Estimating native forest carbon stocks

Estimates of the carbon stored in native forest ecosystems, and how this might change over time, assists our understanding of how management, climate change and natural events such as bushfires may impact the total carbon pool. However, comprehensive carbon accounting for native forests is complex and throughout Australia is challenged by a lack of suitable data and predictive models.

Within the south west forests, the approach adopted for the *Draft Forest Management Plan 2014-2023* (Draft FMP) was also influenced by the type of data and information available for the forests. Carbon is stored in forest ecosystems in the soil, the below-ground biomass (roots), and the above-ground biomass (comprising trees, understorey, surface litter and coarse woody debris such as fallen trees). An extensive review has confirmed there is limited data available to estimate the soil carbon and below-ground biomass components of the total carbon pool, and that data available for the above ground biomass components varied markedly in quality, comprehensiveness and geographic representation.

The scope of the Department's work therefore focussed on estimating that component of the total carbon stock for which reliable, consistent data was available and for which sampling had covered most of the forests – the above-ground component of live standing trees. This generally comprises the largest proportion of the total carbon pool in the forest, and is the component for which quite robust mathematical relationships have been developed to indirectly estimate the below ground components. The change during the period of the Draft FMP in the above- and below-ground biomass carbon stocks was also estimated for each of the two scenarios for sustained yield presented in the plan.

The following sections provide further information on the development and interpretation of the estimates presented in the Draft FMP in Table 5 ('Indicative estimates of the above- and below-ground live tree carbon stocks to 2014 in major native forest types') and Table 6 ('Projected changes in the indicative above- and below-ground live tree carbon within major forest types under the Draft FMP scenarios for sustained yield').

Calculating carbon stocks

Area and stratification

The carbon stock estimates were prepared for the 2.25 million hectares of forests on lands vested in the Conservation Commission within the Regional Forest Agreement boundary. The total forest area was stratified into forest ecosystems (Bradshaw and Mattiske, 1997) for the purpose of calculating carbon stocks, within which timber harvest history and forest structure categories were identified. Appendix 7 in the Draft FMP summarises the areas within each forest ecosystem, and an extract from it is presented next:

Table 1: Total area (hectares) of each forest ecosystem within the Regional Forest Agreement boundary for which carbon stock estimates were prepared.

Forest Ecosystem	**Present extent on all lands vested in the Conservation Commission**
	Area (hectares)
Jarrah dominant	
Jarrah Blackwood	267,210
Jarrah Leeuwin	9,570
Jarrah Mt Lindesay	26,680
Jarrah North East	260,880
Jarrah- North West	448,510
Jarrah Rate's Tingle	1,160
Jarrah Red Tingle	220
Jarrah Sandy	64,180
Jarrah South	420,280
Jarrah Unicup	16,950
Jarrah Woodland	50,160
Jarrah Yellow Tingle	8,260
Karri dominant	
Karri Main Belt	151,430
Karri Rate's Tingle	790
Karri Red Tingle	5,220
Karri West Coast	4,750
Karri Yellow Tingle	11,770
Wandoo dominant	
Western Wandoo forest	99,530
Western Wandoo woodland	44,760
Other	
Bullich and Yate	2,190
Darling Scarp	3,830
Peppermint and Coastal Heath	62,330
Rocky Outcrops	12,620
Sand Dunes	11,320
Shrub, Herb and Sedgelands	255,170
Swamps	6,650
Whicher Scarp	5,190
Total	2,251,600

Inventory

The source of data on the amount of live standing trees was the various timber inventories that have been conducted throughout the south west forests to inform the calculation of sustained timber yields. These are described in the supplementary reading on the calculation of sustained yields for the Draft FMP (see paper '*2.3 Inventory of the forest*' in the sustained yield information sheets).

The available timber inventory datasets were intersected with each forest ecosystem and forest

structure category to estimate the total live tree volume for each ecosystem. However, the sample intensity and representation of the inventory plots varied markedly across the forest ecosystems, with jarrah forest areas in State forest and timber reserves being most heavily sampled (Figure 1), while the peppermint, coastal heath, and the shrub, herb and sedgelands had few plots - hence estimates were supplemented from research plots and published literature.

By design, the available timber inventories sample the forests then available for timber harvesting at the time they were conducted, and so that portion of the forest ecosystems that are located in formal reserves are less well represented in the inventory datasets. Where limited inventory data was available the approach adopted was to attribute those areas in formal reserves with the same volume estimates derived for areas with the same harvest history and structure in State forest.

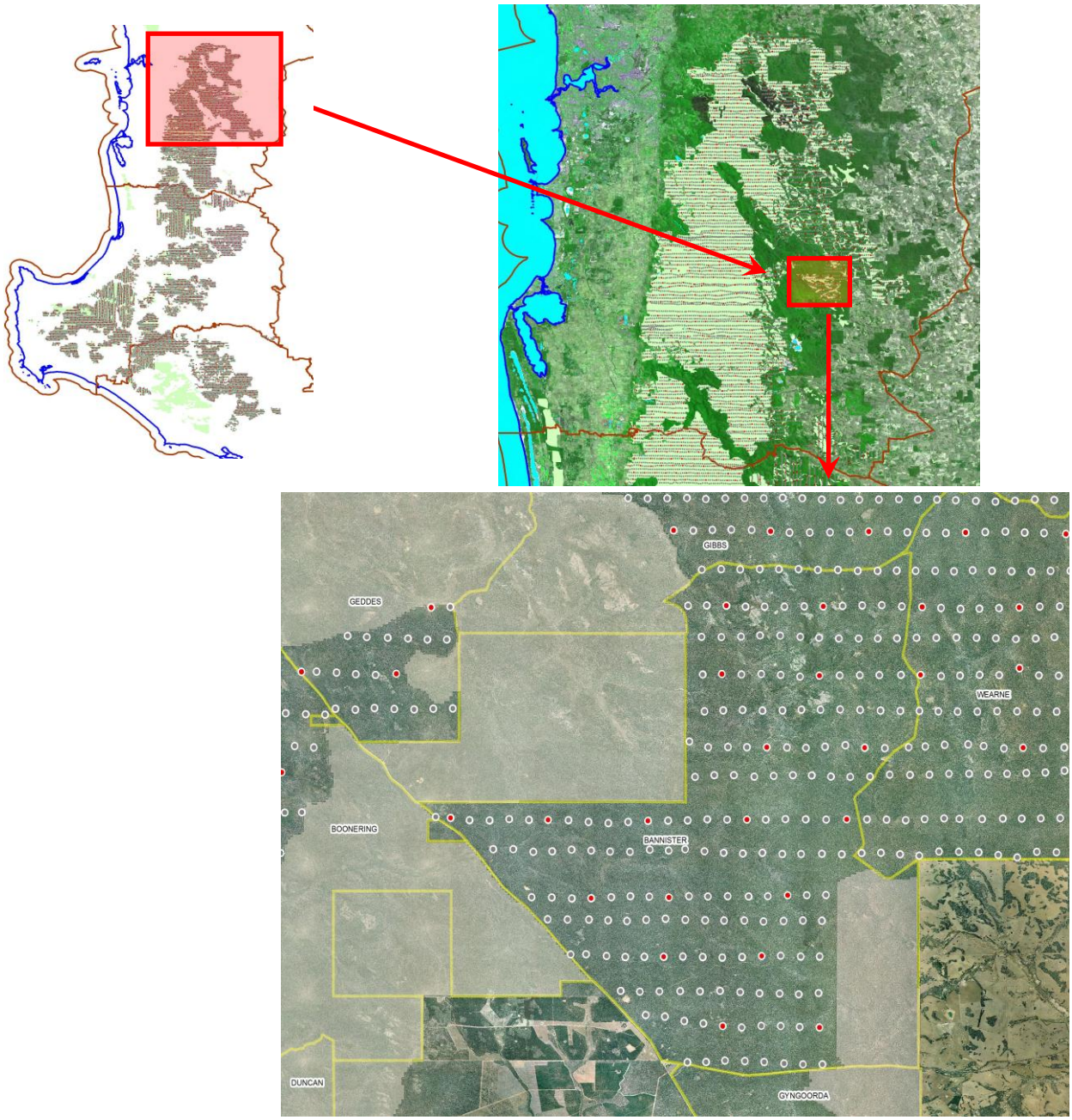

Figure 1: Location of jarrah inventory plots sampling the tree volumes within the forest. The white circles in the above image depict photo plots, the red circles depict ground plots. The dominant forest ecosystems represented in the image are Jarrah North East, Wandoo Forest, and Wandoo Woodland.

Conversion from forest inventory to carbon mass

The forest inventories measured the volume of tree boles. In order to derive an estimate of the carbon stock of live trees, several calculations were required.

1. Tree bole volumes were converted to equivalent biomass by multiplying the volume estimates by the published basic density of the dominant species:

   Table 2: Basic density values of dominant tree species for south west forests.

Dominant species	Basic density (kilograms per cubic metre)
Jarrah (*Eucalyptus marginata*)	658
Karri (*Eucalyptus diversicolor*)	695
Marri (*Corymbia callophylla*)	663
Wandoo (*Eucalyptus wandoo*)	921
Yellow Tingle (*Eucalyptus guilfoylei*)	693
Red Tingle (*Eucalyptus jacksonii*)	589
Blackbutt (*Eucalyptus patens*)	689

Source: Shedley, PN and Challis, D.J. (1984) Mechanical properties of timbers commonly used in Western Australia. Technical Paper No.7, Forests Department of Western Australia. 21 pp.

   In some ecosystems (such as coastal heath and swamps), estimates of total above-ground biomass were available, so conversion factors were not required.

2. The bole biomass was 'scaled up' to include those components of the above ground biomass in trees that are not directly measured in the bole inventory (i.e. the bark, branches and leaves). An 'expansion' or scaling factor of 1.46 was applied to the estimates of live bole biomass to compute the total above-ground live-tree biomass (see Snowdon *et al.* 2000). The total carbon stock estimates are particularly sensitive to the value of the expansion factor, which is likely to vary between forest ecosystems and stand development stages.

3. The below-ground root biomass of the trees was estimated by multiplying the above-ground biomass by 1.25, representing an accepted root-to-shoot ratio.

4. The tree and root biomass was assumed to comprise 50 per cent carbon, and so biomass was multiplied by 0.5 to derive an estimate of the total weight of carbon.

The same expansion factor, root-to-shoot ratio and carbon percentage was applied across each forest ecosystem. Hence, the derived carbon stock values are best estimates and may be refined over time as more information becomes available.

The variation between forest ecosystems in the average above- and below-ground live tree carbon estimates was as follows:

Table 3: Average above- and below-ground live tree carbon (tonnes per hectare) derived for the land tenure categories within each forest ecosystem.

Forest Ecosystem	**Formal reserves and forest conservation areas**	**State forests and timber reserves**
	Biomass carbon (tonnes per hectare)	Biomass carbon (tonnes per hectare)
Jarrah dominant		
Jarrah Blackwood	81	79
Jarrah Leeuwin	104	142
Jarrah Mt Lindesay	53	40
Jarrah North East	54	60
Jarrah- North West	77	85
Jarrah Rate's Tingle	102	-
Jarrah Red Tingle	112	-
Jarrah Sandy	66	78
Jarrah South	85	87
Jarrah Unicup	66	46
Jarrah Woodland	42	39
Jarrah Yellow Tingle	116	-
Karri dominant		
Karri Main Belt	172	173
Karri Rate's Tingle	113	-
Karri Red Tingle	115	-
Karri West Coast	102	95
Karri Yellow Tingle	164	-
Wandoo dominant		
Western Wandoo forest	57	56
Western Wandoo woodland	36	40
Other		
Bullich and Yate	23	23
Darling Scarp	71	3
Peppermint & Coastal Heath	15	15
Rocky Outcrops	-	-
Sand Dunes	-	-
Shrub, Herb, & Sedgelands	15	15
Swamps	4	4
Whicher Scarp	36	41

These values differ slightly from the range reported in the Draft FMP of 30 to 143 tonnes per hectare for jarrah and 80 to 183 tonnes per hectare for karri. This is because the figures above are the average across all harvest history and structures in the forest ecosystem, within which there were individual sites that had higher and lower values that give rise to the ranges of 30 to 143 and 80 to 183.

Indicative estimates of the above- and below-ground live tree carbon stocks

The carbon estimates were summarised for presentation in Table 5 of the Draft FMP by the major forest types (corresponding with the sustained timber yield ranges reported elsewhere in the plan), and by the land categories of formal reserves and forest conservation areas and State forest and timber reserves. The forest types are an aggregation of the forest ecosystems.

Table 4 (Table 5 from the Draft plan): Indicative estimates of the above- and below- ground live tree carbon stocks to 2014 in major native forest types

Major forest type	**Biomass carbon Mt C**	
	Formal reserves and forest conservation areas	**State forest and timber reserves**
Jarrah	47.8	74.0
Karri	15.5	14.3
Wandoo /other	9.5	3.0
Total	**72.8**	**91.3**

Notes:
1. These estimates are for the 2.25 million hectares of south-west forests within the RFA boundary on lands vested in the Conservation Commission.
2. These estimates have been compiled from inventories that vary in sample intensity and geographic coverage, and the relative precision of the estimates therefore vary markedly between vegetation types and tenure categories.
3. These estimates do not include litter, coarse woody debris and shrub components.
4. The 'other' forest types comprise bullich, peppermint and coastal heath, shrub, herb and sedgelands, ecosystems.

The total carbon stock of 164.1 million tonnes is dominated by the contribution of the jarrah forest, which occupies the largest area of the three forest types.

Under the Draft FMP, there is a similar area of land in both 'Formal reserves and forest conservation areas' and 'State forest and timber reserves'. However, Table 5 indicates a substantially higher estimate for the total carbon stocks in State forest and timber reserves than in the formal reserve system. This arises for several reasons:

- the formal reserves contain a higher proportion by area of those forest ecosystems that have fewer trees and hence a lower woody biomass. For example, the Shrub, Herb and Sedgelands, Rocky Outcrops, Sand Dunes and Peppermint and Coastal Heath ecosystems comprise over 28 per cent of the total area in reserves (compared to 3 per cent in State forests);
- the estimated average standing carbon value for many of the larger (by area) jarrah forest ecosystems is less in the formal reserves than in the State forest component of the same ecosystem (particularly Jarrah North West, Jarrah North East, and Jarrah South) (see Table 3). This reflects the current forest structure and composition in these areas, which reflects a history of timber harvesting decades prior to the areas being placed into formal reserves;
- in the karri forest ecosystems, in State forest the areas of karri previously cutover and regenerated have very high regrowth volumes, suggesting some bias to higher site quality stands being preferentially cutover in the early years.

The figures in Table 4 for the State forest and timber reserves includes all the informal reserves and fauna habitat zones, in which timber harvesting is not permitted.

Note too that the overall precision of the estimates will differ between the land categories, as the timber inventories predominantly sampled State forest areas, so there are more plots contributing to the estimates in areas.

Estimating change

Changes to the carbon stock during the period of the Draft FMP will arise from a number of factors, including variations to the extent of forests, varying rates of growth and mortality across the forest, changes initiated by disturbances such as mining and timber harvesting, and natural disturbance events such as forest disease, bushfire and drought. The following adjustments were made to the estimates of total standing carbon to account for the effect of these factors.

Area of forest
The total area of forest in each forest ecosystem was assumed to remain unchanged during the 10-year period of plan. Actions within the Draft FMP seek to maintain the forest estate, and although some loss of vegetation (and hence carbon) may occur from clearing for infrastructure and other requirements. The location of such losses is difficult to predict and they are likely to be very small relative to the total estate.

Forest growth
The basis for growth projection of the two-tiered and regrowth forest structures is documented in the supplementary reading (see paper '*2.4 Growth and yield*').

In a forest dominated by mature and senescent trees, the net growth can be negligible, because the trees have passed their physiological peak and volume increment is offset by tree death and degrade from fire, fungi and insects. In contrast, forests dominated by vigorous regrowth are the most actively growing component of the estate. Two-tiered forests that contain a mixture of mature and regrowth stems have intermediate volume growth rates.

Consequently, the relative growth (and hence contribution to carbon stock change) of the forests varies with forest structure and composition. For example, the karri forest ecosystems with a high proportion of regrowth forest (e.g. karri main belt) accrued most of the projected change in the above-ground carbon estimate.

A lack of tree growth data within some forest ecosystems (such as Peppermint and Coastal Heath; Shrub, Herb and Sedgelands; and Bullich and Yate) was addressed by assuming there was no net change in those ecosystems during the period of the Draft FMP.

Planned disturbances – mining and timber harvesting
Mining and timber harvesting is restricted to a subset of the forest ecosystems, and within those, timber harvesting is restricted to areas within State forest and timber reserves. The Draft FMP incorporates two scenarios for calculating the sustained yields (see Table 7 in the Draft FMP), which differ in the total area potentially cutover each year. The area mined and rehabilitated each year was assumed to be the same under each of the scenarios.

Timber harvesting in the two-tiered forests generates a change in the relative composition of mature and regrowth trees within an area, and potentially in the growth rates of the retained and regenerating components. Thinning in predominantly regrowth stands seeks to maintain the relative growth rate of a stand and therefore not appreciably alter the rate of carbon accrual. Consequently, the changes in the forest structures arising from the levels of harvesting for the sustained yields under each scenario (1 and 2) were incorporated in the calculation of changes to forecast carbon stocks to 2023 for those forest ecosystems.

Bushfire and forest disease events

Over the period of the Draft FMP, the two-tiered forests were assumed at the whole of forest level to contain a relatively stable standing biomass, with any losses arising from substantial bushfire events being offset by the recovery of areas previously impacted elsewhere in the estate.

Episodic pest and disease outbreaks (including *Phytophthora* dieback) were not directly included in these strategic level estimates of change.

The projected changes by forest type are shown next:

Table 5 (Table 6 of the Draft plan): Projected changes in the indicative above- and below-ground live tree carbon within major forest types under the Draft plan scenarios for sustained yield

Major forest type	**Biomass carbon Mt C**		
		Scenario 1	**Scenario 2**
	2014	2023	2023
Jarrah	121.8	123.2	126.0
Karri	29.8	32.8	33.5
Wandoo/Other	12.5	13.0	13.0
Total	**164.1**	**169.0**	**172.5**

Notes:

1. These estimates are for the 2.25 million hectares of south-west forests within the RFA boundary on lands vested in the Conservation Commission.
2. The precision of these estimates differs between forest types due to variations in the quality and quantity of data contributing to projections of growth and change (e.g. limited samples within the 'other' forest types).

Overall, the quantity of carbon stored in the live trees on lands vested in the Conservation Commission is projected to increase over the period of the Draft FMP by between three per cent (sustained yield Scenario 1) and five per cent (sustained yield Scenario 2). While the jarrah, karri and wandoo forest types each contribute to the increase, carbon storage in the karri forest is projected to increase at the fastest rate. During the 10-year period of the Draft FMP, the karri carbon storage is projected to increase by between 10 per cent (Scenario 1) to 12 per cent (Scenario 2), which can be attributed to the high proportion of rapidly growing regrowth stands in State forest areas.

References

Bradshaw, F.J. and Mattiske, E.M. (1997). *Forest Ecosystem mapping for the Western Australian RFA*. Report to the Steering Committee for the Regional Forest Agreement in Western Australia.

Snowdon, P., Eamus, D., and Gibbons, P. (2000). *Synthesis of allometrics, review of root biomass and design of future woody biomass sampling strategies*. *National Carbon Accounting System Technical Report No. 17*. Australian Greenhouse Office, Canberra.