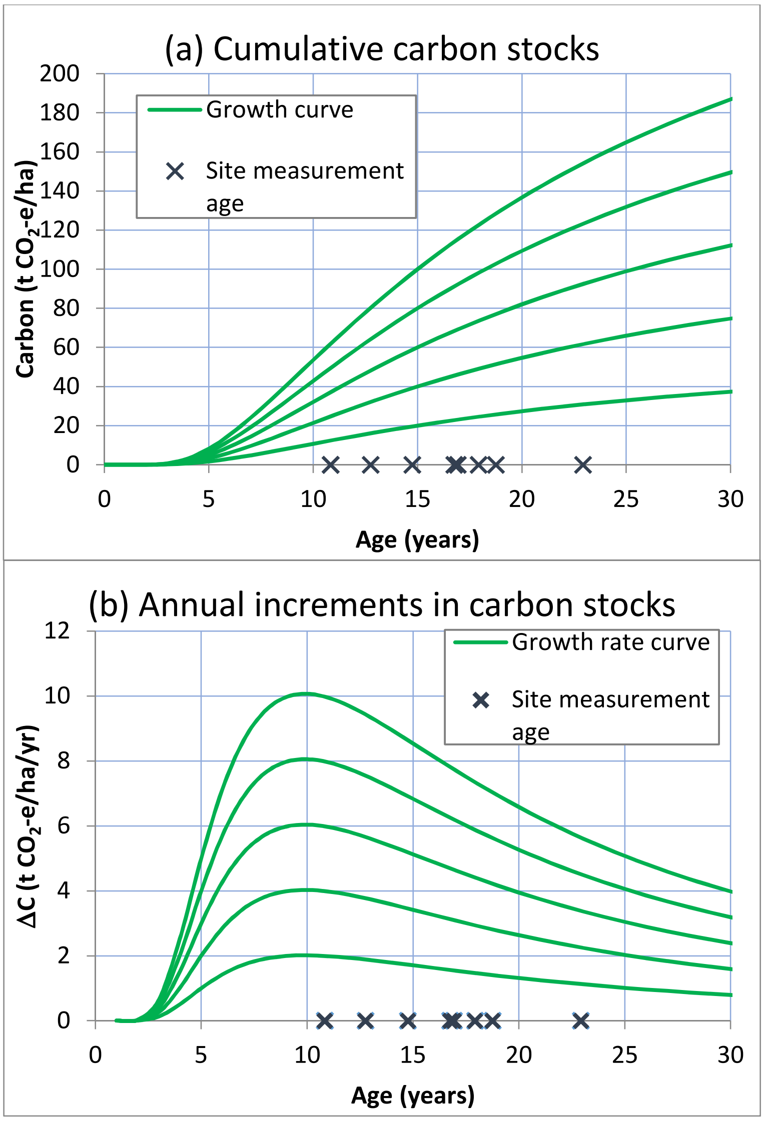


Figure 13. Growth curves with G = 10 years: (a) growth curves and (b) the corresponding growth rate curves.

Model estimates of carbon stocks

Estimates of carbon stocks (t/ha) were also obtained for each site at the measurement from FullCAM. This included carbon in trees and debris (i.e. leaf litter, fallen branches, and other dead fallen tree material) as these are eligible carbon pools in the ‘Environmental and mallee plantings FullCAM’ methodology (Department of the Environment, 2014b) .

Initially, estimates were made using the 3.40 version of FullCAM. However, when version 3.55 became available that was also used to obtain comparison estimates. FullCAM 3.55 has recent calibrations for mallees and environmental plantings (Paul et al., 2014), the calibrations for Mixed Species Environmental Plantings Temperate (MSEPT) being relevant to the study sites.

SALINITY MEASUREMENTS

Apparent electrical conductivity (ECa) was measured with the GEONICS EM38 instrument to indicate soil salinity (Bennett et al., 1995; McNeill, 1986).

The EM38 readings were taken in the vertical mode (EM38V) as most (~ 80%) of the response is from 0 – 1.5 m soil depth. This is considered appropriate for trees and shrubs which typically have deeper roots than pastures or agricultural crops.

Two EM38V readings were taken from each sample plot (5 m north and 5 m south of the plot centre) and averaged. These average EM38V values were temperature corrected following the calibration chart in Bennett et al. (1995). Soil temperature measurements were taken at each site for this purpose.

The EM38V (ECa) measurements were also calibrated against direct measurements of soil salinity. For this purpose, EM38 V was measured and a soil sample taken at 75 cm depth at 10 points throughout the revegetation on each farm.

The soil samples were processed by CSBP Ltd to obtain the electrical conductivity of a saturated soil extract (ECe) following the methods of Rayment and Higginson (1992).

For the calibrations, linear regressions of ECe on ECa were calculated for each farm.

RESULTS AND DISCUSSION

SPECIES

Table 4 lists all species recorded in the sample plots (PSPs and TSPs).

A total 50 species were measured. These were classified as either trees (23 species tree form and five species mallee form) or shrubs (22 species).

Very common species (over 600 individuals measured) were two mallee form Eucalypts (*E. loxophleba* subsp. *lissophloia* and *E. kochii* subsp. *borealis*) and Old man saltbush (*Atriplex nummularia*). Other common species (400 – 600 individuals measured) were the Melaleucas (*M. lateriflora* and *M. uncinata*).

Table 4. Species recorded in the sample plots

Species	Common name	Form	Number measured
Acacia acuminata	Jam wattle	tree	19
Acacia hemiteles	Tan wattle	shrub	28
Acacia merrallii	Merrall's wattle	shrub	1
Acacia microbotrya	Manna wattle	tree	8
Acacia multispicata	Spiked wattle	shrub	13
Acacia rostellifera	Summer scented wattle	shrub	2
Acacia saligna	Golden wreath wattle	tree	2
Acacia tetragonophylla	Kurara	shrub	12
Atriplex amnicola	River saltbush	shrub	304
Atriplex bunburyana	Silver saltbush	shrub	3
Atriplex nummularia	Old man saltbush	shrub	620
Beaufortia squarrosa	Sand Bottlebrush	shrub	4
Calothamnus gilesii	Giles net bush	shrub	6
Calothamnus quadrifidus	Common net bush	shrub	8
Casuarina obesa	Swamp sheoak	tree	226
Eucalyptus accedens	Powderbark wandoo	tree	16
Eucalyptus arachnaea	Black stemmed mallee	tree	18
Eucalyptus camaldulensis	River red gum	tree	137
Eucalyptus capilosa	Wheatbelt wandoo	tree	27
Eucalyptus comitae-valis	Comet vale mallee	mallee	16
Eucalyptus diminuta	Spring mallee	tree	9
Eucalyptus eremophila	Sand mallee	tree	13
Eucalyptus erythronema	Red flowered mallee	tree	8
Eucalyptus forrestiana	Fushia gum	tree	11
Eucalyptus horistes	Mullewa mallee	mallee	11
Eucalyptus kochii subsp borealis	Oil mallee	mallee	604

Eucalyptus kondininensis	Kondinin blackbutt	tree	37
Eucalyptus loxophleba subsp *lissophloia*	York gum	mallee	740
Eucalyptus obtusiflora	Dongara mallee	tree	2
Eucalyptus occidentalis	Flat topped yate	tree	246
Eucalyptus platypus	Coastal moort	tree	62
Eucalyptus salicola	Salt gum	tree	132
Eucalyptus salmonophloia	Salmon gum	tree	14
Eucalyptus salubris	Gimlet	tree	25
Eucalyptus sargentii	Salt river gum	tree	236
Eucalyptus spathulata	Swamp mallet	tree	131
Eucalyptus subangusta	Grey mallee	mallee	11
Eucalyptus torquata	Coral gum	tree	4
Eucalyptus wandoo	Wandoo	tree	40
Melaleuca acuminata	Mallee honey myrtle	shrub	262
Melaleuca adnata	Sandhill honey myrtle	shrub	9
Melaleuca cuticularis	Salt paperbark	shrub	2
Melaleuca eleuterostachya	Hummock honey myrtle	shrub	33
Melaleuca hamulosa	Creek line honey myrtle	shrub	28
Melaleuca holosericea	Silky honey myrtle	shrub	15
Melaleuca lateriflora	Gorada	shrub	489
Melaleuca radula	Graceful honey myrtle	shrub	11
Melaleuca thyoides	Salt lake honey myrtle	shrub	24
Melaleuca uncinata	Broom bush	shrub	418
Melaleuca viminea	Mohan	shrub	61

ALLOMETRICS

Trees

Table 5 summarises the fit statistics for the 22 tree species where AGB was predicted from stem diameter, i.e.

$$B_{AGB} = b_1 D^{b_2} \quad \text{Equation 9}$$

where

B_{AGB} = above ground biomass of an individual tree

D = predictor variable, either DAH_e, DKH_e or DBH_e

b_1, b_2 = parameters

Figures 14 & 15 show some examples of the regression fits for key tree form and mallee species.

In most cases, a good fit of AGB on stem diameter was obtained, e.g. with two exceptions, the R^2 values were in the range 0.75 - 0.998.

Table 5. Allometrics fit statistics for tree form species developed from stem diameter measurements at three heights.
Notation: b_1, b_2 = parameters estimated by regression; *n* = number of biomass sample trees; R^2 = coefficient of determination

Species	DAHe				DKHe				DBHe			
	b_1	b_2	*n*	R^2	b_1	b_2	*n*	R^2	b_1	b_2	*n*	R^2
Casuarina obesa	0.000858	2.145	10	0.87	0.00216	2.020	10	0.91	0.002221	2.085	10	0.98
Eucalyptus accedens	0.000098	2.414	4	0.99	0.00065	2.109	4	0.997	0.000888	2.169	4	0.99
Eucalyptus arachnaea	0.014089	1.655	7	0.96	0.08396	1.329	7	0.94	0.00558	1.956	7	0.98
Eucalyptus camaldulensis	0.000257	2.294	9	0.89	0.00140	2.054	9	0.95	0.008734	1.788	9	0.95
Eucalyptus capilosa	0.000117	2.588	5	0.98	0.00066	2.309	4	0.95	0.001201	2.224	4	0.94
Eucalyptus comitae-valis	2.6E-06	3.327	11	0.87	8.6E-05	2.705	11	0.75	3.3E-06	3.592	10	0.95
Eucalyptus diminuta	0.000447	2.377	7	0.89	0.04076	1.489	7	0.74	0.011463	1.781	7	0.95
Eucalyptus eremophila	0.000036	2.836	5	0.998	0.00018	2.527	5	0.88	0.000869	2.318	5	0.92
Eucalyptus forrestiana	0.001370	2.074	5	0.97	1.3E-05	3.206	5	0.99	0.020591	1.704	4	0.91
Eucalyptus horistes	0.001438	2.074	8	0.96	0.00127	2.104	8	0.99	0.060777	1.391	7	0.79
Eucalyptus kochii	0.000008	3.054	10	0.99	2.6E-05	2.898	10	0.95	0.002086	2.060	9	0.97
Eucalyptus kondininensis	0.000015	2.985	10	0.96	2.2E-05	3.018	10	0.98	0.000543	2.392	10	0.99
Eucalyptus loxophleba	0.007313	1.777	11	0.95	0.00510	1.884	11	0.91	0.004067	1.964	11	0.91
Eucalyptus occidentalis	0.026181	1.542	10	0.94	0.00339	1.974	10	0.93	0.001474	2.157	10	0.91
Eucalyptus platypus	0.003042	1.940	10	0.93	0.00748	1.815	10	0.94	0.043423	1.505	10	0.96
Eucalyptus salicola	0.001314	2.143	8	0.86	0.00042	2.416	9	0.91	0.000203	2.606	8	0.96
Eucalyptus salmonophloia	0.012656	1.574	7	0.67	0.00601	1.815	7	0.85	0.009413	1.808	7	0.78
Eucalyptus salubris	0.001541	2.108	11	0.97	0.00033	2.446	11	0.93	0.000528	2.420	11	0.98
Eucalyptus sargentii	0.006047	1.890	17	0.89	0.00122	2.193	17	0.90	0.006889	1.920	17	0.95
Eucalyptus spathulata	0.002150	2.017	9	0.93	0.00034	2.371	9	0.85	0.013303	1.752	9	0.80
Eucalyptus subangusta	0.009407	1.651	5	0.83	7.2E-05	2.807	5	0.98	0.074238	1.374	3	NA
Eucalyptus wandoo	0.000166	2.500	8	0.96	6.7E-05	2.728	8	0.96	0.000180	2.618	7	0.98
Generic allometric	0.001399	2.102	190	0.86	0.00038	2.383	191	0.92	0.001976	2.125	180	0.95

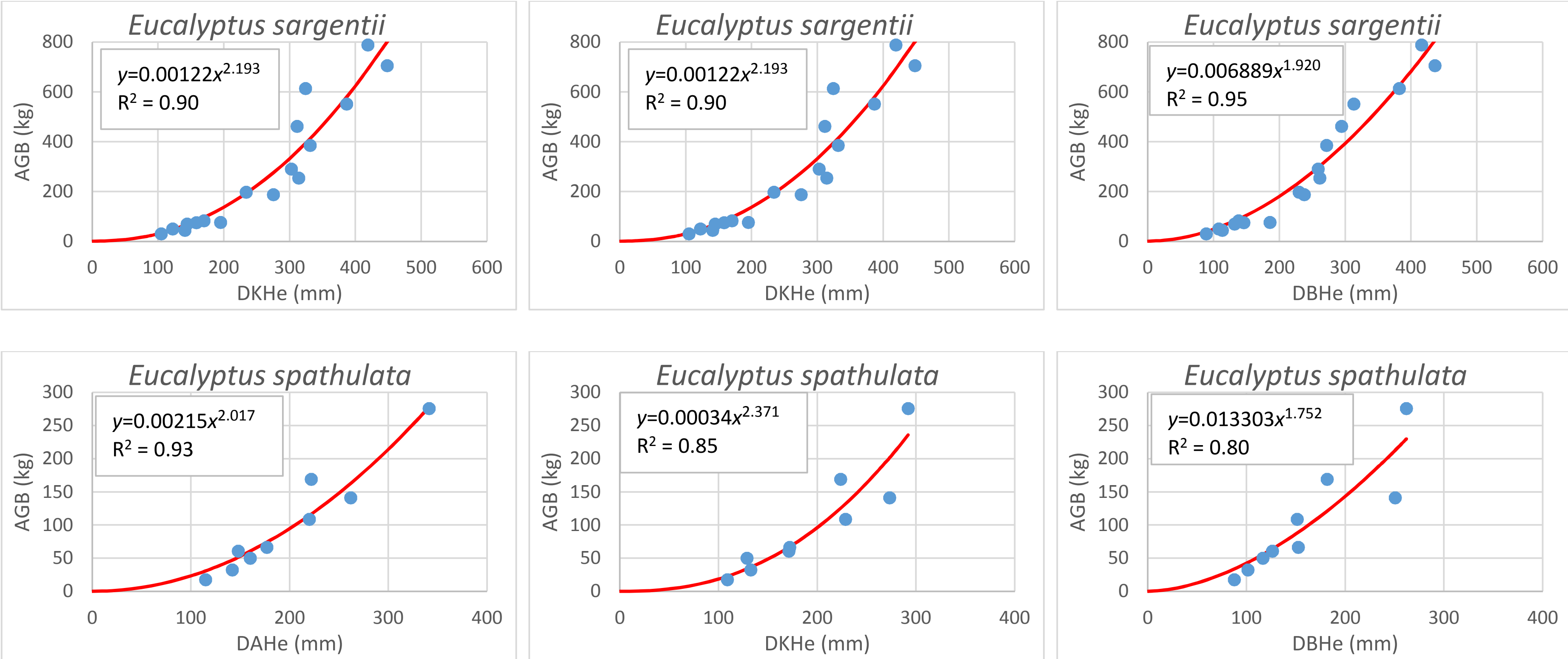


Figure 14. Examples for key tree form species of Above Ground Biomass on stem diameter measurements with fitted regressions.

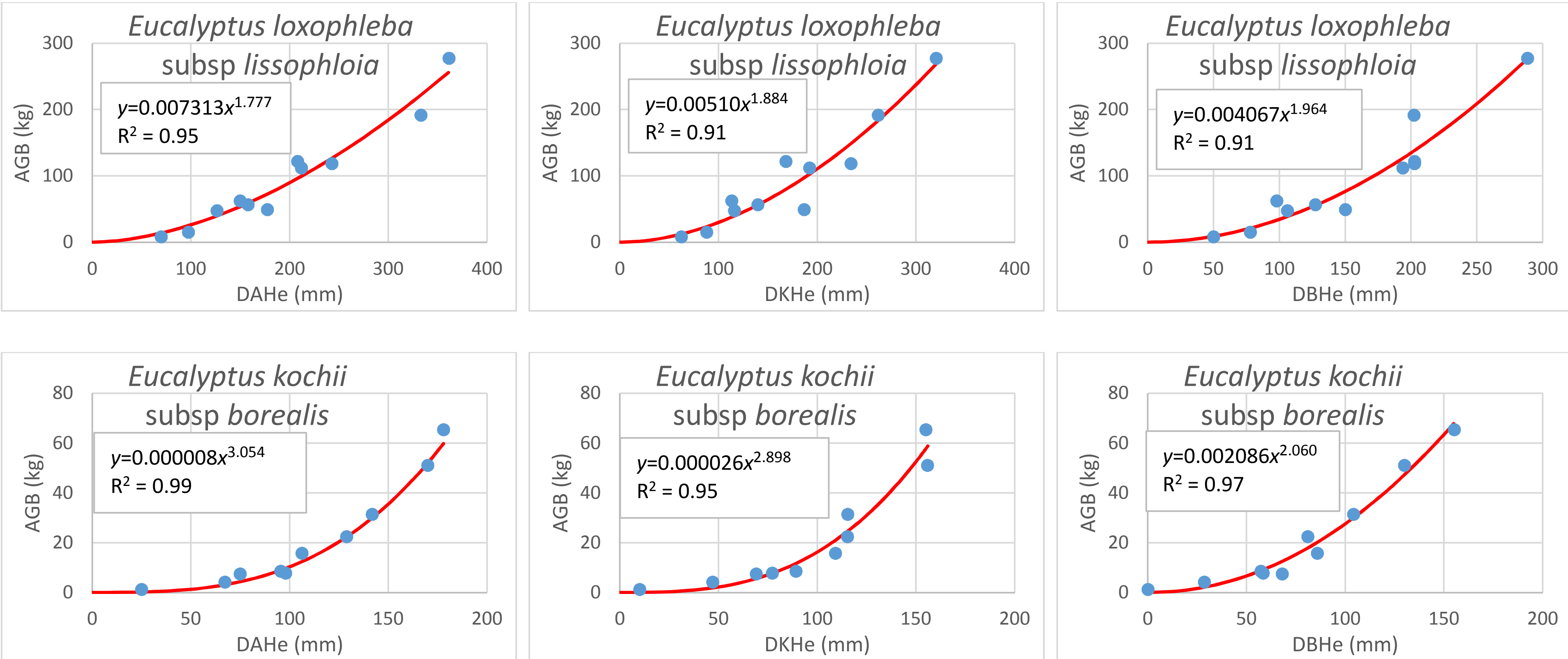


Figure 15. Examples for key mallee form species of Above Ground Biomass on stem diameter measurements with fitted regressions.

Shrubs

Table 6 summarises the fit statistics for the 15 species (14 shrub species and *Acacia acuminata*) where AGB was predicted from Crown Volume Index, i.e.

$$B_{AGB} = b_1 CVI^{b_2} \quad \text{Equation 10}$$

where

B_{AGB} = above ground biomass of an individual shrub

CVI = Crown Volume Index

b_1, b_2 = parameters

Figure 16 shows some examples of the regression fits for key shrub species, i.e. *Melaleuca* shrubs (*M. uncinata* and *M. acuminata*) and saltbush fodder shrubs (*Atriplex amnicola* and *A. nummularia*).

The fits were not as good as for the trees where B_{AGB} was predicted from stem diameter rather than CVI. However, it was not practical to measure stem diameters on the shrub species which usually had many stems (even more stems than the Eucalypt mallees). Generally, the fits were adequate for the purposes of this study.

Table 6. Allometrics fit statistics for shrub form species developed from CVI measurements.
Notation: b_1, b_2 = parameters estimated by regression; n = number of biomass sample trees; R^2 = coefficient of determination.

Species	b_1	b_2	n	R^2
Acacia acuminata	1.17	0.850	9	0.995
Acacia hemiteles	0.58	1.414	10	0.99
Atriplex amnicola	3.41	0.56	9	0.69
Atriplex nummularia	0.19	1.506	17	0.87
Calothamnus gilesii	1.43	1.156	2	NA
Melaleuca acuminata	3.68	0.62	10	0.74
Melaleuca adnata	1.16	1.12	4	0.94
Melaleuca eleuterostachya	3.29	0.63	10	0.48
Melaleuca hamulosa	1.73	0.75	4	0.988
Melaleuca holosericea	1.38	0.98	6	0.64
Melaleuca lateriflora	4.6	0.61	10	0.55
Melaleuca thyoides	0.51	1.3	10	0.98
Melaleuca uncinata	5.93	0.61	11	0.86
Melaleuca viminea	0.76	1.02	10	0.94
Generic allometric	1.66	0.92	125	0.78

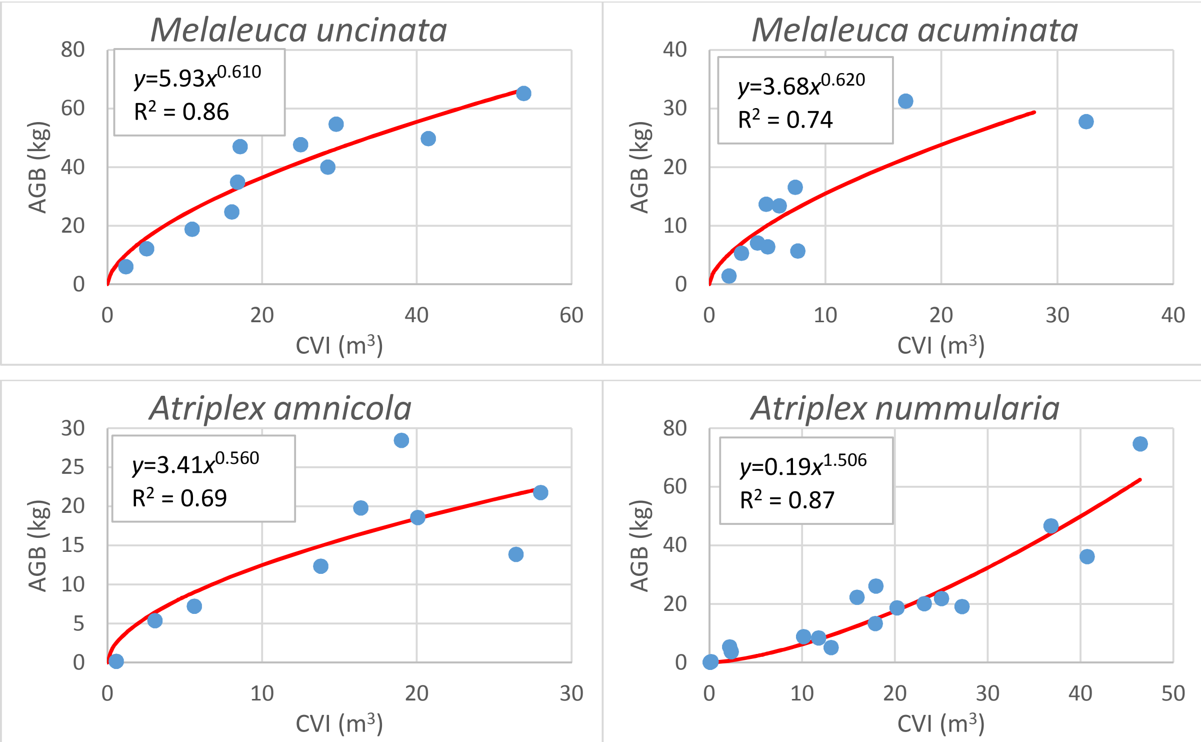
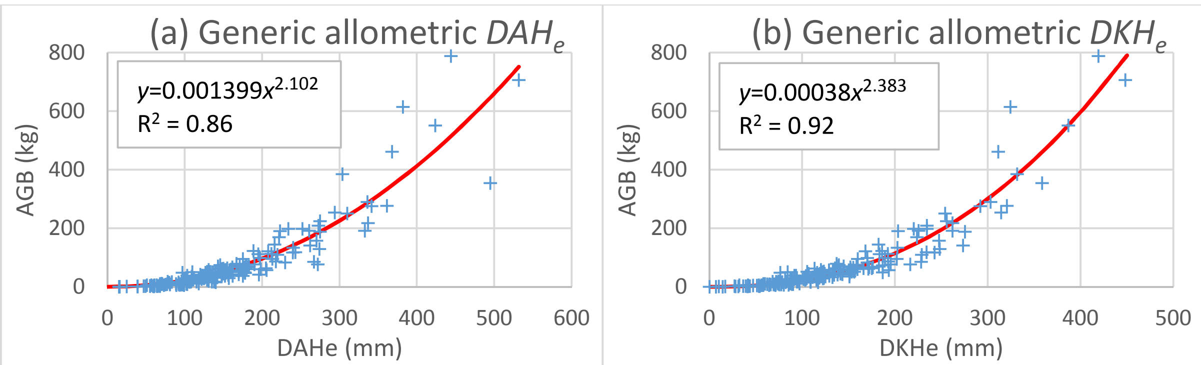


Figure 16. Examples for key shrub species of Above Ground Biomass on Crown Volume Index with fitted regressions.

Generic allometrics

The generic allometric fit statistics are in Tables 5 & 6. See also the graphs in Figure 17.



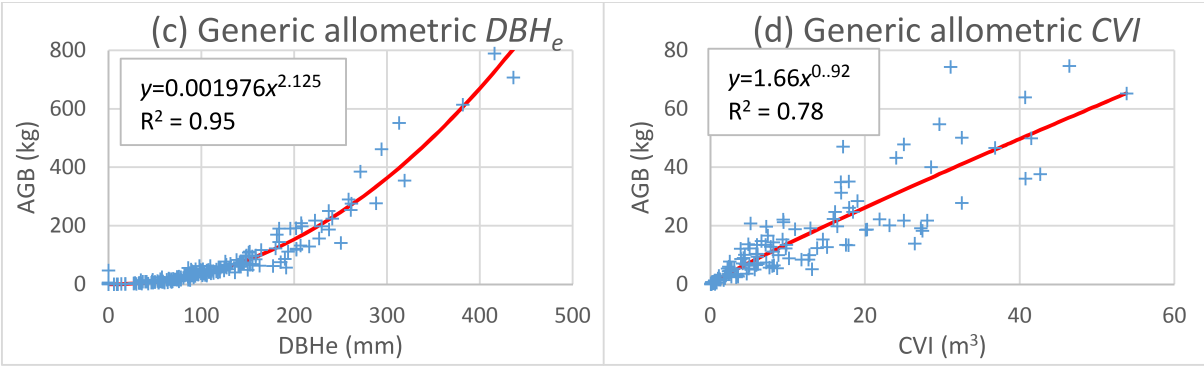


Figure 17. The generic allometrics based on stem diameter (*DAH*$_e$, *DKH*$_e$ and *DBH*$_e$) for tree species and *CVI* for shrub species.

An evaluation of the *DBH*$_e$ generic allometric (Figure 18) indicates moderately small errors from applying the generic allometric to individual tree species. This was also indicated by the moderate spread of measurements around the generic allometric from *DBH*$_e$ (Figure 17(c)), and slightly greater spread for the generic allometrics from *DAH*$_e$ and *DKH*$_e$ (Figures 17(a)(b)).

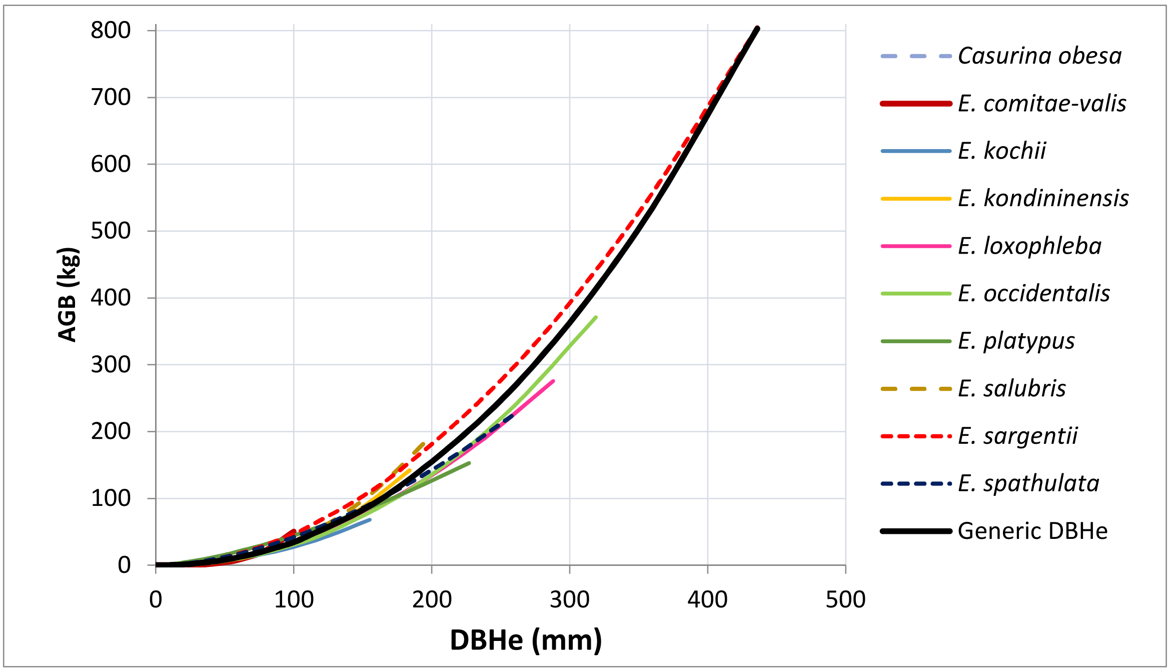


Figure 18. Species allometrics for tree species with ≥ 9 BSTs compared to the generic allometric developed from pooled *DBH*$_e$ data for all BSTs from tree species.

Therefore generic allometrics, based on stem diameter measurements, were applied to trees where a species allometric was not available. Those trees comprised 0.6% of all trees and shrubs measured in the sample plots, and represented 0.4% of the AGB in measured trees and shrubs.

Generic allometrics were not used where species allometrics were developed, even where only a few trees (e.g. less than 9) were destructively sampled. This was based on the assumption that, for an individual species, a species allometric calculated from a few destructive sample trees (BSTs) would be less likely to be biased than a generic allometric.

In contrast to the generic allometrics from stem diameter measurements for tree species, Figure 19 indicates larger errors from applying the generic allometric from CVI for shrub species. This was also indicated by the greater spread of measurements around the generic allometric from CVI (Figure 17(d)).

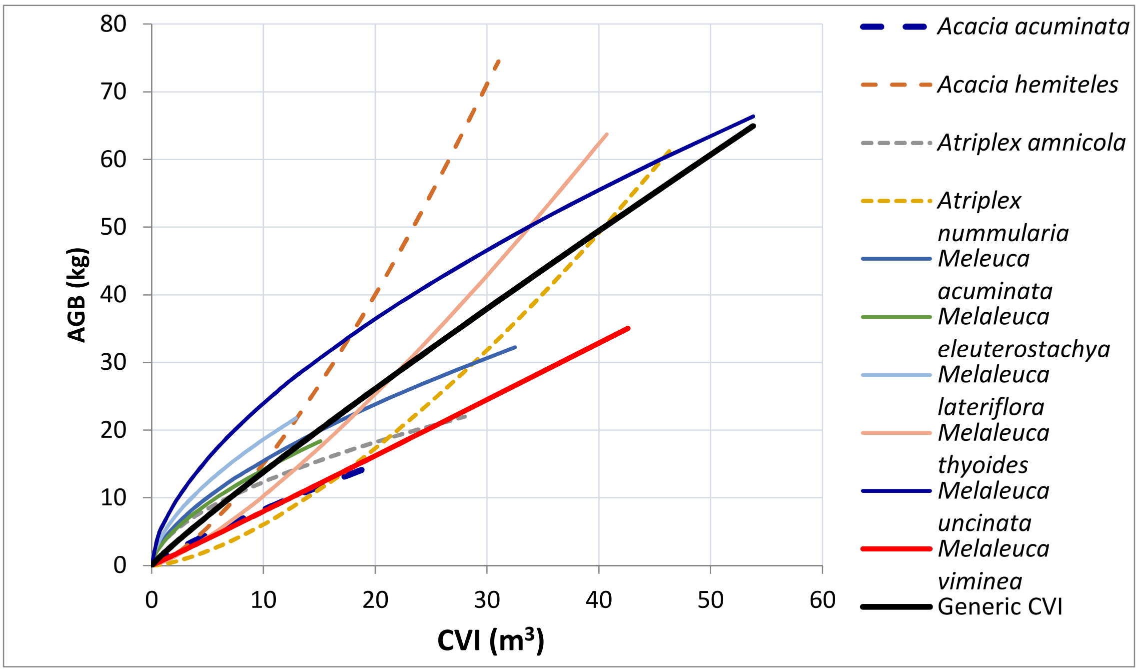


Figure 19. Species allometrics for shrub species with ≥9 BSTs compared to the generic allometric developed from pooled CVI data for all BSTs from shrub species.

However, generic allometrics, based on CVI, were still applied to shrub species where a species allometric was not developed. Those shrub species were a relatively small proportion, e.g. 1.3% of all individual trees and shrubs measured, or around 0.4% of the AGB in measured trees and shrubs.

As with tree species, generic allometrics were not used for shrubs where species allometrics had been developed.

CARBON STOCKS

Measurements

Some details for each of the nine sites are in Table 7.

The latitude and longitude coordinates are for a sample plot central to each site. These points were used as the 'model point' for the FullCAM simulations.

For calculating the measurement age it was assumed all sites were planted on 1 July of the 'Year planted' and measured in the middle of the 'Month measured'.

The Root:Shoot ratios were calculated for Mixed Species Environmental Plantings (MSEP) in FullCAM 3.40. They varied from 0.332 in the youngest plantings measured (10.8 years old) to 0.302 in the oldest plantings measured (22.9 years old).

Table 7. Site details

Site	Latitude	Longitude	Year planted	Month measured	Measurement age (years)	Root: Shoot ratio
Andrew	-29.3882	116.2113	1996	April 2013	16.8	0.316
Butcher saltbush	-30.3637	116.7290	2002	May 2013	10.8	0.332
Butcher waterway	-30.3580	116.7322	1996	June 2013	16.9	0.311
Eva	-29.6229	115.6494	2000	April 2013	12.8	0.323
Falconer	-29.8239	116.1617	2002	May 2013	10.8	0.332
McFarlane E	-30.4738	116.9041	1990	May 2013	22.9	0.302
McFarlane W	-30.4752	116.8900	1995	May 2013	17.9	0.312
McGlew mallee	-29.3417	116.2456	1998	April 2013	14.8	0.318
McGlew Melaleuca	-29.3455	116.2494	1994	April 2013	18.8	0.309

However, with recent calibrations of the model (FullCAM 3.55) the Root:Shoot ratios for Mixed Species Environmental Plantings Temperate (MSEPT) vary from 0.400 for the younger of the narrow belt plantings to 0.356 for oldest of the block plantings. Therefore, application of the Root:Shoot ratios from FullCAM 3.55 would have resulted in slightly higher estimates of Tree Carbon stocks.

Table 8 provides a summary of site measurements.

Salinity, as indicated by the EM38 ECa readings, varied from low levels (ECa < 100 mS/m) at all sites to a maximum 463 mS/m at the Eva site. At three sites (Falconer, McGlew mallee, and McGlew Melaleuca) salinity did not exceed moderately low levels (ECa < 200 mS/m).

The stocking levels of trees and shrubs also varied between sites. Two sites (Butcher saltbush and Falconer) were characterised by dense plantings of shrubs (> 1,000 shrubs/ha) and few trees. Trees dominated at the other sites with the stocking of trees varying from 274 – 458 trees/ha. These moderately low stocking levels for trees are appropriate given the arid environments, e.g. long term mean annual rainfall around 300 mm at all sites.

Estimates of carbon stocks at the measurement ages varied from 8.3 t CO_2-e/ha at the Butcher saltbush site (age 10.8 years) to 121.2 t CO_2-e/ha at the McFarlane East site (age 22.9 years) (Table 8 and Figure 20)

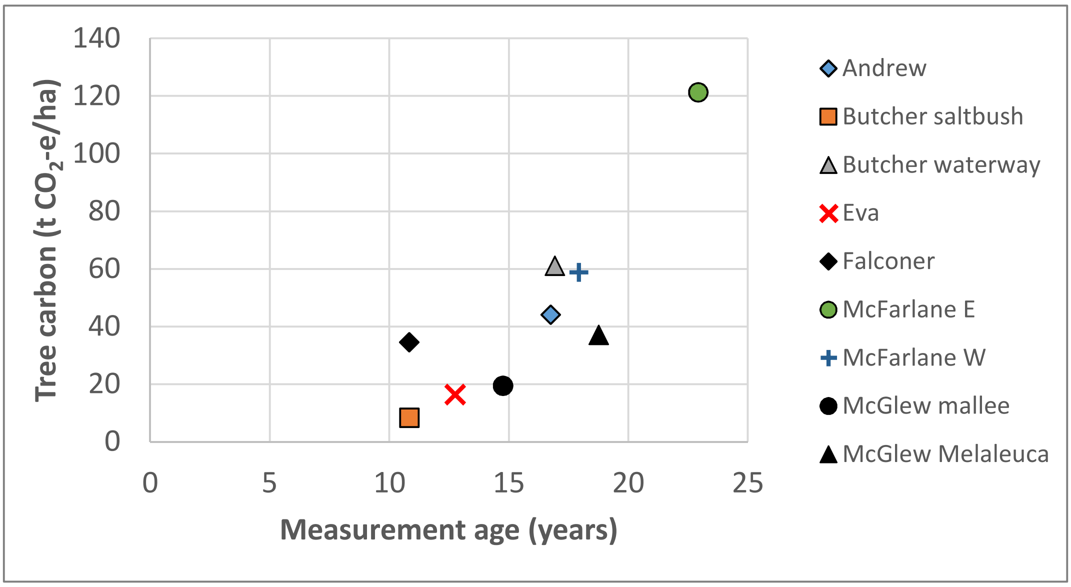


Figure 20. Measured tree carbon stocks at the study sites.

However, ‘age standardising’ the estimates provides a better means of comparing sites. The Butcher saltbush site still had the lowest carbon stocks (13.4 t CO_2-e/ha at age 15 years). Reasons for the low carbon stocks, apart from high salinity levels, include the low density of trees and the annual grazing by sheep of the saltbush (*Atriplex* species) shrubs. Hence, the plantings were providing fodder value as well as carbon and other values.

The highest carbon stocks in the age standardised estimates were at the McFarlane East site (78.7 t CO_2-e/ha at age 15 years). One reason for this was that the plantings included some of the most productive species (see later information on species comparisons). Another reason was the plantings were in belts three to five rows wide with around 40 m unplanted cropping alleys between the belts of trees. The ‘edge effect’ is well recognised, i.e. that trees on edges of plantings grow more quickly due to greater access to water, light and other resources. The ‘outside row’ trees usually grow most quickly and half the rows in a four row belt are outside rows.

The estimates of carbon stocks at age 30 years are provided to indicate the increase in carbon stocks to be expected from age 15 years to age 30 years. Given the shape of the growth curves assumed (Figure 10), the indications are that carbon stocks will nearly double over that period.

Table 8. Site measurements

Site	Meas. age (years)	No. sample plots	Salinity (ECa in mS/m)		Stocking		Tree carbon (t CO_2-e/ha)		
			Mean	Range	Trees /ha	Shrubs /ha	At meas. age	Predicted at age 15 years	Predicted at age 30 years.
Andrew	16.8	30	120	16-282	324	105	44.1	38.7	72.3
Butcher saltbush	10.8	19	153	30-320	74	1337	8.3	13.4	25.1
Butcher waterway	16.9	22	115	32-217	274	82	61.0	53.0	98.9
Eva	12.8	36	245	37-463	371	521	16.4	20.4	38.1
Falconer	10.8	46	81	38-169	126	1143	34.5	55.9	104.4
McFarlane E	22.9	8	167	97-269	416	0	121.2	78.7	147.0
McFarlane W	17.9	32	155	52-322	458	38	58.8	47.9	89.6
McGlew mallee	14.8	35	35	1-139	532	10	19.4	19.8	37.1
McGlew Melaleuca	18.8	7	56	7-138	405	176	37.1	28.9	53.9

Table 9 has the estimates of total carbon stocks for each site and for a 'project' of all nine sites. Thus, for a project of around 150 ha of plantings, around 5,000 t CO_2-e of carbon sequestration was achieved. Depending on the rules of a carbon trading scheme this could result in up to 5,000 t of carbon credits.

Table 9. Sites total carbon stocks in 2013

Site	Tree carbon (t CO_2-e/ha)	Area (ha)	Site total tree carbon (t CO_2-e)
Andrew	44.1	6.6	293
Butcher saltbush	8.3	11.0	91
Butcher waterway	61.0	6.3	381
Eva	16.4	56.8	930
Falconer	34.5	15.8	544
McFarlane E	121.2	8.5	1029
McFarlane W	58.8	21.5	1263
McGlew mallee	19.4	20.5	395
McGlew Melaleuca	37.1	2.2	82
Total all sites		149.1	5,009

Model estimates

There were substantial differences between the measured and predicted tree carbon stocks (Table 10 and Figures 21 & 22).

Table 10. Measured carbon stocks compared to model estimates from two recent versions of the FullCAM model.

Site	Average salinity (ECa in mS/m)	Meas. age (years)	Measured carbon stocks (trees only) (t CO_2-e/ha)	Predicted carbon stocks (t CO_2-e/ha) from FullCAM 3.40		Predicted carbon stocks (t CO_2-e/ha) from FullCAM 3.55	
				Trees only	Trees + debris	Trees only	Trees + debris *
Andrew	120	16.8	44.1	21.4	27.1	52.4	70.8
Butcher saltbush	153	10.8	8.3	18.8	23.4	41.4	55.8
Butcher waterway	115	16.9	61.0	22.4	28.2	53.2	71.8
Eva	245	12.8	16.4	23.4	29.5	64.8	87.4
Falconer	81	10.8	34.5	14.3	17.8	35.9	48.5
McFarlane E	167	22.9	121.2	27.5	34.8	76.3	103.0
McFarlane W	155	17.9	58.8	21.5	27.1	71.2	96.1
McGlew mallee	35	14.8	19.4	17.3	21.7	41.9	56.6
McGlew Melaleuca	56	18.8	37.1	21.9	27.5	52.4	70.8

* Debris carbon stocks predicted by FullCAM 3.55 were higher than Tree carbon stocks for all sites. However, as advised by the Department of the Environment, estimates of Debris carbon stocks were restricted to a maximum 35% of Tree carbon stocks.

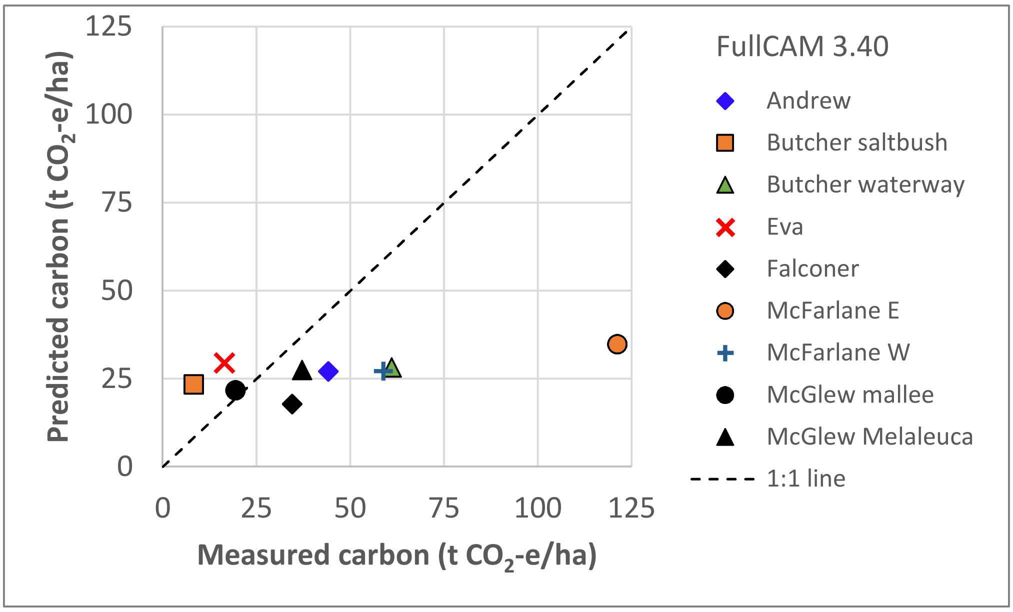


Figure 21. Measured carbon stocks at the study sites compared to carbon stocks predicted for 'mixed species environmental plantings' by FullCAM 3.40.

FullCAM 3.40

The measured tree carbon stocks were higher than those predicted by FullCAM 3.40 at all but the Butcher saltbush and Eva sites. As previously noted, reasons for low tree carbon stocks at the Butcher saltbush site include moderate salinity levels (average ECa = 153 mS/m), the low stocking of trees, and the annual grazing of the saltbush shrubs. The Eva site had the highest salinity readings (average ECa = 245 mS/m) of all the sites which may explain the low tree carbon stocks at that site. However, the FullCAM calibrations do not account for secondary salinity or other human-induced soil conditions that suppress or enhance forest growth rates.

At the McGlew mallee site, measured tree carbon stocks were close to the tree carbon stocks predicted by FullCAM 3.40, and just less than the combined 'tree + debris' carbon stocks predicted by FullCAM 3.40. A reason for the low measured tree carbon stocks may have been the planting arrangement, i.e. unplanted alleys between the mallee belts, with approximately half the land area in the belts. However, the site was assessed as a block planting with all sample plots including belt and alley areas.

FullCAM 3.55

Predicted carbon stocks from FullCAM 3.55 were much higher than from FullCAM 3.40, e.g. around an average 280% higher for 'trees + debris'. For eight of the nine sites, FullCAM 3.55 over-predicted carbon stocks compared to the measured carbon stocks. For the 'Eva' and 'Butcher saltbush' sites the over-prediction exceeded 500%. (Figure 22).

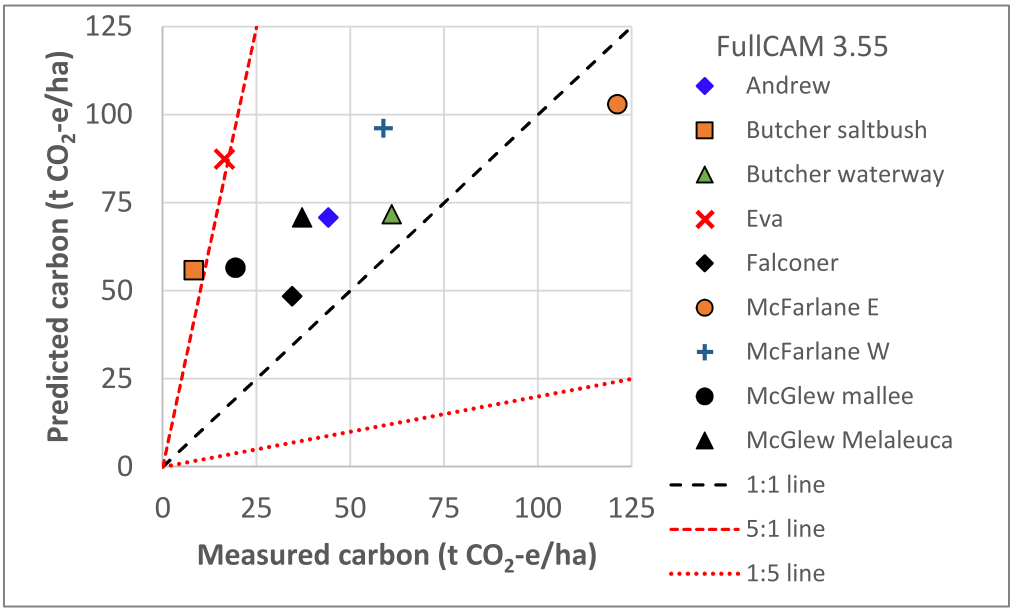


Figure 22. Measured carbon stocks at the study sites compared to carbon stocks predicted for 'mixed species environmental plantings' by FullCAM 3.55.

One reason for the higher predictions of carbon stocks from FullCAM 3.55 is that debris levels were set at 35% of estimated tree carbon stocks. In comparison debris level estimates from FullCAM 3.40 were an average of 26% of tree carbon stocks. In contrast, at all study sites debris were considered too low to be worth measuring, e.g. see pictures of the study sites in Figure 2 (a)-(i) and other pictures throughout the report. A general observation is that this is typical of young (10 – 20 years old) plantings, i.e. evergreen species don't shed many leaves or branches until competition between the planted trees and shrubs occurs, and substantial levels of debris don't accrue until competition, or disturbance events, results in substantial mortality (self thinning).

The only site where measured carbon stocks exceeded the FullCAM 3.55 estimates was the 'McFarlane E' site (Figure 22). Reasons may include that the trees had access to a high water table and the high proportion of the most productive species (*E. sargentii* and *E. spathulata* (see Figure 31 pg 47)) in the plantings. These are factors that the FullCAM 3.55 calibrations are not sensitive to.

SALINITY

Calibration of the EM38

Calibrations (significant regressions) of ECe on ECa were obtained for the sites in four of the farms, i.e. Andrew, Butcher (saltbush and waterway sites), Eva, and McFarlane (East and West sites) (Figure 23). However, calibrations could not be obtained for the Falconer and the McGlew farms. Therefore the calibration line for Falconer and McGlew in Figure 23 is based on the correlation between ECe and ECa for all measurements at the other sites.

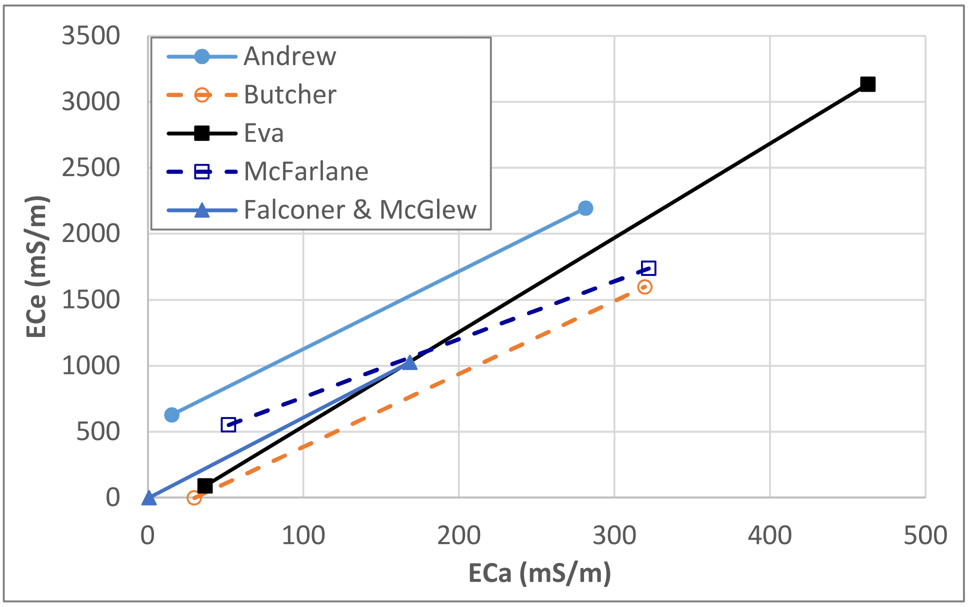


Figure 23. Calibrations for determining ECe from ECa.

From Figure 23 it is possible to determine an approximate conversion from ECa to ECe, e.g. ECa 300 mS/m ≈ ECe 2,000 mS/m. Except for Falconer and McGlew, it is also possible to determine the conversion specific to the farm.

Because of the problems with calibration of the EM38 ECa readings against ECa for some farms it was decided to base all analyses of salinity effects on ECa rather than ECe.

Effect of salinity on carbon stocks

Across all sample plots there was a large variation in tree carbon stocks at age 15 years (TC_{15}) on salinity. However, the maximum rates of carbon accumulation decreased with increasing salinity beyond ECa = 200 mS/m (Figure 24).

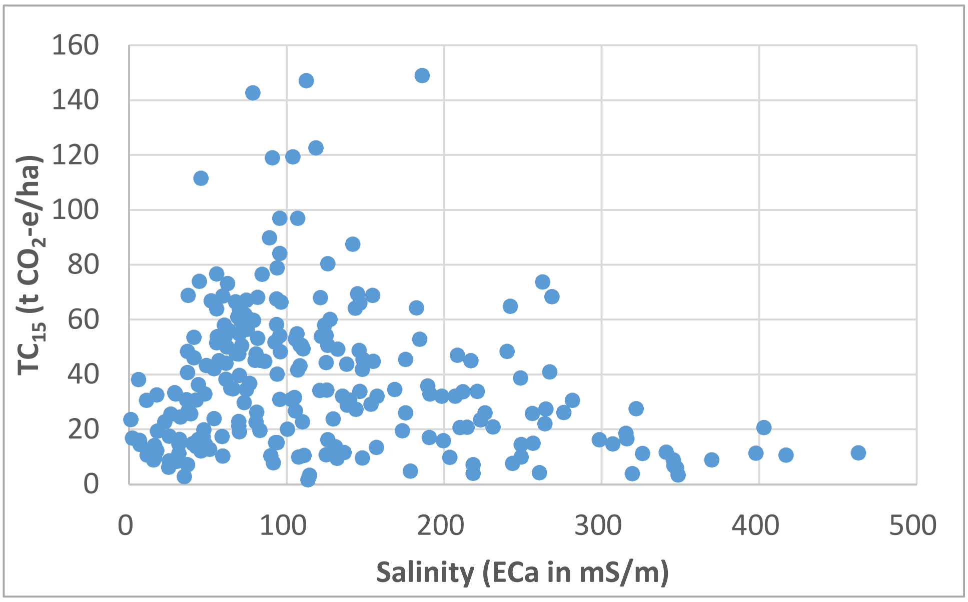


Figure 24. Carbon stocks at age 15 years (TC_{15}) on ECa for all sample plots at all sites.

Comparison of average TC_{15} levels for salinity categories (Figure 25) indicated a similar trend. There was no significant difference in the TC_{15} levels for the two lowest salinity categories (ECa < 100 mS/m and ECa 100 – 199 mS/m). The average salinity of these categories was 42 mS/m. However average TC_{15} in the next category (ECa 200 – 299 mS/m) was significantly lower, and average TC_{15} in the highest salinity category (ECa > 300 mS/m) was significantly lower again. (Significant differences assessed by pairwise t-tests at the $p = 0.05$ level).

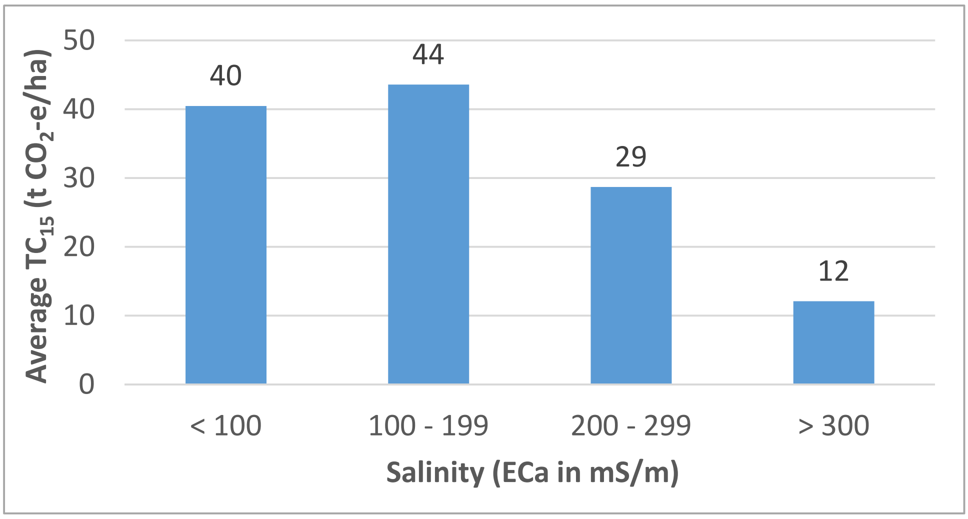


Figure 25. Average Tree Carbon stocks at age 15 years (TC_{15}) for salinity (ECa) categories.

Similar trends of decreasing TC_{15} with increasing salinity were observed at all sites that had sample plots with ECa > 200 mS/m (Figure 26).

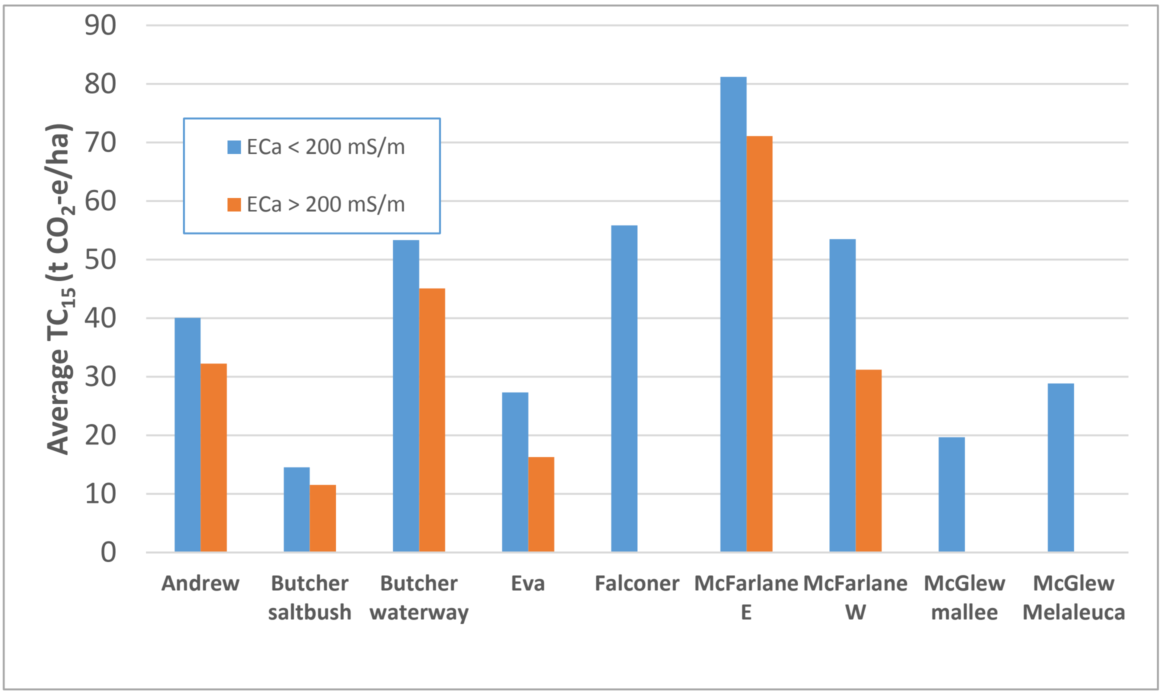


Figure 26. Average tree carbon stocks at age 15 years (TC_{15}) for salinity categories at the study sites. Note: at the Falconer and both McGlew sites there were no plots with ECa > 200mS/m.

SPECIES COMPARISONS

Carbon benefits

Figures 27-30 show, for each of the four salinity categories, the average tree carbon stocks at age 15 years (TC_{15}) of all tree species measured in sample plots in the salinity category. More details for each 'species x salinity' category are provided in Appendix 2.

Based on this information, Table 11 provides a summary of 'recommended' and 'possible suitable' species for each salinity category for maximum carbon benefit. 'Recommended species' are those with the best growth rates (most carbon sequestration) and with sufficient (≥ 3) individuals measured in the sample plots to indicate growth rates.

Table 11. Recommended and possibly suitable species for maximum carbon benefit.

	Salinity category (ECa in mS/m)			
	<100	100-199	200-299	>300
Recommended tree species	*E. sargentii* *E. spathulata* *E. salicola* *E. arachnaea* *E. diminuta* *A. microbotrya* *E. salmonophloia*	*E. sargentii* *E. capilosa* *E. spathulata* *E. eremophila* *E. salicola* *E. loxophleba*	*E. capilosa* *E. sargentii* *E. spathulata* *E. kondininensis* *E. platypus* *E. loxophleba*	*E. spathulata* *E. sargentii*
Possibly suitable tree species	*A. rostellifera*	*E. arachnaea* *A. saligna* *E. salmonophloia* *A. microbotrya*	*E. arachnaea* *E. diminuta*	*E. salicola*
Recommended shrub species	*M. thyoides* *M. adnata* *M. eleuterostachya* *M. uncinata*	*M. adnata* *M. uncinata* *M. eleuterostachya*	*M. uncinata*	*M. uncinata* *M. thyoides*
Possibly suitable shrub species	*A. merrallii*	*M. thyoides*	*M. acuminata* *M. thyoides*	(no recommendation)

'Recommended' = good growth and measured ≥ 3 individuals; 'Possibly suitable' = good growth but measured < 3 individuals (need more measurements).

Other 'possibly suitable' species had less than three individuals measured but those individuals had good growth rates. These species may also have good potential for carbon sequestration. However, more measurements on these species is required to confirm their carbon value. That could be done on the plantings outside of the sample plots.

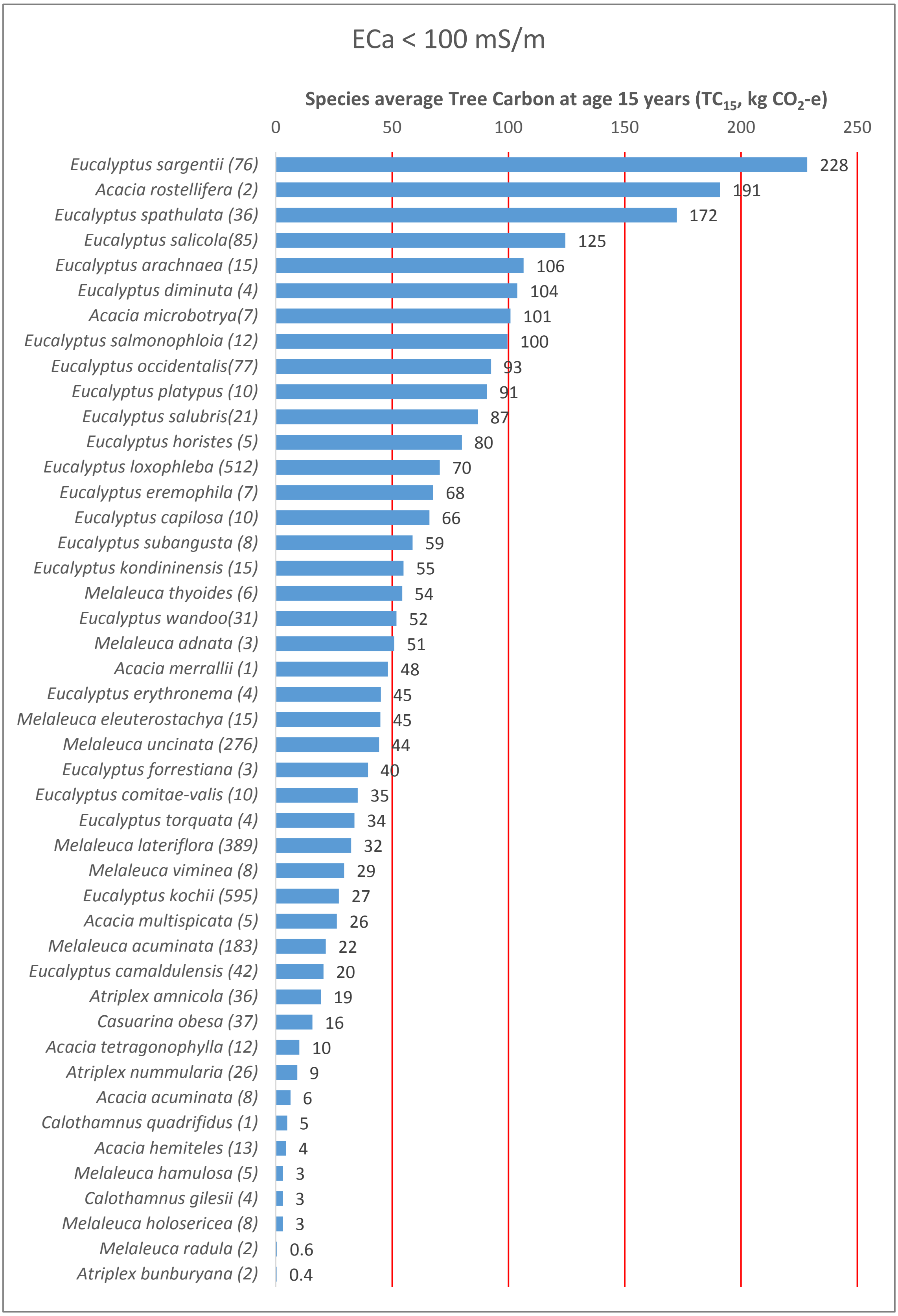


Figure 27. Average TC_{15} for all species in sample plots with salinity (ECa) < 100 mS/m. Numbers in brackets indicate the number of individuals measured.

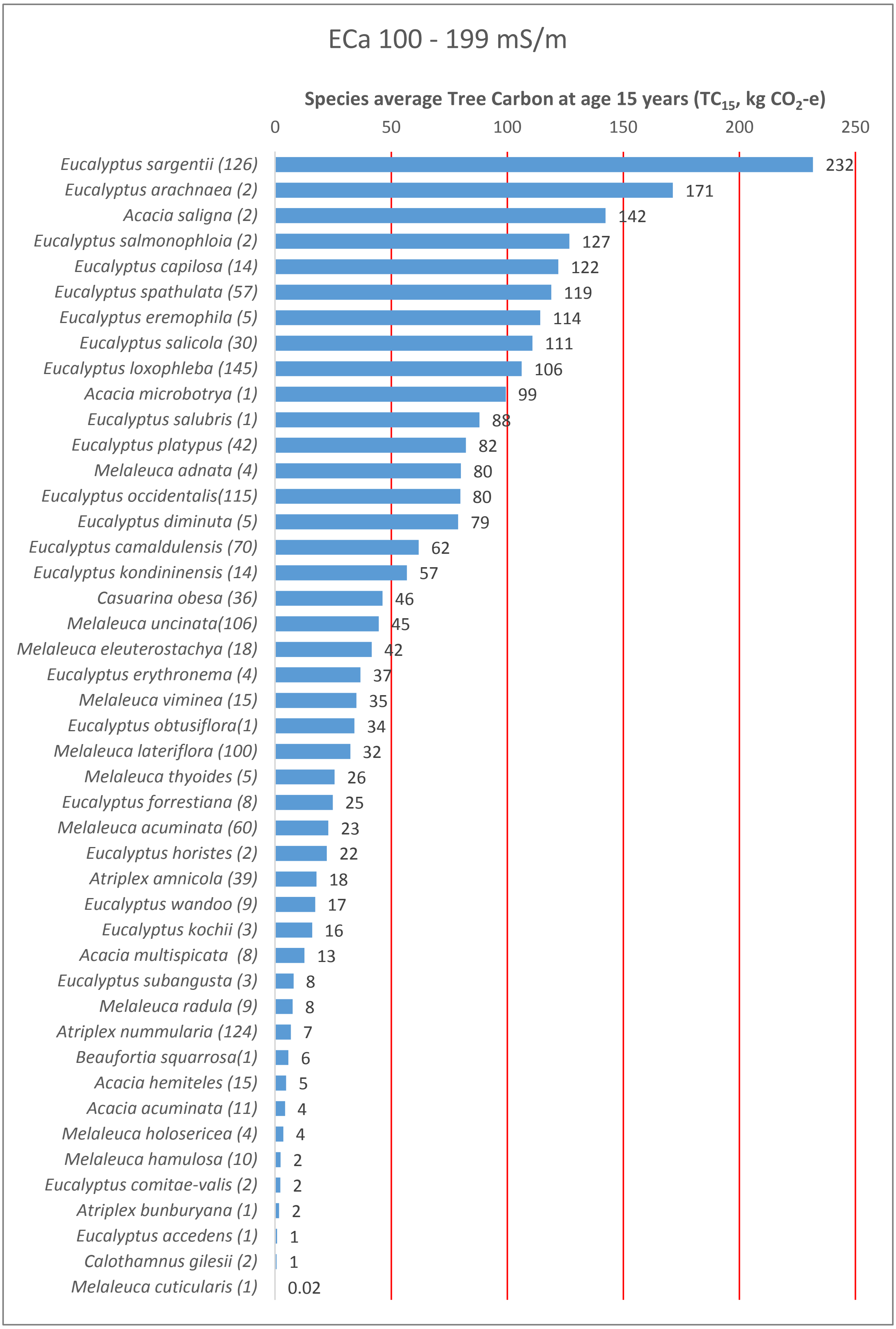


Figure 28. Average TC_{15} for all species in sample plots with salinity (ECa) 100 – 199 mS/m. Numbers in brackets indicate the number of individuals measured.

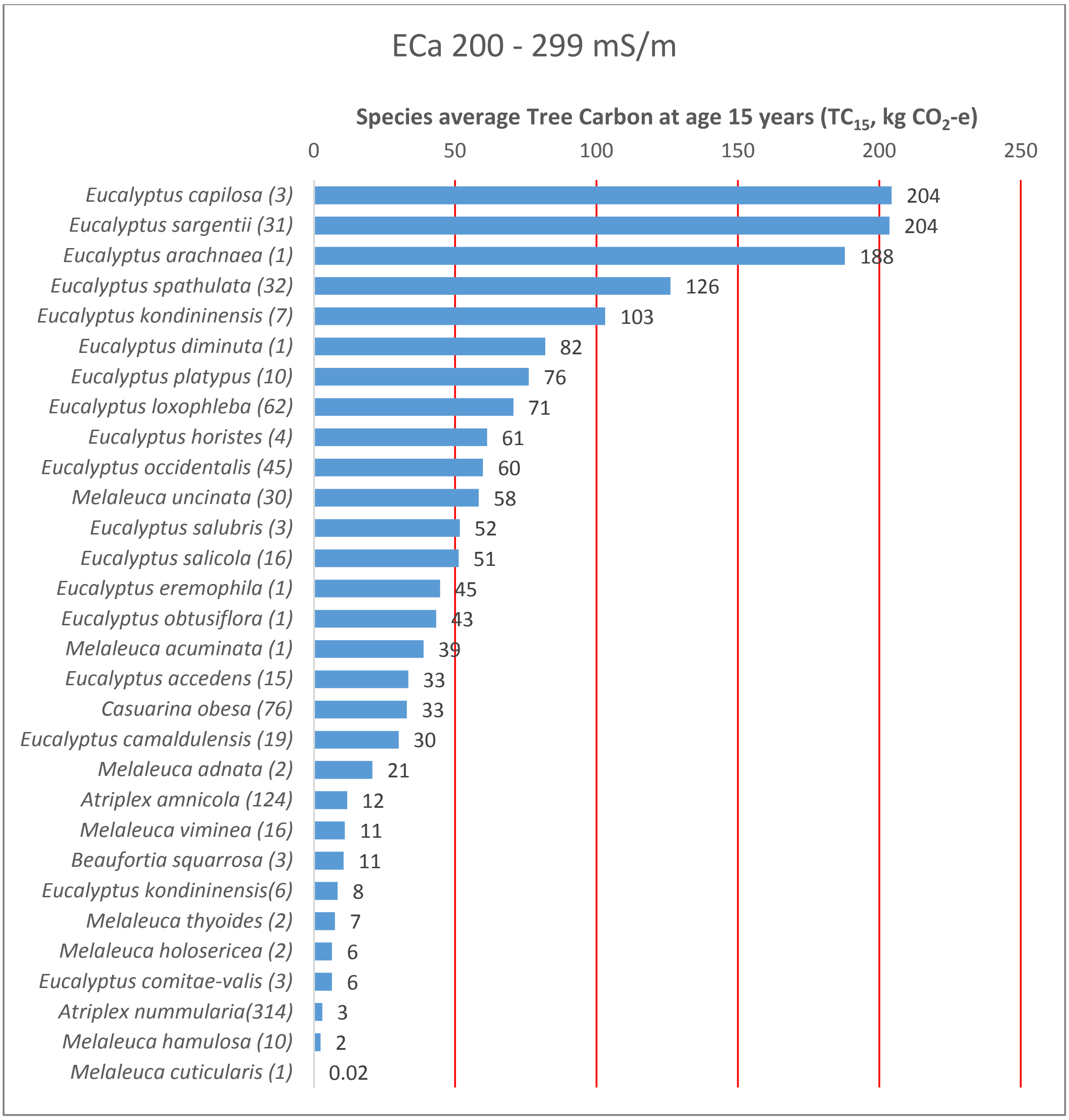


Figure 29. Average TC_{15} for all species in sample plots with salinity (ECa) 200 – 299 mS/m. Numbers in brackets indicate the number of individuals measured.

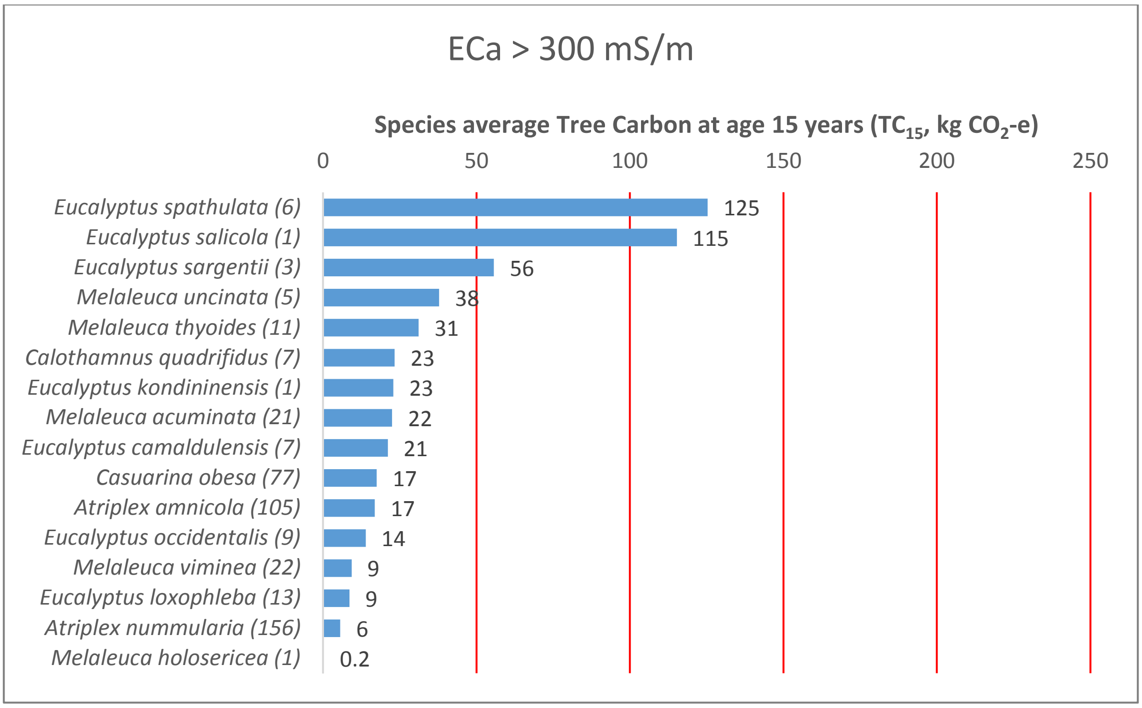


Figure 30. Average TC_{15} for all species in sample plots with salinity (ECa) > 300 mS/m. Numbers in brackets indicate the number of individuals measured.

Multiple benefits

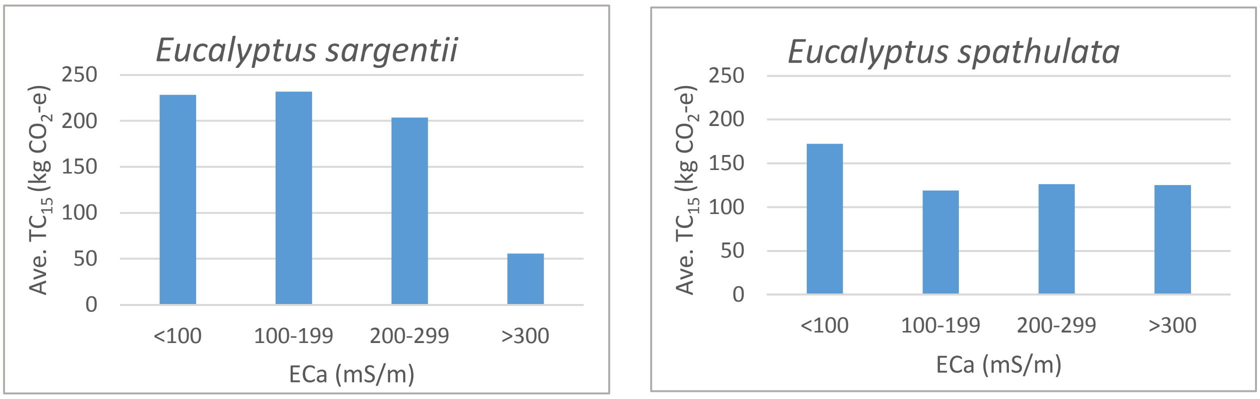
Figure 31 shows the clear superiority of tree form Eucalypts for growth rate and therefore, carbon value in all salinity categories. The best performing tree form species had, at least, double the carbon sequestration rate compared to the best performing species in other categories.

Interestingly, the best performing mallee species (*E. loxophleba* subs *lissophloia* and *E. kochii* subsp *borealis*), both species commonly planted for carbon purposes, achieved far less growth than the best performing tree species (*E. sargentii* and *E. spathulata*) that are seldom, if ever, planted for carbon purposes. For example, see Figure 32.

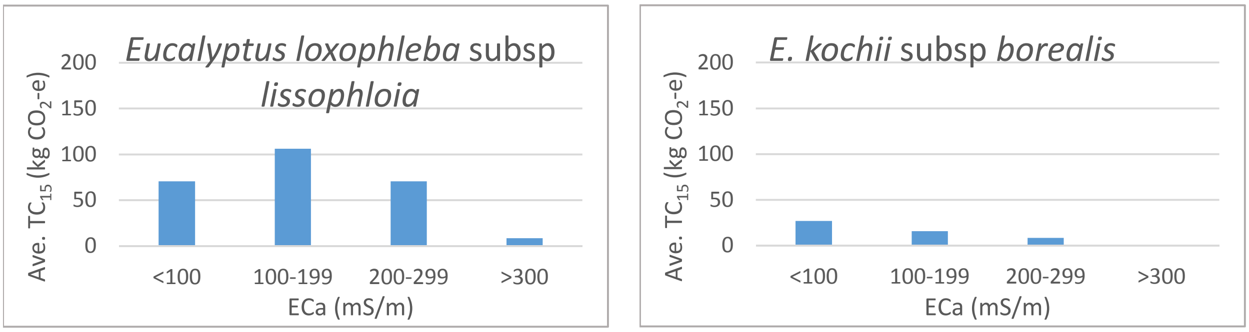
However, mallee and shrub species may provide other benefits besides carbon sequestration. Thus, the mallees were originally selected for leaf oil production and their coppicing ability. Another potential market for mallees is biomass for bioenergy. However, the tree form species will produce more biomass and most tree form *Eucalyptus* species can be harvested and managed on a coppice systems. With tree form species there is also the potential to produce sawn or round timber products as well as biomass.

A simple and worthy follow up study would be to check which of the 38 species that were harvested to develop the allometrics have regrown from coppice.

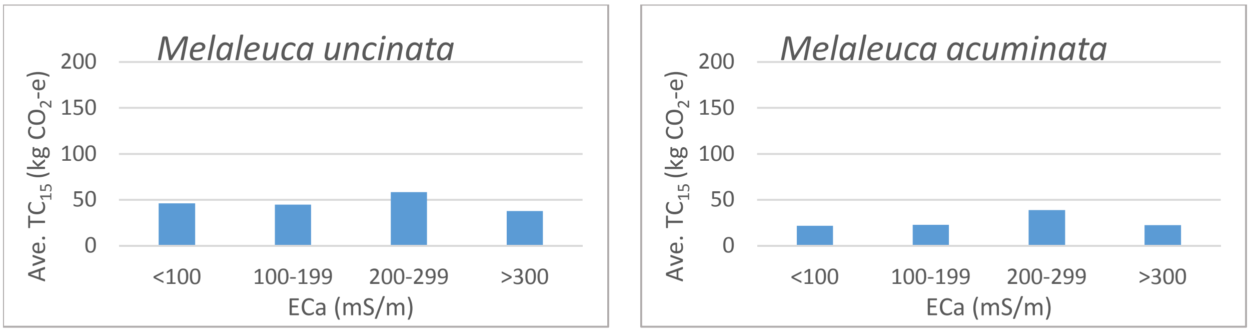
(a) Tree form



(b) Mallee



(c) Melaleuca



(d) Saltbush fodder shrubs

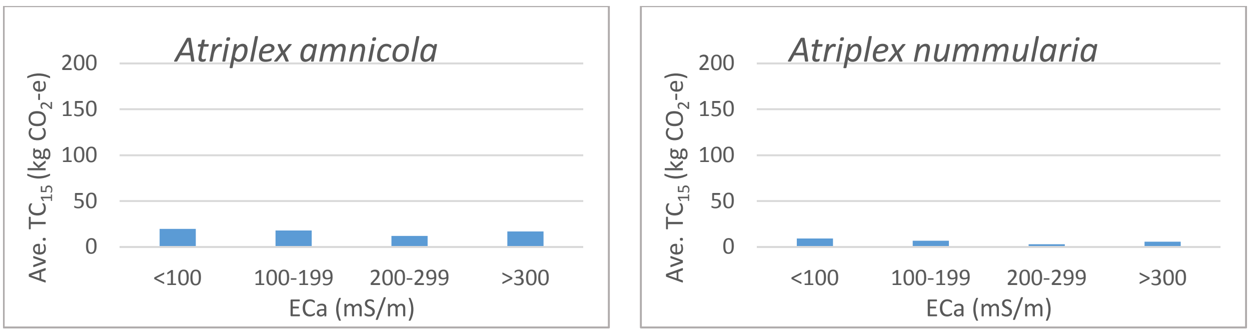


Figure 31. Effect of salinity (ECa) on tree carbon stocks at age 15 years for the best performing species from groups: (a) Tree form, (b) mallee, (c) Melaleuca, and (d) Saltbush fodder shrubs.

Figure 32. An *E. sargentii* established in a belt of *E. loxophleba* subsp *lissophloia* at the McGlew mallee site. This was in a sample plot. The average AGB of the *E. loxophleba* subsp *lissophloia* in that plot was 36 kg, compared to 426 kg for the *E. sargentii*.

The species planted on the sites were generally all native species. Thus, all have biodiversity value, particularly if planted with a diverse mix of tree and shrub species. The *Melaleuca* species, which are often prolific producers of flowers and nectar, will have particular biodiversity value.

Figure 33. Crested Bronzewing nest in *Melaleuca lateriflora*.

One indication of the biodiversity value of the study sites was the many birds observed, not only feeding in the plantings but nesting as well. Nests found during the sampling program included a Mistletoe Bird nest in a *Eucalyptus spathulata*, a Yellow Rumped Thornbill in a *Melaleuca thyoides*, a

Crested Bronzewing in a *Melaleuca lateriflora* (Figure 33), and a Red-Capped Robin in a regenerating *Acacia* species.

Some species, especially saltbush (*Atriplex*) species are suitable fodder for sheep and other livestock.

Revegetation around salt scalds can, in addition to commercial values, have aesthetic value, e.g. improve the visual landscape by putting a green belt around ugly salt scalds.

CONCLUSIONS

STUDY DESIGN

By studying plantings at nine sites, across six farms, with ages from 11 – 22 years, and a range of species and salinity levels, it was possible to evaluate the effect of salinity on growth (carbon sequestration) rates and 'species x salinity' interactions.

Thus the strategy of studying existing plantings established by landowners in the Northern Agricultural Region was an effective way of evaluating carbon farming opportunities for salinity management.

An alternative would have been to establish new plantings, e.g. demonstration sites and/or experimental layouts. However, apart from the cost of establishing new plantings, a considerable disadvantage of such an approach would be that it is necessary to wait for some years, e.g. around 10 years, before meaningful results can be obtained.

Of course longer-term monitoring is desirable. To this end all sample plots were permanently marked and every second sample plot on the study site was left undisturbed as a Permanent Sample Plot (PSP), available for re-measurement. Any disturbance through destructive sampling for allometrics development was confined to the other sample plots, i.e. the Temporary Sample Plots (TSPs).

It is recommended that the PSPs be re-measured in the future. This could be done 3 – 5 years after the first measurements in 2013. This will indicate which species are still healthy and growing vigorously, and which species are declining, e.g. growth rates have slowed or heavy mortality rates.

Interval growth measurements also provide vital data for growth modelling purposes. This would assist with the calibration of FullCAM for Mixed Species Environmental Plantings (MSEP). To date the calibrations for MSEP in FullCAM have been calculated from single (not interval) growth measurements (Paul et al., 2014). However, use of re-measurement (interval) measurement data would greatly assist in determining the shape of the growth curves, especially the G parameter that determines the age of peak growth rate, i.e. the age at which grow rate begins to decline.

ALLOMETRICS

The approach of destructive sampling to develop allometrics for as many of the species on the study sites as possible, rather than relying on generic allometrics for all or most species, was also supported by the results. Thus, the clear differences in the species allometrics, especially the shrub species where CVI was used to predict biomass, indicated that substantial errors would occur in biomass estimates for individual species from applying a generic allometric. Although it could not be tested, the approach of applying a species allometric developed from a small number of destructive sample trees (e.g. < 10 BSTs) was preferred to applying a generic allometric developed from a larger number of BSTs, on the basis that the species allometric would be less likely to be biased.

Use of generic allometrics for the 'minor' species was justified on the basis that those species only accounted for 1.9% of all trees measured in the sample plots and 0.8% of the total predicted AGB over all study sites. Therefore this would have resulted in only small errors in the estimates of carbon stocks at the plot and site level due to the relatively small contributions from those species. However, reliable evaluation of the carbon sequestration value of those minor species is not possible due to lack of a species allometric and the small number of individuals measured.

Use of generic allometrics is sometimes recommended for carbon accounting purposes (Jonson and Freudenberger, 2011; Paul et al., 2014; Williams et al., 2005). However, if there are differences between species as was shown for this study for both the trees and (more so) the shrubs, then this will introduce errors in the estimates of site or project carbon stocks unless the species composition in the sites (or project) is the same as in the sample of BSTs used to develop the generic allometric.

EFFECT OF SALINITY ON CARBON STOCKS

The EM38 meter for measuring soil apparent electrical conductivity (ECA) proved to be a good and efficient method for characterising soil salinity.

Across all sites, carbon stocks decreased with increasing salinity beyond ECa 200 mS/m. There was no significant difference between salinity categories of ECa < 100 mS/m and ECa 100 – 199 mS/m. For these categories the average Tree Carbon stocks at age 15 years (TC_{15}) was 42 t CO_2-e/ha. However, TC_{15} declined to 29 t CO_2-e/ha (68%) for sample plots with ECa 200 – 299 mS/m, and to 12 t CO_2-e/ha (29%) for sample plots with ECa > 300 mS/m.

These levels of carbon stocks indicate modest returns from carbon credits from similar plantings. For example, if carbon credits are worth $20 per t CO_2-e, then after 15 years, the returns from planting on non-saline (ECa < 200 mS/m) land would be $8,400 per ha. However, with the large variation in the growth rates of species observed, it should be possible to increase the returns considerably by planting the more productive species.

Planting on saline lands (e.g. ECa > 200 mS/m) would provide lower returns from carbon credits. However, again there is the potential to increase returns by planting the species identified as the most productive on saline lands. For example, if a site with moderate salinity (ECa 200 – 299 mS/m) was planted with a combination of high productivity trees and shrubs, e.g. 400 trees/ha *E. sargentii* and 400 shrubs/ha *M. uncinata*, then the results of this study indicate the potential to increase TC_{15} from the average 29 t/ha measured to around 105 t CO_2/ha.

It is also worth noting that saline lands are generally not suitable for agricultural crops. Hence, reforestation with trees and shrubs has the potential to get some return from carbon credits from otherwise 'marginal' or 'non-productive' cleared lands and provide other benefits such as reducing the spread of salinity and increasing biodiversity.

FULLCAM

Of the two versions of FullCAM used to predict carbon stocks at the nine study sites at the ages they were measured, FullCAM 3.40 under-predicted carbon stocks except for the 'Eva' and 'Butcher saltbush' sites. The 'Eva' site had the highest salinity levels (average ECa 245 mS/m) of all sites which may explain the low carbon stocks compared to those predicted for the 'Eva' site. The 'Butcher saltbush' site had a moderate salinity level (average ECa 153 mS/m) but other factors that may explain the low carbon stocks compared to predicted were the very low stocking of trees and the annual grazing of the saltbush shrubs.

The more recent version of the model (FullCAM 3.55) gave substantially higher predictions of carbon stocks (average 280% higher). Hence, FullCAM 3.55 over-predicted carbon stocks in all but one site. At the 'Eva' and 'Butcher saltbush' sites the over-prediction exceeded 500%.

The only site where FullCAM 3.55 under-predicted carbon stock was at the 'McFarlane E' site. That may have been because the trees had access to a high water table that was not too salty for the species planted and the high proportion of the most productive species in the mix of species planted.

Possible reasons for the inaccuracy of FullCAM to predict carbon stocks at the site level include:

1. The model is not sensitive to human-induced soil conditions such as secondary salinity and other land degradation processes that may depress growth, or other factors that may stimulate growth such as high water tables and enhanced fertility.

2. The model is not sensitive to the species in a Mixed Species Environmental Planting (MSEP). This study shows that there is very large variation between species in carbon sequestration rates even when all species are local natives.
3. The model appears to overestimate debris carbon stocks compared to the levels generally observed in young plantings such as the study sites (11 – 22 years old).

SPECIES

As previously noted, there were substantial differences between species in the growth (carbon sequestration) rates to age 15 years. Thus, if tree planting is done for a carbon purpose, large gains can be achieved by selecting the more productive species.

Tree form *Eucalyptus* species such as *E. sargentii* and *E. spathulata*, had clearly superior carbon sequestration rates. These species accumulated at least double the carbon stocks to age 15 years compared to the best performing mallee or shrub species in any of the salinity categories.

However, other species may be of more value for other benefits besides carbon sequestration. Thus, mallee species such as *E. kochii* subsp *borealis* and *E. loxophleba* subsp *lissophloia* were originally selected for leaf oil production. Tree form species can provide farm timbers, including fence posts, and *Melaleuca* species can provide material for brushwood fences around houses. (Troup, 2008). All local native tree and shrub species will provide biodiversity value with some, such as *Melaleuca* shrub species that are often prolific producers of flowers and nectar, having particular biodiversity value. The saltbush (*Atriplex*) species provide fodder for sheep and other livestock, and other species may also have fodder value. All revegetation will provide multiple other benefits such as reducing soil erosion and the spread of secondary salinity and the aesthetic value of putting a green belt around ugly salt scalds.

RECOMMENDATIONS FOR FURTHER STUDY

The following are recommendations for follow-up studies if funding can be obtained.

Coppicing ability

The Biomass Sample Trees that were destructively sampled to develop allometrics could be re-visited to check for regrowth from new shoots from the stumps (coppice growth). This would show which of the 37 species involved have the ability to re-grow from coppice. The coppicing ability of many species is unknown but it can be a useful means of regenerating after harvest.

Carbon value of the ‘possibly suitable’ species

Further measurements could be undertaken on the species rated as ‘possibly suitable’ in Table 11. They were species that had less than three individuals measured in the sample plots in a salinity category but those individuals had good growth rates. More measurements on those species are required to confirm their carbon sequestration value.

Any new measurements of the ‘possibly suitable’ species will need to be done outside the original sample plots. This could be done by expanding the sample plots (TSPs and PSPs) where ‘possibly suitably’ species were recorded, i.e. a ‘nested plot’ arrangement.

Of the 10 ‘possibly suitable’ species in Table 11, six had species allometrics developed (from sampling those species in other salinity categories). They were four species of *Eucalyptu*s (*E. salicola, E. arachnaea, E. diminuta, E. salmonophloia*) and two species of *Melaleuca* (*M. acuminata, M. thyoides*). Therefore, it would not be necessary to develop allometrics for those species.

However, species allometrics have not been developed for the remaining four ‘possibly suitable’ species, all *Acacia* species (*A. saligna, A. microbotrya, A. rostellifera, A. merrallii*). For these species, the generic allometrics could be applied or further destructive sampling could be done (e.g. in the expanded TSPs) to develop species allometrics.

Re-measure PSPs

It is also recommended that the PSPs be re-measured three to five years after initial measurement.

It is preferable that the PSPs be remeasured at precise whole year intervals. Therefore, as they were first measured in April to June, 2013, it is recommended that they be re-measured in April to June of either 2016, 2017, or 2018.

As allometrics have been developed, i.e. species allometrics for the 37 main species and generic allometrics for the 13 minor species, it should not be essential that further destructive sampling be done to re-develop allometrics. If further destructive sampling is done then it should be to extend the maximum size of BSTs in the allometrics development data sets. In that case it is important that the BSTs be taken from the TSPs or, elsewhere, outside the PSPs so the PSPs can remain undisturbed.

As previously noted, re-measurement of the PSPs will indicate which species are still healthy and growing vigorously and which species are declining, e.g. little new growth or suffering heavy mortality.

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APPENDICES

APPENDIX 1. PROTOCOL FOR STEM DIAMETER MEASUREMENTS ON TREES

1) For **tree form** species (i.e any species not defined to be a mallee):
   a) Measure diameter over bark of stems at the target height of:
      i) 1.3 m, i.e. Diameter at Breast Height (DBH); or
      ii) 0.5 m, i.e. Diameter at Knee Height (DKH); or
      iii) 0.1 m, i.e. Diameter at Ankle Height (DAH).
   b) Generally measure stem diameter at the greatest height possible where there is at least one stem with a diameter ≥ 10 mm.
   c) Measure the stem diameter over-bark of each **live stem** ≥ 10 mm diameter.
   d) If no stem with a DAH ≥ 10 mm, measure the DAH of the thickest stem, or,
   e) If the tree has not reached a height of 0.5 m, no measurements or record is required.
   f) Do not measure stem diameters of dead stems or any (live or dead) branches.
   g) As a guide to determining stems:
      i. The tallest leader in a tree is a stem. (Most trees will only have one stem.)
      ii. Other co-dominant leaders are also stems, i.e. if they are:
         - Of similar height (generally at least 80% of the height of the tallest leader);
         - of similar diameter (generally at least 80% of the diameter of the tallest leader);
         - unlikely to be supressed by the tallest leader (e.g. they receive sunlight directly from above, not just from the side).

2) For **mallee** species:
   a) Mallee species are defined to be either *E. comitae-valis*, *E. horistes*, *E. kochii*, *E. loxophleba* or *E. subangusta*. (All other species are defined to be tree form species).
   b) Measure diameter over bark of each **live stem and branch** ≥ 10 mm diameter at a target height of:
      i) 1.3 m, i.e. Diameter at Breast Height (DBH); or
      ii) 0.5 m, i.e. Diameter at Knee Height (DKH); or
      iii) 0.1 m, i.e. Diameter at Ankle Height (DAH).
   c) Generally measure DKH of mallees.
   d) However, if very tall mallees, DBH may be measured.
   e) Alternatively, if a very short mallee, DAH may be measured.
   f) If no stem or branch with at the measurement height ≥ 10 mm, measure the diameter of the thickest stem or branch, or
   g) If the mallee has not reached a height of 0.5 m, no measurements or record is required.
   h) Do not measure stem diameters of dead stems or dead branches.
   i) Note: the reason for measuring diameters of live stems and branches in mallees, rather than just live stems, is that it is often difficult in mallees to categorise all leaders as either stem or branch.

3) For **mallee** and **tree form** species:
   a) If a stem is 'not representative' at the target measurement height then move up or down the stem to the nearest representative point and measure stem diameter at that height. Examples of 'not representative' conditions include forks, branches, lignotuber swelling and deformities such as caused by insect damage.
   b) Measure all stem diameters to the nearest whole mm.
   c) For stem diameters ≥ 50 mm, a diameter tape must be used.
   d) For stem diameters < 50 mm, callipers or a diameter tape may be used.
   e) Height to the point of measurement (0.1 m, 0.5 m, or 1.3 m) is measured from ground level on the uphill side of the tree.

f) If the trees were planted in mounds or furrows, height to the point of measurement is measured from the new ground level in the mound or furrow, not the natural land surface.

g) If there is a litter or debris layer > 20 mm thick this should be removed to determine ground level.

h) If a leaning stem (or branch of a mallee), 'height' to the point of measurement is measured along the stem, not vertically.

i) Only very loose bark should be removed from a stem or branch prior to diameter measurement, i.e. only remove bark that is peeling away from the stem.

j) If recording stem/branch diameters on a paper copy of the Recording Form, record multiple diameters as 'comma separated values'. E.g. if 3 stems with diameters of 57 mm, 23 mm, & 48 mm, record as '57, 23, 48'.

APPENDIX 2. ESTIMATES OF SPECIES TREE CARBON STOCKS BY SALINITY CATEGORIES

Notation: TC_{15} = tree carbon stocks at age 15 years; *n* = number of trees and shrubs measured; $\bar{x}$= mean, *s* = standard deviation, 95% CI = 95% confidence interval for the estimate of the mean (±); NA = not available.

Species	All ECa (mS/m)				ECa < 100 mS/m				ECa = 100-199 mS/m				ECa = 200-299 mS/m				ECa > 300 mS/m			
	n	TC_{15} (kg CO_2-e)			*n*	TC_{15} (kg CO_2-e)			*n*	TC_{15} (kg CO_2-e)			*n*	TC_{15} (kg CO_2-e)			*n*	TC_{15} (kg CO_2-e)		
		$\bar{x}$	*s*	95 % CI		$\bar{x}$	*s*	95 % CI		$\bar{x}$	*s*	95 % CI		$\bar{x}$	*s*	95 % CI		$\bar{x}$	*s*	95 % CI
Acacia acuminata	19	5	5	2	8	6	4	3	11	4	5	3	0	NA	NA	NA	0	NA	NA	NA
Acacia hemiteles	28	5	4	1	13	4	4	2	15	5	4	2	0	NA	NA	NA	0	NA	NA	NA
Acacia merrallii	1	83	NA	NA	1	48	NA	NA	0	NA	NA	NA	0	NA	NA	NA	0	NA	NA	NA
Acacia microbotrya	8	101	143	99	7	101	155	115	1	99	NA	NA	0	NA	NA	NA	0	NA	NA	NA
Acacia multispicata	13	18	14	8	5	26	15	13	8	13	12	8	0	NA	NA	NA	0	NA	NA	NA
Acacia rostellifera	2	191	52	72	2	191	52	72	0	NA	NA	NA	0	NA	NA	NA	0	NA	NA	NA
Acacia saligna	2	142	136	189	0	NA	NA	NA	2	142	136	189	0	NA	NA	NA	0	NA	NA	NA
Acacia tetragonophylla	12	10	13	7	12	10	13	7	0	NA	NA	NA	0	NA	NA	NA	0	NA	NA	NA
Atriplex amnicola	304	15	15	2	36	19	15	5	39	18	18	6	124	12	13	2	105	17	15	3
Atriplex bunburyana	3	1	1	1	2	0	0	0	1	2	NA	NA	0	NA	NA	NA	0	NA	NA	NA
Atriplex nummularia	620	5	18	1	26	9	12	5	124	7	23	4	314	3	17	2	156	6	15	2
Beaufortia squarrosa	4	9	3	3	0	NA	NA	NA	1	6	NA	NA	3	11	3	3	0	NA	NA	NA
Calothamnus gilesii	6	2	3	3	4	3	4	4	2	1	0	1	0	NA	NA	NA	0	NA	NA	NA
Calothamnus quadrifidus	8	21	14	10	1	5	NA	NA	0	NA	NA	NA	0	NA	NA	NA	7	23	14	10
Casuarina obesa	226	27	43	6	37	16	16	5	36	46	50	16	76	33	52	12	77	17	33	7
Eucalyptus accedens	16	31	23	11	0	NA	NA	NA	1	1	NA	NA	15	33	23	11	0	NA	NA	NA
Eucalyptus arachnaea	18	120	76	35	15	106	75	38	2	171	26	36	1	188	NA	NA	0	NA	NA	NA
Eucalyptus camaldulensis	137	43	64	11	42	20	28	8	70	62	81	19	19	30	33	15	7	21	22	16
Eucalyptus capilosa	27	110	99	37	10	66	86	53	14	122	99	52	3	204	74	84	0	NA	NA	NA

Eucalyptus comitae-valis	16	24	35	17	10	35	41	26	2	2	0	1	3	6	4	4	0	NA	NA	NA
Eucalyptus diminuta	9	72	44	29	4	104	72	70	5	79	14	13	1	82	NA	NA	0	NA	NA	NA
Eucalyptus eremophila	13	84	66	36	7	68	72	53	5	114	58	50	1	45	NA	NA	0	NA	NA	NA
Eucalyptus erythronema	8	41	31	21	4	45	30	30	4	37	36	35	0	NA	NA	NA	0	NA	NA	NA
Eucalyptus forrestiana	11	29	28	16	3	40	10	12	8	25	32	22	0	NA	NA	NA	0	NA	NA	NA
Eucalyptus horistes	11	63	48	28	5	80	41	36	2	22	15	21	4	61	61	59	0	NA	NA	NA
Eucalyptus kochii	604	24	25	2	595	27	26	2	3	16	15	17	6	8	5	4	0	NA	NA	NA
Eucalyptus kondininensis	37	64	81	26	15	55	52	26	14	57	90	47	7	103	114	85	1	23	NA	NA
Eucalyptus loxophleba	740	76	81	6	512	70	70	6	145	106	113	18	62	71	72	18	13	9	6	3
Eucalyptus obtusiflora	2	39	6	9	0	NA	NA	NA	1	34	NA	NA	1	43	NA	NA	0	NA	NA	NA
Eucalyptus occidentalis	246	78	94	12	77	93	97	22	115	80	98	18	45	60	83	24	9	14	19	12
Eucalyptus platypus	62	83	51	13	10	91	56	35	42	82	53	16	10	76	41	26	0	NA	NA	NA
Eucalyptus salicola	132	112	187	32	85	125	215	46	30	111	141	50	16	51	59	29	1	115	NA	NA
Eucalyptus salmonophloia	14	104	59	31	12	100	52	29	2	127	119	165	0	NA	NA	NA	0	NA	NA	NA
Eucalyptus salubris	25	83	61	24	21	87	65	28	1	88	NA	NA	3	52	20	23	0	NA	NA	NA
Eucalyptus sargentii	236	225	254	32	76	228	230	52	126	232	276	48	31	204	226	80	3	56	35	40
Eucalyptus spathulata	134	133	111	19	36	172	138	45	57	119	95	25	32	126	103	36	6	125	64	52
Eucalyptus subangusta	11	45	45	27	8	59	46	32	3	8	7	8	0	NA	NA	NA	0	NA	NA	NA
Eucalyptus torquata	4	34	23	22	4	34	23	22	0	NA	NA	NA	0	NA	NA	NA	0	NA	NA	NA
Eucalyptus wandoo	40	44	126	39	31	52	142	50	9	17	22	14	0	NA	NA	NA	0	NA	NA	NA
Melaleuca acuminata	262	22	11	1	183	22	10	1	60	23	14	4	1	39	NA	NA	21	22	17	7
Melaleuca adnata	9	57	61	40	3	51	51	57	4	80	80	79	2	21	11	15	0	NA	NA	NA
Melaleuca cuticularis	2	0	NA	NA	0	NA	NA	NA	1	0	NA	NA	1	0	NA	NA	0	NA	NA	NA
Melaleuca eleuterostachya	33	43	18	6	15	45	22	11	18	42	14	7	0	NA	NA	NA	0	NA	NA	NA
Melaleuca hamulosa	28	3	1	0	5	3	2	2	10	2	1	1	10	2	1	1	0	NA	NA	NA
Melaleuca holosericea	15	3	3	1	8	3	2	1	4	4	1	1	2	6	8	11	1	0	NA	NA

Melaleuca lateriflora	489	32	12	1	389	32	12	1	100	32	11	2	0	NA	NA	NA	0	NA	NA	NA
Melaleuca radula	11	11	10	6	2	1	0	0	9	8	10	7	0	NA	NA	NA	0	NA	NA	NA
Melaleuca thyoides	24	34	52	21	6	54	91	73	5	26	22	19	2	7	5	7	11	31	40	23
Melaleuca uncinata	418	47	25	2	276	46	23	3	106	45	29	6	30	58	30	11	5	38	19	17
Melaleuca viminea	61	19	29	7	8	29	33	23	15	35	43	22	16	11	17	8	22	9	15	6

APPENDIX 3. METHOD FOR PROJECTION OF TREE CARBON STOCKS

(i) The projection model

The FullCAM growth model (Waterworth et al., 2007) can be expressed in yield form as

$$y = \mathrm{a}\mathrm{e}^{(-2\mathrm{G}+1.25)/A} \qquad \text{Equation 11}$$

where:

y = response variable, e.g. tree carbon stocks

a = asymptote (e.g. maximum tree carbon stocks)

e = exponential (base of natural logarithms)

G = tree (stand) age of maximum growth rate, i.e. approximately the age of crown closure;

A = tree age.

In FullCAM the asymptote is also expressed as

$$\mathrm{a} = \mathrm{Mr}$$

where

M = predicted maximum value for native forests

r = rate parameter (non-endemic species multiplier).

A suitable projection form of Equation 11 can be calculated (e.g. following method in (Clutter et al., 1983, pp 50-54)) as

$$y_2 = y_1 \mathrm{e}^{(-2\mathrm{G}+1.25)\left(1/A_2 - 1/A_1\right)} \qquad \text{Equation 12}$$

where

y_1 and y_2 = the response variable at ages A_1 and A_2

Equations 11 & 12 do not account for any Type 1 or Type 2 responses (Snowdon, 2002). However, this was not considered necessary. Any Type 1 and Type 2 responses at the study sites will have occurred at the time of planting (Age = 0 years) and, therefore, will have been included in the calibrations of the G and r parameters, respectively, in the FullCAM growth model.

Also, Equations 11 & 12 do not account for the effects of any variation in actual climate in forward or back projections (to age 15 years). However this, of course, is not possible if projecting forward into the future as future climate is unknown. An assumption for the forward projections is that future climate will be similar to actual climate in the measurement period (from the time of planting to the time of measurement). The same assumption applies to the back projections, i.e. that the actual climate in the back projection period was similar to the actual climate in the measurement period. This also seems a reasonable assumption.

(i) Estimating the G parameter value

To estimate the G parameter value, Equation 11 was fitted to the measurement data for the nine sites (Figure 34). The measured carbon stocks in the belt plantings at the McFarlane E & W sites were reduced by half to simulate carbon stocks expected in block plantings.

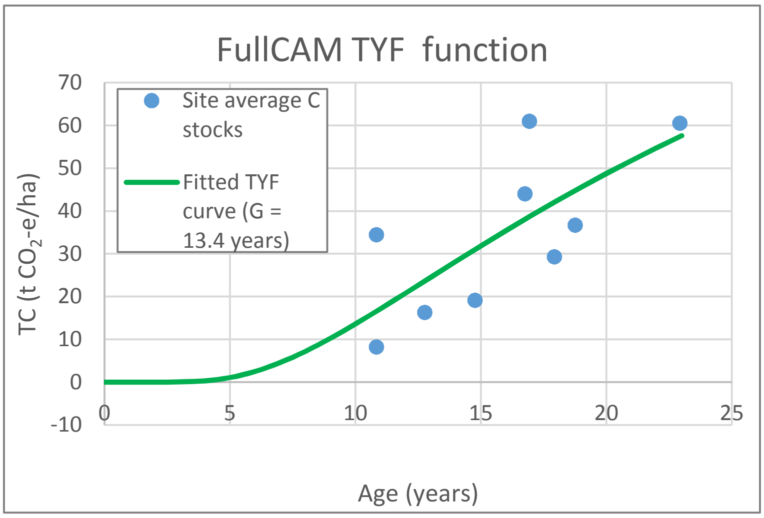

Figure 34. The FullCAM growth model in yield form (Equation 11) fitted to the measurement data of Tree Carbon (TC) stocks.

This indicated the asymptote (a) = 175 t CO_2-e/ha and G = 13.4 years. Both these estimates seem reasonable. However, Paul et al. (2014) estimated G = 5.2 – 8.5 years for MSEPT and the default in FullCAM is G = 10 years for MSEPT. Therefore, for all projections of carbon stocks in this study G = 10 years was assumed (see Carbon stocks pg 32-35).

However, the above estimate of the G parameter value and those of Paul et al. (2014) were derived from single measurements of carbon stocks at each site. If the PSPs in the study sites are re-measured as recommended, then the interval measurements of carbon stocks should allow more accurate estimation of the G parameter value.