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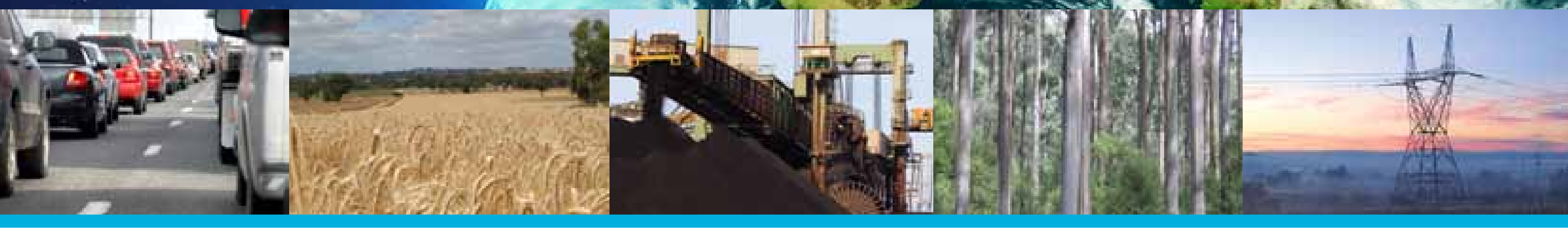

AUSTRALIAN NATIONAL GREENHOUSE ACCOUNTS

National Inventory Report 2010
Volume 2

The Australian Government Submission to the
United Nations Framework Convention on Climate Change
April 2012

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7. LAND USE, LAND USE CHANGE AND FORESTRY

7.1 OVERVIEW

The net emissions from the *land use, land use change and forestry* (LULUCF) sector were 37.9 Mt CO_2-e in 2010.

Table 7.1 Land Use, Land Use Change and Forestry net CO_2-e emissions, 2010

Greenhouse gas source and sink categories	CO_2-e emission (Gg)			
	CO_2 [(a)]	CH_4	N_2O	Total
5 Land use, land use change and forestry	32,561	3,596	1,799	37,956
A. Forest land	-52,877	2,325	634	-49,917
A.1 Forest land remaining forest land	-35,618	2,324	634	-32,658
A.2 Land converted to forest land	-17,258	0.01	0.06	-17,258
B. Cropland	19,075	489	286	19,851
B.1 Cropland remaining cropland	7,433	-	-	7,433
B.2 Land converted to cropland	11,642	489	286	12,418
C. Grassland	69,533	782	213	70,529
C.1 Grassland remaining grassland	27,040	IE	IE	27,040
C.2 Land converted to grassland	42,493	782	213	43,488
D. Wetlands	NE	NE	NE	NE
E. Settlements	NE	NE	NE	NE
F. Other land	NO,NA	NO,NA	NO,NA	NO,NA
G. Other[(b)]	-3,171		665	-2506

[(a)] A negative sign denotes a sink. [(b)] Includes Harvested Wood Products, Agricultural lime application and N_2O from disturbance associated with land-use conversion to Grassland. N_2O from disturbance associated with land-use conversion to Cropland is reported under Cropland.

Notes: NE = not estimated (voluntary reporting categories), IE = included elsewhere (reported in the agriculture sector), NA = not applicable, NO = not occurring.

Forest land (5A) comprises emissions and removals from *plantations*, *harvested native forests* and *other native forests.* Emissions from *fuelwood consumption* and *biomass burning* in forests (*slash burning, prescribed burning* and *wildfire)* are also included as are the removals associated with post fire recovery. The forest land category is estimated to have constituted a net sink of 50.0 Mt CO_2-e in 2010.

Cropland (5B) comprises emissions and removals from *cropland remaining cropland* and *forest land converted to cropland*. The *cropland* subsector is estimated to have constituted a net source of 20.0 Mt CO_2-e in 2010.

Grassland (5C) comprises emissions and removals from *grassland remaining grassland* and *forest land converted to grassland.* The *grassland* subsector is estimated to have constituted a net source of 70.0 Mt CO_2-e in 2010.

Forest land converted to cropland and *grassland* was a net source of 55.9 Mt CO_2-e in 2010 while the associated emissions of *N_2O from soil disturbance* were 1.3 Mt CO_2-e.

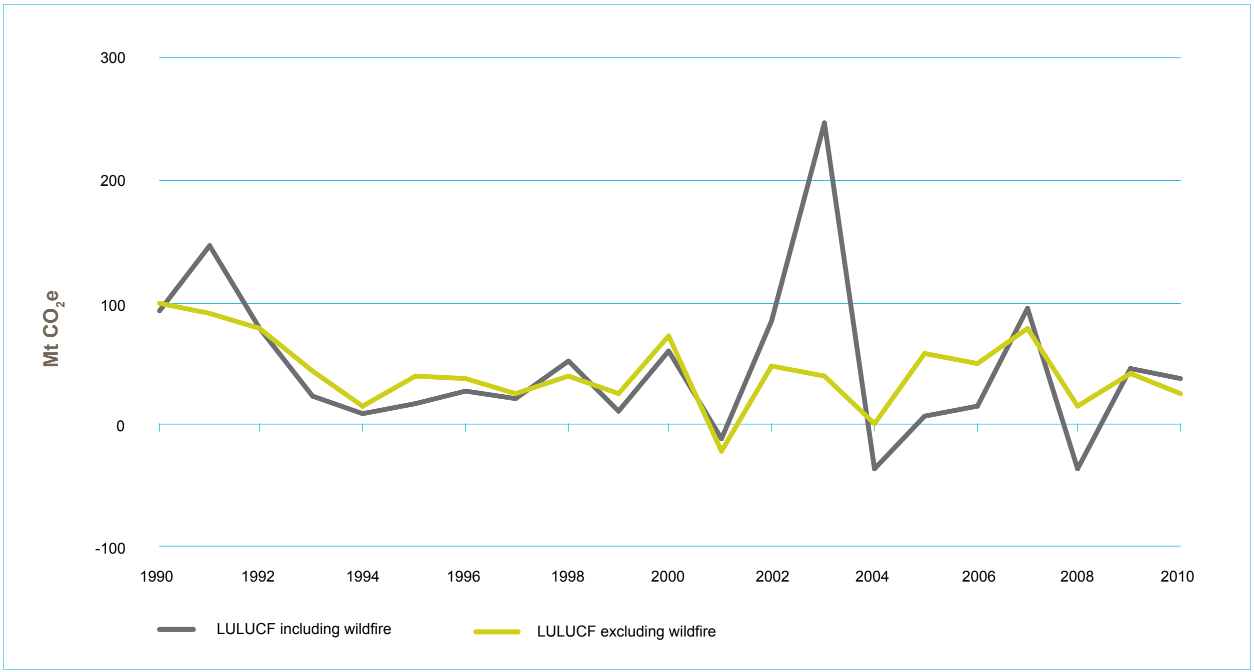
Harvested wood products are not reported in the *forest land* category and carbon stocks are transferred to 5G *Other – harvested wood products*. As the reporting tables do not account for transfers of carbon stocks between forests and harvested wood products, this leads to an apparent, but not real, emission from *forest land* and a 4.4 Mt 'sink' in *harvested wood products*.

Agricultural lime application is estimated to have contributed emissions of 1.3 Mt CO_2-e in 2010.

Trends

By 2010, the net *land use, land use change and forestry* emissions had decreased from 82 Mt CO_2-e in 1990 to 37.9 Mt CO_2-e in 2010.

Figure 7.1 Net CO_2-e emissions from Land Use, Land Use Change and Forestry, 1990–2010



The decreasing trend in emissions from LULUCF since 1990 has been mainly driven by the decline in emissions from *forest land converted to cropland* and *grassland* (Figure 7.2). Change in LULUCF emissions from year-to-year are affected by other factors, principally natural disturbances such as wildfire.

Figure 7.2 Net CO_2-e emissions from Land Use, Land Use Change and Forestry by sub-sector, 1990–2010

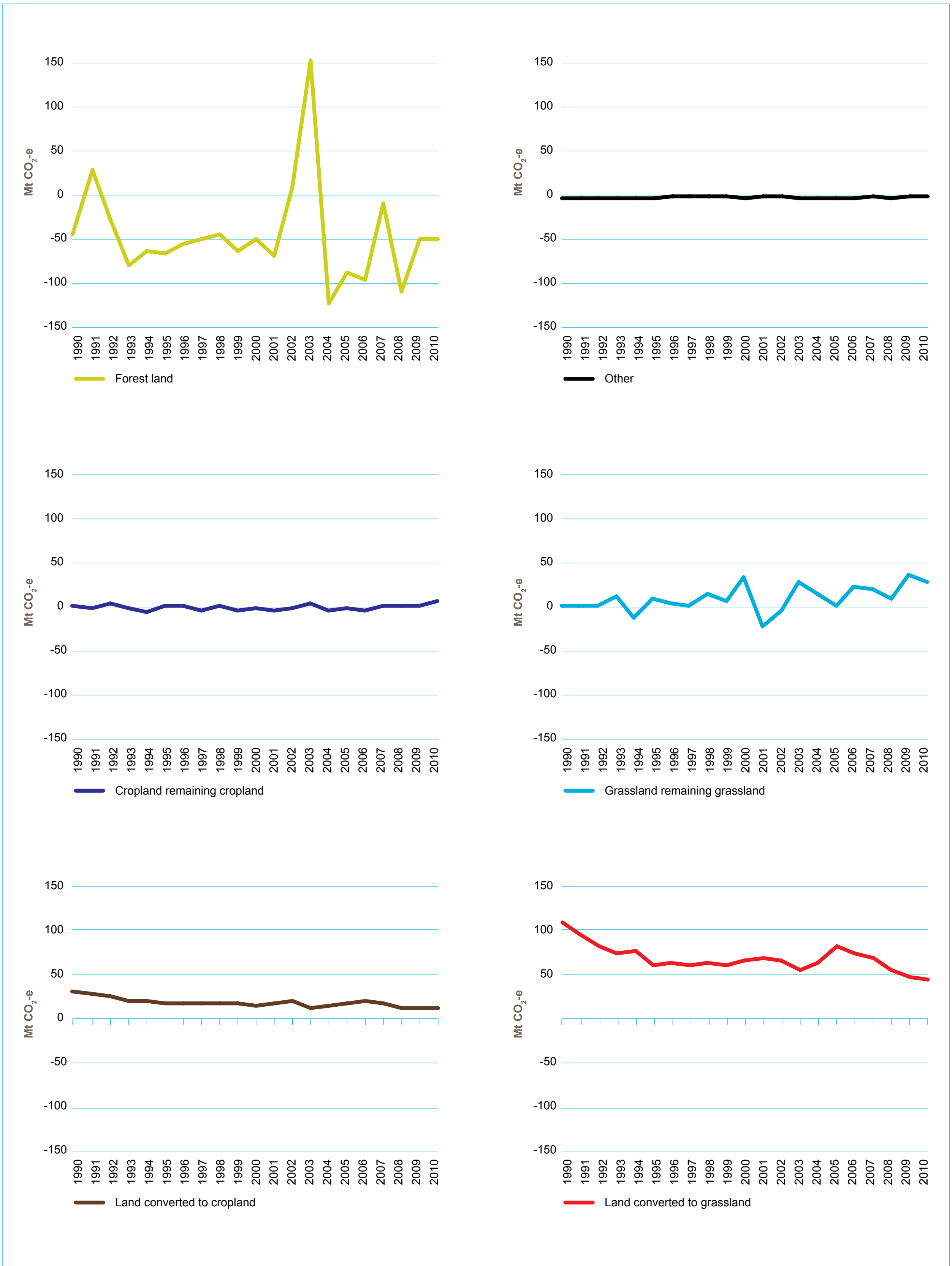


Table 7.2 Net emissions from the Land Use, Land Use Change and Forestry sector, Australia, 1990-2010 (Gg)

Year	Forest land remaining forest land	Grassland converted to forest land	Cropland remaining cropland	Forest land converted to cropland	Grassland remaining grassland	Forest land converted to grassland	Other	Total
1990	-45,297	-152	1,754	31,091	604	109,288	-4,246	93,042
1991	27,539	-527	-1,210	28,091	1,744	94,760	-3,838	146,560
1992	-28,542	-732	3,389	24,973	2,108	81,903	-3,848	79,252
1993	-77,823	-1,348	-1,171	20,197	12,769	73,839	-3,974	22,491
1994	-61,335	-2,035	-6,055	19,843	-13,683	75,560	-4,170	8,125
1995	-63,697	-3,411	164	16,908	8,744	61,809	-4,288	16,229
1996	-50,942	-4,927	2,261	18,212	2,868	63,630	-3,349	27,753
1997	-43,908	-5,790	-4,790	16,629	1,009	61,666	-3,256	21,561
1998	-37,235	-7,305	1,797	17,394	15,167	65,382	-3,526	51,676
1999	-55,454	-9,240	-5,470	15,892	5,496	63,213	-3,295	11,143
2000	-39,567	-10,825	-2,475	14,751	34,510	67,292	-3,789	59,898
2001	-57,055	-12,744	-3,841	16,861	-22,279	70,105	-3,316	-12,269
2002	19,920	-10,662	-555	18,516	-4,905	66,337	-3,313	85,340
2003	164,303	-13,270	3,825	11,676	27,938	56,517	-3,637	247,353
2004	-109,202	-13,510	-4,227	15,292	14,566	63,362	-3,869	-37,587
2005	-73,562	-14,923	-1,294	16,103	1,985	81,722	-3,785	6,246
2006	-83,407	-12,866	-3,526	20,048	23,287	73,803	-3,609	13,730
2007	7,159	-16,622	1,400	17,256	20,185	67,826	-3,347	93,857
2008	-93,065	-16,155	-217	12,211	8,352	55,111	-3,681	-37,444
2009	-34,106	-14,647	1,693	12,367	37,154	46,109	-2,752	45,820
2010	-32,659	-17,259	7,434	12,418	27,040	43,488	-2,507	37,956

Forest land

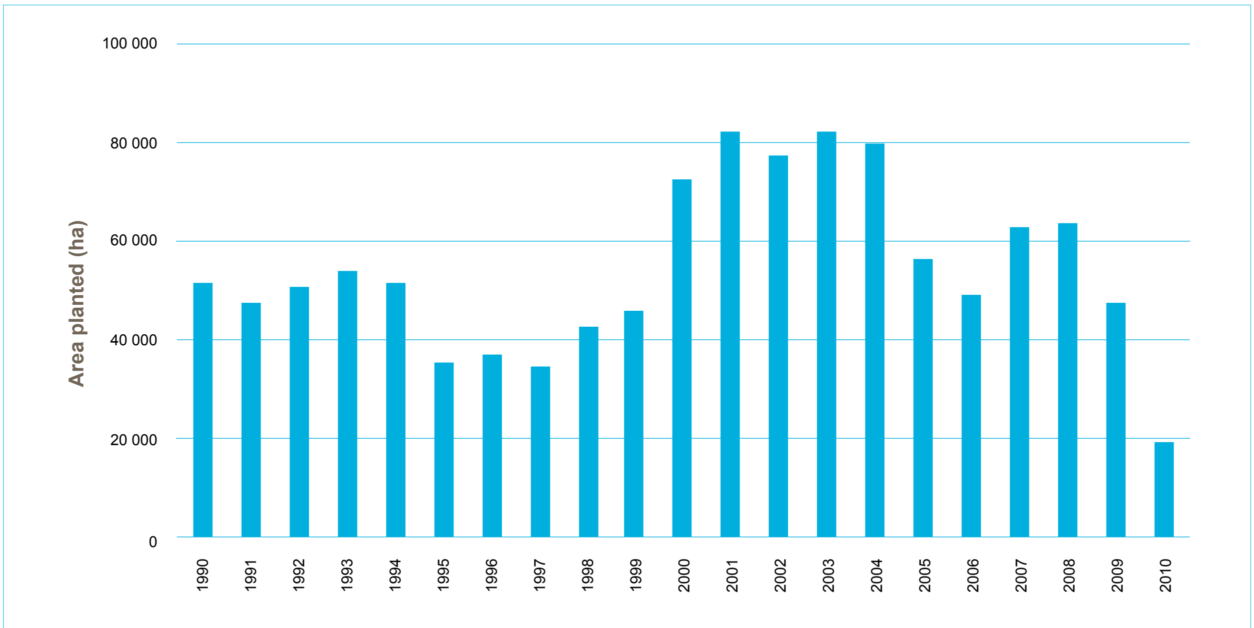
Within *forest land* (5A), *forest land remaining forest land* decreased from a net sink of 45.3 Mt CO_2-e in 1990 to a net sink of 32.7 Mt CO_2-e in 2010, while the removals from *lands converted to forest land* increased from 0.2 in 1990 to 17.2 Mt CO_2-e in 2010 (Table 7.2). The combined effect of these changes is a decrease in the *forest land* net sink of 9.8% (- 4.5 Mt CO_2-e) between 1990 and 2010.

Table 7.3 Net emissions for 5.A Forest Land, Australia, 1990-2010 (Gg)

Year	Multiple use forests	Private native forests	Native forests formerly managed for wood production	Pre-1990 plantations	Other native forests	Grassland converted to forest land	Fuel wood consumed	Biomass burning (non CO_2)	Total
1990	-16,798	5,962	-22,405	-9,178	-13,887	-152	9,246	1,763	-45,449
1991	-16,748	6,976	-23,724	-9,166	56,203	-527	9,506	4,493	27,011
1992	-15,822	7,665	-24,449	-9,176	1,044	-732	9,665	2,530	-29,273
1993	-14,029	8,186	-24,896	-8,786	-49,307	-1,348	9,902	1,107	-79,170
1994	-12,815	8,610	-25,185	-6,059	-37,574	-2,035	10,061	1,627	-63,370
1995	-11,691	8,973	-25,375	-6,076	-40,971	-3,411	10,117	1,327	-67,108
1996	-10,249	9,295	-25,497	-6,182	-30,405	-4,927	10,129	1,967	-55,869
1997	-10,402	9,473	-25,571	-6,164	-23,005	-5,790	10,208	1,554	-49,698
1998	-10,202	9,656	-25,608	-6,157	-17,426	-7,305	10,151	2,352	-44,540
1999	-9,894	9,804	-25,615	-1,772	-39,065	-9,240	10,151	937	-64,694
2000	-8,950	10,784	-25,597	-1,333	-25,525	-10,825	10,061	994	-50,392
2001	-6,877	11,515	-25,599	-853	-47,868	-12,744	10,389	2,239	-69,799
2002	-10,965	8,144	-25,656	-750	36,847	-10,662	8,725	3,574	9,259
2003	-10,606	8,147	-25,704	-742	171,511	-13,270	9,868	11,829	151,034
2004	-10,220	9,510	-25,738	981	-94,153	-13,510	8,974	1,445	-122,712
2005	-13,013	8,264	-25,760	1,386	-54,527	-14,923	8,352	1,736	-88,485
2006	-13,254	8,773	-25,769	1,461	-64,362	-12,866	8,239	1,506	-96,272
2007	-14,274	9,999	-25,766	1,875	21,834	-16,622	8,408	5,083	-9,463
2008	-12,617	8,098	-25,753	1,118	-75,721	-16,155	10,038	1,773	-109,219
2009	-16,998	9,407	-25,730	2,608	-14,099	-14,647	8,590	2,117	-48,752
2010	-17,322	7,511	-25,697	2,110	-10,627	-17,259	8,408	2,960	-49,917

For most of the period since 1990 forest land has been accumulating carbon stock (net sink of CO_2, see Figure 7.2) at an average rate of approximately 12 Mt of carbon each year (equivalent to approximately 46 Mt CO_2 per year). A contributor to the steady accumulation of carbon in forest land has been the expansion of Australia's plantation estate (Figure 7.3) since 1990.

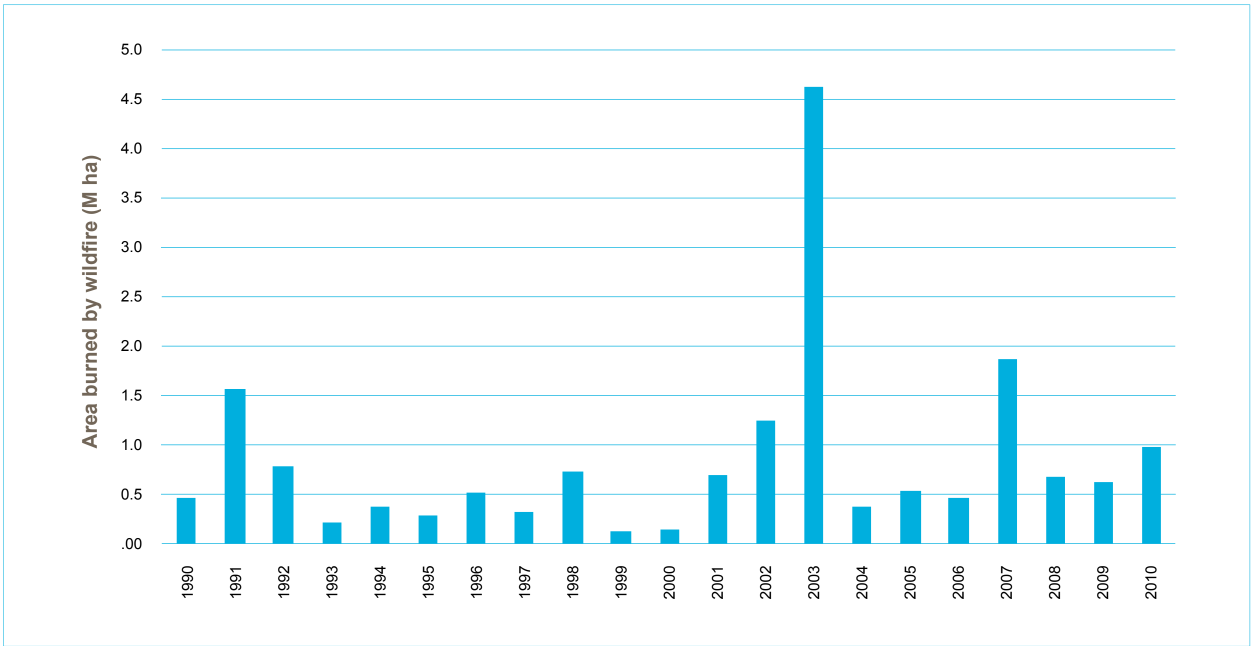
Figure 7.3 Area of plantation establishment since 1990 detected as part of the remote sensing program of Australia's National Inventory System



There has been a large expansion of Australia's plantation estate in the period 1990-2010, especially in the five years from 2000. However, in 2010 the rate of conversion of *land to forest land* was the lowest since 1990 (Figure 7.3). This may have been caused by the economic conditions for forest products, including the historically high value of the Australian currency in 2010, making it more challenging to export plantation products overseas. Furthermore, several major players exited the market resulting in the reduction of plantation establishment.

The key drivers of variation in emissions in forest lands from year-to-year are annual harvest areas, the age classes of the forests, climate variability and wildfires. Of these, wildfires are the largest cause of variability in emissions from *forest land remaining forest land*. Wildfires occur annually across Australia's 106 million hectares of forests with the area burnt varying considerably from year to year (Figure 7.4).

Figure 7.4 Annual area of forests burned by wildfire 1990-2010



Wildfires have been part of the Australian environment for thousands of years and constitute a major natural and socio-economic hazard, costing Australia in excess of $80 million annually. Around 552 people have perished as a result of wildfires in the past century, while more people are injured in Australia by wildfires than by all other natural disturbances combined.

The fire events of 2003 resulted in the largest area to be burnt by wildfire in the period 1990-2010 (Figure 7.4). The wildfire events of 2003 resulted in approximately three times the area being burnt compared to the year with the next largest area burnt, 2007. The large area burnt during 2003 resulted in anomalously high emissions from forest land in 2003 (Figure 7.2).

Cropland remaining Cropland

Within 5B, *cropland remaining cropland* is estimated to be a source of 7.4 Mt CO_2-e in 2010.

Since 1990, there has been no discernable trend in emissions which has slightly varied above and below zero by approximately 5 Mt CO_2-e (Figure 7.2). The small net emissions rate reflects a steady loss of carbon from these lands (Figure 7.5) due to agricultural management practices and following transition from *forest land* in the past. Across the period 1990-2010 there have been no significant shifts in management practice which could slow this rate of loss of carbon from *cropland remaining cropland*. Minor variations in emissions from year-to-year reported in Figure 7.2 are primarily driven by fluctuations in climatic conditions

Figure 7.5 Soil Carbon Stock, Cropland remaining Cropland, 1990-2010

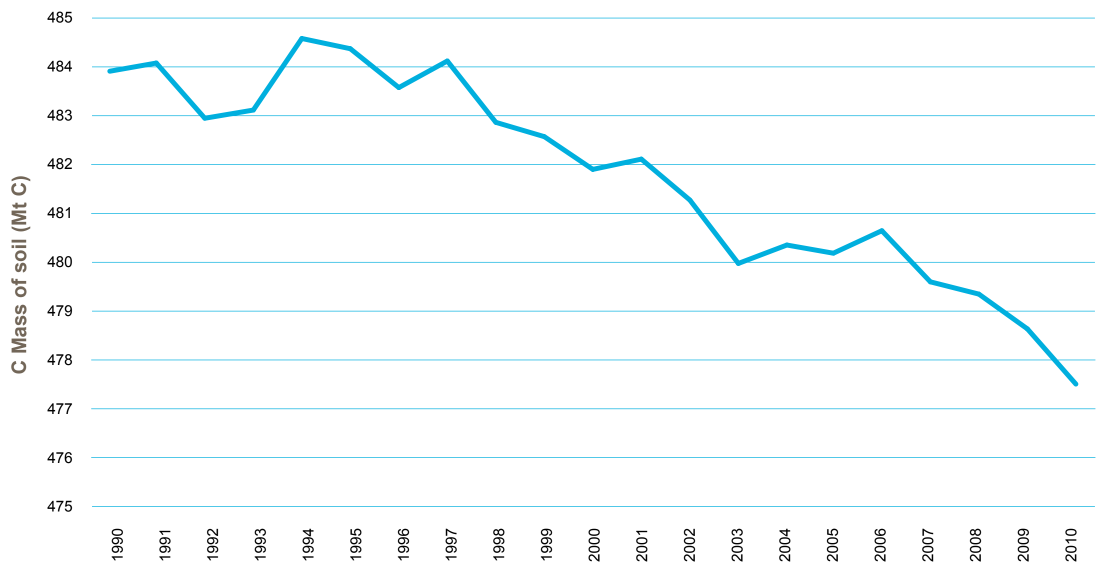


Table 7.4 Net emissions from changes in carbon stocks for 5.B Croplands, Australia, 1990-2010 (Gg)

Year	Cropland remaining cropland		
	Soil carbon	Perennial woody biomass (horticulture)	Total
1990	2,374	-620	1,754
1991	-590	-620	-1,210
1992	4,009	-620	3,389
1993	-551	-620	-1,171
1994	-5,434	-620	-6,054
1995	785	-620	164
1996	2,882	-620	2,261
1997	-1,964	-2,825	-4,790
1998	4,592	-2,796	1,797
1999	1,091	-6,560	-5,470
2000	2,517	-4,991	-2,475
2001	-759	-3,081	-3,841
2002	3,054	-3,609	-555
2003	4,783	-958	3,825
2004	-1,418	-2,809	-4,227
2005	563	-1,857	-1,294
2006	-1,735	-1,791	-3,526
2007	3,889	-2,490	1,400
2008	858	-1,076	-217
2009	2,632	-939	1,693
2010	4,206	3,228	7,434

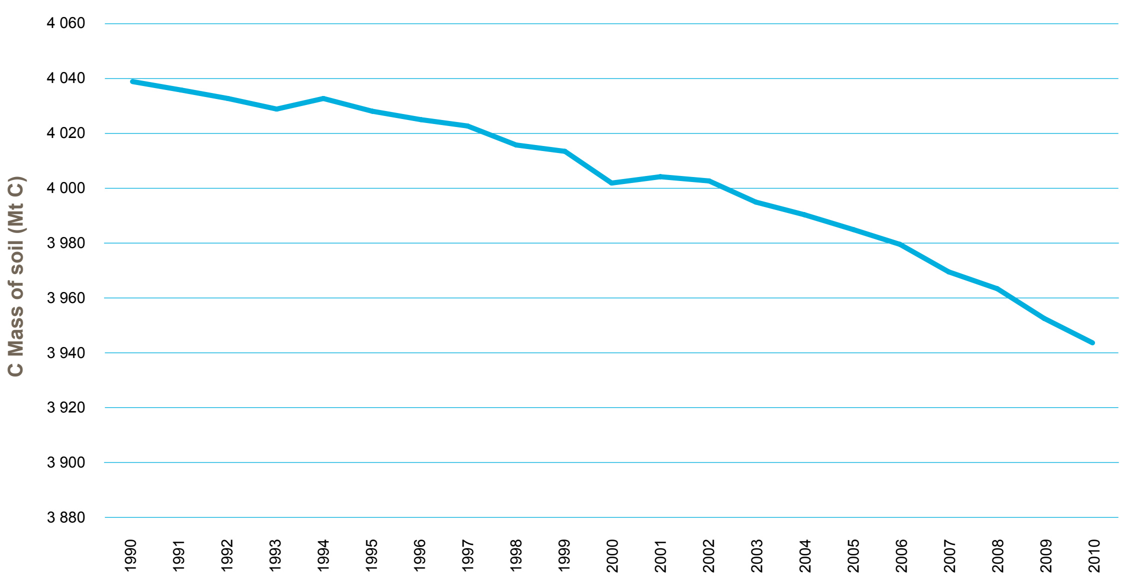
Grassland remaining Grassland

As with croplands, there has been no significant longer term trend in emissions discernable from the estimates reported for 5C *grassland remaining grassland*. In the reported estimates for *grassland remaining grassland* there is a steady net emission rate from soil carbon from the management of annual herbaceous grasslands, reflecting an ongoing loss of the stock of soil carbon in the reported estimates especially in coastal regions where land has been converted to grassland since European settlement. In the arid and semi-arid regions of central Australia, however, soil carbon stocks under natural grassland have reached a steady-state.

Changes in carbon stocks in *grassland remaining grassland* are largely affected by changes in land management practices, natural disturbances and climate. These factors determine the amount of live biomass and dead organic matter as well as the amount of residues, root and manure inputs to soil carbon. The results are reported in three parts to reflect the three elements of the emission estimation:

- grassland dynamics;
- changes in shrubland extent; and
- fire.

Figure 7.6 Soil Carbon Stock, Grassland remaining Grassland, 1990-2010



Woody shrubs are a key component of grassland ecosystems in semi-arid and arid regions of central Australia. There are many processes that lead to transitions between shrubs and grasses in these ecosystems which cause fluctuations in emissions from *grassland remaining grassland*. These processes are driven by factors that include how palatable the shrubs are to herbivores and whether they are resistant or susceptible to fire, drought and water logging. The species concerned may be endemic, native (but not endemic), or introduced. Anthropogenic activities also result in transitions between shrub and grass systems. For example, land clearing and the subsequent establishment of shrub plantations (e.g., saltbush for grazing and tea-tree for oils) can be a cause of these transitions. Another natural phenomenon that impacts carbon stocks and transitions between grasses and shrubs is climate driven changes in the shrub condition.

Table 7.5 Net emissions from changes in carbon stocks for 5.C Grasslands, Australia, 1990-2010 (Gg)

Year	Grassland remaining Grassland			
	Herbaceous grasslands (soil carbon)	Perennial woody biomass		All
		Transitions	Fire	
1990	17,714	-4,108	- 13,001	605
1991	11,767	-2,130	- 7,892	1,745
1992	9,660	-277	- 7,275	2,108
1993	12,919	-1,174	1,024	12,769
1994	- 13,181	-2,187	1,684	-13,684
1995	16,848	-2,569	- 5,535	8,744
1996	11,978	-3,225	- 5,885	2,868
1997	6,897	-2,969	- 2,919	1,009
1998	24,687	-4,325	-5,194	15,168
1999	9,505	-4,365	356	5,496
2000	39,841	-3,156	- 2,175	34,510
2001	- 7,948	-8,584	- 5,747	-22,279
2002	6,482	-5,990	- 5,398	-4,906
2003	26,331	-5,621	7,227	27,937
2004	16,538	-9,717	7,744	14,565
2005	21,328	-8,923	- 10,419	1,986
2006	18,710	-8,464	13,040	23,286
2007	35,646	-6,045	- 9,416	20,185
2008	22,667	-6,813	- 7,501	8,353
2009	36,881	-3,994	4,267	37,154
2010	33,089	-4,841	- 1,207	27,041

Forest land converted to cropland and grassland

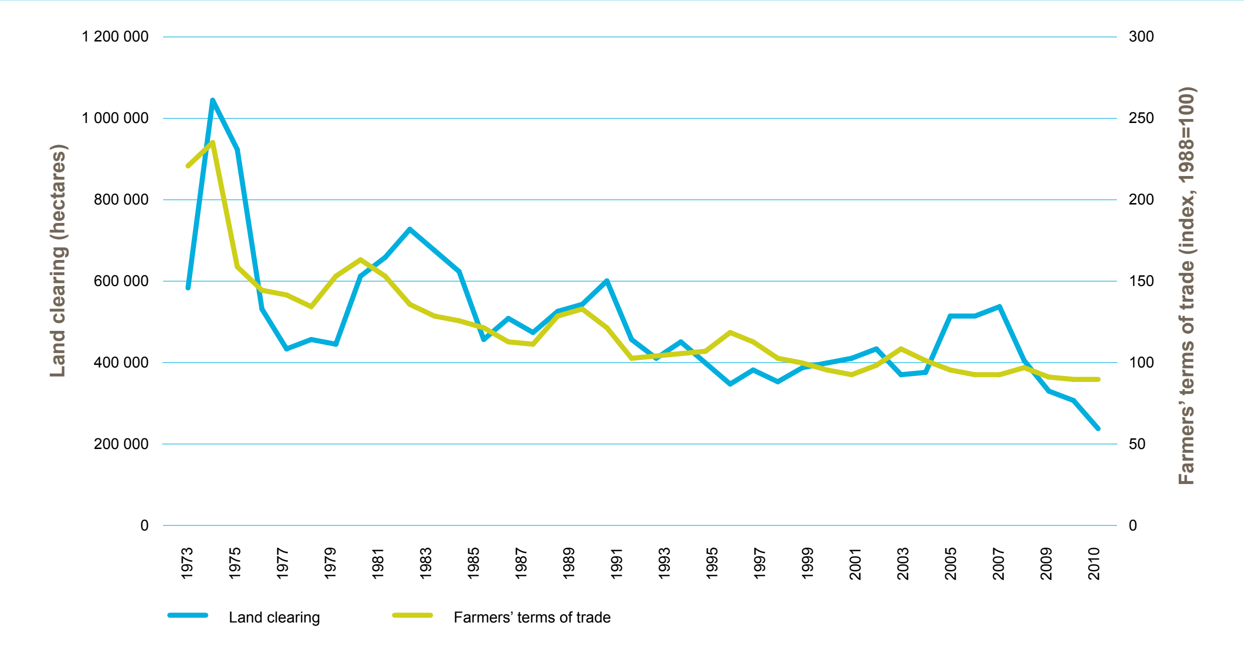
The 2010 estimate of total emissions from *forest land converted to cropland* and f*orest land converted to grassland* was 60% (84.9 Mt) lower than in 1990. This reduction is due to a long running trend for reducing land clearing activity in Australia which is evident from the 1970s to the present. This transition from forest to non-forest land use results in an immediate loss of carbon as trees are ripped and burnt, as well as a long-run loss of soil carbon as it decays to a new equilibrium stock level.

Today most land cleared in Australia is used for cattle grazing. In the past large areas were also cleared for crop production. For farmers and other landowners, economic considerations are an important driver of land clearing. When the prices of agricultural products, for example beef, are high, landowners have a strong incentive to clear land and expand production.

The farmers' terms of trade are a key indicator of economic conditions in the agriculture sector. They are defined as the ratio of an index of prices received by farmers to an index of prices paid by farmers. Prices received include agricultural products such as beef, while prices paid include inputs such as fertiliser and diesel. The farmers' terms of trade increase if either the price of an agricultural product rises or the price of an input falls.

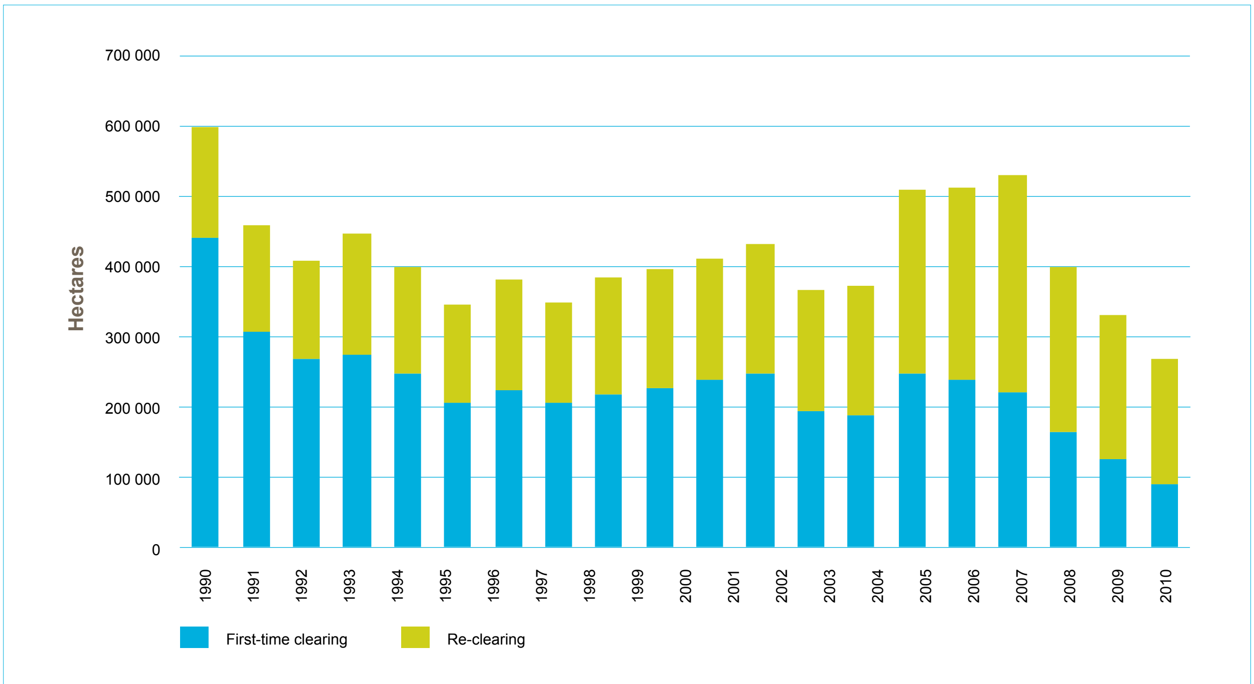
As shown in Figure 7.7, there is a clear relationship between the farmers' terms of trade and land clearing. The data also indicate a lag of approximately one year in the relationship. Typically, an increase (or decrease) in the farmers' terms of trade is followed by a corresponding increase (or decrease) in land clearing around one year later. A linear least squares regression using yearly percentage changes in the land clearing area and the farmers' terms of trade from 1974 to 2010, with a lag of one year, confirms this relationship is statistically significant at the 1% significance level ($R^2 = 0.34$).

Figure 7.7 Time-series of land clearing in Australia from 1972 as used for Australia's greenhouse accounts and the farmers' terms of trade



Government policies are another important factor affecting the rate of land clearing. In recent decades, state governments have passed legislation to significantly restrict land clearing, especially in environmentally significant areas. First-time clearing of undisturbed forest is now prohibited in many areas. Figure 7.8 illustrates the trend in land clearing in Australia between 1990 and 2010. First-time clearing of undisturbed forest is shown in green, and re-clearing of forest cover that has re-grown on previously cleared land is in orange. The figure demonstrates a strong shift away from first-time clearing over this period. In 1990, first-time clearing accounted for 74% of the total area cleared while by 2010 the proportion had fallen to 33%. This reflects the progressive introduction of land clearing restrictions by state governments from the early 1990s onwards.

Figure 7.8 Time-series of first-time clearing and re-clearing in Australia from 1990 as used for Australia's greenhouse accounts



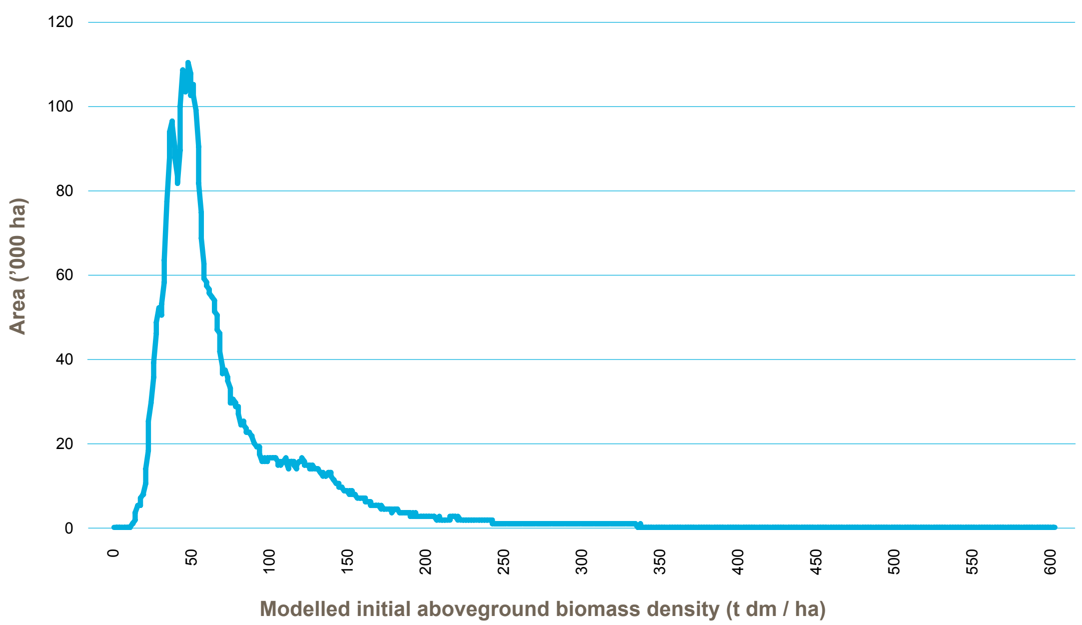
The national trends also demonstrate the effects of a major policy change implemented recently in Queensland. In 2004, the Queensland government passed amendments to land clearing legislation to substantially restrict clearing from 2007 onwards. Further restrictions were passed in 2009.

The effects of this policy change can be seen in the sharp drop in land clearing, especially first-time clearing, from 2007 onwards (Figure 7.8). In addition, there was a temporary increase immediately prior to the drop, between 2004 and 2006. This may reflect landowners clearing extra land in anticipation of the new restrictions as it occurred in the period between the passage of the new laws and before they came into force. Unlike most previous large shifts in the rate of land clearing, the recent shifts in 2004 and from 2007 onwards were not accompanied by significant changes in the farmers' terms of trade (Figure 7.7).

This recent shift in the balance between first time clearing and re-clearing (Figure 7.8) also contributes to the ongoing decrease in emissions from *forest land converted to cropland* and *grassland*. Where land is re-cleared the biomass stock at clearing is modelled from the date at which re-growth occurred and will be less than the initial biomass of first time clearing.

Analysis has been undertaken to identify the initial aboveground biomass of forest entering *forest land converted to cropland* and *grassland* since 1990. The results represent an estimate of the long-term average aboveground biomass density that was present in these areas prior to the first clearing event. Figure 7.9 shows a frequency distribution of the modelling results, expressed as the area of land clearing (in hectares) at every value of the modelled initial aboveground biomass density (in tonnes of dry matter per hectare, t dm / ha). The mean of the distribution occurs at 80 t dm / ha. This represents the modelled average aboveground biomass density prior to first-time clearing in these areas. The median occurs at 59 t dm / ha.

Figure 7.9 Distribution of modelled initial aboveground biomass density of land cleared since 1990



The mean is significantly higher than the median due to the effect of relatively infrequent units of land with very high modelled initial biomass densities.

As can be seen in the figure, most estimates are quite low, between around 25 and 85 t dm / ha. This reflects the fact that most land clearing since 1990 has occurred in forests of relatively low biomass forest, such as woodland areas in inland Queensland and New South Wales.

However, there is also a 'bulge' in the distribution between about 100 and 160 t dm / ha, as well as a long tail that extends to much higher values. This is due to clearing events detected in high productivity areas, where the model predicts higher initial aboveground biomass densities.

7.2 OVERVIEW OF SOURCE CATEGORY DESCRIPTION AND METHODOLOGY – LAND USE, LAND USE CHANGE AND FORESTRY

Land use and management activities influence a variety of ecosystem processes that affect greenhouse gas fluxes. The focus of reporting for the LULUCF sector is the estimation of emissions and removals of carbon dioxide (CO_2) from these activities. Carbon dioxide fluxes between the atmosphere and managed land systems are primarily controlled by uptake via plant photosynthesis and releases from respiration, decomposition and oxidation of organic material. Nitrous oxide (N_2O) may be emitted from the ecosystem as a by-product of nitrification and denitrification and the burning of organic matter. Other gases released during biomass burning include methane (CH_4), carbon monoxide (CO), other oxides of nitrogen (NO_x) and non-methane volatile organic compounds (NMVOC).

The Australian LULUCF methodology contains predominantly country specific methodologies and Tier 3 models (Table 7.6). The methods used in the reporting of the LULUCF categories of the inventory are described in detail in Appendices 7.A to 7.J:

- Appendix 7.A – Overview of the implimentation of Land Sector Reporting with Australia's National Inventory System;
- Appendix 7.B – Harvested Native Forests (forest land remaining forest land);
- Appendix 7.C – Pre-1990 Forest Plantations (forest land remaining forest land);
- Appendix 7.D – Post-1990 Forest Plantations (grassland converted to forest land);
- Appendix 7.E – Other Native Forests (forest land remaining forest land);
- Appendix 7.F – Forest land converted to Cropland and Grassland;
- Appendix 7.G – Cropland remaining Cropland;
- Appendix 7.H – Grassland remaining Grassland;
- Appendix 7.I – Harvested Wood Products; and,
- Appendix 7.J – Cross-Cutting issues (QA/QC).

Table 7.6 Summary of methodologies and emission factors – Land use, Land use change and forestry sector

Greenhouse Gas Source And Sink	CO_2		CH_4		N_2O		NO_x, CO and NMVOC	
	Method applied	EF	Method applied	EF	Method applied	EF	Method applied	EF
5. Land Use, Land Use Change and Forestry								
A. Forest Land								
1. Forest land remaining Forest land								
Harvested Native Forests	T2	M						
Other Native Forests	T2	CS						
Pre-1990 Plantations	T3	M						
Fuelwood consumed	T1	CS						
5(V) Biomass Burning – 5.A.1.			CS	CS	CS	CS	CS	CS
2. Land converted to Forest land	T3	M						
B. Cropland								
1. Cropland remaining Cropland	T3	M						
2. Land converted to Cropland	T3	M						
5(III) Disturbance associated with land conversion					T2	CS		
5(V) Biomass Burning – 5.B.2			CS	CS	CS	CS	CS	CS
C. Grassland								
1. Grassland remaining Grassland	T3, T2	M, CS						
2. Land converted to Grassland	T3	M						
5 (V) Biomass Burning - 5.C.2			CS	CS	CS	CS	CS	CS
D. Wetlands								
1. Wetlands remaining Wetlands	NE	NE						
2. Land converted to Wetlands	IE	IE						
E. Settlements								
1. Settlements remaining Settlements	NE	NE						
2. Land converted to Settlements	IE	IE						
F. Other Lands								
1. Other Lands remaining Other Lands	NA	NA						
2. Land converted to Other Lands	NO	NO						
G. Other								
Harvested Wood Products	T3	M						
5(I) N fertilisation					IE	IE		
5(II) Drainage of Soils					NE	NE		
5(III) Disturbance associated with land conversion to grassland					T2	CS		
5(IV) Agricultural lime application	T1	CS						

EF = emission factor, CS = country specific, D = IPCC default, M = Model, NA = not applicable, NE= not estimated, NO = not occurring, IE=included elsewhere, T1 = Tier 1, T2 = Tier 2 and T3 = Tier 3,

7.2.1 Land Sector reporting in Australia's National Inventory System

In 1998 Australia embarked on a development program for a system to support land sector reporting within Australia's National Inventory System to provide a complete accounting capability for Australia's land based sectors (AGO, 2005). The National Inventory System has been developed progressively to provide greenhouse gas accounting capability for LULUCF (including all carbon pools, gases, lands and land use activities). The current capacity supports full spatial enumeration with emissions and removals calculated using an empirically constrained process-based, mass balance, carbon cycling ecosystem model for:

- Forest land converted to cropland and grassland;
- Grassland converted to forest land; and
- the agricultural system components of Cropland remaining cropland and Grassland remaining grassland.

The conversion of forest to cropland and grassland represents the major part of emissions in the LULUCF sector.

The other principal reporting elements, *forest land remaining forest land* and *grassland remaining grassland*, are reported using a combination of interim approach 2 and Tier 2 and 3 methods.

The full spatial enumeration is achieved through the use of medium resolution (50 m and 25 m) Landsat satellite data in a time-series since 1972 (Furby, 2002; Caccetta *et al*., 2003). There are currently 20 national coverages in the time-series which are used to determine change in forest extent, and to determine plantation area, age and type through time.

Monthly climate maps at 1 km resolution since 1968 have been derived to model annual variability in emissions and removals due to climate (Kesteven *et al*., 2004). Comprehensive databases on land management practices are also integrated within the system. Coupled together, the information on vegetation cover change, ongoing management and climate allows Australia to comprehensively account for the principal causes of emissions.

7.3 LAND AREAS AND LAND USE CATEGORY DEFINITIONS

7.3.1 National Circumstances

7.3.1.1 Land Use in Australia

Australia has a land area of 769 million hectares containing unique land, water, vegetation and biodiversity resources. The areas of the continent under different land uses are shown in Figure 7.11. The most significant agricultural activities include wool, beef, wheat, cotton and sugar production. Australia is also a significant exporter of dairy produce, fruit, rice and flowers. Australia's forest resources consist of native forests (primarily dominated by *Eucalyptus* species) which are used for wood production, recreation and conservation, and plantations of native (primarily *Eucalyptus* species) and exotic species (primarily *Pinus* species).

7.3.1.2 Climate

Australia is a dry continent where rainfall is highly variable with floods and droughts a common feature. There are a number of distinct climatic zones, with summer dominant rainfall in the tropics/subtropics in the north, Mediterranean climates in the south, arid and semi-arid regions in the centre, and areas of high rainfall on the coastal fringes and in the ranges of the east (Figure 7.12 and 7.13).

The tropical north is suited to grazing (predominately cattle) as well as the production of fruit and sugar cane. Agricultural land use in the subtropical and Mediterranean climates is cereal cropping and sheep and cattle grazing.

Figure 7.10 Land use in Australia 2010

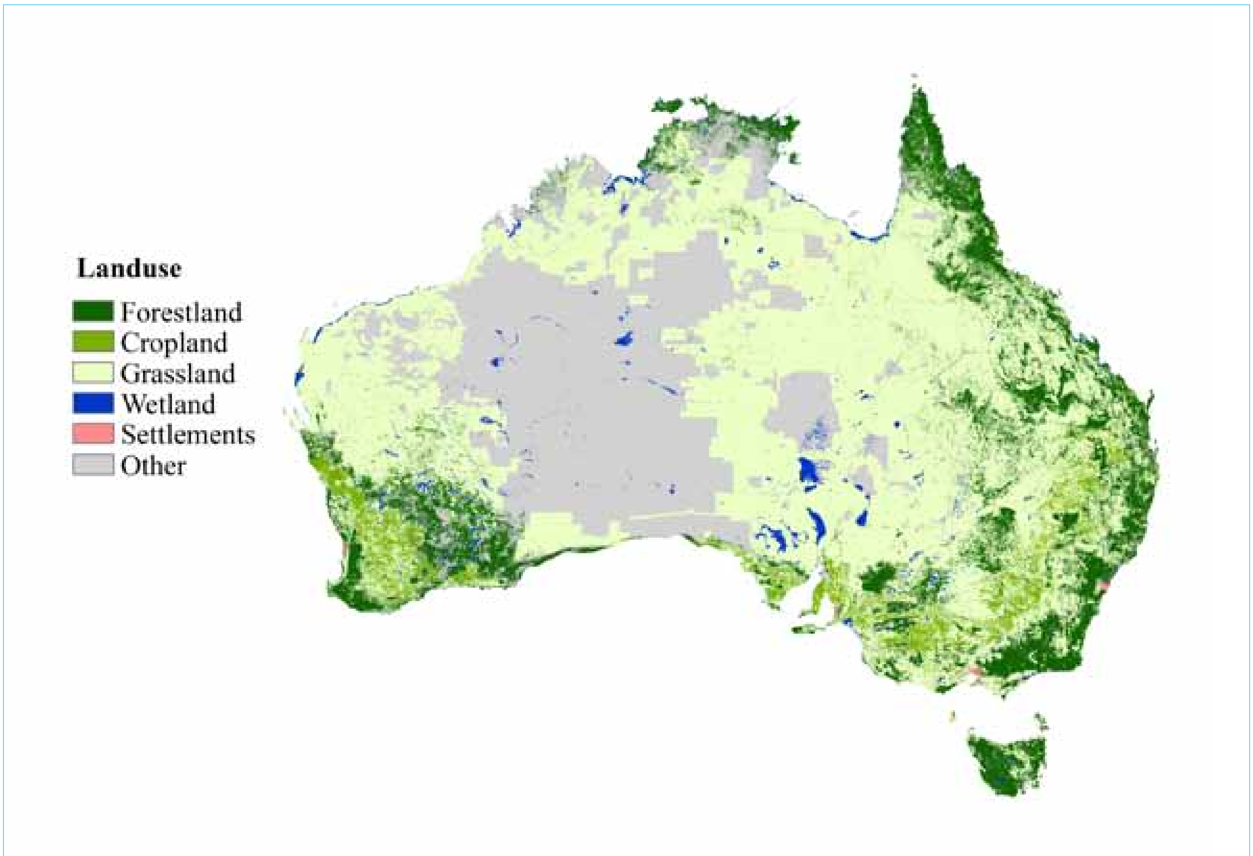


Figure 7.11 Average annual rainfall 1970 to 2008

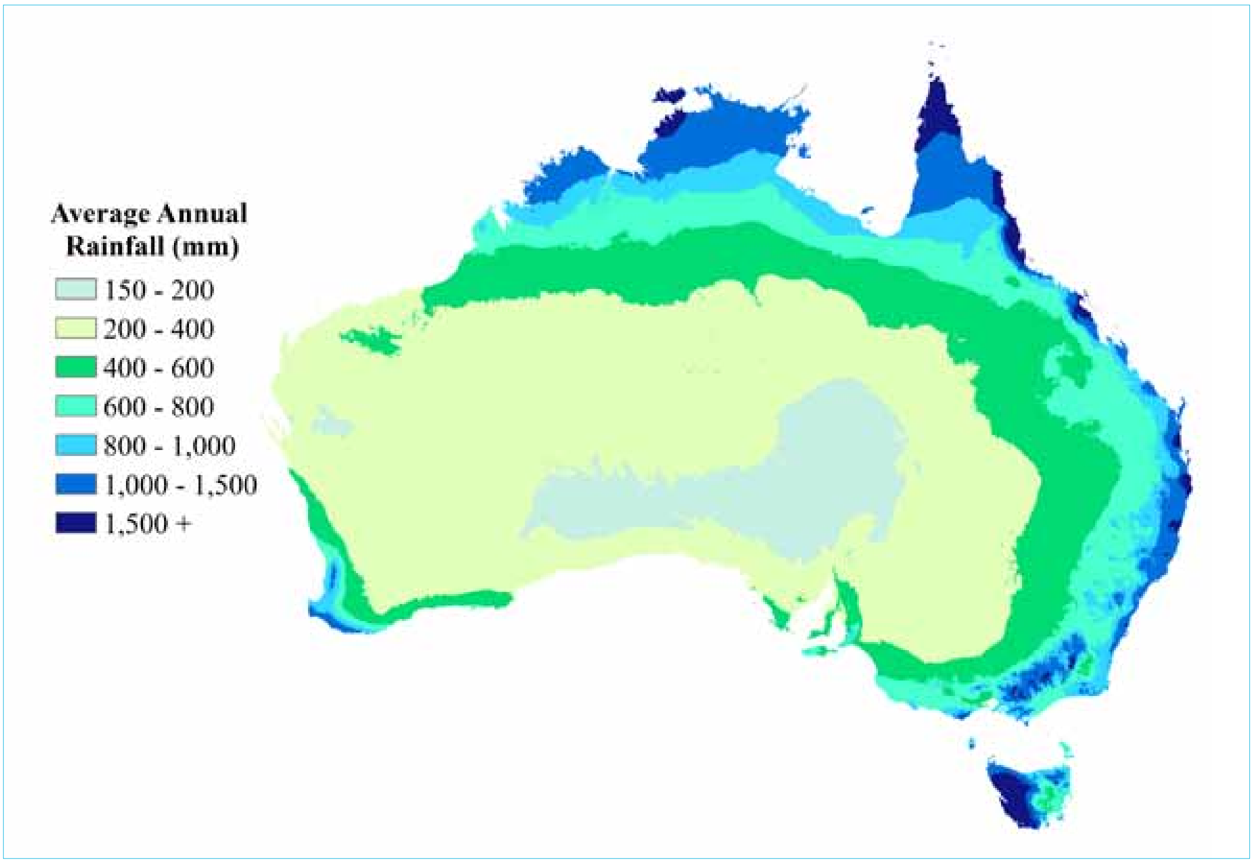
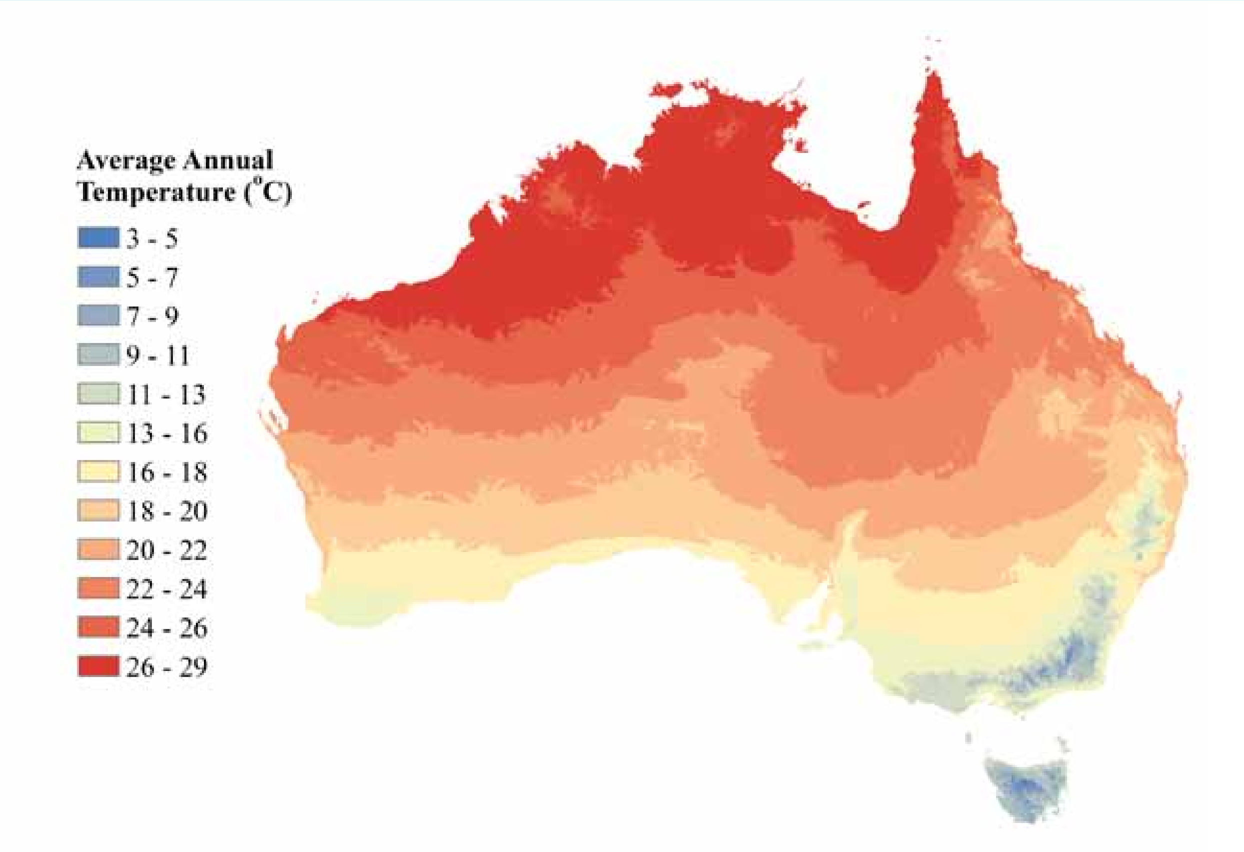


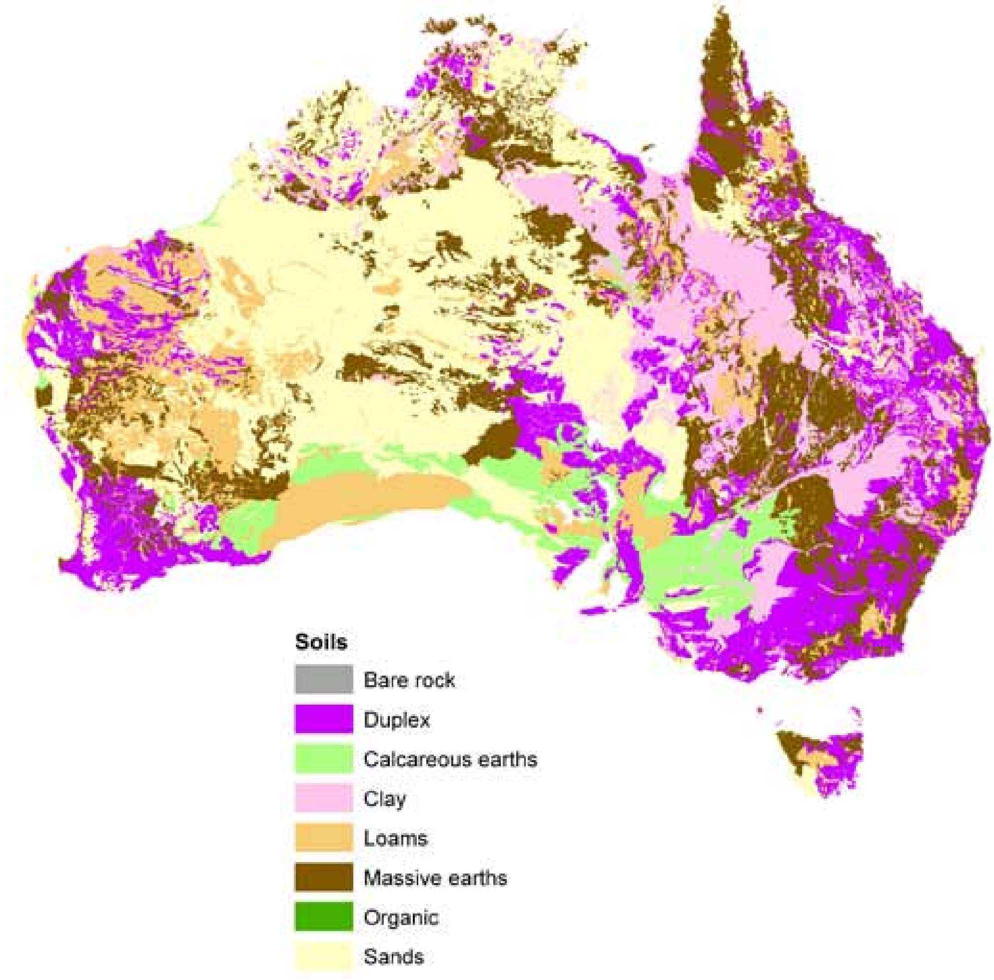
Figure 7.12 Average annual temperature 1970 to 2008



7.3.1.3 Soils

Australia has a diversity of soil types ranging from old, highly weathered and infertile, to younger, more fertile soils derived from volcanic rocks and alluvium (Figure 7.14). Approximately 50% are dominated by sandy surface soil horizons, 37% are dominated by loam and sandy clay loams in the surface horizon and 13% are dominated by light to medium clay textured soil in the surface horizon. Most of these soils have low levels of nitrogen, phosphorus and other nutrients. Soils under well managed agricultural landuse are managed by maintaining ground cover, avoiding disturbance especially on steep slopes and the timely use of fertilizer (mainly phosphorus and nitrogen) to avoid nitrification of waterways through surface and subsurface flows.

Figure 7.13 Soil types of Australia



Source: Bureau of Rural Sciences

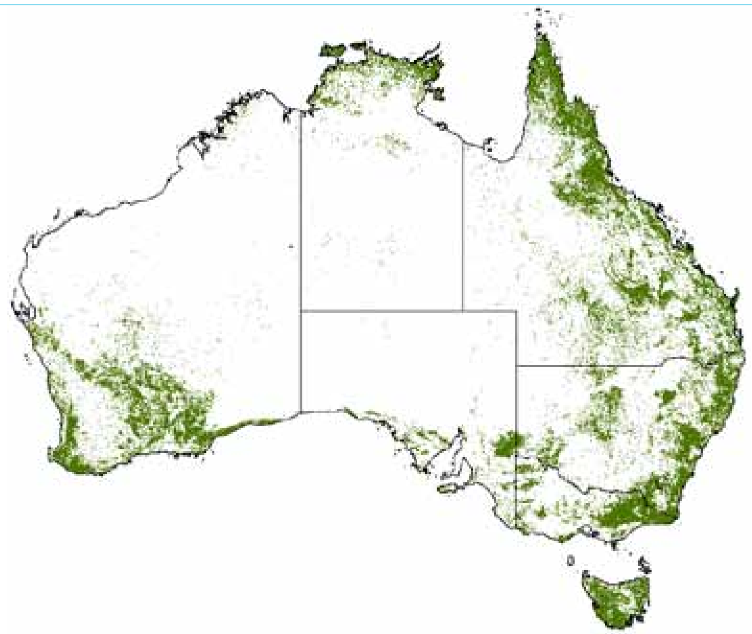
7.3.2 Land Category Definitions

7.3.2.1 Forest Land

Forest land includes all lands with a tree height of at least 2 metres and crown canopy cover of 20% or more (Figure 7.15). These thresholds are consistent with the definition used in existing international reporting for Australia's National Forest Inventory that has been used for reporting to the FAO and Montreal Process.

Australia has adopted a minimum forest area of 0.2 ha. As the National Forest Inventory does not apply a minimum area requirement in its definition, an extensive process was undertaken to select an appropriate minimum area value. The selection process considered the structure and distribution of forest canopy cover change in Australian forests, and the capacity of available data and processing systems to identify change at different spatial resolutions. The selection process is described in Appendix 7.A.

Figure 7.14 Forest extent in Australia 2010

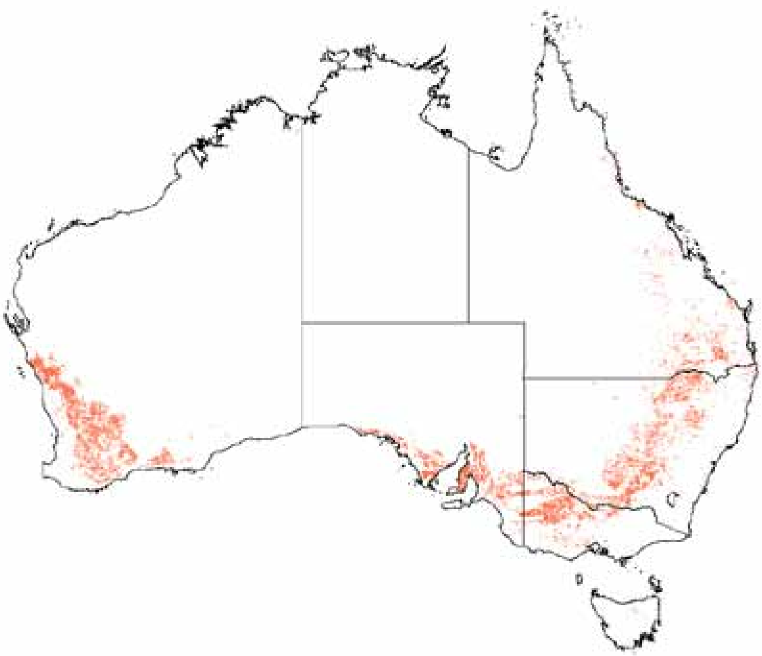


7.3.2.2 Cropland

Cropland includes all land that is used for continuous cropping, and those lands managed as crop-pasture (grassland) rotations. Crop-pasture rotations are a common form of landuse in Australia. These systems are considered as *cropland* because the crop stage of the rotational system has the greatest influence on declining carbon stocks and therefore greenhouse gas emissions. For this reason, whenever land is cropped it is considered *cropland* and reported under a *cropland* category although the emission estimates take into account those management systems that may have transferred intermittently between crop and pasture activities. This is consistent with section 3.3 of the 2003 IPCC *Good Practice Guidance for Land Use, Land Use Change and Forestry* (IPCC, 2003).

Non-CO_2 emissions from *cropland remaining cropland* are reported in the Chapter 4 *agriculture* sector.

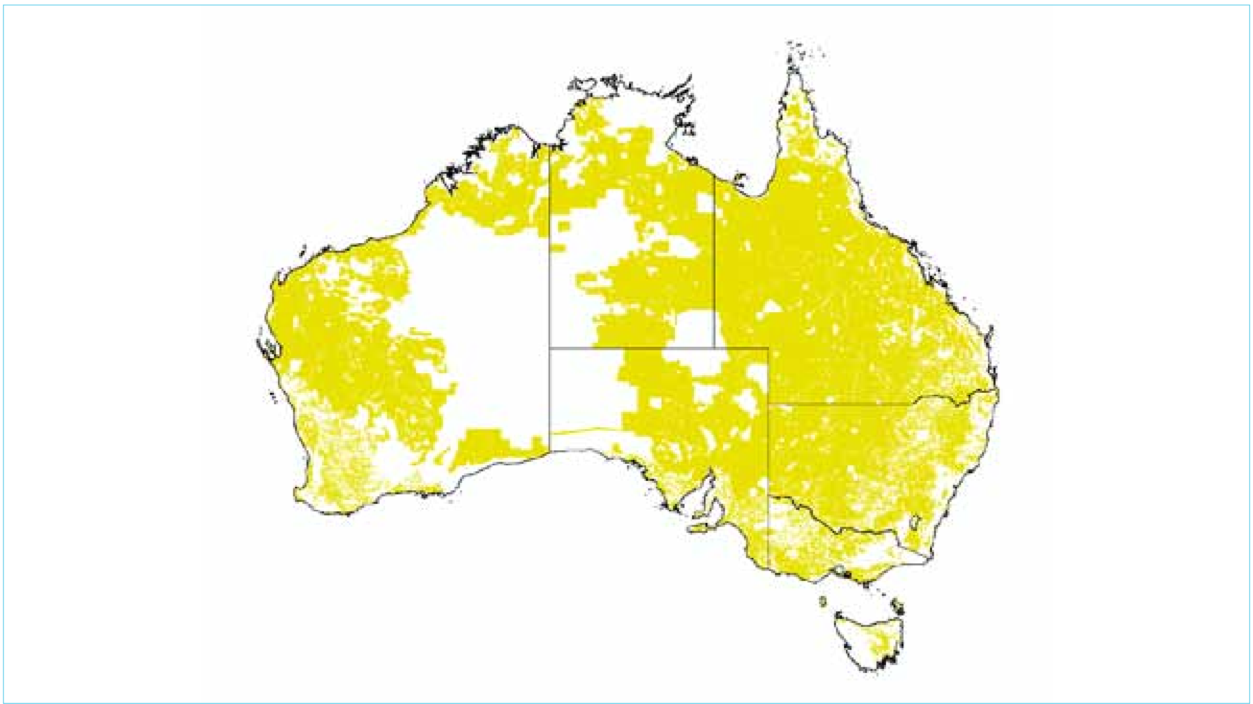
Figure 7.15 Cropland distribution in Australia 2010



7.3.2.3 Grassland

In Australia, the *grassland* category represents a diverse range of climate, management and vegetation cover. Grasses range from highly productive, improved introduced pastures, with applications of fertiliser and irrigation, through to unimproved native grasses and introduced grass species that receive little or no fertiliser and which cover vast inland areas extending into the semi-arid and arid regions. The *grassland* category also includes sub-forest forms of woody vegetation (shrubs) and areas of sparse tree cover that do not meet the height, crown canopy cover and minimum forest area criteria for *forest land*.

Figure 7.16 Grassland distribution in Australia 2010



7.3.2.4 Settlement

Settlements include areas of residential and industrial infrastructure, including cities and towns, and transport networks.

7.3.2.5 Wetland

Wetlands include areas of lakes, rivers, natural wetlands, and man-made dams.

7.3.2.6 Other land

The *other land* category includes all areas that are not included in the *forest land, cropland, grassland, settlement* or *wetland* categories. *Other land* in Australia typically occurs in arid regions.

7.3.2.7 Managed and unmanaged lands

Australia has diverse and extensive forest and agricultural systems with highly varied uses. Forest use is typically evident by physical disturbance, such as in commercial forest harvest, or clearly delineated by land tenure, such as conservation reserves. In extensive systems, such as grazed woodlands, there is a continuum in the intensity and intent of use, but no clear boundary by which to separate managed from unmanaged forest.

In the absence of a definable boundary between managed and unmanaged lands, and given the very broad definition that applies to managed land under the IPCC *Good Practice Guidance for Land Use, Land Use Change and Forestry* (IPCC, 2003), Australia has included all forests in its area of managed land. However, while all forests are included in the area of managed land, this does not imply that all emissions and removals from those forests on managed lands are anthropogenic.

Other land is the only land category considered to be unmanaged.

7.4 REPRESENTATION OF LAND AREAS

The principal method of representing land is through a time-series national remote sensing program. This consistent representation of land is a full spatial time-series application of Approach 3 as described in the IPCC *Good Practice Guidance for Land Use, Land Use Change and Forestry* (IPCC, 2003). Reconciliations are performed on a land unit by land unit basis to ensure that there are no gaps or overlaps which would lead to omission or double counting of areas of land. To support estimation of emissions and removals in the *forest land* category, Australia uses some non-spatial data drawn from Australia's National Forest Inventory. This is used exclusively within a reporting category consistent with Approach 3. Land areas in the *cropland remaining cropland*, *grassland remaining grassland, wetlands,* and *settlements* categories are drawn from the Land Use Mapping programme of Australia's Bureau of Rural Sciences. Areas of *forest land* and *forest land converted to grassland and cropland* are excluded from this mapping to prevent double counting of land areas. Table 7.7 shows the representation of land according to the IPCC land use categories (IPCC, 2003). Annual land area matrices are shown in Table 7.8.

Table 7.7 Land representation matrix (start of 1990 to end of 2010)

Note: (a) The land areas for 1990 in this table are the land areas at the start of 1990. The net change is therefore the change in land area including change that occurred in 1990 through to 2010 inclusive.

Land use	1990 (Mha)	2010 (Mha)	Net Change (Mha)
Forestlands total	**111.9**	**106.8**	**-5.1**
Forestland remaining Forestland	11.9	105.7	**-6.2**
Harvested Native Forests	14.9	14.9	**0.0**
Plantations	0.8	0.8	**0.0**
Other Native Forest	96.2	90.0	**-6.2**
Grassland converted to Forest Land	0.0	1.1	**1.1**
Grasslands total	**444.4**	**448.0**	**3.6**
Grassland remaining Grassland	437.1	434.8	**-2.3**
Forest Land converted to Grassland	7.3	13.2	**5.9**
Cropland total	**24.7**	**26.2**	**1.4**
Cropland remaining Cropland	21.8	21.8	**0.0**
Forest Land converted to Cropland	2.9	4.4	**1.4**
Wetlands total	**13.5**	**13.5**	**0.0**
Seetlements total	**1.6**	**1.6**	**0.0**
Other Lands	**172.9**	**172.9**	**0.0**
TOTAL LAND AREA(a)	**769.0**	**769.0**	**0.0**

(a) Total area does not include external territories.

Table 7.8 Annual land area matrices from 1990 – 2010 (the area reported in the final area column is the land area by category at the end of the year)

1990

	Forest land	Grassland	Cropland	Wetlands	Settlements	Other land	Final Area
Forestland	111	1					112
Grassland	0	444					444
Cropland	0		25				25
Wetlands				13			13
Settlements					2		2
Other land						173	173
Initial Area	112	444	25	13	2	173	769
Net change	0	0	0	0	0	0	0

1991

	Forest land	Grassland	Cropland	Wetlands	Settlements	Other land	Final Area
Forestland	112	1					112
Grassland	0	444					444
Cropland	0		25				25
Wetlands				13			13
Settlements					2		2
Other land						173	173
Initial Area	112	444	25	13	2	173	769
Net change	0	0	0	0	0	0	0

1992

	Forest land	Grassland	Cropland	Wetlands	Settlements	Other land	Final Area
Forestland	112	1					112
Grassland	0	443					444
Cropland	0		25				25
Wetlands				13			13
Settlements					2		2
Other land						173	173
Initial Area	112	444	25	13	2	173	769
Net change	0	0	0	0	0	0	0

1993

	Forest land	Grassland	Cropland	Wetlands	Settlements	Other land	Final Area
Forestland	112	0					112
Grassland	0	443					443
Cropland	0		25				25
Wetlands				13			13
Settlements					2		2
Other land						173	173
Initial Area	112	444	25	13	2	173	769
Net change	0	0	0	0	0	0	0

1994

	Forest land	Grassland	Cropland	Wetlands	Settlements	Other land	Final Area
Forestland	112	0					112
Grassland	0	443					443
Cropland	0		25				25
Wetlands				13			13
Settlements					2		2
Other land						173	173
Initial Area	112	443	25	13	2	173	769
Net change	0	0	0	0	0	0	0

1995

	Forest land	Grassland	Cropland	Wetlands	Settlements	Other land	Final Area
Forestland	112	0					112
Grassland	0	443					443
Cropland	0		25				25
Wetlands				13			13
Settlements					2		2
Other land						173	173
Initial Area	112	443	25	13	2	173	769
Net change	0	0	0	0	0	0	0

1996

	Forest land	Grassland	Cropland	Wetlands	Settlements	Other land	Final Area
Forestland	112	0					112
Grassland	0	443					443
Cropland	0		25				25
Wetlands				13			13
Settlements					2		2
Other land						173	173
Initial Area	112	443	25	13	2	173	769
Net change	0	0	0	0	0	0	0

1997

	Forest land	Grassland	Cropland	Wetlands	Settlements	Other land	Final Area
Forestland	112	0					112
Grassland	0	443					443
Cropland	0		25				25
Wetlands				13			13
Settlements					2		2
Other land						173	173
Initial Area	112	443	25	13	2	173	769
Net change	0	0	0	0	0	0	0

1998

	Forest land	Grassland	Cropland	Wetlands	Settlements	Other land	Final Area
Forestland	112	0					112
Grassland	0	443					443
Cropland	0		25				25
Wetlands				13			13
Settlements					2		2
Other land						173	173
Initial Area	112	443	25	13	2	173	769
Net change	0	0	0	0	0	0	0

1999

	Forest land	Grassland	Cropland	Wetlands	Settlements	Other land	Final Area
Forestland	112	1					112
Grassland	0	443					443
Cropland	0		25				25
Wetlands				13			13
Settlements					2		2
Other land						173	173
Initial Area	112	443	25	13	2	173	769
Net change	0	0	0	0	0	0	0

2000

	Forest land	Grassland	Cropland	Wetlands	Settlements	Other land	Final Area
Forestland	112	1					113
Grassland	0	443					443
Cropland	0		25				26
Wetlands				13			13
Settlements					2		2
Other land						173	173
Initial Area	112	443	25	13	2	173	769
Net change	0	0	0	0	0	0	0

2001

	Forest land	Grassland	Cropland	Wetlands	Settlements	Other land	Final Area
Forestland	112	0					112
Grassland	1	443					444
Cropland	0		26				26
Wetlands				13			13
Settlements					2		2
Other land						173	173
Initial Area	113	443	26	13	2	173	769
Net change	-1	1	0	0	0	0	0

2002

	Forest land	Grassland	Cropland	Wetlands	Settlements	Other land	Final Area
Forestland	111	0					111
Grassland	1	444					444
Cropland	0		26				26
Wetlands				13			13
Settlements					2		2
Other land						173	173
Initial Area	112	444	26	13	2	173	769
Net change	-1	1	0	0	0	0	0

2003

	Forest land	Grassland	Cropland	Wetlands	Settlements	Other land	Final Area
Forestland	110	0					110
Grassland	1	444					445
Cropland	0		26				26
Wetlands				13			13
Settlements					2		2
Other land						173	173
Initial Area	111	444	26	13	2	173	769
Net change	-1	1	0	0	0	0	0

2004

	Forest land	Grassland	Cropland	Wetlands	Settlements	Other land	Final Area
Forestland	109	0					109
Grassland	1	445					446
Cropland	0		26				26
Wetlands				13			13
Settlements					2		2
Other land						173	173
Initial Area	110	445	26	13	2	173	769
Net change	-1	1	0	0	0	0	0

2005

	Forest land	Grassland	Cropland	Wetlands	Settlements	Other land	Final Area
Forestland	108	0					108
Grassland	1	446					447
Cropland	0		26				26
Wetlands				13			13
Settlements					2		2
Other land						173	173
Initial Area	109	446	26	13	2	173	769
Net change	-1	1	0	0	0	0	0

2006

	Forest land	Grassland	Cropland	Wetlands	Settlements	Other land	Final Area
Forestland	107	0					107
Grassland	1	447					448
Cropland	0		26				26
Wetlands				13			13
Settlements					2		2
Other land						173	173
Initial Area	108	447	26	13	2	173	769
Net change	-1	1	0	0	0	0	0

2007

	Forest land	Grassland	Cropland	Wetlands	Settlements	Other land	Final Area
Forestland	106	0					106
Grassland	1	448					449
Cropland	0		26				26
Wetlands				13			13
Settlements					2		2
Other land						173	173
Initial Area	107	448	26	13	2	173	769
Net change	-1	1	0	0	0	0	0

2008

	Forest land	Grassland	Cropland	Wetlands	Settlements	Other land	Final Area
Forestland	106	0					106
Grassland	0	449					449
Cropland	0		26				26
Wetlands				13			13
Settlements					2		2
Other land						173	173
Initial Area	106	449	26	13	2	173	769
Net change	0	0	0	0	0	0	0

2009

	Forest land	Grassland	Cropland	Wetlands	Settlements	Other land	Final Area
Forestland	106	1					107
Grassland	0	448					448
Cropland	0		26				26
Wetlands				13			13
Settlements					2		2
Other land						173	173
Initial Area	106	449	26	13	2	173	769
Net change	1	-1	0	0	0	0	0

2010

	Forest land	Grassland	Cropland	Wetlands	Settlements	Other land	Final Area
Forestland	106	0					107
Grassland	0	448					448
Cropland	0		26				26
Wetlands				13			13
Settlements					2		2
Other land						173	173
Initial Area	107	448	26	13	2	173	769
Net change	0	0	0	0	0	0	0

7.4.1 Land Classification

Australia's reporting meets the IPCC *Good Practice Guidance for Land Use, Land Use Change and Forestry* (IPCC, 2003) land representation criteria of being consistent over time and that land is represented in only one category. Movement of land between categories is reported where a land use change occurs, such as a conversion of *forest land to cropland* and *forest land to grassland*, and *grassland to forest land*. Areas of forest may also change to grassland and vice versa due to forest regrowth and dieback. This process is largely driven by climate variability and is not directly human induced. These naturally caused ephemeral transitions are included as transfers between *other native forest* and *grassland remaining grassland* in the land area matrices. Australia is progressively adopting IPCC *Good Practice Guidance for Agriculture Forestry and Other Land Use* (IPCC, 2006) and is investigating methods to separate the reporting of lands that transfer between forest and non-forest due to natural variability that will provide greater transparency in the areas of land transferred between land categories without changing land use.

In accordance with the *Good Practice Guidance* (IPCC, 2003), in cases where there is a temporary change, such as a forest harvest, that land remains in its original category and is not temporarily transferred in and out of that land category. Equally, a temporary regrowth of woody biomass following land use change, as occurs in many grassland systems in Australia, is continuously reported under the *grassland* category. This ensures consistency in the treatment of temporary changes in land classification is maintained and reflects *Good Practice Guidance* (IPCC, 2003).

The IPCC (2003) recommends that for Tier 1 and Tier 2 methods, land should be reported in a "conversion sub-category" for 20 years, and then moved to a "remaining sub-category", unless a further change occurs. However, the IPCC (2003) also state that the 20 year period may be extended where the carbon dynamics are influenced by the conversion and these dynamics are represented in a Tier 3 model.

Australia has elected to move lands from the conversion sub-category to the remaining category after periods of up to 50 years. This longer period of time reflects the long term impacts of conversion on carbon dynamics in some systems under low rainfall conditions. Given the long time period, additional sub-categories are used to separate recent land conversions from older land conversions. The respective periods for these sub-categories are zero to 20 years and 21 to 50 years. After 50 years, the lands will be moved into the "land remaining" sub-categories. Following the recommendation of the 2010 Expert Review Team (ERT), Australia is working to apply this consistently across all land use categories in future submissions.

Australia maintains an extensive archive of Landsat satellite data collected since the first Landsat sensor delivered data in 1972 to support monitoring of *forest land converted to cropland* and *grassland*, and *grassland converted to forest land*. While these archives of satellite data currently support 38 years of conversion monitoring, additional methods and data sources will need to be identified to enable emissions estimates for land which remains in conversion categories for 50 years.

7.4.2 Monitoring of Forest Conversion

Patterns of forest conversion in Australia vary between southern and northern Australia. Broadly, in southern Australia, patterns of deforestation since 1990 have strongly featured small 'patch' clearance for rural residential development, infrastructure such as roads, and the removal of remnant tree patches in agricultural lands. Reforestation includes broad-scale plantation establishment as well as many small-scale environmental plantings for revegetation and rehabilitation purposes.

In the north of Australia, where the majority of deforestation occurs, the clearing patterns were for large development fronts involving the removal of remnant forest for expansion of the agricultural estate. Ongoing maintenance of removal of woody regrowth on eight to 15 year cycles was also very common within the existing agricultural estate.

7.4.2.3 Mapping Resolution and Re-sampling

Modelling grid resolution

The pixel resolution of data applied in a Tier 3 grid-based spatial ecosystem model and Approach 3 land representation predicates the use of both time-series consistent and spatially consistent data. To achieve time-series consistency in the land representation, 50 m re-sampled Landsat data are always compared to 50 m data where this is the best available data and comparisons are made at 25 m resolution where more recent data are available. The approaches used to do this are described in Appendix 7.A.

The pixel resolution of 50 m and 25 m are also guided by the need to integrate these spatial data with other spatial data sets. To achieve consistency in this integration, a minimum 25 m resolution or select multiples of 25 m (e.g. 50 m, 100 m, 200 m, 250 m, 1 km) are applied to achieve pixel to pixel registration.

Land cover grid resolution

To deal with the change in pixel size of the various Landsat sensors over time and the need for spatially and temporally consistent integration with other spatial data used in the model, the ‘native’ pixel size of the Landsat MSS (57 m x 79 m) was re-sampled to a 50 x 50 m pixel. The Landsat TM (~30 x 30 m native resolution) and ETM+ data available after 1988 were re-sampled to 25 x 25 m pixels (see details in Appendix 7.A).

To apply the pixel-by-pixel analysis over the period where the pixel size changed from 50 m to 25 m (in 1988), a 50 m MSS equivalent (in both spatial and spectral resolution) was derived from the 1989 TM (25 m) data, and forest extent calculated separately from both the 50 m and 25 m data sets. Differences in the extents of forest between these two outputs are due to “sensor change”. An overlap technique, as recommended by the IPCC (2003), is used to ensure time-series consistency such that the assessment of land cover change for 1988-89 was then based on a 50 m to 50 m comparison, while the 1989-1991 data was a 25 m to 25 m comparison. This permitted the use of best available data while maintaining time-series consistency.

All Landsat derived data are utilised at a consistent 25 m resolution for the full time-series analysis by re-sampling the 50 m pixels (1972-1988) into four 25 m pixels. The spatial-temporal model is important at this time, as it reduces the effect of “mixed” isolated and edge pixels. The period of the transition to the true 25 m data takes place prior to the period where it would have any significant effect on the first reported year of emissions. The 50 m data resolution is effectively only used to run-in the model to establish forest age (if the forest is regrowth from non-forest land or in response to a forest removal since 1972). The ability to determine, from 1990 onwards, the effects of land use change to 0.2 ha minimum areas is robust, given that this area is greater than the pixel resolution (approximately 0.0625 ha) and the approach used removes mixed and other pixels which are temporally and spatially inconsistent. These methods ensure that the change area within the Kyoto Protocol LULUCF accounting period (1990 onwards) is consistent at the 0.2 ha resolution.

Re-sampling Landsat TM and ETM+ data to 25 m pixels is common practice. Using a 50 m re-sample to provide consistency over the multiple resolutions of Landsat MSS sensors also provides for uniformity in the time-series. Quality assurance (QA) and validation processes confirm that accurate results are achieved with this re-sampled data (see Appendix 7.J). Further details on the grid resolution and minimum areas are provided in Appendix 7.A.

7.4.2.4 Time-series Consistency

Australia draws upon the services of a number of companies to undertake satellite data processing to specifications, specifically developed for the national inventory, and uses standard inputs including a consistent digital elevation model. Operational methods (Furby, 2002) have been developed to give explicit emphasis through documented rules to support time-series consistency in image data pre-processing, analysis, and subsequent formation of time-series forest presence/absence labels. For time-series classification, these standards also include the use of a joint spatial-temporal model - in this case a conditional probability network (Caccetta, 1997; Caccetta *et al*., 2003; Kiiveri *et al*., 2001, 2003) for determining the time-series of forest covers presence/absence labels.

The conditional probability network uses a series of spatial and temporal rules for determining forest presence/absence and change (forest and non-forest conversions). The temporal rules reduce the occurrence of unlikely events such as multiple one year conversions between forest and non-forest – for example conversion from non-forest to forest and then back to non-forest is an unlikely event over a short period, for example, three years. The rules are particularly effective when the time between observations is less than that of a forest growth and harvest cycle.

The spatial rules consider the pixel label in the context of the surrounding pixel labels. Labels that are consistent with the neighbouring labels are reinforced, whereas neighbouring labels that are inconsistent (e.g., isolated pixels) are treated as uncertain. The spatial and temporal rules work together providing spatial and temporal consistency, minimising temporally varying "mixed pixel" effects (due to spatially varying sampling from independent satellite overpass year to year) and subsequent error in pixel and change labelling.

7.5 SOURCE CATEGORY 5A FOREST LAND

7.5.1 Methodology

7.5.1.1 Forest Land Remaining Forest Land

There are four broad sub-divisions to *forest land remaining forest land*: *harvested native forests, other native forests, fuelwood consumed* and *plantations*. These are treated as independent sub-divisions and emissions estimates are modelled independently (Table 7.9). The definition of *forest land* is provided in section 7.3.2.1 and the description of managed and unmanaged land is discussed in section 7.3.2.7.

Table 7.9 Sub-divisions used in the Forest land remaining Forest land category

Harvested Native Forests	Fuelwood	Plantations	Other Native Forests			
			Single change in extent	Ephemeral change in extent	Loss of foliage mass in continuous forest	Fire
Areas of native forest that have been harvested at some time, or were considered to be available for harvest in 1990.	Fuelwood is extracted from dead organic matter across all forest categories and not against any individual category or categories. The majority of fuelwood is collected from agricultural landscapes.	Commercial plantations that were established prior to 1990.	Forest areas that have had a permanent change in their cover status, but there has been no identifiable human intervention and they are likely to change again.	These forest areas fluctuate above and below the forest cover thresholds, largely as a result of climate influences.	These forest areas always meet forest cover status, but without commercial forest production.	CO_2 emissions due to wildfire and prescribed burning and subsequent removals from post-fire recovery across all forest categories.

Harvested Native Forests

Harvested native forests are those forests comprised of endemic species arising from natural regrowth (including old forests), although various silvicultural techniques may be applied to initiate and promote particular growth characteristics. The areas included in this sub-category are those subject to harvest, those regrowing from prior harvest for which age class (harvest record) data are available, and those considered available for harvest in 1990. In Australia, many areas that were historically harvested are no longer available for harvest, having been withdrawn from commercial use due to changes in policy, such as new codes of practice, and transfer to conservation and recreation reserves. The removal of greenhouse gases due to recovery from former harvesting, continue to be reported in this category, even if the lands have moved to a reserve status. Areas of deforestation that change *forest land* to a non-forest land use or areas converted to plantation forest (native and exotic) are excluded from this account and are reported elsewhere.

The method used for the estimation of emissions and removals is Tier 2; using country specific data representing specific silvicultural techniques, harvest residue management, growth and decomposition rates. The reporting of *harvested native forests* includes both above and belowground biomass, debris accumulation, harvest residue (including roots) generated from forest harvest, and the effects of residue burning. Emissions and removals from soil carbon are not considered to be significant with the potential losses during forest harvest presumed to be in balance with re-accumulation in areas of regrowth for any inventory period. The detailed methods used are described in Appendix 7.B.

The current methods do not support emissions estimation from other activities in harvested forest lands, but these activities (e.g., grazing and beekeeping) do not have a significant effect on carbon stocks in *harvested native forests*.

Harvested Native Forests and the Forest Management reference level

As part of the negotiations for further commitments for Annex I Parties under the Kyoto Protocol, Australia submitted a Forest Management reference level to the United Nations Framework Convention on Climate Change (UNFCCC) Secretariat[1].

The anthropogenic emissions and removals due to the management of Australia's forests are primarily the result of management activities and practices related to the production of wood and wood products. Consequently Australia has defined Forest Management lands as those forests that are managed under a system of practices that include: forest harvesting; silvicultural practices; and, the protection of natural resources within the areas of land available for harvest. Publically owned native forests that fit this definition are identified as Multiple Use Forests (Australia's State of the Forests Report, 2008).

Forest Management activities (harvesting and silvicultural practices) also occur on privately managed native forests. As the management intent on these lands is largely unknown, to ensure balanced and complete accounting for emissions and removals from forest management activities, harvesting on these lands since 1990 has been estimated and included under Forest Management.

The Forest Management reference level therefore utilises the most recent data available for delineating areas of land included under Forest Management. Forest Management therefore includes all native timber production areas including public Multiple Use Forests mapped under Australia's State of the Forests Report 2008 and privately owned native forest harvested since 1990. Once fully developed, a remote sensing program will be used to identify the areas of native forests harvested since 1990. This approach provides a clearly delineated and verifiable basis for monitoring and measuring changes in carbon stocks from Forest Management activities in the period to 2020. In contrast, existing national inventory estimates of net emissions from *forest land remaining forest land* are based on areas of land that have not been spatially mapped and which therefore do not provide a basis for delineating Forest Management activity lands in the future.

As part of the development of the Forest Management reference level a reconciliation of *harvested native forests* with the native forests included under Forest Management was developed (Table 7.10). As the data used to define the area of *harvested native forests* was estimated using non-spatial data almost 20 years ago, it was difficult to accurately reconcile the harvested native forest area with the area of forest included under Forest Management as Multiple Use Forests and Private *harvested native forests.*

Table 7.10 Reconciliation of forest areas between UNFCCC Forest land remaining forest land harvested native forests and native forests considered under Australia's Forest Management reference level as Article 3.4 Forest Management

UNFCCC Forest land remaining forest land	Estimated area in 2009 (Mha)	2012 NIR Disaggregation (bold categories are *Forest management lands*)	Estimated area in 2009 (Mha)
Harvested native forests	14.89	**Multiple Use Forests**	9.41
		Private harvest native forests	0.39
		Native forests no longer identified as managed for wood production in 2009 (e.g. new conservation areas, private native forests previously considered as production forests but not harvested since 1990, statistical discrepancy, etc)	5.09

1 Submission of a Forest Management reference level and supporting information as requested by Decision 2/CMP.6 (Land use, land use change and forestry)

The emissions and removals from harvested native forests according to Forest Management sub-categories have been estimated (Table 7.11). The allocation of historical harvest areas in public native forests between Multiple Use Forests and native forests that are no longer identified as managed for wood production as at 2009 had to be estimated. As there is no information currently available to determine this, the assumption was made that all harvesting on public native forests from 1990 onwards occurred on Multiple Use Forests. While this assumption has little impact on the emissions and removals during the projected forest management reference level period (2013-2020) this is likely to result in an overestimate of removals in the early 1990s for Native Forests no longer identified as managed for wood production in 2009, and a possible overestimate of emissions from Multiple Use Forests in the early 1990s.

Table 7.11 Indicative estimate of emissions from UNFCCC Forest land remaining Forest Land – harvested native forests disaggregated by Forest Management native forest sub-category.

Year	Multiple Use Forests	Private native forests	Areas not considered to be managed for wood production as at 2009	Harvested native forests total
		Emissions (Mt CO_2)		
1990	-16.8	6.0	-22.4	-33.2
1991	-16.7	7.0	-23.7	-33.5
1992	-15.8	7.7	-24.4	-32.6
1993	-14.0	8.2	-24.9	-30.7
1994	-12.8	8.6	-25.2	-29.4
1995	-11.7	9.0	-25.4	-28.1
1996	-10.2	9.3	-25.5	-26.5
1997	-10.4	9.5	-25.6	-26.5
1998	-10.2	9.7	-25.6	-26.2
1999	-9.9	9.8	-25.6	-25.7
2000	-8.9	10.8	-25.6	-23.8
2001	-6.9	11.5	-25.6	-21.0
2002	-11.0	8.1	-25.7	-28.5
2003	-10.6	8.1	-25.7	-28.2
2004	-10.2	9.5	-25.7	-26.4
2005	-13.0	8.3	-25.8	-30.5
2006	-13.3	8.8	-25.8	-30.2
2007	-14.3	10.0	-25.8	-30.0
2008	-12.6	8.1	-25.8	-30.3
2009	-17.0	9.4	-25.7	-33.3
2010	-17.3	7.5	-25.7	-35.5

Harvested wood products are not reported in this category and carbon stocks are transferred to category *5G Other - harvested wood products*. As the structure of the reporting tables does not account for transfers of carbon stocks, this leads to an apparent, but not real, emission from *harvested native forests* and a ‘sink’ in *harvested wood products* in the year of harvest.

Other Native Forests

Other native forests include those forests that are (a) comprised of endemic species, (b) not *harvested native forests* (c) not *forest land converted to cropland* or *grassland*, and (d) are not *plantations* (native or exotic) or *grassland converted to forest land*. The area of *other native forests* is determined using the remotely sensed area of forest, excluding areas of *forest land converted to cropland* or *grassland, plantations*, *grassland converted to forest land* and *harvested native forests*. The area of *other native forest* changes through time due to ongoing processes such as dieback and regrowth, and also fluctuates due to climate.

Other native forests are divided into several sub-categories for modelling purposes. Each sub-category uses country specific emissions factors or models. These sub-categories include emissions and removals for: permanent changes in forest extent (such as thickening and dieback); ephemeral changes in forest extent due to climate; loss of foliage mass in continuous forest areas due to climate; and controlled burning and wildfire (including removals post-fire). The emissions and removals in the *other native forests* category are overwhelmingly driven by natural disturbances and annual climate variability. The detailed methods used are described in Appendix 7.D.

Climate variability and natural ecological processes result in the area of *other native forests* varying between years. The main driver of these non-anthropogenic changes in forest cover is variability in water availability, particularly as a result of drought conditions. This can lead to a decrease in the area of *other native forests* due to forest cover loss during drought and can also lead to an increase in the area of *other native forests* with the recovery of forest cover after drought. This appears as an inconsistency in the land area matrices because the net change in forest area due to natural variability and the related emissions and removals are reported under *other native forests*. The 2010 expert review team recommended the separate reporting of natural forest cover loss and gain in appropriate conversion sub-categories (in sub-divisions of *forest land converted to grassland* and *grassland converted to forest land*). Australia is developing methods to implement these changes for the inventory and also methods to report units of land that have ephemeral change in forest cover, that is, units of land that have natural variability above and below the forest cover threshold and hence do not have a permanent change to or from forest. These changes will be implemented in future submissions when the methods have been finalised, and verified.

Plantations (established prior to 1990)

This sub-category contains plantations established prior to 1990 and have remained as forest since 1990. The plantations forests include those forests that (a) meet the definition of forest, (b) are not *harvested native forests*, (c) are not areas of *forest land converted to cropland* or *grassland*, and (d) *grassland converted to forest land* (post-1990). Areas included are typically either harvested native forest converted to plantation or long term (second or third rotation) plantation systems. Prior to 1985 it was relatively common practice to convert native forest to forest plantation. By 1990, this practice had largely ceased, and now only occurs in limited areas.

The Tier 3 *FullCAM* model is used to estimate emissions and removals from plantations (although not yet utilising the Landsat times series activity data, see below) employing growth increment tables and species specific conversion factors, combined with regionally specific silvicultural practices. The carbon pools considered for plantations include above and belowground biomass, dead organic matter and soil. Soil carbon is modelled using a Tier 2 method based on national reviews of forest soil carbon data (Polglase *et al*., 2004; Paul *et al*., 2002b; Paul *et al*., 2003b). The spatial soil carbon model will be used to estimate soil carbon emissions when the full spatially explicit modelling (Tier 3, Approach 3) of *FullCAM* is applied to the plantations sub-category. The methods for estimating emissions and removals from pre-1990 plantations are detailed in Appendix 7.C.

The areas of plantations have been drawn from Australia's National Forest Inventory. The National Forest Inventory makes no distinction between native forest conversions to plantations, second rotation plantations and other non-forest land uses converted to forests. As historic Australian forest inventory data on plantation establishment does not separate new forest establishment from second rotation forests (Jaakko Pöyry Consulting, 2000) it is not currently possible to separate plantations from *forest land remaining forest land*. Post-1990 this separation is made possible through the plantation mapping using Landsat data as described in Appendices 7.A and 7.D. In future inventories, this separation will be made in the plantations sub-category using the pre-1989 Landsat data as described in Appendix 7.A. Mapping of plantations established prior to 1990 using Landsat MSS data is ongoing. This data will allow for separation, from 1972 to 1988, of native forest to plantation conversion, second rotation planting and conversion from other land uses in future inventories.

Harvested wood products are not reported in this category. Carbon stocks removed as products are reported under 5G *Other – harvested wood products*. As the structure of the reporting tables does not account for transfers of carbon stocks, this leads to an apparent, but not real, emission from the *plantations* forests and a 'sink' in *harvested wood products* in the year of harvest.

Fuelwood Consumed

Emissions of CO_2 from the consumption of *fuelwood* are estimated using data on the residential and industrial consumption of wood and wood-waste. The consumption of wood for energy by the sawmilling and pulp and paper sectors is considered as part of the wood mass removed in *harvested native forests* which is modelled as an emission upon harvest and therefore, to prevent double-counting, is not included here. The energy use of *fuelwood* was converted to kilo tonne dry matter by multiplying the energy unit (PJ) with a conversion factor (0.0162) from AGO (2004). Subsequently, dry matter is converted to carbon content (0.5) and then multiplied by 44/12 to give CO_2 emissions.

Annual fuelwood data is obtained from the Australian Bureau of Agricultural and Resource Economics-Bureau of Rural Sciences (ABARES) to estimate CO_2 emissions. These statistics report three separate fuelwood classes: residential, industrial, and wood and paper. Fuelwood consumed in the residential sector represents over 92% of the total emissions of all fuelwood consumed. Only emissions from the burning of fuelwood for the residential and industrial sectors are reported under the *Fuelwood consumed* sub-category.

Fuelwood is extracted from dead organic matter across all forest categories and as such the CO_2 emissions associated with the consumption of *fuelwood* are reported separately rather than against any specific sub-category of *forest land*. The CO_2 emissions associated with *fuelwood* consumption are based on energy use (Petajoules, PJ) of fuelwood by industry as reported by ABARES (2010). The data used to estimate CO_2 emissions are updated annually based on the most recent ABARES statistics.

The wood and paper emissions arise from the use of log processing residues, typically to support the energy needs of that processing activity. These log transfers are reported under the transfers from live biomass into the wood products pool. This ensures there is no double counting between this and the collections of dead organic matter for the residential and industrial sectors.

There is no double counting of *Fuelwood consumed* between the LULUCF and Energy sectors. Emissions from biomass consumption in the Energy sector are provided as an information item but are not reported as emissions for the Energy sector.

7.5.1.2 Land Converted to Forest Land

Grassland converted to Forest Land

Grassland converted to forest land contains forest established since 1990 on land that was non-forest in 1990. In Australia, lands converted to forest are almost always formerly grassland. All emissions and removals are therefore reported as *grassland converted to forest land*. High land values and high soil nutrient status both limit the access to, and suitability of, former cropland for plantation establishment.

The definition of forest is the same as reported for all other land categories. The areas of *grassland converted to forest land* are drawn from remotely sensed data as per the methods described in Appendix 7.A. The multiple national time-series of Landsat satellite data (25 m) is analysed to provide the previous vegetation cover, area, time of establishment and type of plantation (Caccetta and Chia, 2004).

Grassland converted to forest land uses the spatially explicit (Tier 3, Approach 3) modelling system and includes carbon in living biomass, dead organic matter and soil pools. The modelling methods used to estimate emissions are described in Appendix 7.D and have been published in peer reviewed literature (Waterworth *et al,* 2007; Waterworth and Richards, 2008).

7.5.2 Uncertainties and Time Series Consistency

Uncertainties for the *forest land* category are estimated to be ±30% for CO_2. The majority of this uncertainty is due to the *other native forests* sub-category. Uncertainty in the plantations and *land converted to forest land* sub-categories is expected to be less than 10%. Further details are provided in Annex 7. Time series consistency is ensured by the use of consistent methods and full recalculations in the event of any refinement to methodology.

7.5.3 Source Specific QA/QC

Specific QA/QC and verification activities undertaken for this source category are described in detail in Appendix 7.J.

7.5.4 Recalculations Since the 2009 Inventory

There have been improvements and updates made to estimates of emissions and removals in the *forest land* category for the previous inventory submission in line with ERT recommendations for greater transparency in accounting and reporting. This has resulted in small recalculations to the time series of some of the sub-categories.

The *harvested native forests* sub-category has been modelled using the Tier 2, non-spatial capabilities of the *FullCAM* model as implemented in the previous submission. Annual activity data updates and a correction to the parameters for turnover of tree components to debris to be consistent with the plantations model and the turnover rates reported in the NIR resulted in a 3,237 Gg CO_2-e increase in the 1990 sink and a 1,729 Gg CO_2-e increase in the 2009 sink. For *other native forests* a recalculation occurred due to the annual update of forest extent data and revised data on wildfire and prescribed burning. this has resulted in a 74 Gg decrease in the 1990 sink and an 8,614 Gg CO_2-e decrease in the 2009 sink. Revised data for *Fuelwood* consumed for 2009 also resulted in an increase in the 2009 sink of 849 Gg CO_2-e.

The annual update of remote sensing data of forest cover change has resulted in a recalculation of the *grassland converted to forest land* sub-category. The update resulted in a small increase in the area confirmed as *grassland converted to forest land* in 2009 as well as an updated attribution of plantation type producing a 382 Gg CO_2-e decrease in the 2009 sink estimate.

The net effect of all recalculations was to increase the 1990 sink estimate by 3,150 Gg CO_2-e and to reduce the 2009 sink estimate by 6,403 Gg CO_2-e.

Table 7.12 Forest land: recalculation of total CO_2-e emissions (Gg), 1990-2009

Year	2011 submission	2012 submission	Change	
	(Gg CO_2)		(Gg CO_2)	(%)
1990	-42,299	-45,449	-3,150	-7.45
1991	29,440	27,011	-2,429	-8.25
1992	-27,265	-29,273	-2,009	-7.37
1993	-77,195	-79,170	-1,975	-2.56
1994	-61,324	-63,370	-2,046	-3.34
1995	-65,380	-67,108	-1,728	-2.64
1996	-54,394	-55,869	-1,474	-2.71
1997	-48,208	-49,698	-1,490	-3.09
1998	-43,064	-44,540	-1,475	-3.43
1999	-63,210	-64,694	-1,484	-2.35
2000	-48,627	-50,393	-1,765	-3.63
2001	-68,317	-69,799	-1,482	-2.17
2002	10,612	9,259	-1,353	-12.75
2003	152,209	151,033	-1,176	-0.77
2004	-121,646	-122,712	-1,066	-0.88
2005	-85,221	-88,486	-3,265	-3.83
2006	-92,818	-96,273	-3,455	-3.72
2007	-3,256	-9,463	-6,207	-190
2008	-103,204	-109,220	-6,016	-5.83
2009	-55,156	-48,753	6,403	11.61

7.5.5 Source Specific Planned Improvements

The methods used for estimating emissions and removals in the *forest land* category are not yet developed to enable fully spatially explicit (Approach 3), Tier 3 ecosystem modelling. The methods described in Appendices 7.B, 7.C and 7.E. describe the current methods which involve using a combination of Tier 2 and Tier 3 methods.

It is Australia's intention to have comprehensive use of Tier 3, Approach 3 modelling in the future for the plantations and *harvested native forests* sub-categories of the national inventory submission. Australia currently uses National Forest Inventory statistics to estimate the area of pre-1990 *plantations* (see Appendix 7.C). The remote sensing programme is currently developing methods to identify areas of plantation established prior to 1988 using Landsat MSS data. Work to assess the areas of *harvested native forest* (see Appendix 7.B) using remote sensing data is ongoing.

Australia has commissioned CSIRO to gather biomass data for mallee eucalypt and native mixed species plantings (mixed species environmental plantings) reported under the *Grassland converted to forest land* sub-category. This project has involved the collection and screening of data from a range of sources and collection of high precision measurements of biomass through destructive sampling. In addition to this work CSIRO has been asked to analyse the collected data and determine if a new set of statistically valid *FullCAM* growth parameters could be defined for mixed species environmental plantings and mallee eucalypt plantings.

During 2011 DCCEE initiated a process to review the relationships and data underpinning the *assumed initial above ground biomass regression model*. The *assumed initial above ground biomass regression model* underpins the estimation of emissions and removals for UNFCCC *forest land converted to cropland* and *grassland* and Kyoto Protocol Article 3.3 *deforestation* (NIR, 2009). The surface also underpins the growth and biomass calibrations developed for UNFCCC *land converted to forest land* and Kyoto Protocol Article 3.3 *Afforestation/Reforestation.*

The aim of reviewing the model is to enhance the transparency and accuracy in reporting while addressing the need for consistency. This review is an opportunity to ensure that the National Inventory System is equipped with the most recent data available, with the aim of supporting enhanced accuracy of the biomass estimates underlying Australia's National Greenhouse Accounts.

7.6 SOURCE CATEGORY 5B CROPLAND

7.6.1 Methodology

7.6.1.1 Cropland Remaining Cropland

Cropland remaining cropland covers an area of over 20 million hectares and includes both continuous cropping and the rotational crop and pasture systems that are dominated by mixed farming systems that swap between *grassland* and *cropland* on an annual basis.

Cropland remaining cropland is generally located along a broad inland fringe across the southern and eastern land areas of Australia, with the highest yields commonly obtained where rainfall is highest; in the south west and the eastern regions. In the southern regions, *cropland remaining cropland* is dominated by wheat production, with barley, oats, lupins and canola being the other dominant crops. In the north sugarcane, sorghum and cotton dominate. Irrigated crops account for approximately 5% of the total cropped land.

The majority of crops are predominantly reliant on winter rainfall and yields are subject to the climatic conditions in any given year. Crop yields vary according to the annual distribution of rainfall and the types of crops grown within a region. The various crop types that are in this land use category are shown in Table 7.12. Wheat grain yields commonly range from 0.5 – 6 t/ha depending upon location within the 'grain belt' and the available rainfall both before and during the growing season.

The areas in the *cropland remaining cropland* sub-category are estimated using the National Land Use 2001/2002 (Version 3) Summary Statistics provided by the Bureau of Rural Sciences (http://adl.brs.gov.au).

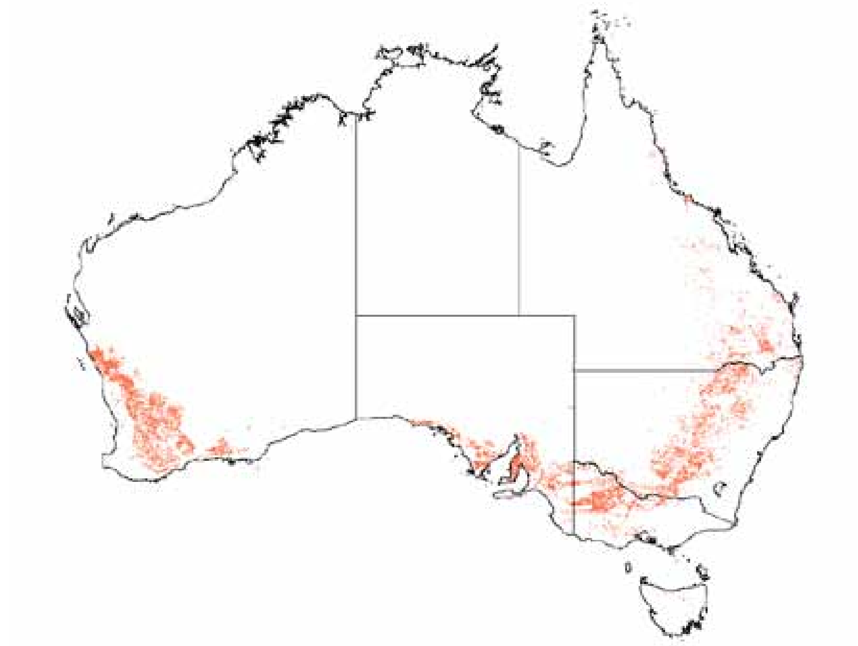
The current reporting structure for *cropland remaining cropland* includes all those lands that have been cropped prior to 1972 including cropped land that has been converted to grassland for grazing as part of a crop-pasture rotation. After this date, new areas of cropland are included in the forest land converted to cropland conversion category. No lands are converted from *cropland to forest land* or from *cropland to grassland*.

The estimation of emissions and removals in *cropland remaining cropland* are estimated using *FullCAM*, as described in Appendix 7.A. The data used in the modelling are provided in Appendix 7.G. Estimates for all carbon pools (living biomass, dead organic matter, soil) are modelled through the year.

In order to model changes in soil carbon *FullCAM* requires initial soil carbon values to commence the simulation in 1990 for the *cropland remaining cropland* account. Prior to land-clearing on agricultural lands the native vegetation ranged from woodland to sparse woody vegetation. In order to obtain appropriate soil carbon values to commence simulations in 1990, the model was equilibrated for croplands, assuming standard practices including cultivation and crop-pasture rotations for both pastoral and cropping activities since 1800. Land clearing activities for both pastoral and cropped soils is based on the historical records for landuse that show the introduction of cropping practices and transitional land clearing from 1800 (Heathcote 1987).

For living biomass, the change in carbon stocks from year to year is estimated at the end of each crop cycle to be zero, consistent with the guidance provided in the IPCC *Good Practice Guidance* for LULUCF (page 3.71), which indicates that any increase in the biomass from annual crops will tend to equal the losses from harvest and mortality in that same year. Consistent with the UNFCCC reporting guidelines, changes in the carbon stocks of living biomass or dead organic matter are not reported.

Figure 7.17 Distribution of Cropland in 2001/02 from National Land Use Summary Statistics



Source: Bureau of Rural Sciences

Note: figure presents areas of both cropland remaining cropland and forest land converted to cropland

Table 7.13 The crop types and approximate areas in Cropland in 2001/02 from National Land Use Summary Statistics

Crop type	Area (M ha)
Cereals	19.21
Legumes	2.35
Oil seeds	1.52
Irrigated cereals	0.64
Irrigated cotton	0.44
Sugar	0.30
Irrigated sugar	0.26
Irrigated vegetables and herbs	0.16
Irrigated vine fruits	0.16
Cropping	0.13
Irrigated tree fruits	0.11
Irrigated cropping	0.05
Cotton	0.04
Perennial horticulture	0.03
Hay and silage	0.03
Tree fruits	0.03
Tree nuts	0.02
Irrigated oil seeds	0.02
Vine fruits	0.02
Irrigated tree nuts	0.11
Irrigated legumes	0.02
Irrigated perennial horticulture	0.01
Vegetables and herbs	0.01
Irrigated hay and silage	0.01

Source: Bureau of Rural Sciences

Note: table presents data for both cropland remaining cropland and forest land converted to cropland

7.6.1.2 Land Converted to Cropland

Forest land converted to Cropland

The definition for a forest used by Australia (2 m height, 20% crown canopy cover and minimum area of 0.2 ha) is also used to define areas of forest conversion. That is, the conversion of greater than 0.2 ha of forest to another (non-forest) land use is taken as a forest conversion. When the land use subsequent to a forest conversion contains a cropping activity, associated emissions are reported under *forest land converted to cropland*.

The areas are identified by the remote sensing activity data as described in Appendix 7.A. Emissions and removals are estimated using the Tier 3, Approach 3 mass balance, process-based ecosystem model *FullCAM*, as described in Appendix 7.A. The reporting of *forest land converted to cropland* includes all carbon pools (living biomass, dead organic matter and soil).

N_2O emissions from disturbance associated with land-use conversion to cropland are estimated as described in section 7.11.1.4. Non-CO_2 emissions from on-site burning associated with land conversion are estimated as described in section 7.12.1.3. Other non-CO_2 emissions from these lands are reported in the *agriculture* sector.

7.6.2 Uncertainties and Time Series Consistency

Uncertainties for *forest land converted to cropland* at the national scale were estimated to be ±10% for CO_2. Based on a qualitative assessment the uncertainties for *cropland remaining cropland* were estimated to be medium. Further details are provided in Annex 7. Time series consistency is ensured by the use of consistent methods and full recalculations in the event of any refinement to the methodology.

7.6.3 Source Specific QA/QC

The calibration and verification of the *FullCAM* model, along with the associated quality assurance and quality control program are fully described in Appendices 7.A, 7.E and 7.J.

7.6.4 Recalculations Since the 2009 Inventory

Australia's inventory for the land sector is prepared in line with the 2003 IPCC *Good Practice Guidance* for Land Use, Land Use Change and Forestry. As part of the broader process of on-going development and future planning the current methods were also reviewed against guidance provided in the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Volume 4: *Agriculture, Forestry and Other Land Use* , which must be fully implemented across the inventory by 2015.

Both sets of guidelines note that net emissions from living biomass are likely to be ephemeral (IPCC 2003 – page 3.71 *Methodological Issues* and IPCC 2006 – page 5.7 *Choice of Method*) for annual crops. In *FullCAM* living biomass stock is estimated at the end of the crop cycle and is the summation of the increase in biomass stock minus the loss in biomass due to harvest and mortality.

Consistent with IPCC *Good Practice Guidance* (2003), and the IPCC 2006 *Guidelines*, the change in carbon stocks for above and below ground living masses for annual, herbaceous crops has been estimated at the end of the crop cycle for this submission whereas in the previous submission the change in the stock of carbon in the living biomass had been estimated during the course of the crop cycle (and therefore reflected changes in climatic conditions from year to year). In this submission, the increases in biomass stocks associated with plant growth for annual, herbaceous crops are balanced by the losses due to harvest and mortality. Consistent with the UNFCCC reporting guidelines, changes in carbon stocks for dead organic matter have also not been reported in this submission.

Estimates for the change in the stock of carbon for living biomass for perennial woody crops have been included for the first time in this submission, using interim Tier 1 methods.

As part of the transition to the implementation of the 2006 IPCC Guidelines across the national inventory, the Department of Climate Change and Energy Efficiency has commenced an internal review of data inputs used in the estimation of emissions from the *grassland* and *cropland* categories, which has led to a number of improvements to both the *cropland remaining cropland* and *grassland remaining grassland* categories for this submission.

These improvements included the following:

- In addressing the expert review team's requirement for greater disaggregation of crops the analysis of yield data for crop and pasture rotations was more extensively dealt with in the QC process. This investigation led to the re-evaluation of several crop and pasture regimes and the finding that some of the annual, herbaceous crops had growth cycles longer then the annual cycle. These crop and pasture rotations have now been rectified to ensure that they align with an annual cycle of crop growth;
- Improvements to the equilibration of carbon pools prior to allocation of specific regional crop and pasture practices and rotations have now been applied. The model simulation runs commenced in the year 1800 to allow all carbon pools to reach equilibrium before allocation of yield and climate data from 1968;
- Large areas of poorly producing arid and semi-arid agricultural land in central Australia had previously, in the 2011 inventory submission, been remapped from high productivity regions due to the similarity of landuse and the use of a generalised map of net primary productivity. New data from industry (B. Henry, Meat and Livestock Australia, 2011, *pers. comm*. 2011) on pasture production for these arid and semi-arid regions has identified that these original estimates were too high and required an adjustment based on these data and other unpublished recent research findings (Carter and Hunt – *pers. comm.* ACEAS workshop 2011). These changes in yield allocation for arid and semi-arid grass pastures have been applied across the central grazing lands of Australia in the 2012 inventory submission.

Systematic annual updates of new data and improved inputs of crop disaggregation and management practices at the regional scale to improve the *cropland remaining cropland* estimates have continued to be implemented. Implementation of quality control processes for this submission has led to improved crop management and yield data. Yield tables for all crops were updated to improve the quality of input data for years prior to 2009. This improved data set was made available through the use of Australian Bureau of Agricultural Statistics, industry reports and regional estimates of crop and pasture yields where no yield data had previously existed and broad assumptions had been made based on regional locations. Other changes included updated allocation of yields to plant components for a number of crop types in Western Australia and Tasmania that were previously allocated to roots. These allocations were updated for the entire time series to ensure time-series consistency. Recalculations were also made for sugar cane crop types in 2010 as a result of the availability of revised yield data. Harvest events have been adjusted for sorghum in Queensland to better reflect the timing and length of growing season for sub-tropical plants that differ to the majority of temperate crops growing in southern Australia. Grazing events were modified to reflect the lower stocking rates in drier regions and to allow for the grazing of crop debris (cereal residues after harvest).

The changes made to the modelling of the *cropland remaining cropland* subcategory have also been implemented in the *forest land converted to cropland* subcategory. However, the emissions and removals from all biomass pools are reported still reported under this sub-category.

Table 7.14 Croplands: recalculation of total CO_2-e emissions, 1990-2009

Year	2011 submission	2012 submission	Change	
	($Gg\ CO_2$-e)		($Gg\ CO_2$-e)	(%)
1990	221	32,844	32,622	14,737
1991	-4,352	26,881	31,233	717
1992	11,895	28,361	16,466	138
1993	-13,875	19,025	32,901	237
1994	-26,123	13,788	39,912	152
1995	-1,830	17,072	18,902	1,032
1996	5,127	20,473	15,346	299
1997	-10,189	11,839	22,028	216
1998	19,248	19,190	-57.89	-0.30
1999	2,256	10,422	8,165	361
2000	-10,688	12,276	22,965	214
2001	-17,845	13,020	30,866	172
2002	52,599	17,961	-34,637	-65.85
2003	-22,418	15,501	37,919	169
2004	-33,460	11,064	44,525	133
2005	-47,902	14,808	62,711	130
2006	20,802	16,521	-4,280	-20.58
2007	29,915	18,656	-11,259	-37.64
2008	-14,122	11,993	26,116	184
2009	-25,264	14,060	39,325	155

7.6.5 Source Specific Planned Improvements

Planned improvements include progressive review of the inventory for consistency with the 2006 IPCC Guidelines as well as the systematic review of all data inputs and modelling parameters.

An important planned improvement relates to the introduction of a systematic collection process for data on management practices applied in croplands in Australia. The ABS has been commissioned to conduct regular surveys across Australian agriculture. In addition, a new farming survey will be conducted by the Australian government (ABARE) that will provide an update to the 2001/2002 national land use data.

Annual crop yields are currently obtained from Australia Bureau of Statistics (ABS) and validated using industry data. In areas where there is poor quality data an estimate of crop yield is modelled from rainfall availability during the crop growth period. A crop growth model has been developed by CSIRO for integration within the existing inventory methods. This simplified crop growth model performs well against other crop growth models used by industry and science to estimate crop yields at the start and during the growing season for forward selling of grain (e.g. APSIM). The new crop growth model is being investigated as a new module to be implemented into *FullCAM* when calibration, verification and quality assurance has been finalised.

The model is also being further developed to include a non-CO_2 capacity. This will be achieved by enhancing the model to include nitrogen cycling. To date, the model code has been implemented and initial calibrations tested. This module still requires further testing and validation and will only be introduced following quality assurance, testing and review.

7.7 SOURCE CATEGORY 5C GRASSLAND

7.7.1 Methodology

7.7.1.1 Grassland Remaining Grassland

The *grassland remaining grassland* category includes all areas of *grassland* that are not reported under *forest land converted to grassland*. Areas that are in rotational use between *grassland* and *cropland* are reported under either *forest land converted to cropland* or *cropland remaining cropland*.

The distribution of land areas in the *grassland remaining grassland* sub-category are estimated using the National Land Use 2001/2002 (Version 3) Summary Statistics provided by the Bureau of Rural Sciences (http://adl.brs.gov.au). In 2010 *grassland remaining grassland* covered an area of 435 million hectares (of the 448 million hectares of grassland reported in Table 7.4) which is evenly distributed around Australia (Figure 7.18). The remaining area of grassland is reported under the *forest land converted to grassland* sub-category.

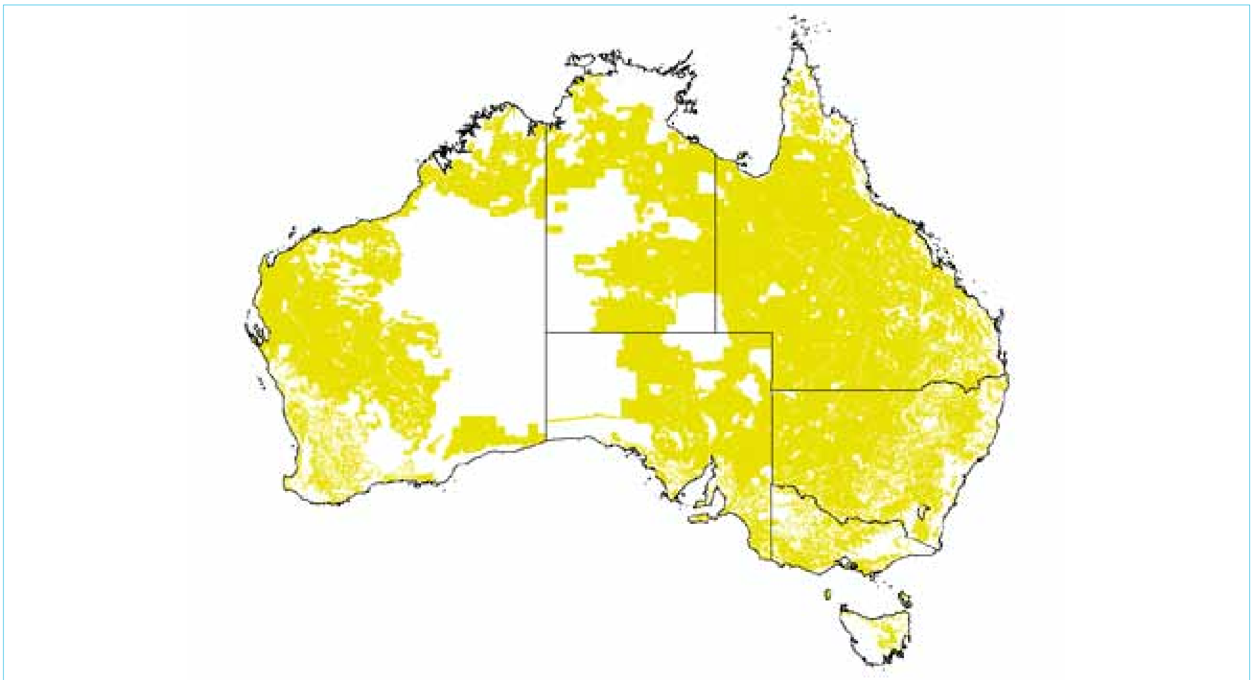
There are three components of the *grassland remaining grassland* emission estimates – the grassland component, the shrubland transitions component and the CO_2 emissions and post fire removals associated with savanna burning. Shrublands are areas of woody vegetation that are not, by definition, 'forest'. Shrublands are typically sparse tree and shrub formations and are not separable into areas made up of uniquely tree or shrub plant types.

Emissions from the *grassland remaining grassland* category are estimated using interim methods. The Tier 3 *FullCAM* model is used to estimate emissions and removals of all pools (living biomass, dead organic matter and soil) for the grass only areas of the *grassland remaining grassland* category. A Tier 2 method is used to estimate emissions and removals for the shrubland (sub-forest) areas for live biomass and dead organic matter. Shrubland emissions are estimated for transitions of land between shrubs and grasses for the *grassland remaining grassland* sub-category. These methods are described in Appendix 7.H. The methods for estimating CO_2 emissions and removals associated with fires are described in section 7.12.1.2.

Reporting of the grassland remaining grassland category includes estimates of emissions from the change in carbon stock from the soil carbon pool and changes in the carbon stock of perennial woody biomass.

Non-CO_2 emissions from *grassland remaining grassland* are reported in the *agriculture* sector.

Figure 7.18 Distribution of Grassland remaining Grassland in 2001/02 from National Land Use Summary Statistics.



Source: Bureau of Rural Sciences

Grass component

The estimation of emissions for the grass component includes the modelling of all on-site carbon pools (living biomass, dead organic matter and soil). Emissions and removals are estimated using the Tier 3, Approach 3 *FullCAM* mass balance, process-based ecosystem model, as described in Appendix 7.A. The calibration and verification of this model, along with the associated quality assurance and quality control program are described in Appendix 7.J. The data used in the model runs include plant growth rates, grazing intensity and pasture management practices such as burning. Grazing intensities are determined from industry and research data and include a generalised regional assessment based upon average livestock carrying capacity linked to pasture production (ABARES 2011). These data are described in Appendices 7.A and 7.F.

For the *grassland remaining grassland* sub-category, there are three main agro-ecological categories; native arid and semi arid which occupy about 340 M ha and the high rainfall improved pastures that occupy about 60 M ha. Historical data on land use from early European settlement identifies that extensive grazing practices (primarily sheep) commenced in the late 1700's and continued to expand to a maximum sheep flock of more than 180 million head by 1900 (Henzell 2007). It is therefore presumed that land in the grass component of the arid and semi-arid regions, which comprised sparse woody vegetation and woodlands, remained as native pastures with some introduced species transitioning over this entire period. Soil carbon pools were modelled for the semi-arid and arid regions from 1500 to remove the influence of above and below ground masses from forest soil inputs. For the high rainfall pastoral regions grazing was stabilised from 1800 to 1971 to reflect the gradual clearing of native forest soils for grazing purposes. The date of deforestation of each pixel is randomly allocated in the period between these years with the amount of clearing approximately evenly distributed in each year. The model is then equilibrated using typical grazing practices at the Iterim Biogeographical Regionalisation of Australia (IBRA) scale from 1972 to 1989, for the initial reporting year of 1990. The equilibration of the soil carbon pool reflects soils under long-term grazing management, i.e., soil carbon is not significantly affected by the initial pasture establishment or former land use. This equilibration allows the model to represent both areas which have always been grassland and those cleared for grazing prior to 1972.

For the current *grassland remaining grassland* grass component estimates, several generic management practices have been identified for the arid, semi-arid, and improved pasture systems prior to 1972. Post 1972 more specific regionalised grazing practices were applied and modelled across all pasture regions to better reflect the differences in stocking rate (grazing pressure), pasture growth and climate as identified from more recent industry and ABARES data. Hence variation in the live biomass, dead organic matter and soil pools is largely driven by variations in pasture yield, grazing pressure and climate.

7.7.1.2 Land Converted to Grassland

Forest Land Converted to Grassland

The definition of a forest used by Australia (2 m height, 20% crown canopy cover and minimum area of 0.2 ha) is also used to define areas of forest conversion. That is, the conversion of greater than 0.2 ha of forest to another (non-forest) land use is taken as a forest conversion. When the land use subsequent to a forest conversion is grassland only (i.e., no crops), associated emissions are reported under *forest land converted to grassland*.

The reporting of *forest land converted to grassland* includes all carbon pools. The areas are identified by Australia's remote sensing program as described in Appendix 7.A. Cyclic forest regrowth and re-clearing of woody regrowth in grasslands is continuously reported under *forest land converted to grassland*. This is because these lands are considered to remain as grasslands due to the cyclic nature of re-clearing. Moving lands continually between the *grasslands converted to forest land* and *forest land converted to grassland* categories would lead to a false increase in emissions from the *forest land converted to grassland* category. Lands which are managed under a crop-pasture rotation are reported under *forest land converted to cropland*.

Emissions and removals from this category are estimated using the Tier 3, Approach 3, mass balance, empirically constrained ecosystem model *FullCAM*, as described in Appendix 7.A.

N_2O emissions from disturbance associated with land-use conversion to grassland are estimated using the methods described in section 7.11.1.4. As it is not possible to include these emissions under *lands converted to grassland* in the UNFCCC CRF tables they are reported under 5G *other*. Non-CO_2 emissions from on-site burning associated with land conversion are estimated as described in section 7.12.1.3. Other non-CO_2 emissions from these lands are reported in the *agriculture* sector.

7.7.2 Uncertainties and Time Series Consistency

Uncertainties for *grassland* conversion at the national scale were estimated to be ±10% for CO_2. Based on a qualitative assessment the uncertainties for *grassland remaining grassland* were estimated to be medium. Further details are provided in Annex 7. Time series consistency is ensured by the use of consistent methods and full recalculations in the event of any refinement to methodology.

7.7.3 Source Specific QA/QC

The calibration and verification of *FullCAM* along with the associated quality assurance and quality control programs are described in Appendices 7.A, 7.E and 7.J.

7.7.4 Recalculations Since the 2009 Inventory

Methodology for the soils and fire components of this category has changed since the 2009 inventory. In addition the area burnt activity data has also been revised since the previous inventory.

Soils

Australia's inventory for the land sector is prepared in line with the 2003 IPCC *Good Practice Guidance* for Land Use, Land Use Change and Forestry. As a part of the broader process of on-going development and future planning the current methods were also reviewed against guidance provided in the 2006 IPCC *Guidelines* for National Greenhouse Gas Inventories, Volume 4: *Agriculture, Forestry and Other Land Use* (which must be fully implemented across the inventory by 2015).

Consistent with IPCC *Good Practice Guidance* (2003) and the IPCC 2006 *Guidelines* the change in carbon stocks for above and below ground living biomasses for annual, herbaceous grasses has been estimated at the end of the crop cycle for this submission whereas in the previous submission the change in the stock of carbon in the living biomass for annual, herbaceous grasses had been estimated during the course of the crop cycle (and therefore reflected changes in climatic conditions from year to year). In this submission the increases in biomass stocks associated with plant growth for annual, herbaceous grasses are balanced by the losses due to harvest and mortality. Consistent with UNFCCC reporting guidelines, changes in carbon stocks of dead organic matter are not reported in this submission.

As part of its preparation for the full implementation of the 2006 IPCC *Guidelines*, embedded within revised UNFCCC reporting guidelines, the Department of Climate Change and Energy Efficiency has commenced an internal review of data inputs used in the estimation of emissions from the *grassland* and *cropland* categories, which has led to a number of improvements to both the cropland *remaining cropland* and *grassland remaining grassland* categories.

To estimate the change in emissions from soil and below ground biomass using the Tier 3 approach, the *FullCAM* model uses the same climate data as for all other Tier 3 accounting together with regional estimates of grazing intensity and pasture yields. There have been several updates to data in both the quality of the yield data and the management practices used at the regional scale from the previous 2009 national inventory. The arid and semi-arid regions of central Australia were previously attributed pasture yields of 5 – 12 t/ha and a grazing intensity of 80%. For these regions where stocking rates rarely exceed 0.2 DSE/ha both pasture yield and grazing pressure were reduced to better reflect the change in soil carbon and below ground root masses.

For the high rainfall improved pastures, improvements were made to the sequence of pasture rotations used by *FullCAM* to estimate emissions and removals from all carbon pools. The outcome of this error in pasture sequence allowed for higher than expected yields causing the soil carbon stocks for the grassland remaining grassland account to increase over the reporting period. This increase in soil carbon stocks also resulted in a high rate of removal of CO_2 from the atmosphere.

In this inventory report the incorporation of more appropriate pasture rotations including senescence over the summer period has resulted in a decline of soil carbon stocks and is thus more reflective of the current knowledge of pasture systems in Australia (Grace et al, 1996).

The overall impact of these changes is presented in Table 7.14.

Australia has continued to implement annual updates of remote sensing data to identify the area of *forest land converted to grassland*. Australia has implemented the same changes to the post conversion modelling of *forest land converted to grassland*; however for this sub-category the emissions from all biomass pools are still reported.

Fire

The fire methodology for this source category has been amended from the 2009 NIR submission. The fire methodology is a variant of the previous methodology and has the following dependencies:

- Fire patchiness as a function of fire season;
- Burning efficiency as a function of fire season; and
- Fuel load as a function of vegetation class.

The fire methodology differs from the previous methodology by no longer reporting emissions and removals from dead fuels and only reporting those from live perennial biomass. In these vegetation communities live fuel loads are significantly lower than dead fuel loads and the burning efficiencies of live fuels are, overall, lower than dead fuels due to higher fuel moisture contents which inhibits pyrolysis. In combination these result in significantly reduced emissions over the previous method and are consistent with UNFCCC CRF tables for source category 5C, *grassland remaining grassland*.

Area burnt activity data has also been revised since the previous inventory as described in 4.E. Previously data was available since 1983.

The effect of the fire recalculations on the *grassland remaining grassland* sub-category is presented in Table 7.15.

Transitions

The methodology to estimate emissions associated with transitions in sparse woody vegetation has been amended from the 2009 NIR submission. The methodology is a variant of the previous methodology with the following modifications:

- Emissions associated with transition from sparse woody grassland to herbaceous grassland occur over a 20 year period rather than in the year of transition; and
- Removals associated with transition to sparse woody grassland from herbaceous grassland occur over a 20 year period rather than over five years.

The effect of the fire recalculations on the *grassland remaining grassland* sub-category is presented in Table 7.15.

Table 7.15 Emissions and removals (Mt CO_2) for 5C grassland: Recalculation of CO_2-e emissions 1990-2009

Year	2011 submission	2012 submission	Change	
	(Gg CO_2-e)		(Gg CO_2-e)	(%)
1990	89,514	109,891	20,377	22.76
1991	145,223	96,505	-48,718	-33.55
1992	143,801	84,011	-59,789	-41.58
1993	72,177	86,608	14,431	20.00
1994	71,963	61,875	-10,087	-14.02
1995	176,264	70,552	-105,711	-59.97
1996	50,960	66,498	15,537	30.49
1997	52,358	62,675	10,317	19.71
1998	154,670	80,550	-74,120	-47.92
1999	74,749	68,709	-6,039	-8.08
2000	49,557	101,802	52,245	105
2001	46,910	47,824	914	1.95
2002	273,101	61,432	-211,669	-77.51
2003	40,897	84,455	43,557	106
2004	-36,244	77,928	114,173	315
2005	181,899	83,708	-98,191	-53.98
2006	124,011	97,090	-26,921	-21.71
2007	319,144	88,011	-231,132	-72.42
2008	190,354	63,463	-126,891	-66.66
2009	137,156	83,263	-53,893	-39.29

7.7.5 Source Specific Planned Improvements

Planned improvements include progressive review of the inventory for consistency with the 2006 IPCC Guidelines as well as the systematic review of all data inputs and modelling parameters.

A new grass growth model is being developed for integration with the existing inventory methods. The new crop growth model will be implemented when calibration, verification and quality assurance has been finalised. The model is also being further developed to include a non-CO_2 capacity. This will be achieved by enhancing the model to include nitrogen cycling. To date, the model code has been implemented and initial calibrations tested. This module still requires further testing and validation and will only be introduced following quality assurance, testing and review.

In addition to the new modelling capabilities, Australia is completing a full national time series of change in sparse woody (shrub) vegetation cover from 1988 onwards using Landsat data in conjunction with improved fire mapping capabilities. These new inputs will be available to undertake further method development using the data for application in future inventory submissions (see Appendix 7.H for details).

Improvements to data inputs (i.e. yield) and management practices (i.e. grazing intensity, soil management) will be delivered through research programs funded by Federal and State government initiatives. Current programs will provide new data in 2012 that can be incorporated into the national inventory that will further improve the outputs for the *grassland remaining grassland* account.

Additional *FullCAM* model improvements are planned for 2012 that include the updating of parameters for pasture regimes and management practices.

7.8 SOURCE CATEGORY 5D WETLAND

7.8.1 Methodology

7.8.1.1 Wetland Remaining Wetland

Australia does not estimate emissions and removals from this voluntary reporting category.

7.8.1.2 Land Converted to Wetland

Australia has no peat extraction and any removals of forest biomass for the purposes of water storage infrastructure are reported under *forest land converted to grassland*. Therefore emissions and removals from this category are reported as 'Included Elsewhere'.

7.9 SOURCE CATEGORY 5E SETTLEMENTS

7.9.1 Methodology

7.9.1.1 Settlements Remaining Settlements

Australia does not estimate emissions and removals from this voluntary reporting category.

7.9.1.2 Land Converted to Settlements

The conversion of forest prior to infrastructure development is captured and reported under *forest land converted to grassland*. Therefore emissions and removals from this category are reported as 'Included Elsewhere'.

Australia reports emissions from *forest land converted to settlements* under *forest land converted to grassland* because time-series consistent mapping of settlement expansion is not currently available. Settlements in Australia only represent approximately 0.2% of the total land area of Australia and the rate of forest conversion for settlements is low.

Nevertheless, Australia continues to ensure that its inventory is in accord with the IPCC *Good Practice Guidance* (IPCC, 2003), and is currently involved in ongoing research and development to map urban areas through time using Landsat data. Australia plans to separate the reporting of land converted to settlements from land converted to grassland in future inventories.

7.10 SOURCE CATEGORY 5F OTHER LANDS

7.10.1 Methodology

7.10.1.1 Other Lands Remaining Other Lands

All *other lands* are considered unmanaged and as such Australia does not report emissions and removals from this voluntary reporting category. *Other lands* typically occur in unmanaged regions of central Australia, e.g., deserts.

7.10.1.2 Land Converted to Other Land

It is assumed that no lands are converted to *other land.*

7.11 SOURCE CATEGORY 5G OTHER

7.11.1 Methodology

7.11.1.1 Harvested Wood Products

Australia reports the carbon stock changes and associated emissions and removals of CO_2 from the *harvested wood products* pool. The carbon pool considered is defined as the wood products in service life within Australia. This includes the national production (including transfers from *forest land* after harvest that are recorded as a carbon stock reduction in *forest land remaining forest land* and *grassland converted to forest land*) plus the imported material, minus exported material and losses to landfill and the atmosphere. The methods used are described in detail in Appendix 7.I.

7.11.1.2 N_2O Emissions from N Fertilisation 5(I)

Nitrous oxide emissions associated with nitrogen fertilisers are reported under the *agriculture* sector (4D). N_2O released from the application of N fertiliser on forests is reported as IE (agriculture). The amount of N applied to lands in Australia is obtained from national statistics of the amount of N purchased. It is not possible to split the use of N fertiliser between agriculture and forests.

N fertilisation of native forests is very rare, if occurring at all. There is a limited amount of N fertiliser applied to forest plantations in Australia. Fertiliser application in plantations is typically done to correct for nutrient deficiencies and trace element correction at establishment. N may be applied on sites where it is shown that it is a significant limiting nutrient, but as most establishments are on pasture systems, background nutrient levels are typically sufficient.

7.11.1.3 N_2O Emissions from Drainage of Soils 5(II)

Australia does not estimate emissions and removals from this voluntary reporting category.

7.11.1.4 N_2O Emissions from Disturbance Associated with Land-Conversion to Cropland and Grassland 5(III)

An increase in N_2O emissions can be expected following the conversion of *forest land to cropland* and *grassland*. This is a consequence of enhanced mineralisation of soil organic matter that takes place as a result of forest conversion. The conversion not only results in the net loss of soil organic carbon but the corresponding effects on mineralised nitrogen can result in N_2O emissions from the process of nitrification and denitrification.

The IPCC (2003) methods are used to calculate N_2O emissions from this source. The amount of nitrogen mineralised is calculated from the C:N ratio of soil. The C:N value used is 18, reflecting the approximate median value extracted from a survey of national estimates (Snowdon *et al*., 2005). The country specific emission factor for fertiliser additions to pasture (0.004) is then applied. Also, following the methods outlined by the IPCC, nitrogen sequestered into carbon stocks is not taken into account, leading to zero emissions for forest to cropland and grassland conversions where appropriate at the regional level (State, by vegetation class by age class).

7.11.1.5 CO_2 Emissions from Agricultural Lime Application 5 (IV)

Limestone and dolomite are used in Australia to ameliorate soil acidity, improve soil structure, and improve plant growth in *cropland* and *grassland* and to a very limited degree in *forest land*. Adding carbonates to soils in the form of lime (eg. calcic limestone ($CaCO_3$) or dolomite ($CaMg(CO_3)_2$) leads to CO_2 emissions as the carbonate reacts with acids in the soil to produce bicarbonate and eventually leading to the production of CO_2 and water.

For agricultural lime application, the annual emissions of CO_2 are calculated as:

$$E_{ijk} = ((M_{jk} \times FracLime_{jk} \times P_{k=1} \times EF_{k=1}) + (M_{jk} \times (1- FracLime_{jk}) \times P_{k=2} \times EF_{k=2})) \times C_l / 1000 \quad .....(5IV\_1)$$

Where: E_{ijk} = annual emission of CO_2 from lime application (Gg)

M_{jk}= mass of limestone and dolomite applied to soils (t)

$FracLime_{jk}$ = fraction limestone

$P_{k=1}$ = fractional purity of limestone = 0.9

$P_{k=2}$ = fractional purity of dolomite = 0.95

$EF_{k=1}$ = 0.12 - IPCC (2006) default emission factor for limestone

$EF_{k=2}$ = 0.13 - IPCC (2006) default emission factor for dolomite

C_i = 44/12 factor to convert elemental mass of CO_2 to molecular mass

7.11.2 Uncertainties and Time Series Consistency

A qualitative assessment of uncertainty was undertaken and uncertainties for *harvested wood products* were estimated to be medium. Time series consistency is ensured by the use of consistent methods and full recalculations in the event of any refinement to methodology.

National data on limestone and dolomite applications to agricultural soils are only available from the Australian Bureau of Statistics for six years (1993, 1994, 1996, 2001, 2002 and 2008) with limestone and dolomite reported separately for only four (1996, 2001, 2002, 2008) of those years. Additional data are available for Western Australia (1991, 1995, 1998-2000 and 2004). Interpolation and extrapolation techniques have been used to estimate the mass of limestone and dolomite applied in years for which data are not available. The fraction of the estimated mass applied that is assumed to be limestone was based on the average of years for which data are available.

7.11.3 Source Specific QA/QC

Specific QA/QC and verification activities undertaken for *harvested wood products* are described in detail in Appendix 7.J.

7.11.4 Recalculations Since the 2009 Inventory

As the emissions estimates for *forest land converted to cropland* and *grassland* have been recalculated, the estimate of N_2O emissions from disturbance associated with land-use conversion has also been subject to a small recalculation.

There were minor revisions of the national Australian Forest and Wood Products Survey Statistics by the Australian Bureau of Agriculture and Resource Economics and Sciences.

Table 7.16 Other: recalculation of total CO_2-e emissions, 1990-2009

Year	2011 submission	2012 submission	Change	
	(Gg CO_2-e)		Change (Gg CO_2-e)	Change (%)
1990	-4,288	-4,245	42.69	1.01
1991	-3,868	-3,837	30.62	0.80
1992	-3,862	-3,847	15.17	0.39
1993	-3,998	-3,973	24.78	0.62
1994	-4,198	-4,169	28.55	0.68
1995	-4,308	-4,288	20.16	0.47
1996	-3,388	-3,349	39.56	1.18
1997	-3,302	-3,255	46.68	1.43
1998	-3,569	-3,525	43.66	1.24
1999	-3,322	-3,295	26.84	0.81
2000	-3,746	-3,788	-42.38	-1.12
2001	-3,274	-3,315	-41.77	-1.26
2002	-3,330	-3,312	17.71	0.53
2003	-3,634	-3,637	-2.40	-0.07
2004	-3,979	-3,869	110	2.86
2005	-3,939	-3,785	153	4.07
2006	-3,783	-3,609	173	4.81
2007	-3,336	-3,347	-10.75	-0.32
2008	-3,540	-3,681	-141	-3.83
2009	-2,765	-2,751	13.78	0.50

7.11.6 Source Specific Planned Improvements

All data and methodologies are kept under review and development. Appendix 7.A specifies the detailed development plans for the National Inventory System.

7.12 SOURCE CATEGORY 5(V) BIOMASS BURNING

7.12.1 Methodology

7.12.1.1 Forest Land (5A.1)

Prescribed Burning and Wildfires

Only methane nitrous oxide emissions are reported for this category. In *forest land*, burning occurs in Australia as a result of both anthropogenic and wildfires. Anthropogenic burning is carried out for a variety of reasons including fuel reduction for the prevention of uncontrollable wildfires and traditional Aboriginal burning. These anthropogenic fires influence natural fire regimes and may ameliorate the frequency and intensity of wildfires that would occur naturally otherwise, albeit with differing frequency and at other times of the year. Climatic variability contributes large year-to-year variations in biomass burning in Australia.

For prescribed burning and wildfires, the total mass of fuel burnt is calculated as:

$$M_{jk} = A_{jk} \times FL_{jk} \times Z_{jk} \times 10^{-3} \quad \text{(5V\_1)}$$

Where: M_{jk} = mass of fuel burnt annually (Gg),

A_{jk} = area of category burnt annually (ha),

FL_{jk} = fuel loading (dry weight) (Mg ha^{-1}) (Table 7.16 and Table 7.17),

Z_{jk} = burning efficiency (Table 7.18).

then for CH_4, CO and NMVOCs the total annual emissions are calculated as:

$$E_{ijk} = M_{jk} \times CC_{jk} \times EF_{ijk} \times C_i \quad \text{(5V\_2)}$$

Where: E_{ijk} = annual emission of gas *i* from biomass burning (Gg),

M_{jk} = mass of fuel burnt annually (Gg yr^{-1}).

CC_{jk} = carbon mass fraction in vegetation (Table 7.19),

EF_{ij} = emission factor for gas *i* from vegetation (Table 7.20),

C_i = factor to convert from elemental mass of gas species *i* to molecular mass (Table 7.21),

and total annual emissions for NO_x and N_2O are:

$$E_{ijk} = M_{jk} \times CC_{jk} \times NC_{jk} \times Ei_{jk} \times C_i \quad \text{(5V\_3)}$$

Where: E_{ijk} = annual emission of gas *i* from biomass burning (Gg),

M_{jk} = mass of fuel burnt annually (Gg),

CC_{jk} = carbon mass fraction in vegetation (Table 7.19)

NC_{jk} = nitrogen to carbon ratio in biomass (Table 7.21)

EF_{ijk} = emission factor for gas *i* from vegetation (Table 7.20)

C_i = factor to convert from elemental mass of gas species *i* to molecular mass (Table 7.21)

The CO_2 emissions and removals associated with the burning and subsequent regrowth of forest lands are reported under 5.A.1 *other native forests* and thus are not reported under 5(V) *biomass burning* to ensure no double counting occurs. A description of the method used to estimate these emissions and removals is provided in Appendix 7.D. The method uses the same data used to estimate non-CO_2 emissions.

Table 7.17 Fuel load for Prescribed Burning of Forest in Australia (Mg dry matter ha^{-1})

State	ACT[a]	NSW[a]	NT[a]	Qld[a]	SA[b]	Tas[b]	Vic[a]	WA[a]
	FL_{jk} (Mg ha^{-1})							
Load	17.6	18.2	4.1	9.7	9.6	20.0	17.9	12.0

(a) State agencies, (b) Tolhurst (1994)

Table 7.18 Fuel load for Wildfires in Australia (Mg dry matter ha^{-1})

State	ACT[a]	NSW[a]	NT[a]	Qld[a]	SA[b]	Tas[b]	Vic[a]	WA[a]
	FL_{jk} (Mg ha^{-1})							
Load	35.2	36.4	7.2	19.4	19.2	40.0	35.8	33.4

(a) State agencies, (b) Tolhurst (1994)

Table 7.19 Burning efficiencies for Prescribed Burning and Wildfires in Australia

Category	Burning efficiency Z_{jk}
Prescribed burning	0.42
Wildfires	0.72

Tolhurst (1994)

Table 7.20 Forest biomass composition

System	Carbon mass fraction in dry residue CC_{jk}	Nitrogen to carbon mass fraction NC_{jk} [a]
Forest	0.5	0.011

(a) Hurst *et al*., (1994a,b)

Table 7.21 Mean emissions factors for carbon and nitrogen trace gases from forest biomass burning

	Gas species *i*	Emission factor E_{ijk} (Gg element in species/Gg element in fuel burnt)
1.	CH_4	0.0054
2.	N_2O	0.0077
3.	NO_x	0.15
4.	CO	0.091
5.	NMVOC	0.022

Hurst *et al*., (1996) mean of 4 Australian temperate forest fires.

Table 7.22 Elemental to molecular mass conversion factor (C_i)

CH_4	N_2O	NO_x	CO	NMVOC
1.33	1.57	3.29	2.33	1.17

Slash Burning

The CO_2 emissions associated with slash burning in *harvested native forests* are estimated by *FullCAM* and as such CO_2 emissions are reported under 5.A.1 *harvested native forests*. The mass of carbon burnt annually (FC_{jk}) is taken directly from *FullCAM* and is used to estimate the non-CO_2 gas emissions associated with slash burning.

There are no direct measurements of trace gas emissions from slash burning in Australia; however it is considered that these fires will have similar characteristics to hot prescribed fires and wildfires (Hurst *et al*., 1996).

The algorithms for total annual emissions of CH_4, CO and NMVOCs are:

$$E_{ijk} = FC_{jk} * EF_{ijk} * C_i \qquad (5V\_6)$$

and for total annual emissions for NO_x and N_2O are:

$$E_{ijk} = FC_{jk} * NC_{jk} * EFi_{jk} * C_i \qquad (5V\_7)$$

Where: FC_{jk} = annual fuel carbon burnt in slash burning (obtained from *FullCAM*) (Gg),

EF_{ijk} = emission factor for gas *i* from vegetation (Table 7.20),

NC_{jk} = nitrogen to carbon ratio in biomass (Table 7.21)

C_i = factor to convert from elemental mass of gas species *i* to molecular mass (Table 7.21).

7.12.1.2 Grassland remaining Grassland (5C.1) – Prescribed Burning of Savannas

The CO_2 emissions and removals associated with the burning and subsequent regrowth of savannas and temperate grasslands are reported under 5.C.1 *grassland remaining grassland* and thus are not reported under 5(V) *biomass burning* to ensure no double counting occurs. The description of the method used to estimate these emissions and removals is provided in Appendix 7.H.

Non-CO_2 emissions are reported under 4.E *prescribed burning of savannas* in the *agriculture* sector.

7.12.1.3 Forest Land converted to Cropland and Grassland (5B.2 and 5C.2)

Carbon dioxide emissions from on-site burning associated with land conversion are using *FullCAM* (Appendices 7.A and 7.F) and as such these emissions are reported under 5.B.2 and 5.C.2. The mass of carbon burnt annually (FC_{jk}) is a *FullCAM* output and is used to estimate the non-CO_2 gases associated with burning.

There are no direct measurements of trace gas emissions from the burning of cleared vegetation in Australia; however it is considered that these fires will have similar characteristics to hot prescribed fires and wildfires (Hurst *et al*., 1996).

The algorithms for total annual emissions of CH_4, CO and NMVOCs are:

$$E_{ijk} = FC_{jk} * EF_{ijk} * C_i \qquad (5V\_8)$$

and for total annual emissions for NO_x and N_2O are:

$$E_{ijk} = FC_{jk} * NC_{jk} * EFi_{jk} * C_i \qquad (5V\_9)$$

Where: FC_{jk} = annual fuel carbon burnt in land conversion (Gg),

EF_{ijk} = emission factor for gas *i* from vegetation (Table 7.20),

NC_{jk} = nitrogen to carbon ratio in biomass (Table 7.21)

C_i = factor to convert from elemental mass of gas species *i* to molecular mass (Table 7.21).

7.12.2 Uncertainties and Time Series Consistency

Uncertainties for biomass burning emissions of CH_4 and N_2O were estimated to be in the order of -45 to +93% for forest land, and ±20% for forest conversion categories. The narrower uncertainty range for forest conversion categories is due to the more accurate fuel load estimates provided by *FullCAM*. Further details are provided in Annex 7. Time series consistency is ensured by the use of consistent methods and full recalculations in the event of any refinement to methodology.

7.12.3 Source Specific QA/QC

Specific QA/QC and verification activities undertaken for *FullCAM* are described in Appendix 7.J.

7.12.3.1 Methane emission factor

The country specific CH_4 emission factor for forest fires (0.54% of C in fuel burnt or 3.6 g/kg dry matter (dm) burnt) is lower than the IPCC default values (1.2% ±0.3 or 9 g/kg dm) (IPCC, 2003). To explain these differences, as requested by the UNFCCC expert review team, the source literature for the country specific emissions factor (Hurst *et al*., 1996) and the IPCC defaults (Delmas, 1994 and Delmas *et al*., 1995) were reviewed.

The country specific emission factor reported by Hurst *et al*., (1996) is based on measurements undertaken in Australia during four temperate forest fires. As there can be large variation in CH_4 emissions between vegetation types it was considered that the Australian measurement data would provide the most accurate estimate of CH_4 emissions.

The IPCC defaults for CH_4 are based only on the estimates for tropical forests reported by Delmas, (1994) and Delmas *et al*., (1995). Both papers also provide estimates for temperate boreal forests (1.0% ± 0.5 or 5.4 (2.7-8.1) g kg dm^{-1} (Delmas, 1994) and 0.61% ± 0.2 (Delmas *et al*., 1995). The Australian emission factor is consistent with these ranges and that reported for extra tropical rainforests (4.7±1.9 g kg dm^{-1}) by Andreae and Merlet, (2001) (the source for the 2006 IPCC Guidelines defaults).

7.12.4 Recalculations Since the 2009 Inventory

Small recalculations to the *forest land remaining forest land, forest land converted to cropland* and *forest land converted to grassland* biomass burning emissions have resulted in a small decrease in emissions estimates across the time series from 1990 to 2009 (Table 7.23).

In addition, activity data was revised in for prescribed burning and wildfires in the *other native forests* category, resulting in a decrease in emissions estimates from *biomass burning* in 2008.

Table 7.23 Biomass Burning: recalculation of total CO_2-e emissions, 1990-2009

Year	2011 submission	2012 submission	Change	
	(Gg CO_2-e)		Change (Gg CO_2-e)	Change (%)
1990	6,182	6,149	-32.4	-0.52%
1991	8,487	8,449	-37.5	-0.44%
1992	5,929	5,883	-45.8	-0.77%
1993	4,058	4,013	-44.3	-1.09%
1994	4,788	4,722	-66.4	-1.39%
1995	3,801	3,743	-58.2	-1.53%
1996	4,538	4,460	-78.0	-1.72%
1997	4,087	4,016	-71.1	-1.74%
1998	4,788	4,712	-75.8	-1.58%
1999	3,567	3,504	-62.5	-1.75%
2000	3,643	3,565	-76.1	-2.09%
2001	5,166	5,103	-63.3	-1.23%
2002	6,252	6,187	-66.0	-1.06%
2003	14,180	14,120	-59.7	-0.42%
2004	4,079	4,009	-69.4	-1.70%
2005	5,328	5,174	-153.4	-2.88%
2006	4,813	4,607	-207.1	-4.30%
2007	8,165	7,859	-306.3	-3.75%
2008	4,345	3,843	-502.5	-11.56%
2009	3,947	3,906	-42.4	-1.07%

7.12.5 Source Specific Planned Improvements

All data and methodologies are under review and development. Australia is currently funding research to help improve understanding of emissions from fire. This research includes conducting field analysis of emissions factors during the 2009 burning season. The CH_4 emissions factor for biomass burning will be reviewed once the data from this research becomes available.

APPENDIX 7.A: OVERVIEW OF THE IMPLEMENTATION OF LAND SECTOR REPORTING WITHIN AUSTRALIA'S NATIONAL INVENTORY SYSTEM

7.A.1 Introduction

Land sector reporting within Australia's National Inventory System integrates a wide range of spatially referenced data through a hybrid process-empirical model to estimate carbon stock change and greenhouse gas emissions at fine spatial and temporal scales. Analysis and reporting includes all carbon pools (biomass, dead organic matter and soil), all principal greenhouse gases (CO_2, CH_4 and N_2O), covers both forest and non-forest land uses.

The terrestrial ecosystem model implemented within Australia's Nation Inventory System is the Full Carbon Accounting Model (*FullCAM*) (Richards, 2001; Richards and Evans, 2004). As most emissions and removals of greenhouse gases occur on transitions between forest and agricultural land use, integration of agricultural and forestry modelling was essential.

FullCAM also forms the basis of the publicly available Reforestation Modelling Tool (RMT) which allows users to develop project-level carbon accounts for reforestation projects using the same data as used for deriving national accounts, thus achieving consistency between national and project level accounting.

This Appendix reviews the ongoing development of *FullCAM* and supporting activity data which support land sector reporting within the National Inventory System. Appendix 7.J outlines in detail the quality assurance and quality control processes, calibration, verification and sensitivity analysis for land sector reporting within Australia's National Inventory System.

7.A.2 Activity Data

Human induced land cover change is a key driver of the pattern of greenhouse gas emissions and removals in Australia's land sector. Australia has developed a national time series of land cover change maps showing both where and when change occurs as the key source of activity data in the LULUCF sector. National coverages of Landsat satellite data (MSS, TM, and ETM+) across 20 time epochs from 1972 to 2011 have been assembled and analysed for change. The historic cover and cover change information is important in two ways:

- Firstly, the effects on greenhouse gas emissions from land cover change are typically long lasting, and historic activities may still contribute to current estimates; and
- Secondly, the emissions and removals by current activities will be affected by the site history. For example, a current deforestation event will likely generate fewer emissions if the forest cleared is secondary forest (regrowth after a previous deforestation) rather than a primary (mature) forest.

7.A.2.1 Data Selection

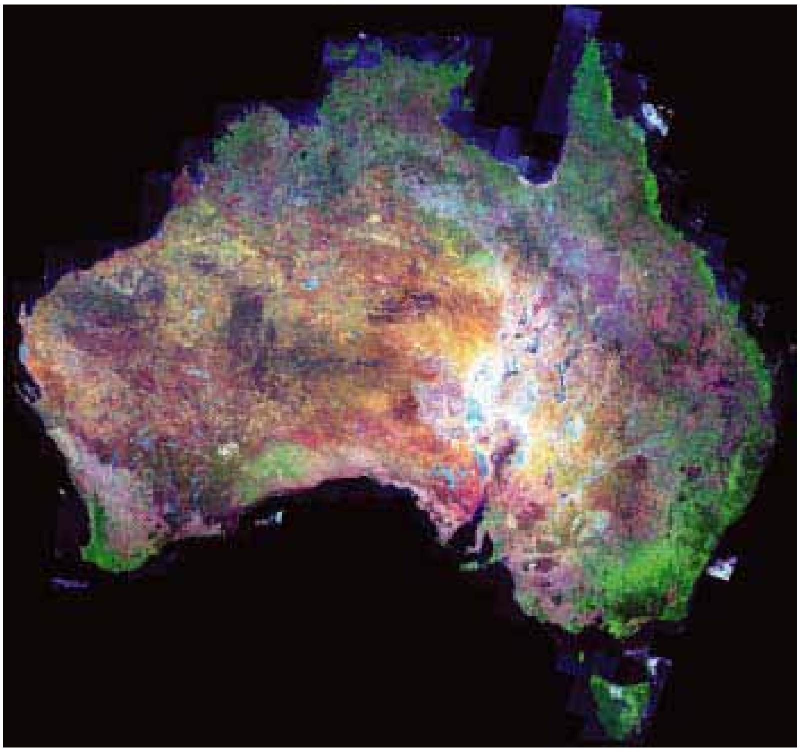
Areas of land cover change[2] that contribute to emissions include those areas with lagged emissions from activities undertaken since the early 1970s. The ability to map land cover change over an extended period is therefore required for the emissions inventory. With Australia's land area of some 769 million hectares, establishing this record of activity presented many challenges. A remote sensing approach using archival coverage of Landsat satellite data of Australia since the early 1970s has been used to address this challenge.

2 Land Cover Change refers to a change from forest to non-forest (or vice-versa) vegetation cover.

The use of Landsat data to analyse land cover change through time at a fine pixel resolution requires a consistent geographically registered[3] and spectrally calibrated[4] reference base (Figure 7.A1). Also, standard specifications for processing and interpretation (including attribution[5]) of the sequence of Landsat data are used to achieve a consistent national assessment of land cover change over the time-series.

Australia has used an overlap technique to move from the 50 m resolution MSS data to the 25 m resolution TM and ETM+ data without introducing false land cover change due to instrumentation differences. This approach is consistent with the good practice methods recommended by the IPCC for ensuring time-series consistency where the instruments used to collect activity data change or degrade through time (IPCC, 2003 page 5.58). To do this, a MSS equivalent 1989 image coverage was created from the TM images at 50 m resolution using a subset of the TM spectral bands corresponding to the MSS bands. Land cover change assessments bridging the switch from MSS to TM/ETM+ were then based upon MSS to MSS and TM/ETM+ to TM/ETM+, across similar image spectra and pixel size.

Figure 7.A 1 The year 2000 mosaic registration and calibration base



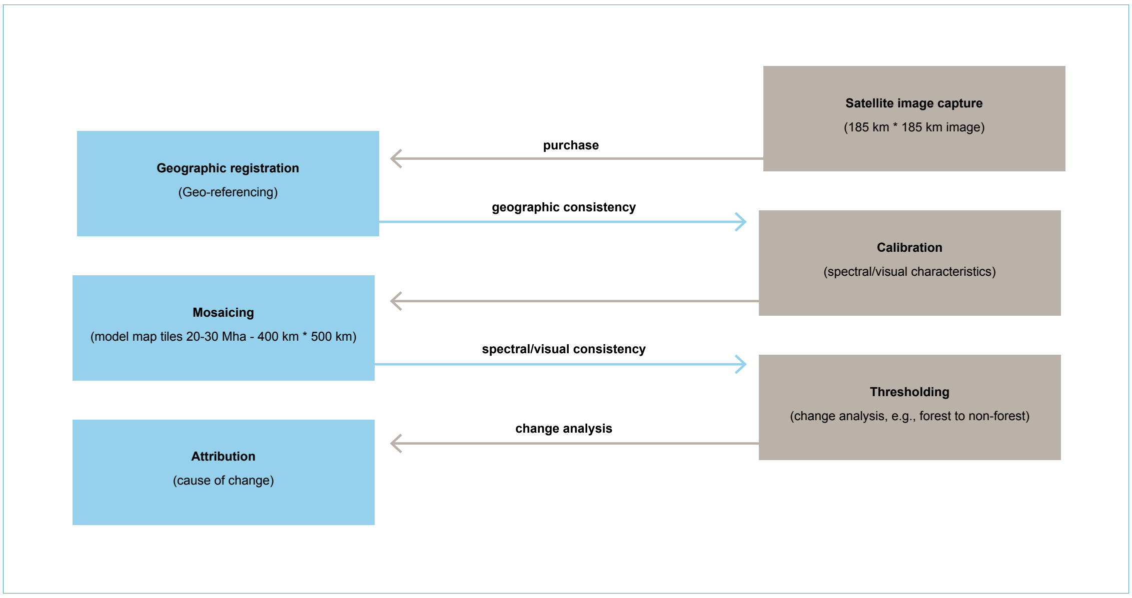
3 Registration uses stationary and identifiable ground features (ground control points) as constant reference points for the image sequence.
4 Calibration uses a reference image to adjust spectral characteristics to remove inconsistencies such as illumination caused by sun angle at time of image capture etc.
5 Attribution uses a combination of automation and visual inspection of the image sequence to determine the cause of land cover change and determine subsequent/existing land use.

7.A.2.2 Data processing

In producing the assessment of an Australia-wide land cover change over the time series (shown schematically in Figure 7.A2) the sequence of processing stages carried out is:

- image identification;
- image registration and calibration;
- mosaicing[6] of registered and calibrated images to the single map tiles for each time sequence (Figure 7.A3);
- sun-angle (terrain illumination) correction;
- thresholding[7] through all time sequences; and,
- attribution of change to direct human-induced change.

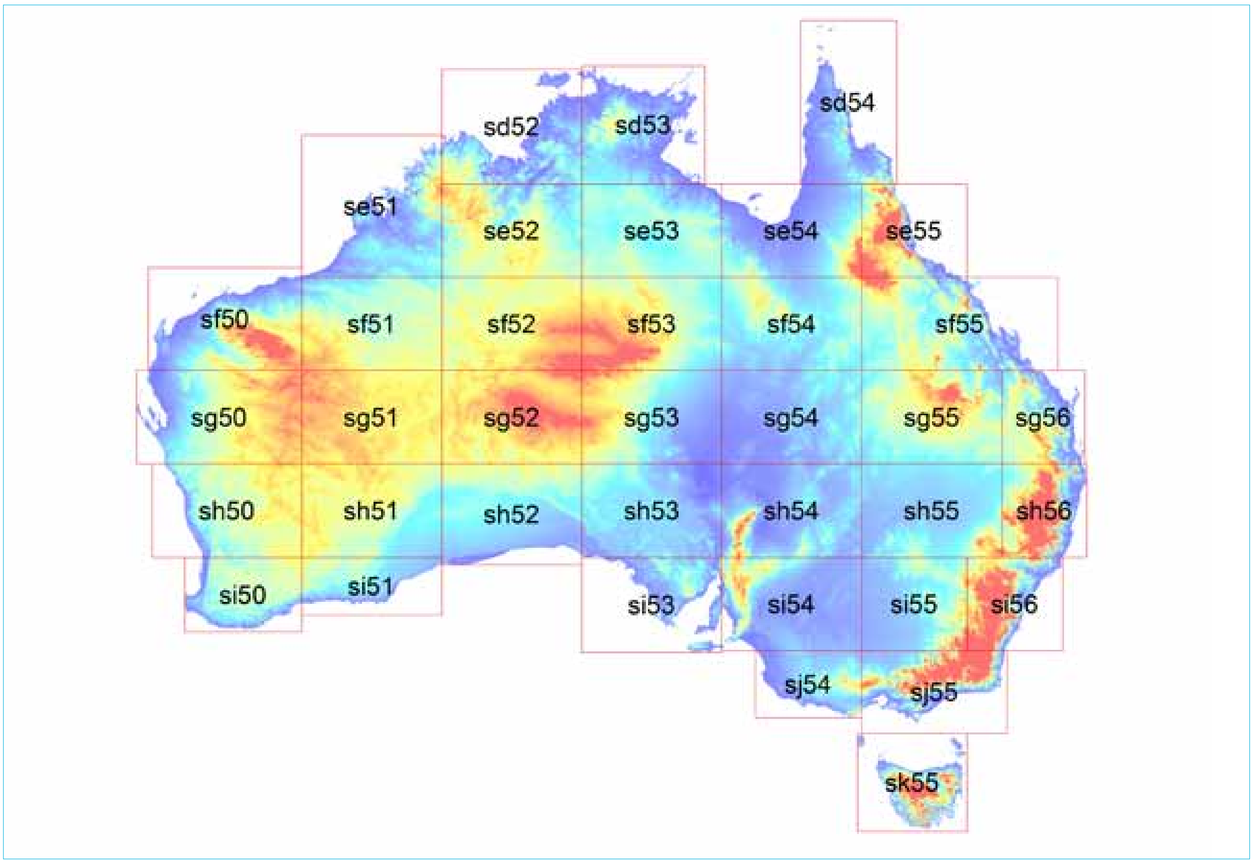
Figure 7.A 2 Land Cover Change Program conceptual framework



6 Mosaicing aggregates images into the map tiles shown in Figure 7.A3, removing overlaps in the original 185 km*185 km images.

7 Thresholding compares each image pixel to a reference set of spectral characteristics formed by specific band mixes (indices) that represent forest and non-forest conditions.

Figure 7.A 3 The 37 1:1 million scale map tiles used in the remote sensing program

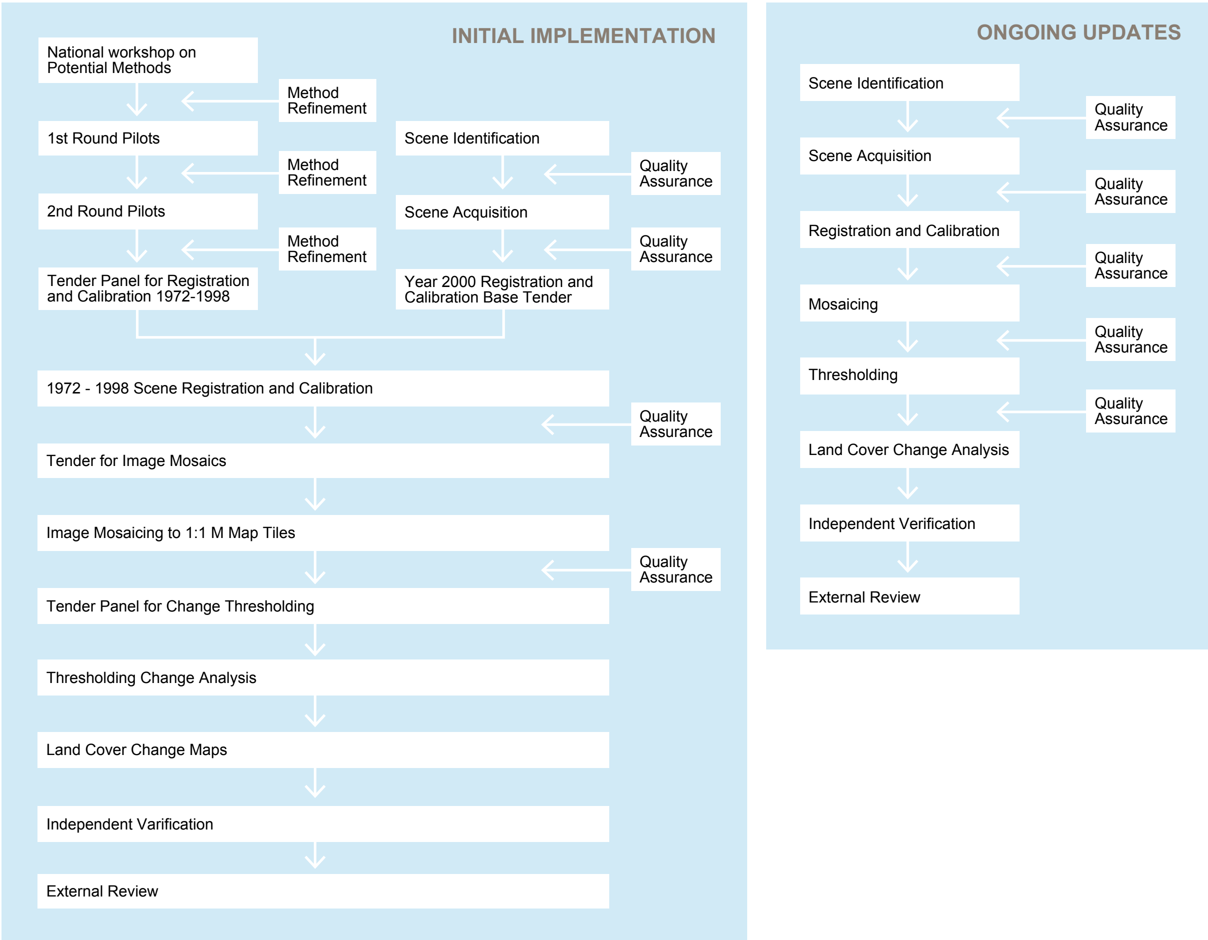


7.A.2.3 Program implementation

Pilot tests were used to train and develop industry capacity, refine methods and software and to develop logistical systems to maximise both output and opportunity for progressive quality assurance and quality control (QA/QC). The results of the pilot studies are published in Furby and Woodgate (2002). A full description of QA/QC, calibration, validation, verification and sensitivity and uncertainty analyses is reported in Appendix 7.J.

The approach to program administration provides for centralised progress monitoring and QA/QC at each stage in the processing of the Landsat data. Figure 7.A4 outlines the program stages and their sequence. Each processing stage is a regionally defined package of work based on 37 1:1,000,000 (1:1 M) map tiles of Australia (Figure 7.A3). The finalised program approach maximised quality assurance opportunities, expanded the use of competitive service acquisition and enhanced information flow. A set of 19 national coverages of Landsat data were compiled at intervals between 1972 and 2010. The sequence of images shown in Table 7.A1 was designed to give maximum temporal resolution immediately before and after 1990, so as to achieve the best possible accuracy of emissions in 1990. The return to annual acquisition of data from 2004 onwards allows for the best possible accuracy for every year in the first Kyoto commitment period (2008-2012).

Figure 7.A 4 Sequence of implementation of the Land Cover Change Program



The median of the actual capture dates of the approximately 5,000 185 km x 185 km Landsat images processed for this project are summarised in Table 7.A1. The image selection criteria (Furby, 2002) require the images to be within three months of the nominated target date. The target dates vary between the north (winter or dry season) and south (summer) of the country and aim to provide the best possible forest discrimination. The precise date allocated to each land cover change (clearing and regrowth) pixel is randomly generated by *FullCAM* (see section 7.A.3), within the sequence of coverage dates for the relevant map tile. This method provides a random (unbiased over a large sample) distribution of initialisation dates (timing of land cover change event) for the carbon model, within the constraint of the two dates in the overall interval of the image sequence.

Table 7.A 1 Landsat Image sequence

Year	Resolution (m)	Time Since Previous Image (yrs)
1972	50	-
1977	50	5
1980	50	3
1985	50	5
1988 (early)	50	3
1989 (end)	25/50	2
1991 (early)	25	1
1992	25	2
1995	25	3
1998	25	3
2000	25	2
2002	25	2
2004	25	2
2005	25	1
2006	25	1
2007	25	1
2008	25	1
2009	25	1
2010	25	1
2011	25	1

Technical Specifications

The technical specifications for the land cover change program (Furby, 2002; Furby and Woodgate, 2002) reflect the key technical decisions on method selection and implementation. These include:

- using a Landsat ETM+ national mosaic (year 2000) as the base for registration and calibration;
- using an orbital (earth surface) correction model as implemented through the PCI (PCI Geomatics 2000) software package;
- using a BRDF (Bi-Directional Reflectance Distribution Function) atmospheric correction model;
- applying a sun angle correction (Wu *et al.*, 2004);
- using an 'automated' change thresholding, using derived indices within zones based on specific vegetation and soil characteristics;
- digitising areas of fire scars, later using these as fire masks to differentiate change associated with fire from change associated with mechanical land clearing;
- applying a 'Conditional Probability Network' (CPN[8]) so that the probability of forested condition for each pixel at each time in the image sequence is placed in the context of the preceding and subsequent images; and,
- use an integration spatial utility to integrate the full change sequence of each pixel. This utility analyses each pixel and establishes whether a clearing or regrowth event has occurred between each image sequence for that pixel and allocates a time.

8 Conditional Probability Network (CPN) is a rule set which enables the status of a pixel of uncertain land cover status at a point in time to be resolved by reference to the previous and subsequent land cover status.

Selection of Indices

Thresholding is the process through which pixels in the land cover image sequence are identified as either forest or non-forest. Pixel identification involves comparing the spectral indices of each pixel in the land cover image sequence with reference indices that identify areas of forest in select strata. Reference indices are established through the use of air photographs, ground data and very high resolution satellite data. Air photographs with known forested areas are interpreted and compared with the Landsat data of the same area and around the same time. The Landsat data spectral bands of the forested area are then identified as reference indices for a given forest and soil type. The air photograph interpretation was undertaken centrally by appropriately qualified and experienced air photograph interpreters. The interpreters provided brief descriptions of forest or non-forest areas at a set of known locations. These descriptions were then used in the selection of reference indices from the Landsat data.

The final reference indices allow for variability in both forest and soil type by selecting indices within homogeneous strata. The stratification to deal with this variability was achieved largely through vegetation and soils mapping. The final reference indices used to identify areas of forest/non-forest are consistent with the definition of a forest, i.e., a minimum of 20 % canopy cover and a minimum potential height of 2 m.

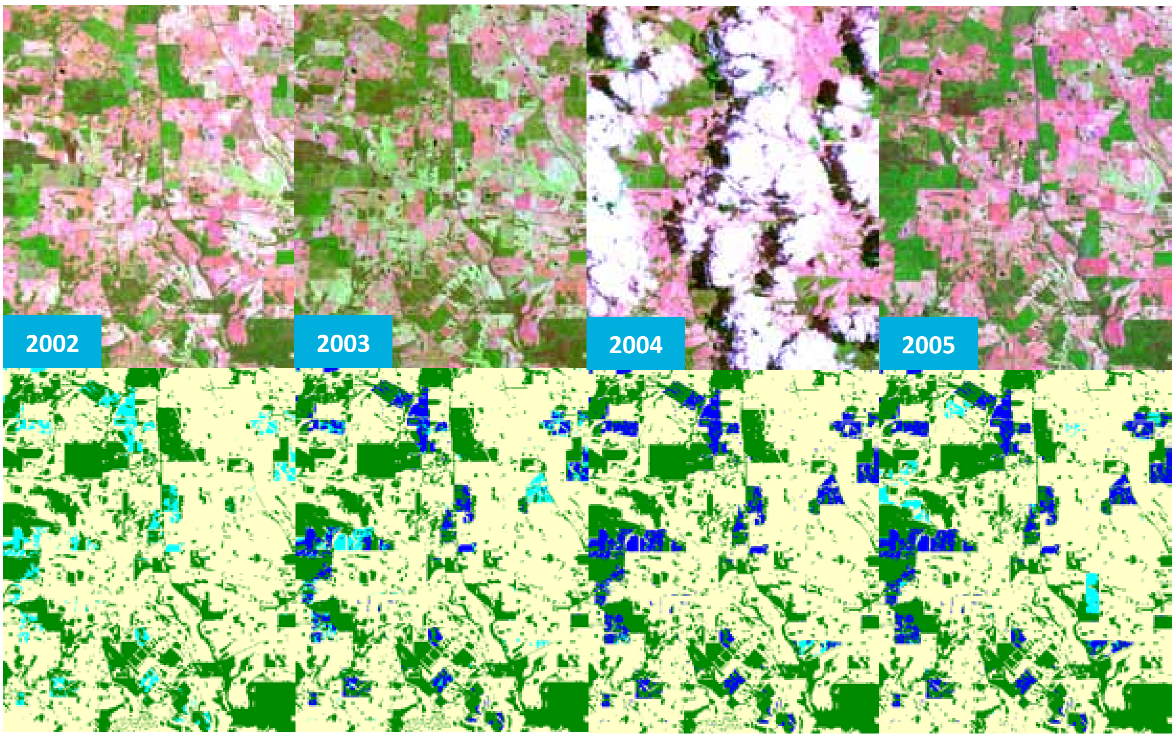
Conditional Probability Network

The multiple sequences of geographically referenced images are essential for the robust analysis of land cover change. The Conditional Probability Network (CPN) strengthened confidence in the 'forest' or 'non-forest' classification of a pixel by considering the previous and subsequent images in a sequence to resolve any uncertainty in the classification (forest/non-forest) of a particular image. This comparative analysis of the same land unit over time was made possible by the accurate and consistent geographic registration and spectral calibration of the image sequences, providing the ability to 'drill' through time on a pixel-by-pixel basis.

Geographic registration ensures that the same pixel is being looked at through the time sequence. It avoids incorrect change status determination due to substitution of neighbouring pixels having potentially different forest cover status, relative to the correct pixel for that location. Spectral inconsistency can also potentially increase the area attributed to clearing and regrowth events by variable status determination due to image calibration difference. This is addressed by consistent (spectral) calibration, thereby preventing the identification of false clearing or regrowth events and results in a more accurate land cover change map. Consistent registration and calibration are both required to ensure robust multi-temporal change analyses.

The CPN empirically assesses the logic of a forest cover status determination of a pixel at a point in time compared to the previous and subsequent images. That is, it ensures that the forest cover status of a pixel at a point in time is sensible based upon the forest cover status of that pixel in the previous and subsequent images. This helps to eliminate false change from a single image that may be due to anomalies in the data such as unseasonal greenness, wetness or flooding. The CPN also allows areas of missing data, such as cloud cover, to be filled in based on the cover status of the surrounding images (Figure 7.A5).

Figure 7.A 5 Images of forest extent and change based on CPN analysis 2002-2004



Green: forest 2000 Green: forest 2000 Green: forest 2000 Green: forest 2000
Blue: new forest 2000-02 Dark Blue: new 2000-02 Dark Blue: 2000-04 Dark Blue: 2000-05
Light Blue: new 2002-04 Light Blue: 2004-05 Light Blue: 2005-06

Area – 16 x 20 km

There is also potential for sub-pixel shifts to change the forest/non-forest status on the edges of forest systems where a small edge portion of the pixel may have previously been just over the forest area, but a small shift in geographical registration (e.g., 10 m) would be enough to move the pixel out of the forest area. The nearest-neighbour approach to the CPN has been developed and applied to reduce this effect. The nearest neighbour CPN (Caccetta *et al*., 2003) evaluates the status of adjoining pixels as well as the pixel of interest. This has the effect of reducing 'flickering' false change in scattered and edge forest pixels. This method ensures that individual and small clusters of forest pixels have a high classification certainty in relation to their neighbouring pixels and through time, minimising false detection of individual forest pixels and minimising false change in forest classification that would otherwise occur as a result of small changes in the crown cover of isolated pixels.

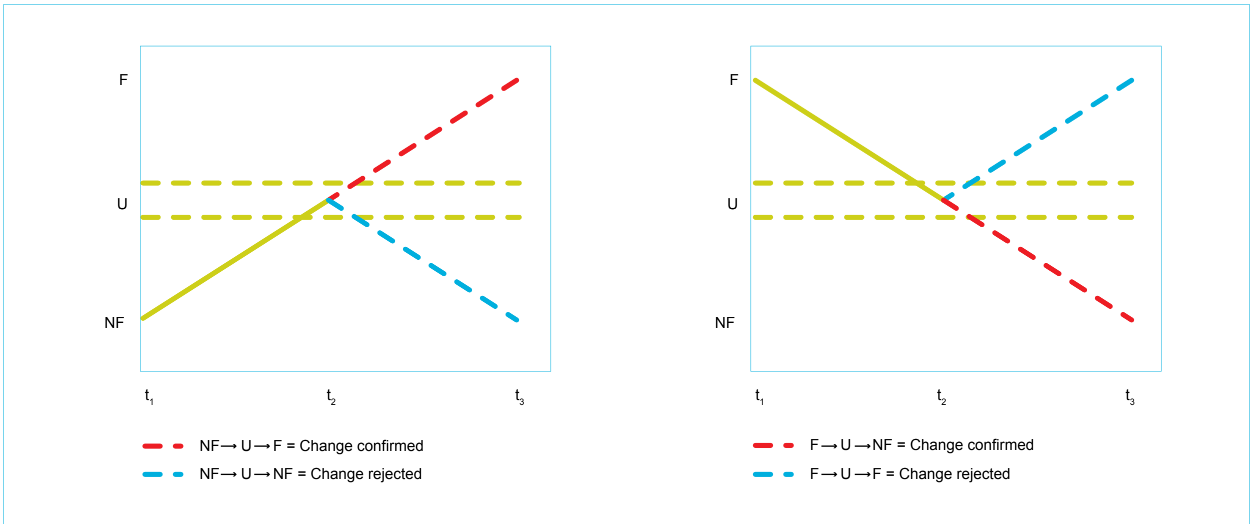
Forest extent and change analysis

Once the change in forest cover status has been determined for each pixel for a point in time, the spatial relationship of each change pixel to other surrounding or nearby change pixels is assessed to identify isolated pixels with forest cover that do not form part of a forest system. This allows for the identification of pixels that are isolated trees not meeting the minimum canopy criterion defining a forest, as opposed to those pixels that may be part of sparse linear features such as roadsides and riparian zones which do meet the canopy criterion.

The area of land cover change is determined as the sum of the changed pixels through time (See for example Figure 7.A6). This approach avoids inclusion of pixels that represent gaps in the forest canopy. An independent study which looked at the implication of the inclusion or exclusion of forest canopy gaps in this way found that the resultant area estimate could vary significantly between approaches (ERIC, 2001). The approach used only includes the area of forest canopy loss and not 'gaps' in the forest canopy. This approach provides a much lower estimate of area cleared than specified in clearing permits, which usually define the area bounded by the clearing, including gaps in forest canopy cover. Subsequent carbon stock and emissions estimates are computed consistently with the spatial area calculation method. That is, the carbon stock values should reflect the area under canopy, and are not an average that includes 'gaps' between areas of tree canopy.

Further robustness in the certainty of identifying forest cover change is provided by the use of a three class determination of forest cover: non-forest, forest and uncertain forest. Pixels identified as uncertain forest have a lower probability of being forest, and unless confirmed as forest after the CPN application, are determined as non-forest. The same applies to non-forest determination. This will typically yield lower (more certain and conservative) cover change statistics than more common analytic methods using only a two-class (forest, non-forest) analytic procedure. Therefore, the last step allows uncertainties to be confirmed in a time-series update and CPN re-run (See Figure 7.A6). The three-class approach is most relevant to a multiple time series (as opposed to pair-wise) change analysis. It is this approach that leads to small adjustments to the areas cleared over the last two to three years of the time series as the CPN becomes more definitive as new images become available to confidently assign change from a prior condition.

Figure 7.A 6 Three class determination of forest cover and confirmation/rejection of change over time using the CPN.



F- Forest, U – uncertain, NF – Not Forest

7.A.2.4 Attribution of Change

The high resolution spatial assessment (by pixel) across the continent identifies land cover change resulting from many causes. For unique identification of conversion to another land use it is necessary to attribute the change event to a cause and subsequent land use. Examples of forest cover loss events that do not meet the definition of forest conversion to another land use include forest harvesting, dieback of forest during drought periods, and wildfires.

Loss of forest cover due to factors other than a change in land use are initially identified through the application of both the fire masks developed during the image processing, and tenure masks to define areas of public forest management. Subsequently, land cover change due to salinity, tree dieback, natural dynamics of tree mortality and recruitment, drought and both seasonal and inter-annual variability (causing green 'flushes' of growth with similar spectral signals to regrowth) are also identified and excluded. These are separated from those changes that can be attributed to a forest conversion.

This attribution is achieved by the development of a second series of 'masks' that are derived via visual interpretation of the sequences of images against change mapping. Masks derived include:

- forest harvest on private land;
- intermittent water features and irrigation areas that may give a false change signal;
- salinity;
- drought and growth flushes; and,
- terrain illumination.

7.A.2.5 Plantation typing

To allow for more accurate modelling of emissions and removals from newly established forests (under *Grassland converted to Forest Land*), new plantings (reforestation) identified in the remote sensing are mapped into three classes; native forest (environmental type plantings), hardwood plantation and softwood plantation. Plantation forests are those that are identified as being due to deliberate human action and are identified by type (e.g., introduction of non-endemic species), evidence of establishment practices (e.g., rip lines) and planting patterns (e.g., rows and stand geometry). The identification of conversion between forest and non-forest condition follows the same general approach described above. Plantation classes are identified by discrimination against regionally specific ground training data. The method uses an automated spectral discrimination and is described in Caccetta and Chia (2004). Currently, only Landsat TM or ETM+ data is used for plantation classification.

7.A.2.6 Quality Assurance and Quality Control

Full documentation of the quality assurance and quality control processes, calibration, verification and sensitivity analysis for the development and implementation of Australia's National Inventory System is reported in Appendix 7.J (Section 7.J.3.2).

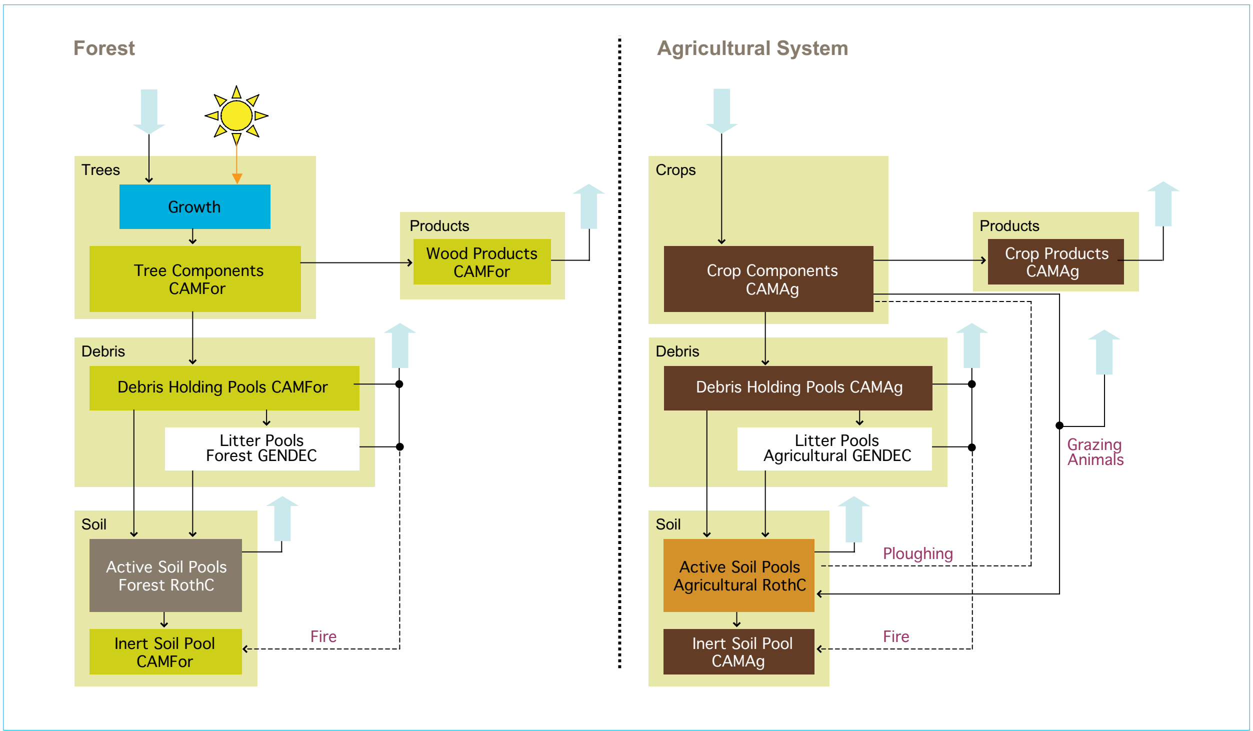
7.A.3 FullCAM framework

7.A.3.1 Overview of model framework

The *FullCAM* framework and its development are described in Richards (2001) and Richards and Evans (2004). In addition to providing spatial modelling, *FullCAM* also provides for mixes and transitions between forest and agricultural systems. *FullCAM* also has the capability to support the modelling of changes to plant species and management over both space and time. *FullCAM* has been developed as an integrated compendium model that provides the linkage between various sub-models. *FullCAM* has components that deal with both the biological and management processes which affect carbon pools and the transfers between pools in forest, agricultural and transitional systems. The exchanges of carbon, loss and uptake between the terrestrial biological system and the atmosphere are accounted for in the full/closed cycle (mass balance) model which includes all biomass, litter and soil pools (Figure 7.A7) (Attachment A1). The four sub-models integrated to form *FullCAM* are:

- a variant of the physiological growth model for forests, 3–PG (Landsberg and Waring, 1997, Coops et al., 1998, Coops et al., 2001);
- the carbon accounting model for forests, CAMFor (Richards and Evans, 2000a);
- the carbon accounting model for cropping and grazing systems, CAMAg (Richards and Evans, 2000b); and
- the Rothamsted Soil Carbon Model, Roth-C (Jenkinson, et al., 1987, Jenkinson et al., 1991).

Figure 7.A 7 The *FullCAM* model pool structure



7.A.3.2 Sub-Model development

A Forest Productivity Index (FPI) was developed from a simplified version of *3-PG* to estimate plant productivity and is in turn used to model forest growth. This FPI is a simplified, spatial version of *3-PG* based on the work of Coops and Waring (2001) and described in Kesteven *et al*., (2004). Further details are provided in section 7.A.4.

The principal work required to implement this model was to compile the fundamental input data. This entailed:

- the development of slope and aspect corrected solar radiation direct and diffuse surfaces on a 250 m grid;
- the use of a digital elevation model of AUSLIG (2001) – Geodata 9 second DEM (version 2);
- access to CSIRO Division of Land and Water Fertility and Soil Moisture Continental Surfaces (McKenzie et al., 2000a);
- creation of monthly rainfall, temperature and radiation surfaces from ANUCLIM (software package) (McMahon et al., 1995) utilising data from the Bureau of Meteorology;
- derivation of a Normalised Difference Vegetation Index (NDVI) 10-year average; and,
- the development of frost surfaces.

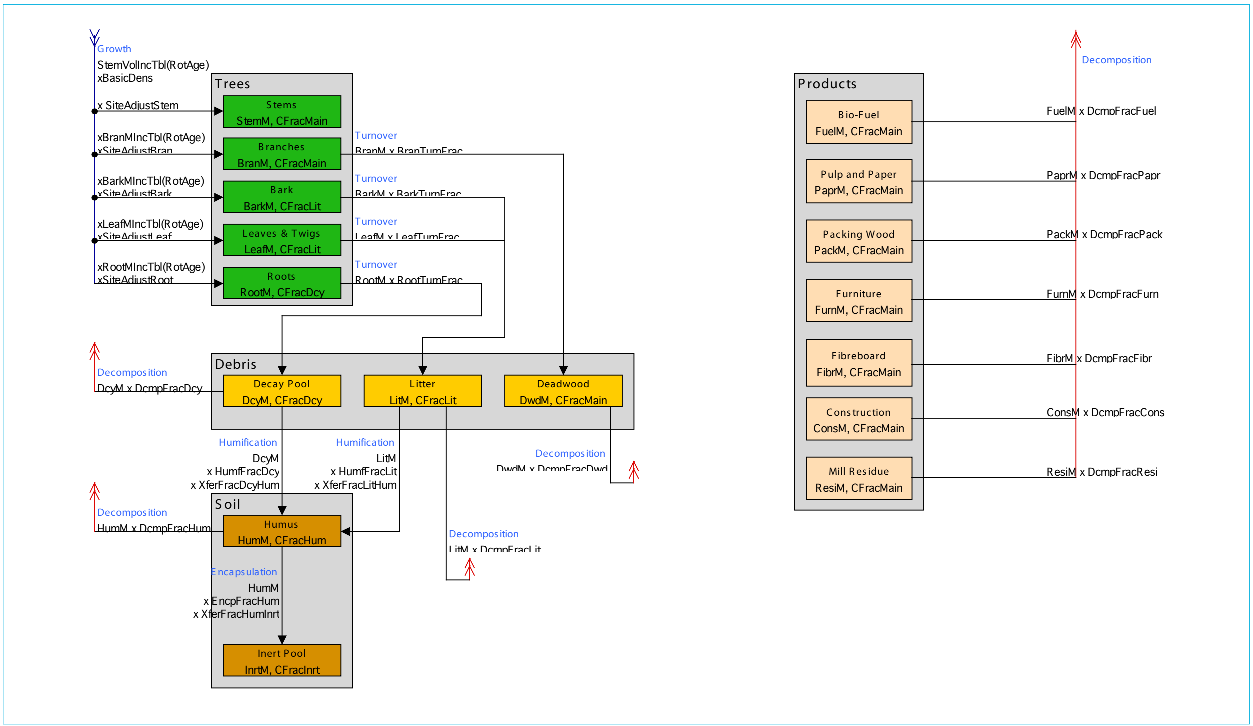
CAMFor

CAMFor (Carbon Accounting Model for Forests) (Richards and Evans, 2000a) was developed to provide capacity for both project and continental scale accounting (Figure 7.A8). *CAMFor* primarily focused on carbon sequestration in forests using basic species information and standard forestry yield tables entered by the user, with limited debris and soil carbon modelling capabilities. *CAMFor* has its origins in the 1990 *CO_2 Fix* model of Mohren and Goldewijk (1990).

Within *FullCAM*, the *CAMFor* sub-model can take its growth information from any one of four sources:

1. a generalised productivity-driven growth model (see section 7.A.4);
2. measures of aboveground biomass increment;
3. measures of stem biomass increment; or
4. measures of stem volume increment.

Figure 7.A 8 The CAMFor model pool structure



CAMAg

Within *FullCAM*, *CAMAg* serves the same roles for cropping and grazing systems as *CAMFor* does for forests. The *CAMAg* model reflects the impacts of management on carbon accumulation and allocates masses to various plant product pools and to decomposable and resistant organic residues. Yields need to be prescribed in the model, as either aboveground, total or product mass – as do above- and belowground turnover rates. The key factors that allow *CAMAg* to model emissions and removals due to agricultural practices are:

- growth of crops and grasses by component pools including leaves, GBF (grains, buds and fruit), stalks, fine and coarse roots;
- turnover and decay of plant material; and,
- simulation capabilities for grazing, harvesting, ploughing or tillage, herbicide application and fire.

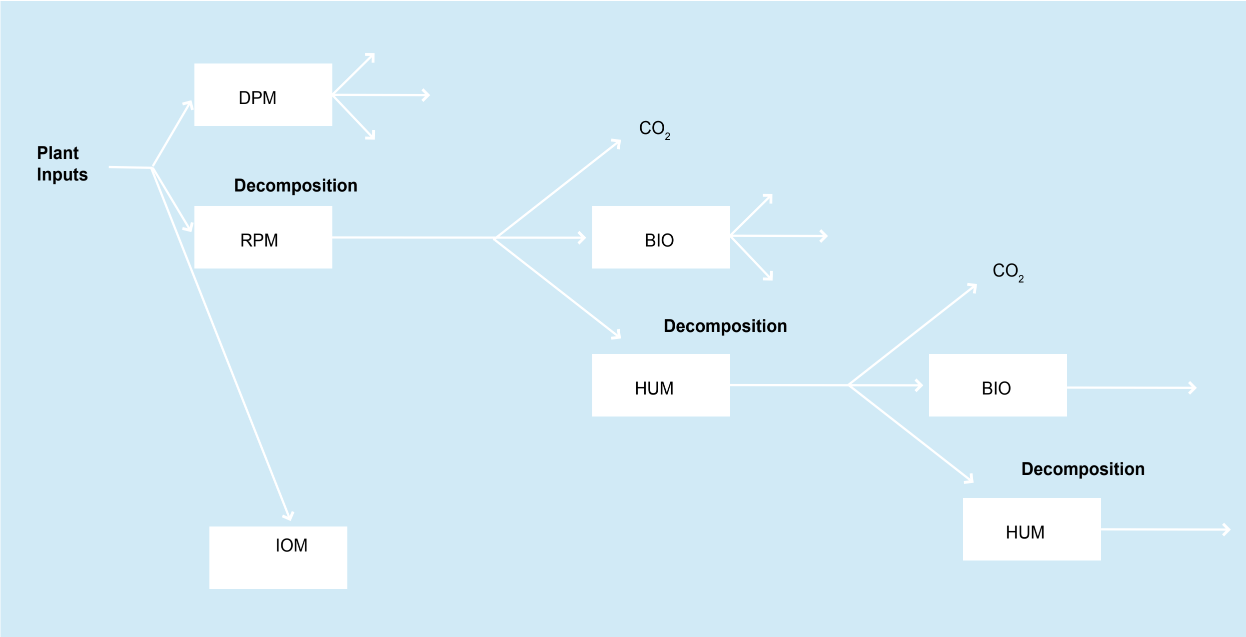
CAMAg also includes a products model (biofuel, grains, bud and fruit products, cane products, leaf products, root products, hay, straw and silage products, and animal products) that uses a similar structure to the *CAMFor* forest products model.

Roth-C

The Rothamsted soil carbon model (*Roth-C*) is a soil carbon model developed by Jenkinson *et al*., (1991). *Roth-C* models changes in soil carbon based on the inputs of organic matter from dead plant material and soil carbon decomposition rates. Plant residues are firstly split into decomposable and resistant plant material. Soil carbon is fractionated into various soil carbon pools, generally defined by classes of resistance to decomposition. Turnover rates for each soil fraction are determined by rainfall, temperature, groundcover and evaporation. *Roth-C* is used in conjunction with both *CAMFor* and *CAMAg* to model soil carbon stocks in the national account. The model and its calibration and validation for Australian conditions are discussed further in section 7.A.5.

On the basis of previous successful testing in a range of environments in Australia, the *Roth-C* (Jenkinson *et al*., 1987, Jenkinson *et al*., 1991) soil carbon model was chosen (Webbnet Land Resources Services Pty. Ltd., 2000) for integration into *FullCAM*. The structure of the model is represented in Figure 7.A9.

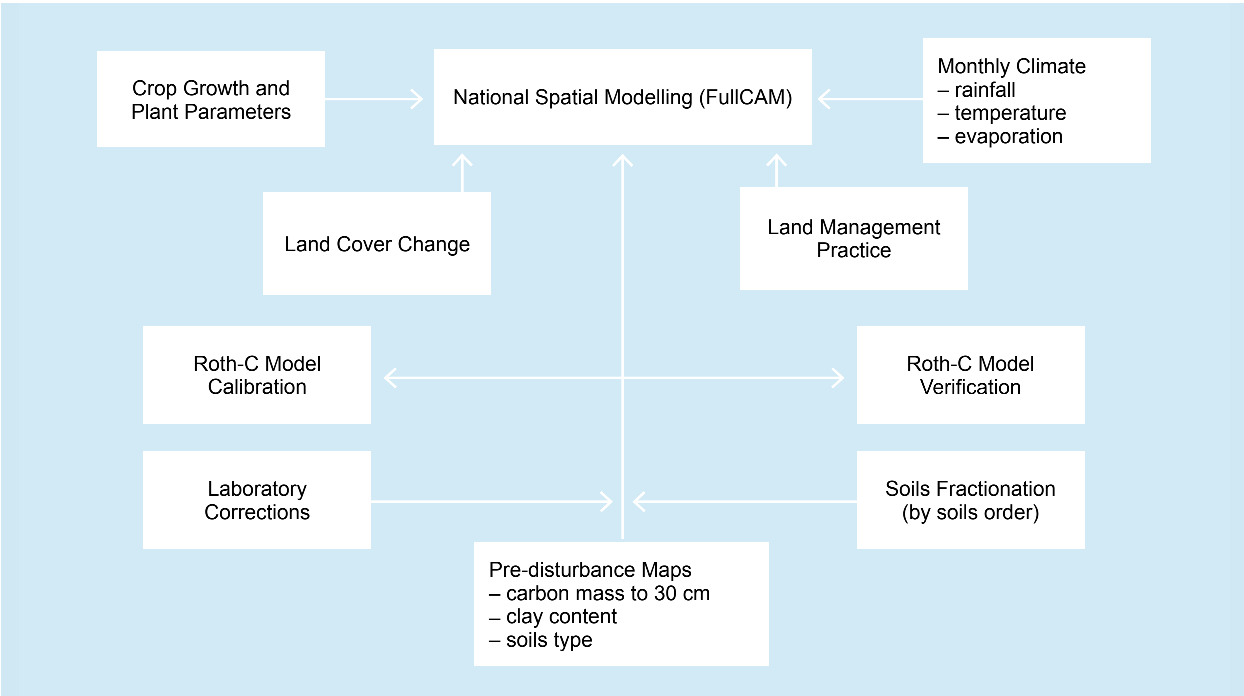
Figure 7.A 9 Structure of the Roth-C soil carbon model as implemented in *FullCAM*



Source: modified from Jenkinson (1990). DPM - decomposable plant matter, RPM - resistant plant matter, BIO - fast and slow decomposing biomass, IOM - inert organic matter, HUM - humified organic matter

The overall soil carbon program developed both resource inventory (mapping) descriptions and model calibration and verification. The integrated soil carbon program is shown in Figure 7.A10. The background to the selection of methods and design of the program can be found in Webbnet Land Resource Services Pty. Ltd. (2000).

Figure 7.A 10 The National Inventory System Soils Program



Source: AGO 2002

7.A.5.2 Soil Carbon Model Calibration and Validation

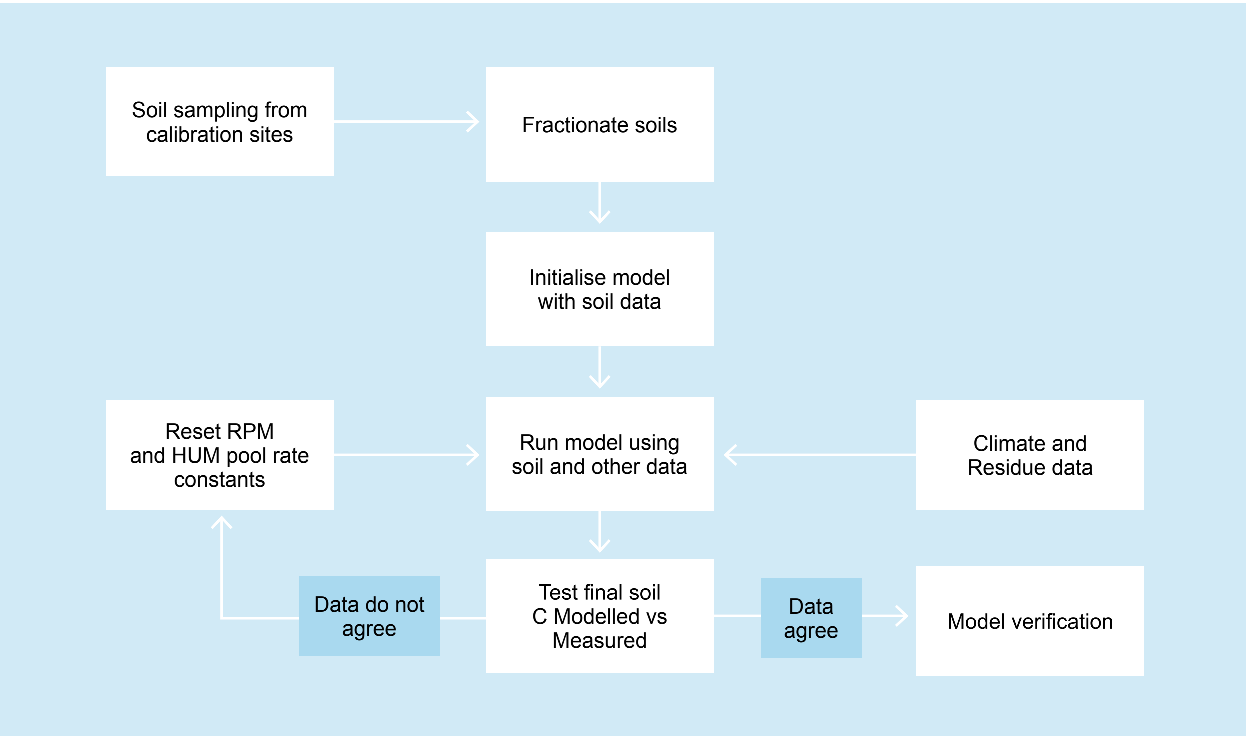
Calibration and verification of *Roth-C* was undertaken using available long-term field trial data, a subset of which had sufficiently detailed and complete long-term data to enable calibration of the model against long-term field measurements. Only a minimum of data supplementation was accepted at these calibration sites. Other sites with incomplete long-term data, but providing a robust temporal pattern of carbon change under known management and climate, were used for model validation and verification (Skjemstad and Spouncer, 2002) (see Appendix 7.J).

In addition to this long-term trial data, approximately 2,500 new soil sites have been sampled in 2011 to provide a range of verification targets for model testing and validation. Sites were established, in collaboration with State Agencies in Queensland, New South Wales, South Australia, Northern Territory and Western Australia, in the areas of major cropping activity. Sites were selected to cover a variety of crop type, soil type and time since change (e.g., clearing) in areas subject to most intensive activity. Sampling of sites was completed according to the standardised soil sample protocol developed described by McKenzie *et al*., 2000b.

Calibration of the soil carbon model was completed around a structured procedure as shown in Figure 7.A11.

A description of the quality assurance, quality control, calibration, validation, verification, and sensitivity and uncertainty analyses of the soil carbon model and data is detailed in Appendix 7.J (see section 7.J.3.4)

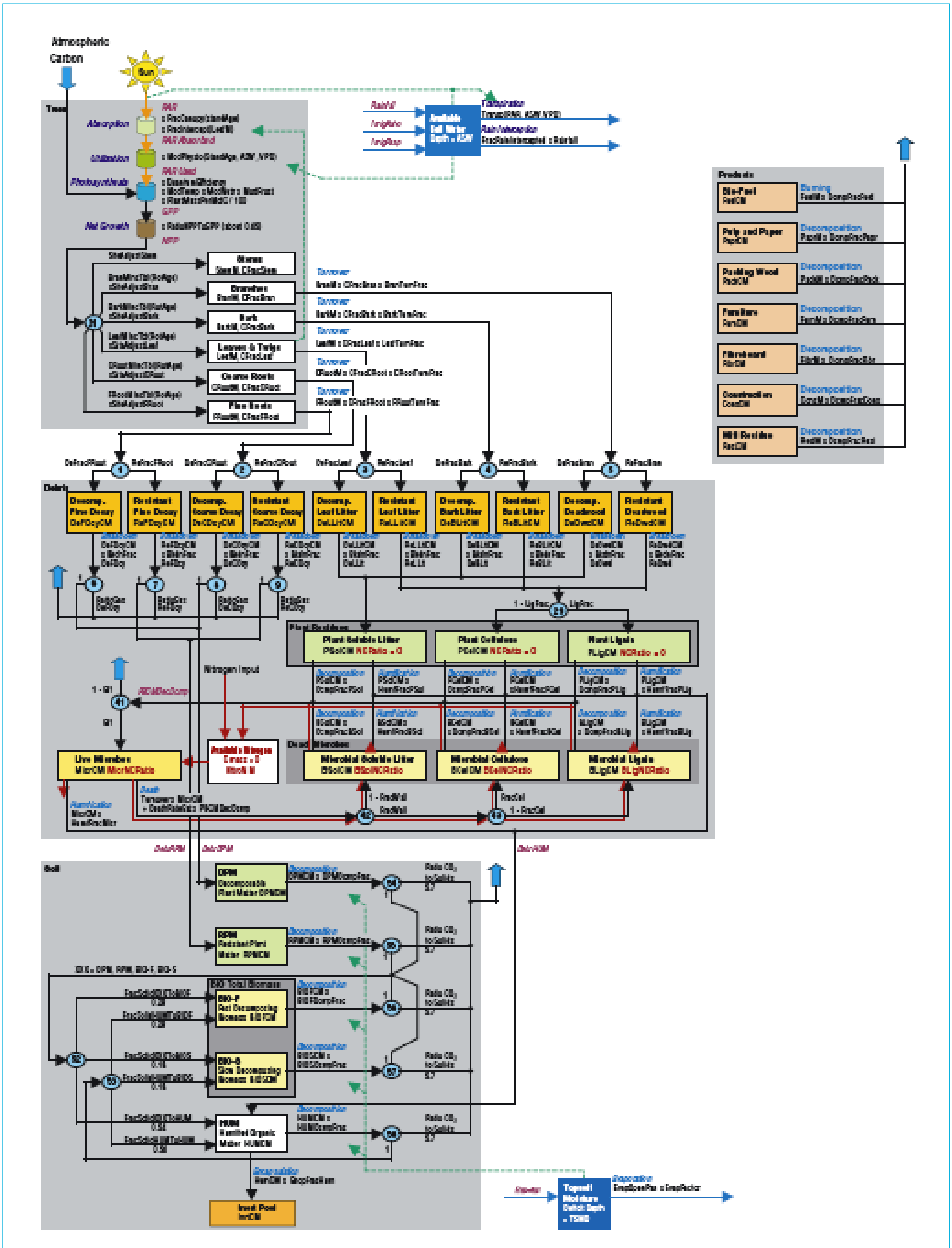
Figure 7.A 11 Procedure for the calibration of the Roth-C soil component of *FullCAM*



7.A.3.3 Sub-model integration

The sub-models described above are integrated into *FullCAM* (Richards, 2001; Richards and Evans, 2004) which was developed in the programming language C++ with a graphical user interface. The individual sub-models can be applied independently or in various combinations within the *FullCAM* framework. By embedding both the forest and agricultural models within *FullCAM*, it is possible to represent completely transitional activities – afforestation, reforestation and deforestation (change at one site) – or a mix of agricultural and forest systems (e.g., agroforestry, discrete activities at separate sites) in a single, mass-balance model framework.

Figure 7.A 12 The forest 'side' of the *FullCAM* model



7.A APPENDIX

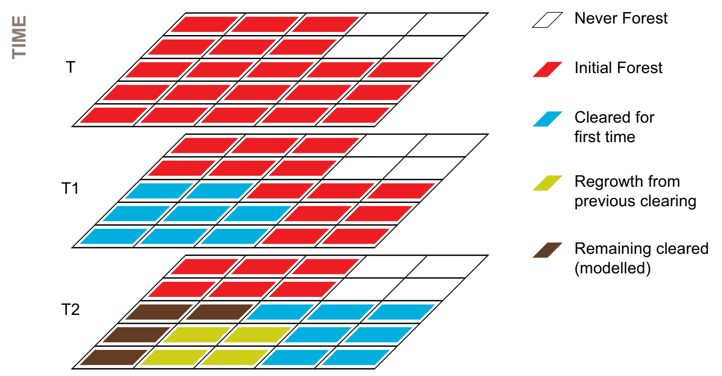
7.A.3.4 Operating *FullCAM* with spatial activity data

Entry of lands into the forest land converted to cropland and grassland accounts

The fundamental analytic unit of Tier 3, Approach 3 land sector reporting in Australia is the land cover change pixel (25 m x 25 m) derived from the satellite remote sensing program. The Approach 3, spatially explicit method applied by Australia as part of the *Forest Land converted* to *Cropland* and *Forest Land converted to Grassland* categories is shown in Figure 7.A13. Beginning in 1972, land clearing events are detected through the remote sensing program. The first time a land clearing event is detected for a pixel, the pixel becomes 'active'. For each year after 1972 an extra set of active pixels which represent new land clearing events are added to the previously accumulated set of active pixels. Therefore, in any given year, there will be three classes of forest pixels represented as shown in Figure 7.A13.

The first class of forest pixel is 'inactive' (red). This means that the forest cover has not been subject to a land clearing event since 1972 and is not in the model. The second class of forest pixel is 'active for the first time'. This means that the forest on that pixel has under-gone a land clearing event in the current year (T_1, blue). The pixel now triggers the initiation of *FullCAM* for the quantification of emissions. *FullCAM* calculates the emissions and removals on that pixel from the moment that the pixel becomes active and the accounting continues each year into the future (T_2, purple and green). These active pixels may remain cleared (purple) or may temporarily regrow some forest cover as part of a cyclic clearing/re-clearing management system (green).

Figure 7.A 13 Diagrammatic representation of the spatially explicit approach used in the National Inventory System



Modelling emissions and removals

Once lands enter the accounts through a land clearing event, based on activity data, *FullCAM:*

- randomly allocates date of clearing between the two dates of satellite images;
- obtains site, climate, management and initial assumed biomass data for that pixel from a series of spatial grids and databases (see section 7.A.4.2);
- begins to model changes in living biomass, debris and soil carbon pools associated with the change in forest cover; and
- sums the estimates for each pixel each year to estimate the emission/removals for the national account.

Where the forest has regrown after clearing (as identified from the remote sensing), *FullCAM* begins to regrow the forest. Where this regrowth is subsequently re-cleared the biomass at re-clearing is based on actual age (through identification of time since regrowth) (see section 7.A.4.4).

Accounting for lagged emissions

Lagged emissions are emissions in any given year that result from a land clearing event in previous years. These lagged emissions are associated with the decay of dead organic matter and soil carbon.

As land remains in the accounts from the time of the initial clearing event, any lagged emissions are reported in the account in the years subsequent to the clearing event. Therefore for any given year, all sinks and sources including any lagged emissions, from all lands that have entered the account since 1972 are reported for every subsequent year to their entry into the account.

The lagged emissions profile in Figure 7.A14 shows that the greatest impact of lagged emissions on overall emissions estimates occurs within the first two years following a land clearing event.

Figure 7.A 14 (a) *FullCAM* outputs for a single pixel from a single model run showing a) carbon stocks (t C ha^{-1}) for tree biomass, debris and soil:

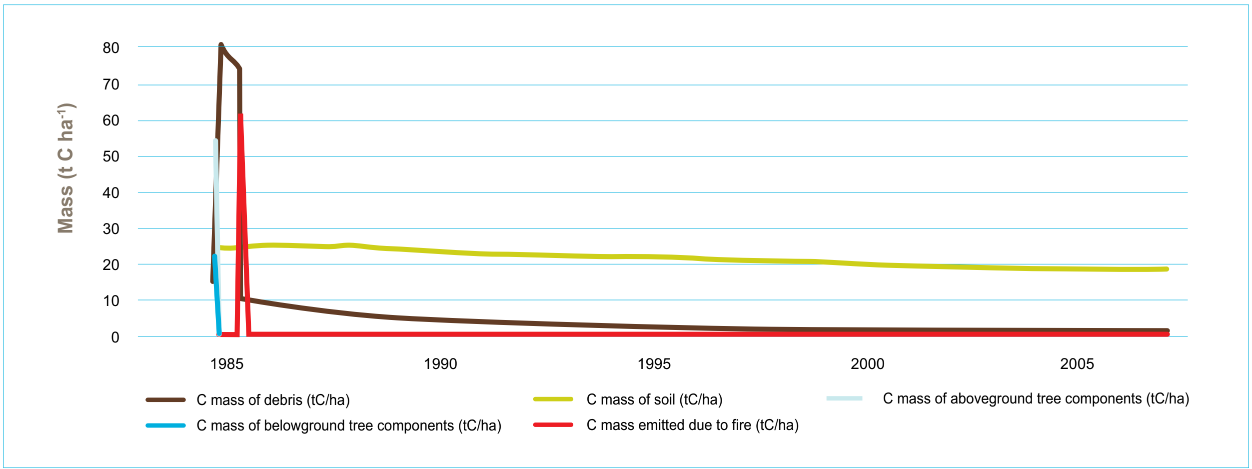
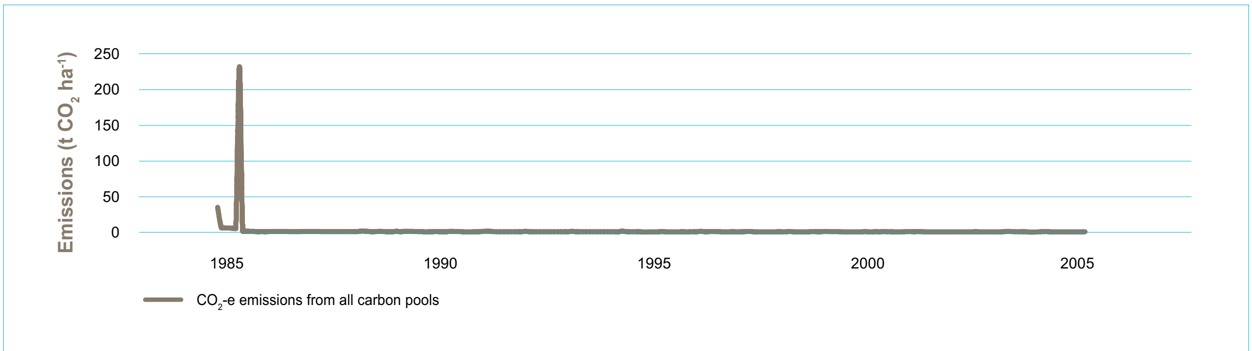


Figure 7.A 14 (b) Emissions (t CO_2-e ha^{-1}) from all carbon pools



7.A.3.6 Model coherence and validation

The results from each pixel which enters the land sector accounts are added together to give the total emissions account in the format of the CRF tables. The average estimate per hectare for the land converted sub-categories (*forest land converted to cropland* and *grassland* and the implied emissions factor or IEF) will not reflect any individual, or cluster of individual pixels. As the number of pixels active in land converted sub-categories accumulates over time, the IEFs for each of the accounts for each year will reflect a mix of area change and change in pixel output. The change in pixel output is also strongly affected by the amount of time since the land was cleared and climate variability. As there are multiple variable factors, the implied emissions factors from the overall inventory cannot be used to test the model's coherence as the model processes can no longer be observed in anything like their original analytic unit.

Testing for coherence in a Tier 3 (Approach 3) model-based pixel by pixel inventory method requires very different techniques to those applied to checks on trends and emissions factors in Tier 1 and Tier 2 models. Tests of model coherence and validation can only be meaningfully undertaken at the pixel level.

This is the approach taken and is consistent with the good practice recommendations of the 2006 IPCC Guidelines. As the robustness of the national account simply flows from the correct summing of the outputs of the individual pixels, testing the results at the individual pixel scale will validate the national results. Therefore, programs to test model cohesion operate in two realms. The first is coherence testing by time series to validate model calibrations and verify the results at the pixel level. The second is quality control to ensure robust summation of the pixels to an aggregate national account.

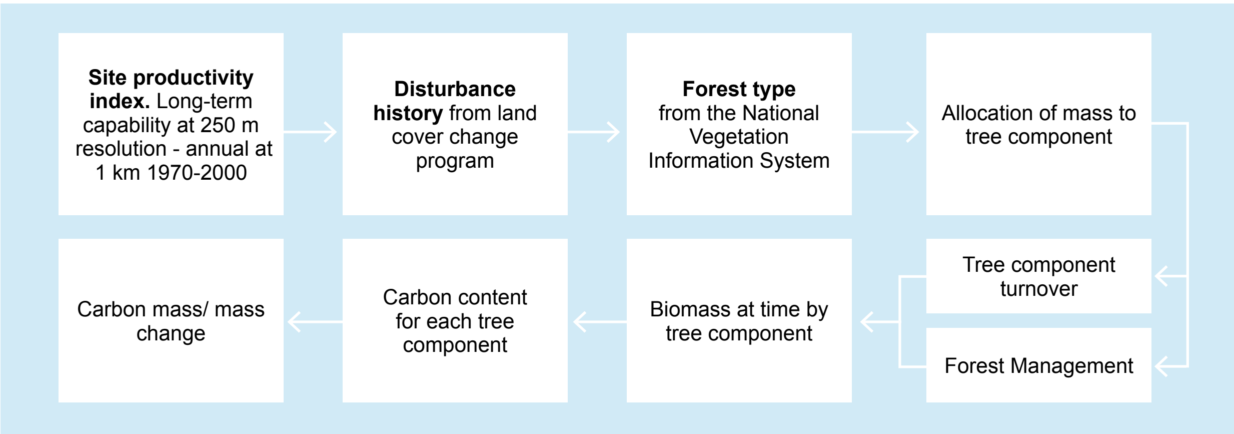
The results from the Tier 3 model have been compared with the results using a Tier 2 method. The Tier 2 method is based on country specific biomass data for three broad ecosystem types and uses the areas from the remote sensing analysis, applied using an Approach 2 method (i.e., not fully spatially explicit). The results from the two models are largely consistent and are reported in Appendix 7.J (see section 7.J.5.1).

7.A.4 FullCAM input data

The forest growth model component of *FullCAM* is an empirically constrained process model. In *FullCAM*, the tree yield formula allows for responses to climatic variability while empirical data and parameters constrain initial aboveground biomass, forest growth, and relative movements between pools (Figure 7.A15). It is the empirical data that constrains the model to reflect extensive field data (both existing and specifically collected).

To derive the spatial and temporal patterns of forest growth the simplified form of the *3-PG* model (Landsberg and Waring, 1997; Coops *et al*., 1998; Coops *et al*., 2001) was used to provide relative indices of growth potential (productivity indices[9]) at a 1 km grid scale on a monthly basis since 1970. The site-based, multi-temporal productivity indices are used to support a generalised empirical growth model. All modelling is done on the basis of aboveground biomass with subsequent factors to account for belowground (fine and coarse root) material.

Figure 7.A 15 Overview of the Forest Biomass Programs



Source: AGO 2002

9 A generic model of Net Primary Productivity derived a classification of productivity, on a scale of 1-30. Temporal and spatial variability is identified by a change in classification. This is not a linear relationship with biomass growth increment.

7.A.4.1 Forest Productivity Index

A truncated version of the *3-PG* model (Landsberg and Waring, 1997), retaining the essential features of biomass net primary production (NPP) estimation, without the carbon partitioning procedures is used to provides a site index of plant productivity that is independent of the type of forest present. The essence of the model is the calculation of the amount of photosynthetically active radiation absorbed by plant canopies (APAR). *APAR* is calculated (Equation 1) as half the amount of short-wave (global) incoming radiation (SWRadn) absorbed by plant canopies.

$$APAR = SWRadn \times 0.5 \times (1-e^{(-0.5 \times LAI)}) \times \text{days in month} \quad (1)$$

Where *LAI* is the Leaf Area Index and the coefficient 0.5 is a general value for the extinction coefficient. *LAI* is derived by the expression *ln*(1-FPAR)/(-0.5) where FPAR is calculated by (NDVI * 1.0611) + 0.3431. *APAR* is multiplied by a factor that converts it to biomass.

This, in effect, amalgamates two steps, the conversion of absorbed CO_2 into initial carbon products (gross primary production) and the loss of a proportion of those products by respiration to give NPP. The value of the conversion factor (*ε, gm Biomass* MJ^{-1} APAR) used was obtained from literature (Potter *et al*., 1993; Ruimey *et al*., 1994; Landsberg and Waring, 1997).

There is substantial variation in ε values, but no clear pattern in relation to plant type, so a value of *1.25 gm Biomass* MJ^{-1} APAR was used based on expert judgement. As the resultant output from the model is used as an index of 'productivity' (the Forest Productivity Index) and not as an absolute mass increase value, precision in the conversion factor is not critical. This NPP value assumes that there are no other constraints on growth. To account for the effects of other factors the potential NPP is reduced by modifiers reflecting non-optimal nutrition, soil water status, temperature and atmospheric vapour pressure deficits.

Calculation of Growth Modifying Factors

Modifiers are dimensionless factors with values between zero (complete restriction of growth) and one (no limitation). Modifiers used in this way are discussed by Landsberg (1986), McMurtrie *et al*., (1992) and Landsberg and Waring (1997).

The modifying factors are:

Soil fertility: Because of natural variation and the considerable uncertainty surrounding soil fertility values, only three levels of soil fertility were used; high (effective modifier = 1), medium (effective modifier = 0.8) and low (effective modifier = 0.6), giving ε values of 1.25, 1 and 0.75, respectively. These were applied for each pixel, depending on soil type, before environmental modifiers were applied. Information on soils and their characteristics was obtained from McKenzie *et al*., (2000a).

Vapour Pressure Deficit (VPD): VPD is a measure of atmospheric drought. VPD affects stomatal, and hence canopy, conductance as trees regulate their water use. This can lead to reduced growth even where soil water content is high. The VPD modifier equation (2) used is:

$$VPDmod = e^{(-0.05 \times VPD)} \quad (2)$$

This modifier essentially acts as a control on the rate of water loss and is conditional upon soil water content (see below).

Soil Water Content: This is derived from water balance calculations, which take into account the maximum soil water holding capacity (Equation 6) in the root zone of plants. Plant water use (Equation 4) is calculated from the equation for equilibrium evaporation (Equation 3, see Landsberg and Gower, 1997; p. 79), modified by feedback from current soil water content, and a conventional water balance equation (Equation 5):

$$EqEvapn = ((0.67 \times NetRadn * (1-0.05)) / 2.47) \times \text{days in month} \quad (3)$$

$$Transpiration = EqEvapn_j \times SWmod_{j-1} \quad (4)$$

$$WaterBal = (Rain \times (1-interception)) - Transpiration \quad (5)$$

$$SoilWaterContent_j = SoilWaterContent_{j-1} + WaterBal_j \quad (6)$$

Initial Soil Water Content was taken as 0.75 x SWcapacity. Soil Water Content carries over from one time step to the next. The soil moisture calculation sequence was run for three years, after which Soil Water Content had essentially equilibrated to stable monthly values. Soil Water Content values in year three were therefore used in the analysis. The soil water modifier (*Swmod*, Equation 8) was calculated from the moisture ratio (*MoistRatio*, Equation 7), which is Soil Water Content normalised to SWcapacity. The equation describes the variable effect of MoistRatio across the range from wet soil (MoistRatio ≈1) to dry soil (MoistRatio ≈0).

$$MoistRatio = SoilWaterContent/SWcapacity \quad (7)$$

$$SWmod = 1 / (1 + ((1-MoistRatio)/0.6)^{0.7}) \quad (8)$$

The soil water and VPD modifiers are not multiplicative; the lowest one applies. The argument is that if plant growth (conversion of radiant energy into biomass) is limited more by VPD than soil water (i.e., if VPDmod < SWmod) then soil water is not a limiting factor, even if soil water content is relatively low. The converse applies, that is, if SWmod < VPDmod, soil water is the limiting factor.

Temperature: The growth of any plant species is limited by temperatures outside the optimum range for that species. Since plants are dealt with in a generic way the assumption was made that, in any particular region, the plants are well-adapted to the temperature range. The equation (9) describing the effect of temperature is:

$$T_{mod} = ((T_{av} - T_{low}) / (T_{opt} - T_{low})) \times ((T_{high} - T_{av}) / (T_{high} - T_{opt})) \quad (9)$$

T_{av} is the average monthly temperature, T_{min} is the monthly average temperature below which plant growth stops, T_{max} is the monthly average temperature above which plant growth stops and T_{opt} is the optimum temperature for growth $(T_{min} + T_{max})/2$. The temperature modifier (T_{mod}) is 1 when $T_{av} = T_{opt}$.

Equation (9) gives a hyperbolic response curve, with $T_{mod} = 0$ when $T_{av} = T_{min}$ or T_{max}. T_{min} is set to ½ the minimum temperature of the coldest month (if the minimum temperature of the coldest month is greater than or equal to 0°C, T_{min} was set to the minimum temperature of the coldest month plus ½ the minimum temperature of the coldest month if the minimum temperature of the coldest month is less than 0°C). T_{max} is set to 5°C above the maximum temperature of the hottest month of the year and T_{opt} as equal to the average of T_{min} and T_{max}. Consequently, T_{mod} generally had relatively small effects on the calculation of NPP.

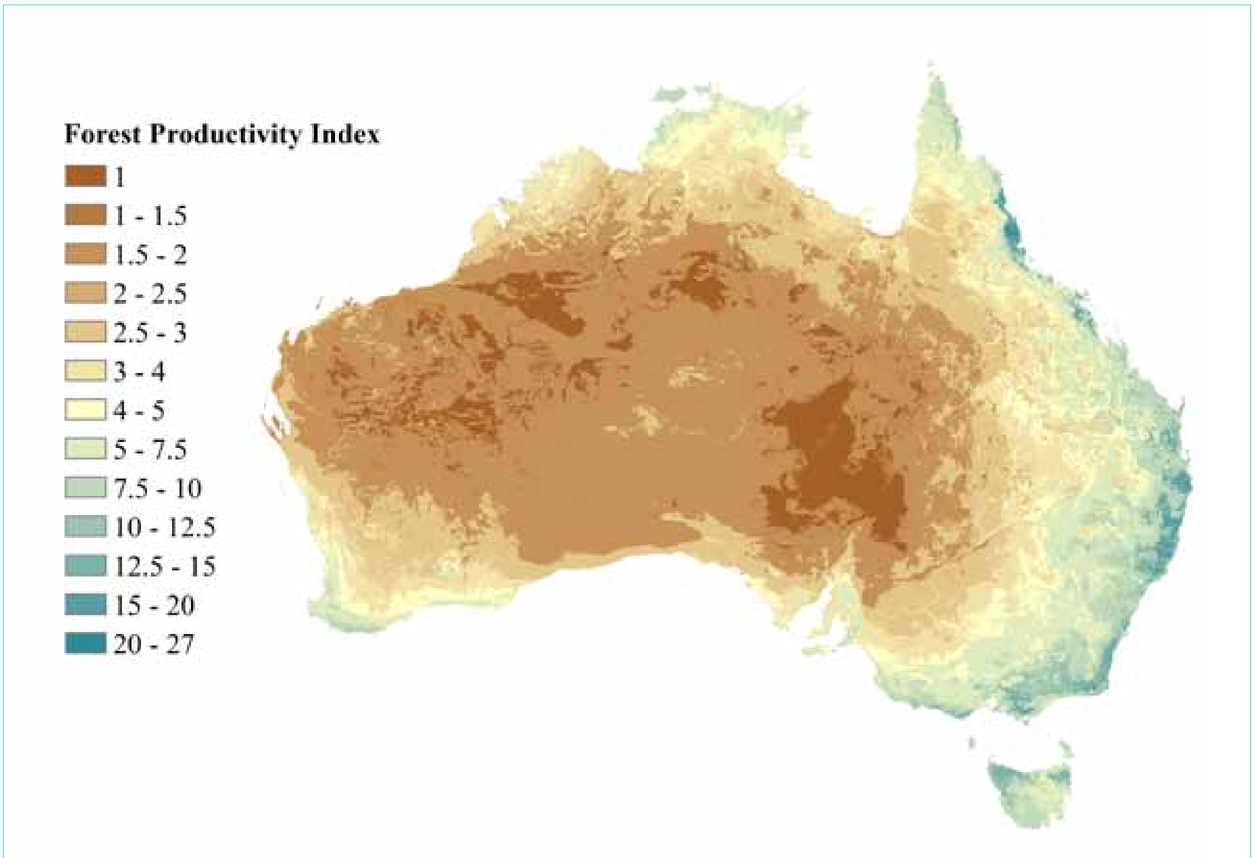
A frost modifier is included, using the simple assumption that frost temporarily inactivates the photosynthetic mechanism in foliage, so there is no growth on a frost day. The modifier is, therefore, simply the ratio of number of frost days/month to the number of days in the month.

Calculation of the Forest Productivity Index

The Forest Productivity Index (FPI) is calculated both temporally and spatially using the monthly (since 1968) 1km grid climate and site information described in section 7.A.6. A further 250 m long-term average FPI is also calculated, using a slope and aspect corrected APAR calculation (Figure 7.A16).

These productivity maps are used to describe the spatial and temporal variation in forest biomass and growth.

Figure 7.A 16 250 m slope and aspect corrected productivity index map



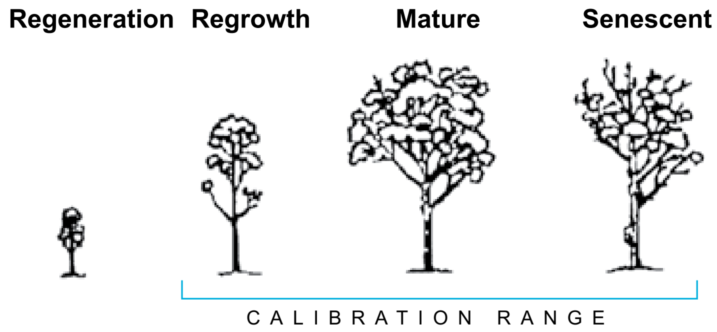
7.A.4.2 Initial assumed biomass

Calibration

An estimate of biomass (the assumed initial biomass) of mature forests is required to estimate emissions due to first time clearing events. The assumed initial biomass is applied to all first time clearing events whenever they occur. It is modelled from site productivity and field measurements reflecting a range of potential prior disturbance histories.

The assumed initial biomass for a pixel which is subject to first time land clearing is calculated based on a regression model of the relationship between the Forest Productivity Index and measured biomass (Raison *et al.*, 2003; Richards and Brack, 2004a). Biomass measurements used in the calibration include all forest conditions except those with visible evidence of recent disturbance such as clearing, harvest or fire since 1970. The lands may, however, have an ongoing low level disturbance such as grazing and low intensity fires. The calibration data covers the mix of age classes from regrowth to senescent (old-growth) (Figure 7.A17) and therefore the potential variation in field biomass conditions.

Figure 7.A 17 Diagram showing the range of data used in the calibration of the model



Regeneration	Includes juvenile and sapling stages where tree is very small and crown exhibits apical dominance.
Regrowth	Tree has well developed stem with crown of small branches, but below maximum height for stand, apical dominance apparent in vigourous trees.
Mature	Tree has reached maximum height and crown reached full lateral development. Branch thickening can occur.
Senescent	Crown form contracting, decrease in crown diameter and crown leaf area.

Source: Base image and text from Florence (1996).

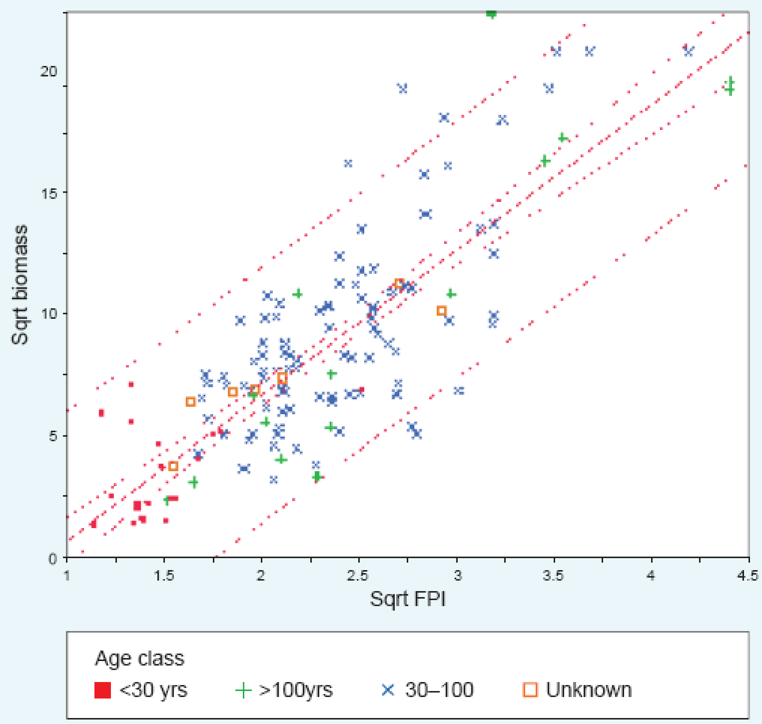
In the collection of the calibration plot data, caution was exercised to exclude forest 'gaps' contained in some field measurements. Plots taken as part of fixed-grid or transect systems could potentially fall in gaps in sparse forests. As the remote sensing program at 25 m resolution is capable of separating such forest gaps from clearing events, the forest carbon mapping needs to represent the biomass of forested plots, not of that averaged over the gaps.

To determine the initial forest biomass for an individual forest site the geo-referenced calibration data set was fitted to the productivity map. The red line in Figure 7.A18 is the line of best fit for predicting the initial forest biomass of an individual forest site.

A regression found a significant correlation ($p < 0.01$, $r^2 = 0.68$) between the stand biomass measures (*M*) and the Long-Term Forest Productivity Index (*P*) (Equation 10). A square root transformation was required to meet assumptions of normality and homogeneity (Figure 7.A18).

$$M = (6.011 \times \sqrt{P} - 5.291)^2 \quad (10)$$

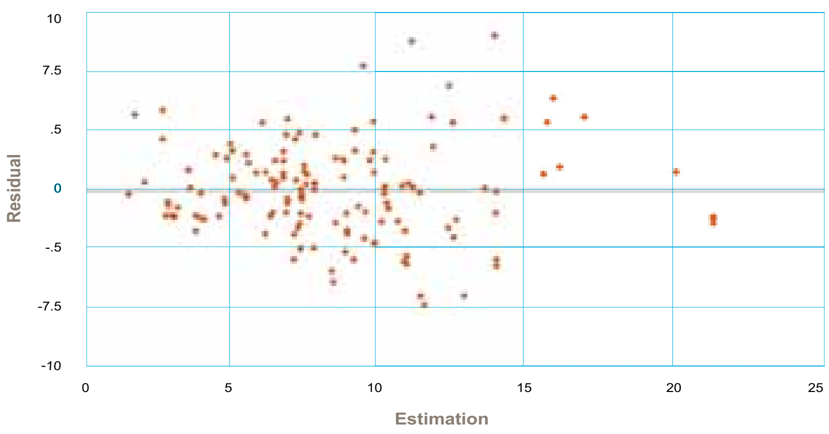
Figure 7.A 18 The assumed initial biomass relationship



The goodness of fit of Equation (10) ($r^2 = 0.68$, $p < 0.01$) to the measured data confirms that a robust relationship exists between the productivity mapping and measured aboveground biomass estimates. The outer 95% confidence limits (outer pair of dotted lines) show the reliability for predicting biomass at any individual site. The inner 95% confidence intervals (inner pair of dotted lines) show the high degree of confidence in the line of best fit being able to represent the variability in the field data at the national scale. It applies throughout the continuum of productivity across the forest estate as a whole. The model shows that the assumed initial biomass is an accurate and unbiased representation of the forest estate (excluding young regrowth) as can be gauged from available data.

The initial assumed biomass at a chosen resolution for the entire continent can then be calculated by applying Equation (10) to the FPI mapping. While the goodness of fit and lack of bias in error estimates (Figure 7.A19) provides confidence in the application of Equation (10) as a model to predict biomass at maturity, there is an obvious scatter in the data. This is attributable to the range of age classes and forest histories used in the model, the differing methods used in the field estimation and to an inherent variability between the 'plot' locations used to scale to one hectare mass estimates compared to the average condition reflected in the 250 m resolution productivity estimation.

Figure 7.A 19 Error distribution for equation 10



7.A.4.3 Key concepts in the initial assumed biomass model

In developing the initial assumed biomass model it was important to consider the way in which the initial biomass values fitted within the modelling framework as a whole. The biomass condition in any individual forest site in Australia is based on its history of both human and natural disturbance, whereas in a national emissions account it is human disturbance that is most significant. The history of human disturbance will fit into one of three different cases:

- Case 1: The forest site was undisturbed/uncleared prior to 1972 and remains undisturbed/uncleared until the first land clearing event.
- Case 2: The forest site was cleared prior to 1972 and is currently regrowing.
- Case 3: The forest site was cleared sometime after 1972 but has since regrown.

Key Terms used in the biomass model

Maximum potential biomass – the highest biomass value that the model will assign to any forest area and is an average of the range of measured biomasses (field) for a range of forest disturbances. It is not the upper limit of the measured biomasses.

Calibration data – field measurements collated nationally to represent the range of forest conditions, except those with visible recent disturbance. The initial condition (maximum potential biomass) is the central estimate of this data spread for any given site productivity.

Field maximum and minimum observed values – reflect the range of measured biomass for any point along the site productivity continuum. The maximum measured values typically represent situations that are least disturbed. The minimum values represent a higher degree of disturbance (but exclude young regrowth sites).

Validation data – data that are independent from the calibration data, and is used to test models built on the calibration data.

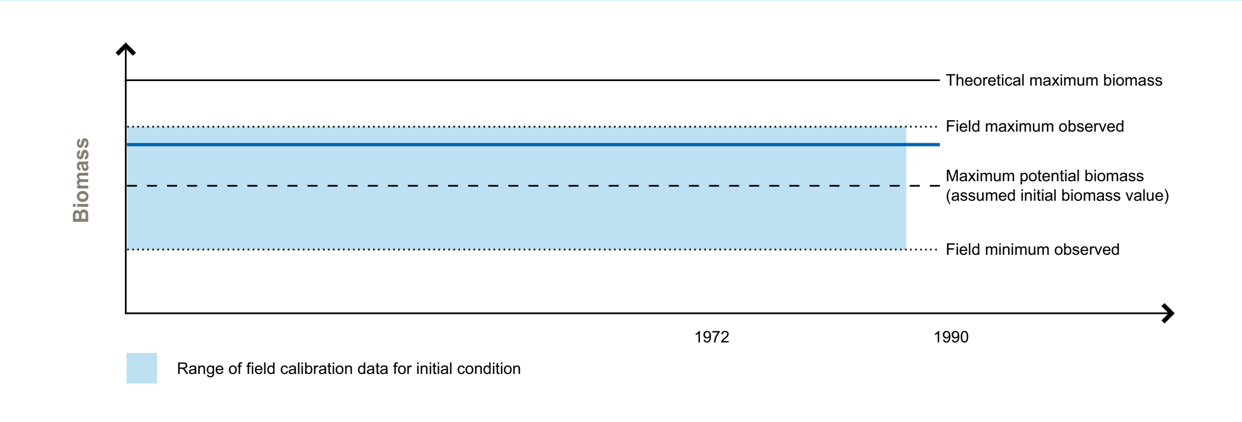
Site productivity – an estimate of the ability of a site to produce biomass (Kesteven *et al*., 2004).

Land clearing event – A land clearing event (deforestation) involves deliberate human actions that remove the forest cover for land management purposes (typically agricultural production). It produces a fundamental disturbance to the forest condition.

Natural Forest Disturbance – Natural climate variability (for example, bushfire and drought periods) affects the forest condition to a lesser extent in the long term as there is a natural recovery to this cyclical natural pattern.

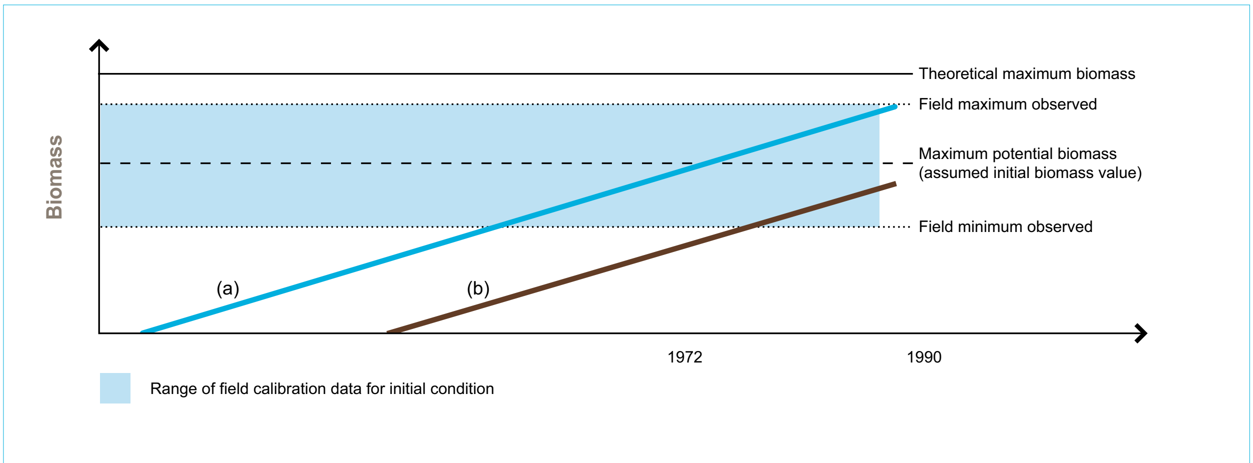
Figures 7.A20 (a) to (c) (below) show the relationship between the model's assumed initial biomass and the likely biomass in each of the three historical disturbance cases. In Case 1 (Figure 7.A20 (a)) the forest site was undisturbed prior to 1972, (as represented by the continuous blue line) and remains in that condition until a time of a first clearing event. The field biomass is represented by the example blue line in Case 1 and will possibly be higher than the maximum potential biomass because the maximum potential biomass was calibrated from sites representing a range of disturbance histories. This reflects the absence of prior disturbance in forest sites fitting into Case 1.

Figure 7.A 20 (a) Biomass of forest undisturbed prior to 1972



In Case 2 (Figure 7.A20 (b)), the forest area was cleared at some time prior to 1972, but was not cleared between 1972 and 2008 and at the time of clearing the forest was still growing. For the majority of forests in this case, the biomass in 1990 will have recovered to be within the range of observed values used in the model calibration but may not have reached the assumed initial biomass value.

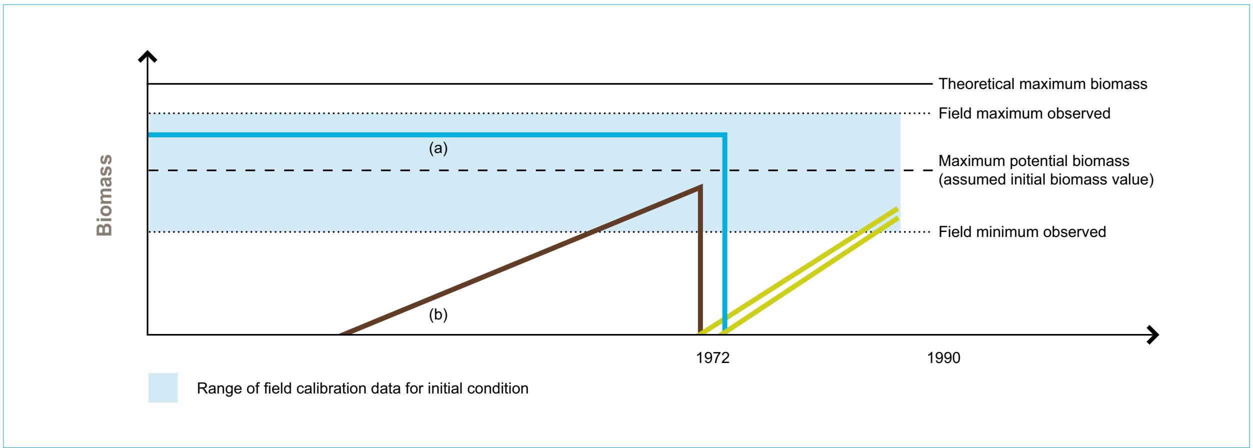
Figure 7.A.20 (b) Biomass of forest cleared prior to 1972



For Case 2 (a) the actual biomass for the site may exceed what would be assigned as the assumed initial biomass condition by the model. This is because the length of time the forest has had to regrow means it resembles the Case 1 scenario. Where the initial clearing occurred soon before 1972 (Case 2 (b)), the biomass for the site will be below that which would be assigned as the assumed initial biomass condition.

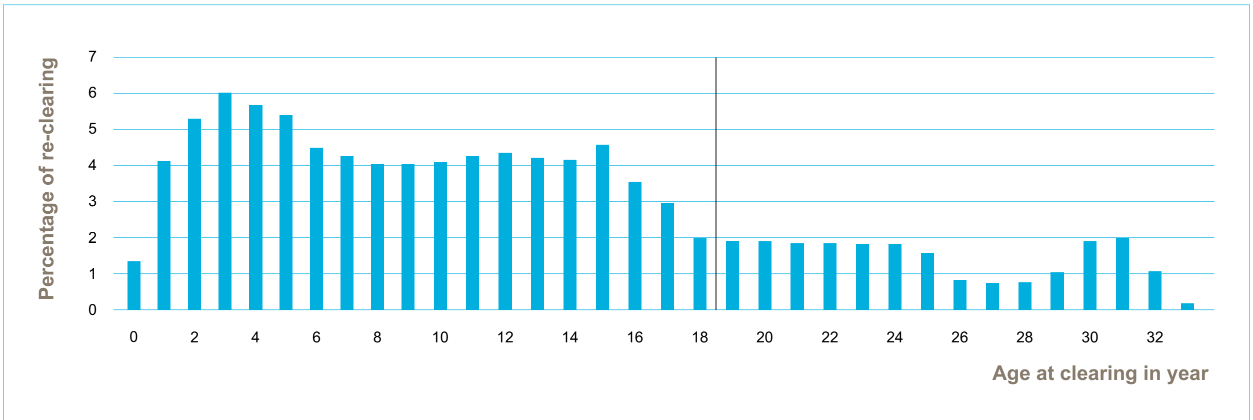
Both Cases 2 (a) and 2 (b) are relatively rare occurrences. This is because the average re-clearing cycle is eight to 11 years, with 80% of re-clearing happening within 18 years of the last regrowth event (Figure 7.A21). This means that of the forests possibly in Case 2 (a) and 2 (b) (that is previously cleared and regrowing at an unknown time before 1972) around 80% would likely have a re-clearing event before 1990 and would actually be in Case 3(b) below. For those forests that are not re-cleared and are actually in Case 2, the assumed initial biomass may be overestimated or underestimated, depending on when the initial (unobserved) clearing took place. There is no basis for presuming that any individual pixel is more likely to be either 2 (a) or 2 (b).

Figure 7.A.20 (c) Biomass of forest cleared post-1972



In Case 3 (Figure 7.A20 (c)) the forest is interpreted from the post-1972 remote sensing data to have been 'cleared for the first time' after 1972 (Case 3 (a)) and has subsequently regrown. In this case the age of the forest is known and the biomass is modelled directly using the age of the forest and site productivity (see Biomass Growth Increments section 7.A.4.4). The green lines in both (a) and (b) represent biomass that can be calculated by the model because the age of regrowth can be observed. The assumed initial biomass is not used for any subsequent re-clearing event as the age of regrowth forest is known at the time of re-clearing. Prior to 1972, the forest may have been undisturbed (represented in the blue line (a)) or disturbed (represented in the red line (b)). Regardless of whether the situation was (a) or (b) the initial biomass assumption at time of first clearing will not affect the biomass estimates for a re-clearing event after an initial clearing has been identified.

Figure 7.A 21 Percentage of re-clearing by age



7.A.4.4 Biomass increment for regrowing forests

As not all forest areas are in a 'mature' state, the remote sensing of land cover change is used to identify disturbance history and, therefore, forest age. The forest type mapping is subsequently spatially overlaid on the multi-temporal productivity maps to determine, for every 25 m pixel, the forest type, productivity and age (inferred from disturbance history using the land cover change data). The following formula

(Equation 11) is then used to provide an estimate of growth of those forests which have regrown since 1972 using the spatial productivity index (mass at maturity and forest type) and multi-temporal spatial data (productivity and land cover change).

$$\text{Aboveground Tree Mass at age a} = M \times e^{(-k/a)} \quad \text{.......... (11)}$$

Where: (a) is the age of the tree stand

(M) is the biomass predicted by the assumed initial biomass model, and

(k) is an estimated constant that determines the rate of approach towards M.

The value of *k* sets the rate of growth. By differentiating the above equation it can be found that the age of maximum biomass increment in this model is 0.5*k*. In *FullCAM* this value is known as BI_a, the age of maximum aboveground biomass increment.

Given Equations (10) and (11), the long-term average annual increment between *a* and *a* + 1 years (I_a) for a stand can be estimated from the Long-Term Average Productivity (*P*):

$$I_a = (6.011 \times \sqrt{P} - 5.291)^2 \times (e^{(-k/a)} - e^{(-k/a+1)}) \quad \text{.......... (12)}$$

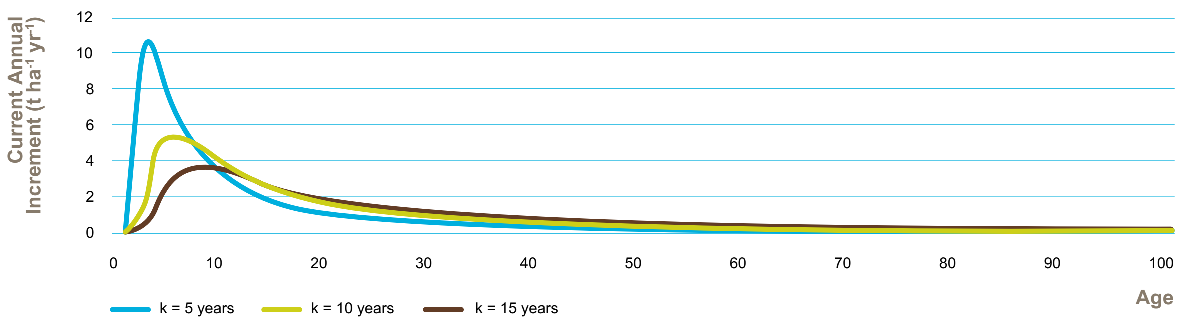
However, as productivity in any given year may vary around the average due to non-average weather or other factors, the average annual increment may be adjusted by the productivity in a given year (P_a) as a ratio with the average productivity (*P*):

$$I_a = I_a \times P_a / P \quad \text{.......... (13)}$$

This approach provides biomass stock estimates for a given land unit at any point in time that recognises prior forest disturbance, and the rates of growth for a land unit at any point in time, specific to site condition and age. The patterns of growth will show variability according to the spatial and temporal patterns of the main process drivers, e.g., water balance, captured in the productivity modelling. This ensures that the estimates of biomass in areas of regrowth are then both spatially and temporally relevant.

Figure 7.A22 provides an analysis of the effects of varying age of maximum aboveground biomass increment between the ranges of five to 15 years. While the early age growth increments are very sensitive to BI_a, even by age 18 there is little difference in the annual aboveground biomass growth increment. The effect of BI_a on any modelling at the national scale will depend on the age, quantity and location of regrowing forest and is discussed separately in Appendix 7.F.

Figure 7.A 22 Effects of varying age of maximum current annual increment



7.A APPENDIX

7.A.5 Soil carbon input data

7.A.5.1 Soil Mapping and Inventory

The modelling of soil carbon change by *FullCAM* uses an initial condition map which defines the pre-disturbance soil carbon content. This pre-clearing soil carbon layer was developed through collaboration with the relevant agencies of State and Territory Governments and the CSIRO to access the best available soil mapping and site sample data suitable to this purpose. To provide comparability between site sample (inventory) results collected over various time periods from a variety of analytical laboratories, typically using different methods, correction factors were derived by standardising wet chemistry methods to the results derived from a dry combustion methodology (Skjemstad *et al*., 2000). Correction factors were derived by re-analysing, via a dry combustion method, archival soil samples and then comparing results to the known results from the original methods.

The mapping of soil units was completed at a level of precision which could be supported by available data. This approach led to variable resolutions in the mapping, generally determined by the regional data availability and heterogeneity of soil landscapes. The results of this project are reported in Webbnet Land Resource Services Pty. Ltd. (2002). Figure 7.A23 shows the derived pre-disturbance soil carbon map.

In conjunction with the development of the pre-disturbance soil carbon map, a map of clay content was also developed (Figure 7.A24) using the same map base. The mapped soil units provide pre-disturbance carbon (organic) content, clay content and soil type. The soil types (Table 7.A2) allow for the initial soil carbon values from the mapping to be partitioned into the carbon pools used by the carbon model via a relational database. These pools are defined by their differences in turnover times (i.e., the resistant versus decomposable). The proportion of material in each soil pool (fractionation) was established by laboratory analysis of soil samples held in CSIRO and State/Territory Government archives.

Additional studies carried out to support this work included the setting of a national soil carbon sampling and analysis protocol (McKenzie *et al*., 2000a) and a standardisation of existing archival data to this new national analytic protocol (Skjemstad *et al*., 2000).

Figure 7.A 23 Pre-disturbance soil carbon map

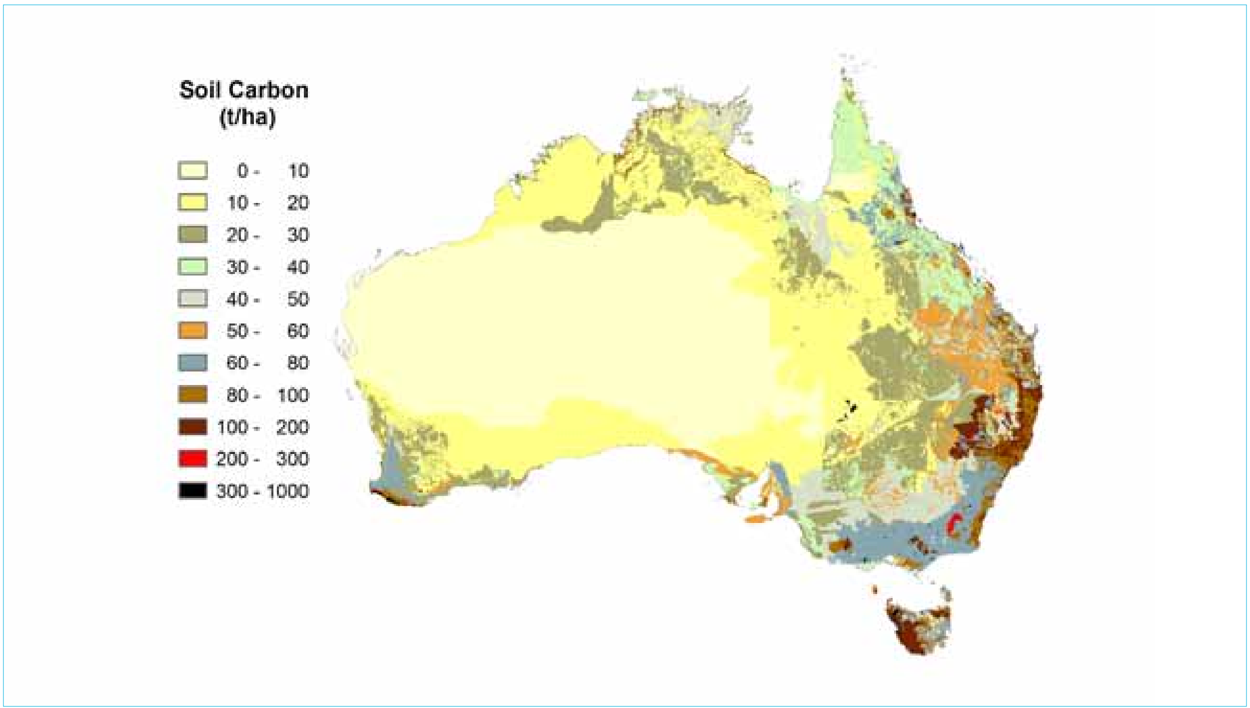


Figure 7.A 24 Clay content map

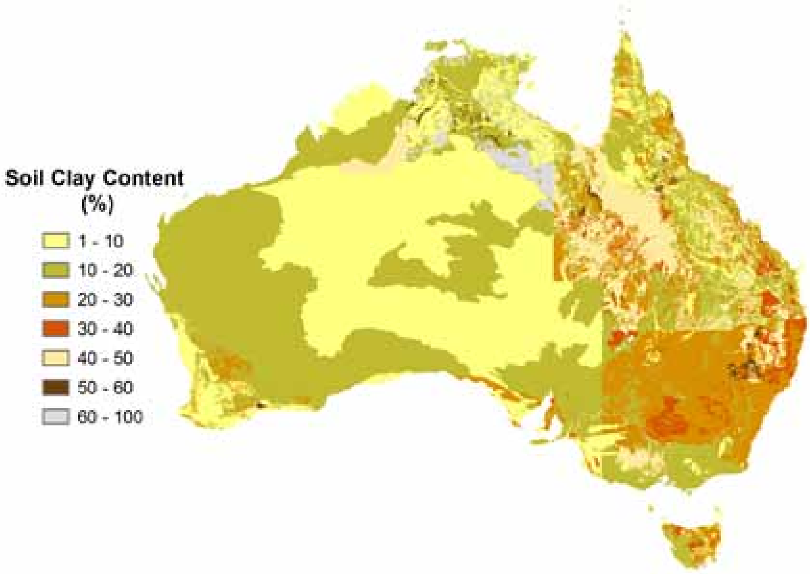


Table 7.A 2 Soil classification used in the modelling

Soil no.	Location	Soil type
s1	TAS	Structured earths
s2	TAS	Bleached sands with subsoil pans
s3	TAS	Other soils
s4	NSW	Clay
s5	NSW	Loam
s6	NSW	Sand
s7	QLD	Duplex – woodland
s8	QLD	Clay – brigalow and gidgee
s9	QLD	Clay – open downs
s10	QLD	Clay – brigalow and belah
s11	QLD	Gradational
s12	QLD	Clay
s13	QLD	Other soils
s14	QLD	Gradational – spinifex
s15	QLD	Clay – mitchell grass (30%) and gidgee
s16	QLD	Duplex – black spear grass & a\b woodland
s17	QLD	Duplex
s18	QLD	Gradational and duplex
s19	QLD	Clay – gidgee
s20	QLD	Open downs
s21	QLD	Earths
s22	QLD	Sands and loams
s23	QLD	Clays and red loams
s24	NT	Kandosol
s25	NT	Other
s26	NT	Tenosol
s27	SA	Sub area 1 -DD
s28	SA	Sub area 2 – Lb5
s29	SA	Sub area 3 – Sandy
s30	SA	DD2/Lb5/E6
s31	VIC	Deep sands
s32	VIC	Calcarosols

Soil no.	Location	Soil type
s33	VIC	Cracking clays
s34	VIC	Yellow duplex soils
s35	VIC	Leached sands
s36	VIC	Brown duplex soils
s37	VIC	Black duplex and gradational soils
s38	VIC	Red-brown earths
s39	VIC	Bleached sands
s40	VIC	Organic soils
s41	VIC	Gradational Red earths
s42	VIC	Non-cracking clays
s43	VIC	Red duplex soils
s44	VIC	Organic loams
s45	VIC	Red earths
s46	VIC	Brown earth
s47	VIC	Grey Cracking Clays
s48	WA	Coloured sands
s49	WA	Gravels
s50	WA	Loams and clays
s51	WA	Non saline wet
s52	WA	Other
s53	WA	Pale sands
s54	WA	Sandy duplexes
s55	WA	Saline

7.A.6 Native forests input data

7.A.6.1 National Forest Inventory

Australia's National Forest Inventory (NFI) is a collection of information on Australia's forests (http://www.daff.gov.au/brs/forest-veg/nfi). Information about Australia's forests is collected by many different organizations, including Commonwealth, State and Territory land management agencies and private companies. The data collected by the NFI is an aggregate of these sources to provide information for national reporting, such as Australia's State of the Forests reports and reporting to the FAO and Montreal Process.

Australia's NFI covers public and private forests, and native and plantation forests. Datasets available from the NFI are used in Australia's National Inventory Report to:

1. define the area of *harvested native forests* and pre-1990 *plantations*;
2. to estimate average growth rates for *harvested native forests* by forest type and age class; and,
3. to determine growth rates of plantation species.

Other input data

7.A.6.2 Climate

Model sensitivity testing identified that inter-annual climate variability has a significant effect on both soil (Janik *et al*., 2002) and forest (Brack and Richards, 2002) carbon stock change. The use of long-term (temporal) average and regionally (spatial) averaged climate data was shown to be inadequate to support spatially and temporally disaggregated carbon modelling, frequently generating spurious results when tested. To account for the effects of climate both spatially and temporally over the modelled period, 1970-2008, weather station data from the Bureau of Meteorology for rainfall, minimum and maximum temperature, evaporation and solar radiation were obtained. Monthly climate surfaces (maps) at 1 km resolution for each variable were then derived using the ANUCLIM (McMahon *et al*., 1995) techniques.

Raw Data

Within the Bureau of Meteorology database there are approximately 1,200 weather stations recording temperature, 13,000 stations recording rainfall, 300 stations recording evaporation and 700 stations recording frost days. Precise location data were available for some 2,500 weather stations, providing a quality reference set of points from which to spatially interpolate climate surfaces. Version 2 of the 9 second (approximately 250 m resolution) national digital elevation model (AUSLIG, 2001) was used to provide terrain (elevation and aspect) mapping to support the spline functions used in the ANUCLIM software.

Derived Outputs

The weather station climate data are interpolated (modelled) using mathematical (multivariate spline) functions that reflect influences on micro-climate such as elevation. Climate maps are derived at variable resolutions (grid sizes), again using the ANUCLIM software (Kesteven *et al*., 2004). The list of outputs and their resolution is shown in Table 7.A3. Figures 7.A25 to 7.A28 illustrate national long-term average annual climate maps generated using the ANUCLIM software.

The surface interpolation from weather station data provides climate mapping which is both temporally (monthly) and spatially (at select resolution) relevant to the application of the *FullCAM* modelling.

A full description of quality assurance, quality control, calibration, validation, verification and sensitivity and uncertainty analyses are reported in Appendix 7.J (see section 7.J.3.4).

Table 7.A 3 List of climate and productivity maps developed for land sector reporting in the National Inventory System

Climate Variable	Description
Rainfall	1 km resolution continentally, monthly 1968-2008
Temperature	1 km resolution min., max., and average continentally, monthly 1968-2008
Evaporation	1 km resolution continentally, monthly 1968-2008
Frost Days	1 km resolution continentally, monthly 1968-2008
Solar Radiation	1 km continentally, monthly direct and diffuse 1968-2008, 250 m resolution continentally, slope and aspect corrected diffuse and direct
Long-term productivity	250 m resolution
Annual productivity	(sum of monthly) 1 km resolution (1970-2008)

Figure 7.A 25 Long-term average rainfall

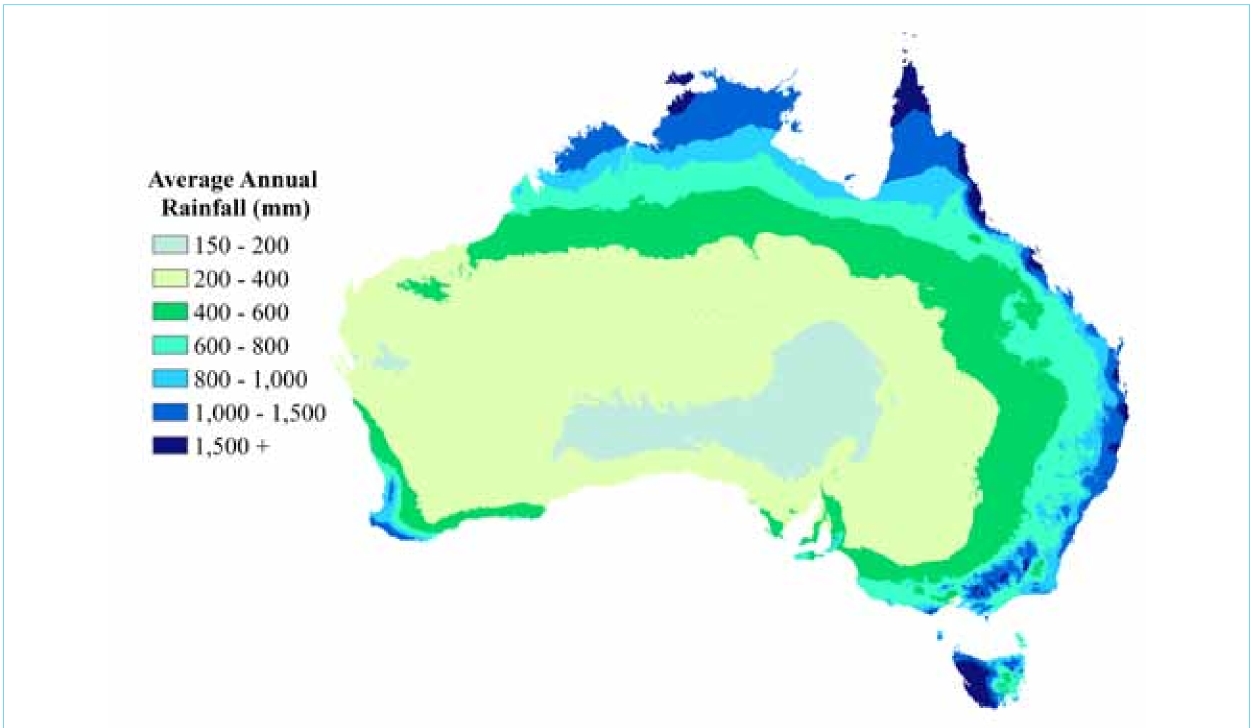


Figure 7.A 26 Long-term average annual temperature

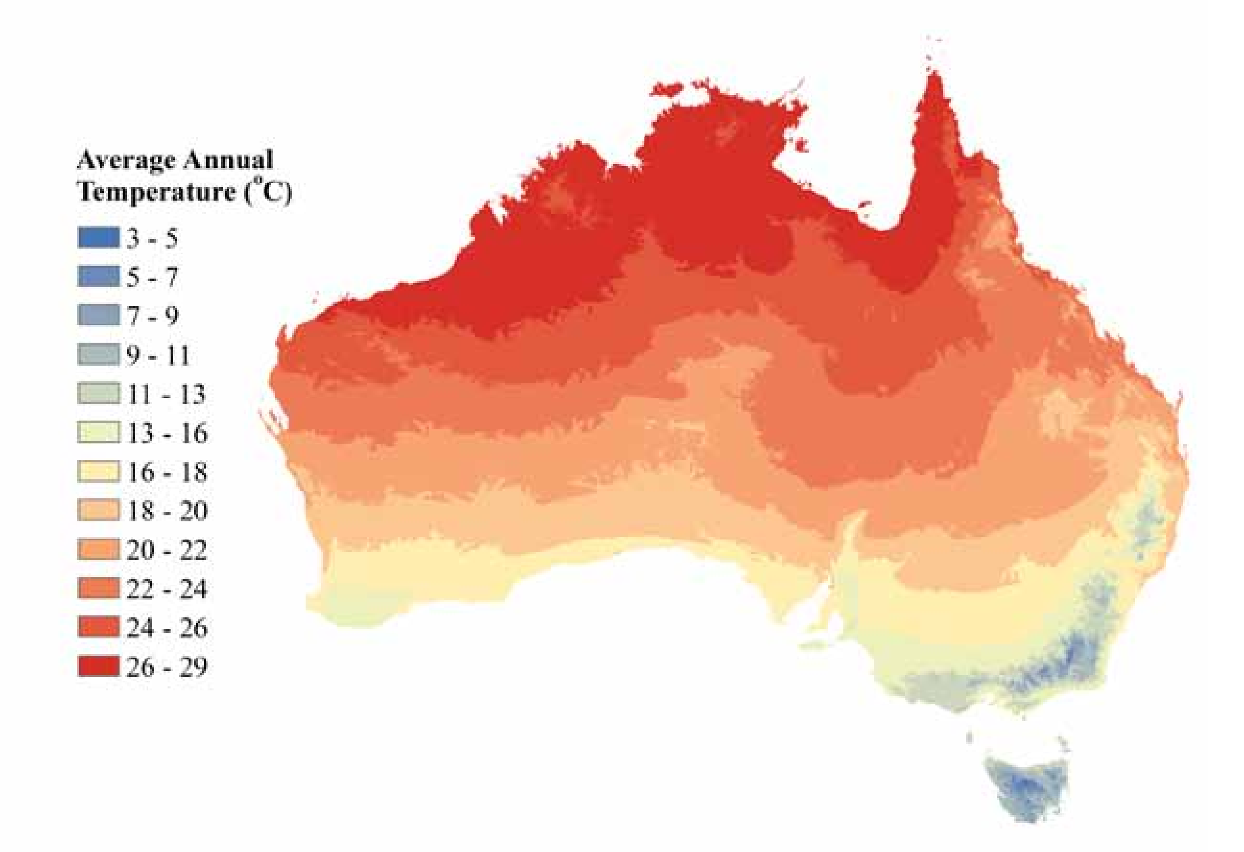


Figure 7.A 27 Long-term average annual evaporation

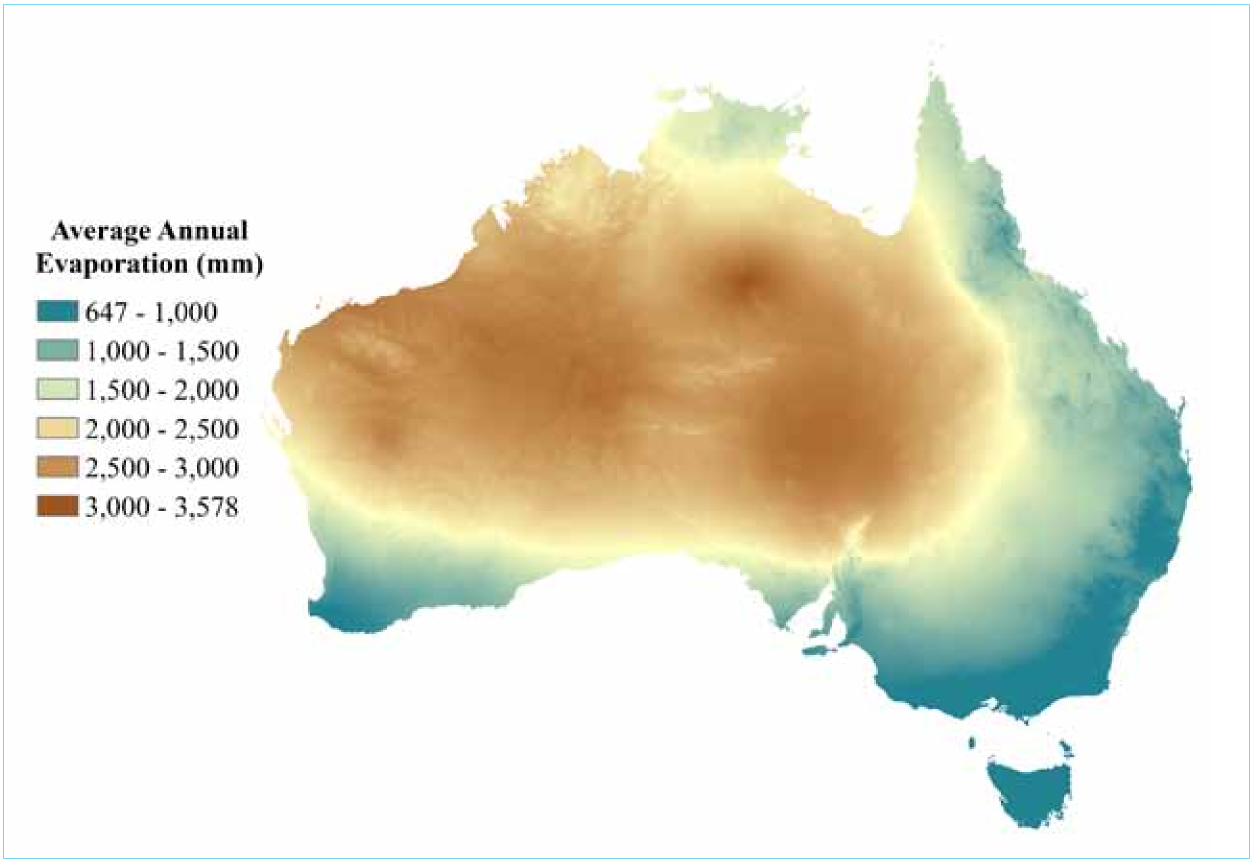
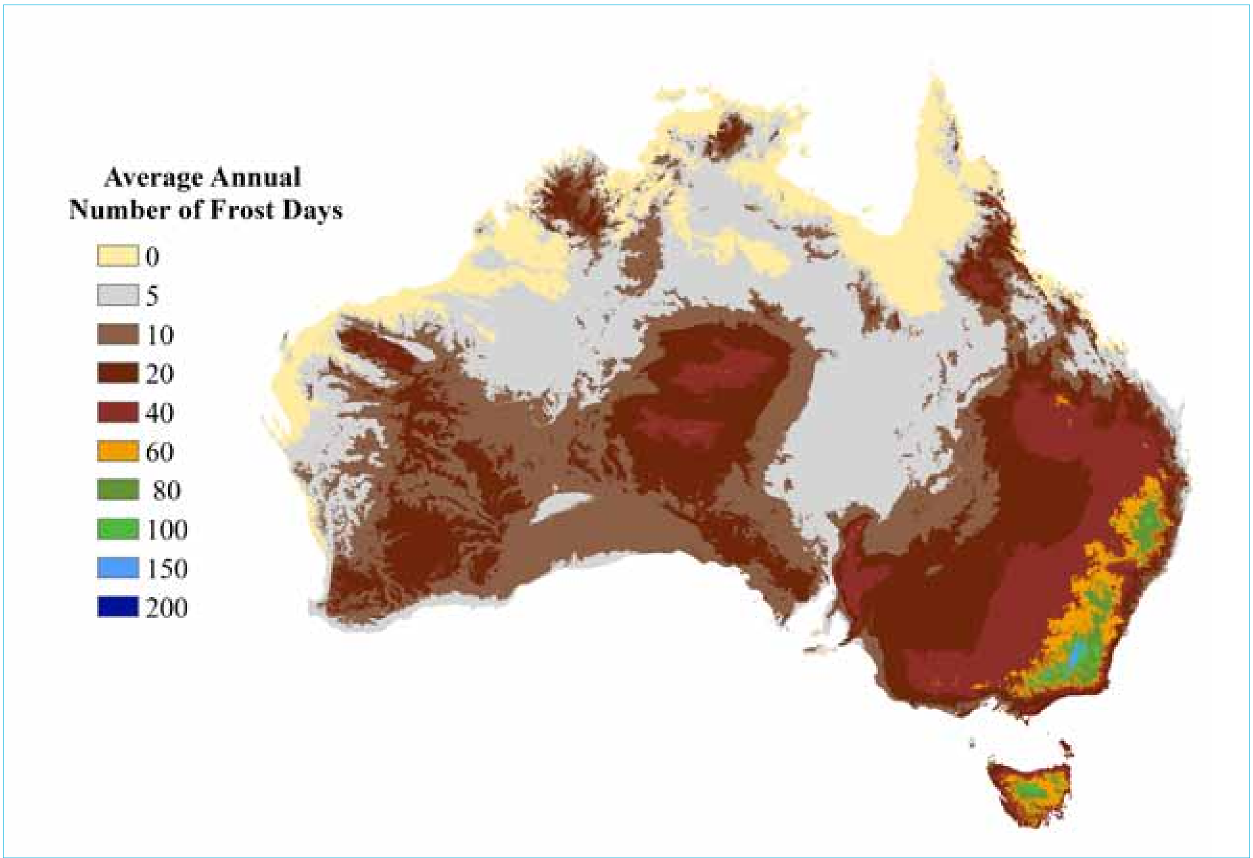


Figure 7.A 28 Long-term average number of frost days per year



7.A.6.3 Soils and other spatial data

Soils

As described in section 7.A.5, several soil maps are required for use by the *Roth-C* model including soil type, carbon content (pre-disturbance) and clay content. Maps of these parameters were developed through a synthesis of resource inventory data, predominantly available from State Governments. Clay content was a consistent measure and relatively easily drawn into national synthesis. Soil type descriptions varied according to jurisdiction, but within the modelling framework these differences could be accommodated (Webbnet Land Resource Services Pty. Ltd., 2002). Considerable additional analytic work was required to achieve consistency in data on pre-disturbance soil carbon contents. This need was primarily derived from the differing analytic techniques used to assess carbon content in soil samples. To provide a common and consistent national map, archived samples of soil were reanalysed and correction factors to a *Leco* dry combustion standard were derived (Skjemstad *et al*., 2000). Fractionation schemes were also derived for partitioning soil carbon into the pool structures used in the soil carbon model.

To calculate the Forest Productivity Index, soil fertility and water holding capacity were obtained from the spatial map of Australian soils provided by CSIRO (McKenzie *et al*., 2000a).

Land Tenure

To separate out forestry activities from relevant land cover change events, a national tenure map is applied, masking out areas with a dedicated public forestry land use as well as National Parks. This tenure map is supplied by the National Forest Inventory (1997a) of the Bureau of Rural Sciences. Areas of deforestation associated with forest harvest on private land were separately identified by visual interpretation of the land cover change sequences. Masks are created to distinguish these events from those associated with forest conversion.

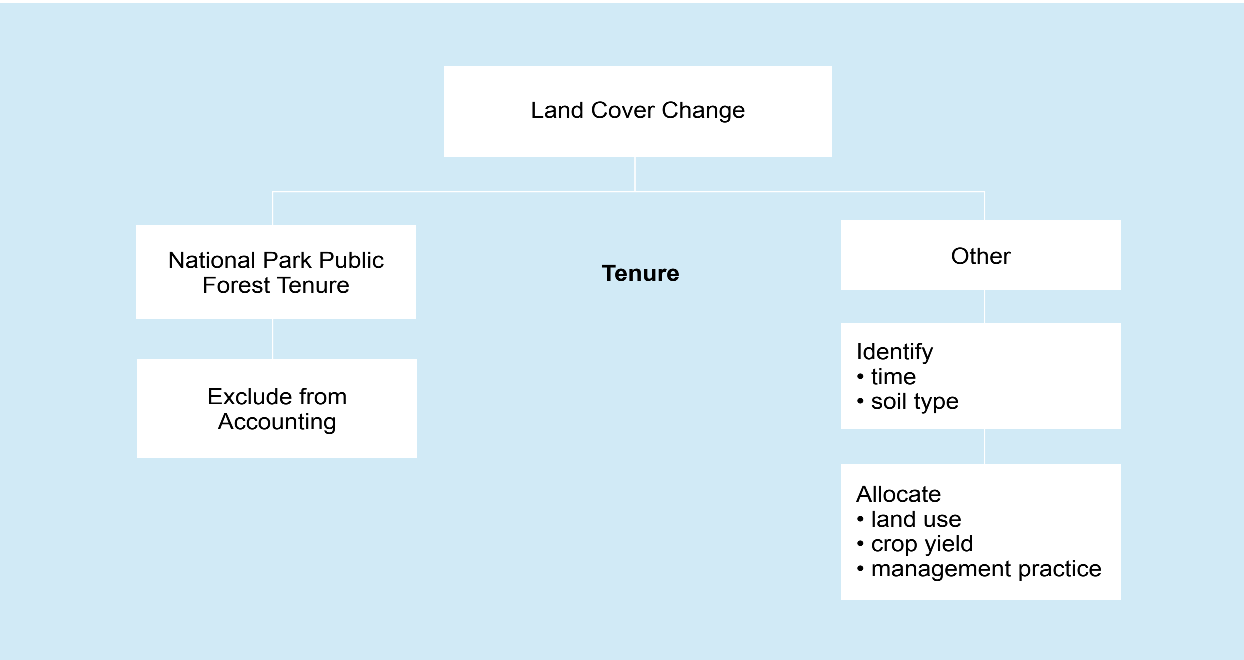
7.A.6.4 Land Use and Management Data

Land management practices in both agriculture and forestry in Australia have varied considerably over time depending on species, region, desired products and site conditions. However there was no consistent, nationally available compilation of this information and separate programs to compile the required information were undertaken. While there was no overlap between the forest and agricultural management data programs, the methods used were similar. In both instances, a focus group was established comprising researchers and practitioners to give all management issues (e.g., forest and crop type, burning, harvesting and thinning) a jurisdictional (geographic) and temporal coverage. All available information was collated and supplemented with expert knowledge to give completeness where records were not available. The information gathered by these groups for use in the management databases is documented in Swift and Skjemstad (2002) and Raison and Squire (2008).

Land cover change has the obvious effect of removing existing tree biomass, resulting in the release of greenhouse gas emissions. The impact of the subsequent land use (e.g., crop or pasture type) and management practices (e.g., tillage, use of fire and grazing intensity) can also impact significantly upon ongoing emissions from that land. Depending on the land use (including forest regrowth) and management practices, the rate of change in carbon stock subsequent to land cover change will vary, and in some instances the direction of change (sink or source) will also be affected. Greenhouse gas emissions from land use and management practices are also affected by the soil type on which they are applied and the climate at, and subsequent to, their application.

Australia's land cover change data allows each event (i.e., land use change) to be attributed a location and time. This information can be spatially overlayed on the soils map so that each event can be attributed to any other spatial data. From a management perspective, soil type is a major driver of land use practices. Data on management practices are therefore able to be linked to units of land that have undergone forest conversion via unique identifiers of soil type and time. Land use and management types are then apportioned within the soil type strata (Figure 7.A29).

Figure 7.A 29 Overview of the land use and management program



7.A APPENDIX

To obtain the agricultural land use and management information, CSIRO Land and Water were commissioned to collect relevant growth and management information via survey and literature searches for each Interim Biogeographic Regionalisation of Australia (IBRA) (Thackway and Cresswell, 1995) region, based on soil type, crop type and crop regime (rotations), management type and time (Table 7.A4). This included time-based crop yield estimation for each identified land use and management type. The results of this study can be found in Swift and Skjemstad (2002), reported by IBRA regions (Figure 7.A30) as a primary stratification, with soil type used as a secondary strata. Initial data collection covered the period from 1970 to 2000. This dataset is updated annually by CSIRO Land and Water with data drawn from a variety of sources including statistical and industry holdings, crop growth modelling and expert opinion.

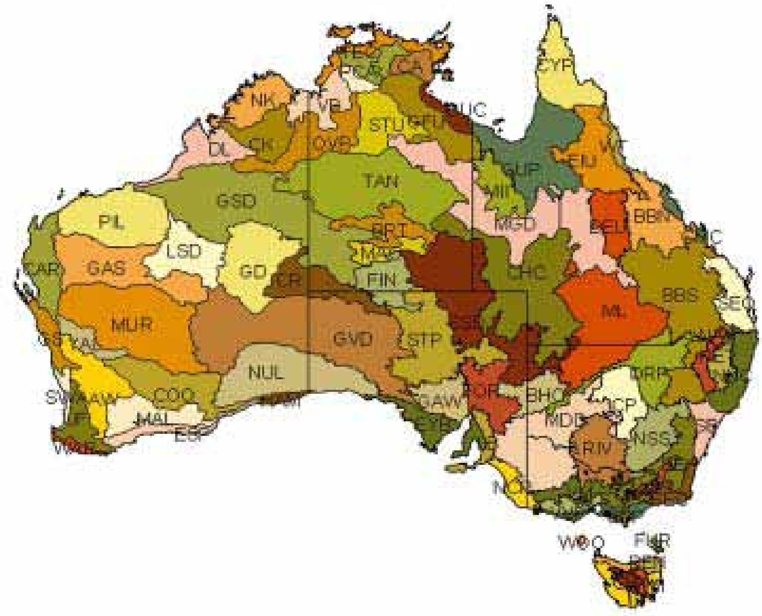
The information collected describes 141 grazing and cropping systems, with associated management practice data also held within the *FullCAM* model relational database. Allocation to a land use and management system is designated according to the relative frequency of land use and management for each soil type in each IBRA region in each year. For each of these systems the key management practices, such as the use of fire, when grazing is applied (months and intensity), ploughing and herbicide treatment, were implemented in the model.

Table 7.A 4 Example land use table

IBRA cell: Darling Riverine Plains (17)				Climate subdivision : nil			Time period: 1975 - 1978		
Soil type	% of cell	Land use	% of soil	Management practices		% of Land use	Phase	% of Managment practices	Yield t/ha
Clay	75	Developed pre-1970	45						
		Naturally clear at end of the time period	29						
		Uncleared forest at end of the time period	5						
		Developed for cropping	10	stubble burnt	–Summer	22	crop	80	1.6
					–Autumn	5	pasture	20	4
							long fallow	0	
				stubble retained		73	crop	80	1.6
							cereal	20	4
							long fallow	0	
		Irrigated cotton	0	trash burnt		0	crop		0
							cereal		0
				trash retained		0	crop		0
							cereal		0
		Dedicated for pasture	11			100		100	5
Loam	25	Developed pre-1970	45						
		Naturally clear at end of the time period	0						
		Uncleared forest at end of the time period	23						
		Developed for cropping	15	stubble burnt	–Summer	22	crop	80	1.1
					–Autumn	5	pasture	20	3
							long fallow	0	
				stubble retained		73	crop	80	1.1
							pasture	20	3
							long fallow	0	
		Irrigated cotton	0	trash burnt		0	crop		0
							cereal		0
				trash retained		0	crop		0
							cereal		0
		Dedicated for pasture	17			100		100	4
Sand	0								

Source: Swift and Skjemstad, 2002

Figure 7.A 30 Interim Biogeographic Regionalisation of Australia (IBRA) regions



Code	Name	Code	Name
CH	Central Highlands	MII	Mount Isa Inlier
AA	Australian Alps	EYB	Eyre and Yorke Blocks
WT	Wet Tropics	SEQ	South Eastern Queensland
LB	Lofty Block	DEU	Desert Uplands
CA	Central Arnhem	BRT	Burt Plain
SB	Sydney Basin	FIN	Finke
GS	Geraldton Sandplains	FOR	Flinders and Olary Ranges
VM	Victorian Midlands	MAL	Mallee
JF	Jarrah Forest	CAR	Carnarvon
VB	Victoria Bonaparte	NSS	NSW South Western Slopes
CK	Central Kimberley	RIV	Riverina
DL	Dampierland	SEH	South Eastern Highlands
NK	Northern Kimberley	STU	Sturt Plateau
CP	Cobar Peneplain	CYP	Cape York Peninsula
AW	Avon Wheatbelt	DRP	Darling Riverine Plains
CR	Central Ranges	BBN	Brigalow Belt North
GD	Gibson Desert	LSD	Little Sandy Desert
ML	Mulga Lands	GFU	Gulf Fall and Uplands
WAR	Warren	OVP	Ord-Victoria Plains
WOO	Woolnorth	EIU	Einasleigh Uplands
HAM	Hampton	COO	Coolgardie
CMC	Central Mackay Coast	PIL	Pilbara
SWA	Swan Coastal Plain	GAS	Gascoyne
DAB	Daly Basin	STP	Stony Plains
SCP	South East Coastal Plain	GUP	Gulf Plains
WSW	West and South West	NUL	Nullarbor
GUC	Gulf Coastal	MDD	Murray-Darling Depression
VVP	Victorian Volcanic Plain	SSD	Simpson-Strzelecki Dunefields
NCP	Naracoorte Coastal Plain	CHC	Channel Country
NAN	Nandewar	MUR	Murchison
NET	New England Tableland	BBS	South Brigalow
SEC	South East Corner	TAN	Tanami

APPENDIX 7.A

Code	Name	Code	Name
YAL	Yalgoo	MGD	Mitchell Grass Downs
MAC	MacDonnell Ranges	GSD	Great Sandy Desert
ESP	Esperance Plains	GVD	Great Victoria Desert
PCA	Pine-Creek Arnhem	DE	D'Entrecasteaux
TEC	Top End Coast	TM	Tasmanian Midlands
GAW	Gawler	BEN	Ben Lomond
BHC	Broken Hill Complex	FRE	Freycinet
NNC	NSW North Coast	FUR	Furneaux

Crop Yield

In almost all instances where crop yields are used, their impact on carbon and nitrogen cycling is determined in concert with the management approach applied. The uses of the crop yield information include:

1. determining plant biomass (crop or grass) at a point in time, via the use of 'harvest indices' that relate total plant biomass to the yield commodity of interest (e.g., grain);
2. determining how much plant biomass is removed from the site as product;
3. determining the amount of root slough as input to soil from plant growth coupled with management practices; and,
4. determining the post harvest/grazing residues burnt, decomposed on soil surface or incorporated into soil.

Data on crop yield and management practice are jointly collected because management practices will affect the crop yields as well as the fate of crop residues.

A description of the quality assurance, quality control, calibration, validation and verification of crop yield and management is detailed in Appendix 7.J (see section 7.J.3.5).

7. A.6.5 Other non-spatial data

Plant characteristics

Species and ecosystem characteristics required for modelling have been systematically collected and documented in the publicly available NCAS technical report series. These include:

- Wood density (Illic *et al*., 2000; Polglase *et al*., 2004);
- Carbon percentages of plant components (Gifford, 2000a,b);
- Expansion factors and root:shoot ratios (Snowdon *et al*., 2000);
- Decay rates (Mackensen and Bauhus, 1999); and,
- Spatial estimates of forest biomass (Raison *et al*., 2003; Ximines *et al*., 2005).

Coarse woody debris and litter

Coarse woody debris and forest floor litter is particularly difficult to estimate using measurement techniques because it is highly variable and dynamically related to forest productivity and disturbance history (particularly fire and harvest). Data was collected from available literature, but was sparse, particularly for forests without timber harvest. Supplementary data were collected during field sampling (Harms and Dalal, 2003; Murphy *et al*., 2002; Griffin *et al*., 2002).

Estimates of coarse woody debris and litter are used to frame the initial model estimates to reflect typical species and management scenarios. *FullCAM* can then be run-in from the initial estimates with inputs to the debris and litter pools based on turnover from live pools (based on the forest growth model) and the imposition of a known disturbance history (from the land cover change data). This allows the conversion of an uncertain historic initial estimate to a site and species specific estimate.

Given the complex and dynamic nature of this pool, it was concluded that verification could not rely on the measurement of inputs, transitions and losses due to disturbance. Instead, the mass balance cycling model approach was used to determine the quality of model calibration. If inappropriate or poorly calibrated parameters of inputs, transfer and losses are used, the mass balance model would, over a long period of time, predict clearly inappropriate pool size (too large or too small in this or surrounding pools). Estimates of coarse woody debris were made from literature and field studies to frame the initial model estimates that reflect typical conditions.

7.A.7 Planned Improvements

Development of the land sector reporting capabilities of the National Inventory System is ongoing, with new reporting capabilities being added as the methods are developed and quality assured. Since the 2006 inventory this development program has resulted in the inclusion of emissions estimates for the *Cropland remaining Cropland*, *Grassland remaining Grassland* and *Other Native Forest* categories and implementation of the full Tier 3, spatially explicit modelling approach to lands converted to *forest land*.

Development of a comprehensive estimation capability for future reporting is ongoing and will be released once the national implementation has been fully calibrated, verified, quality assured and peer reviewed.

Remote sensing

The remote sensing programme is currently further developing methods to identify:

1. areas of plantation established prior to 1988 using Landsat MSS data;
2. areas subject to harvest in the Harvested Native Forests, and
3. areas of sparse vegetation and change in sparse vegetation since 1988.

Modelling

The development of spatial modelling techniques for lands converted to *Forest Land* and *Plantations* and *Harvested Native Forest* is also ongoing. Once completed, the full Tier 3 model will be applied to these sub-categories. This will include the calibration and verification of the soil carbon model to estimate emissions and removals from soils in the *Forest Land remaining Forest Land* category.

FullCAM software flexibility

Since 2010 the output structure of the *FullCAM* model has been revised so as to provide for sub-category reporting for (i) the separation of lands into a category of either less than 20 years or 20 to 50 years since conversion, and (ii) a category of transition from lands converted to lands remaining after 50 years. For each new inventory year in a Tier 3, Approach 3 model, the land units converted each year and the emissions from those land units are reported separately and tabulated to report the converted lands and their emissions, by land category, for each year that conversions occur.

DCCEE has recently commissioned a detailed design for a *FullCAM* Outputs Analysis System (*FullCAM* OASys) which will support quality control whilst enabling complex year-by-year reporting tables and updating the system hardware to manage the task. The task is computationally demanding and an upgrade will be necessary to achieve the processing required. DCCEE anticipates that this will be enabled for the next submission.

7.A.8 Public tools and data availability

Australia is implementing a Carbon Farming Initiative (CFI) that will enable landholders to reduce greenhouse gas emissions through the adoption of eligible activities using approved mitigation methodologies. A key requirement of the CFI program is to ensure consistency between carbon credits claimed through the initiative and the national inventory estimates for the approved land based activities. The modelling capacity of *FullCAM* has been used to provide a user-friendly version of the reforestation component of the model and will also be utilised to provide a user-friendly version of the soil carbon component of the model in 2012.

Development of these tools requires substantive evaluation and verification of the outputs using research data obtained through federal government research programs. New data will be available in 2012 to validate *FullCAM* outputs for both the national inventory and the CFI.

Attachment A1:The FullCAM Model

Naming Conventions

Abbreviations used in names

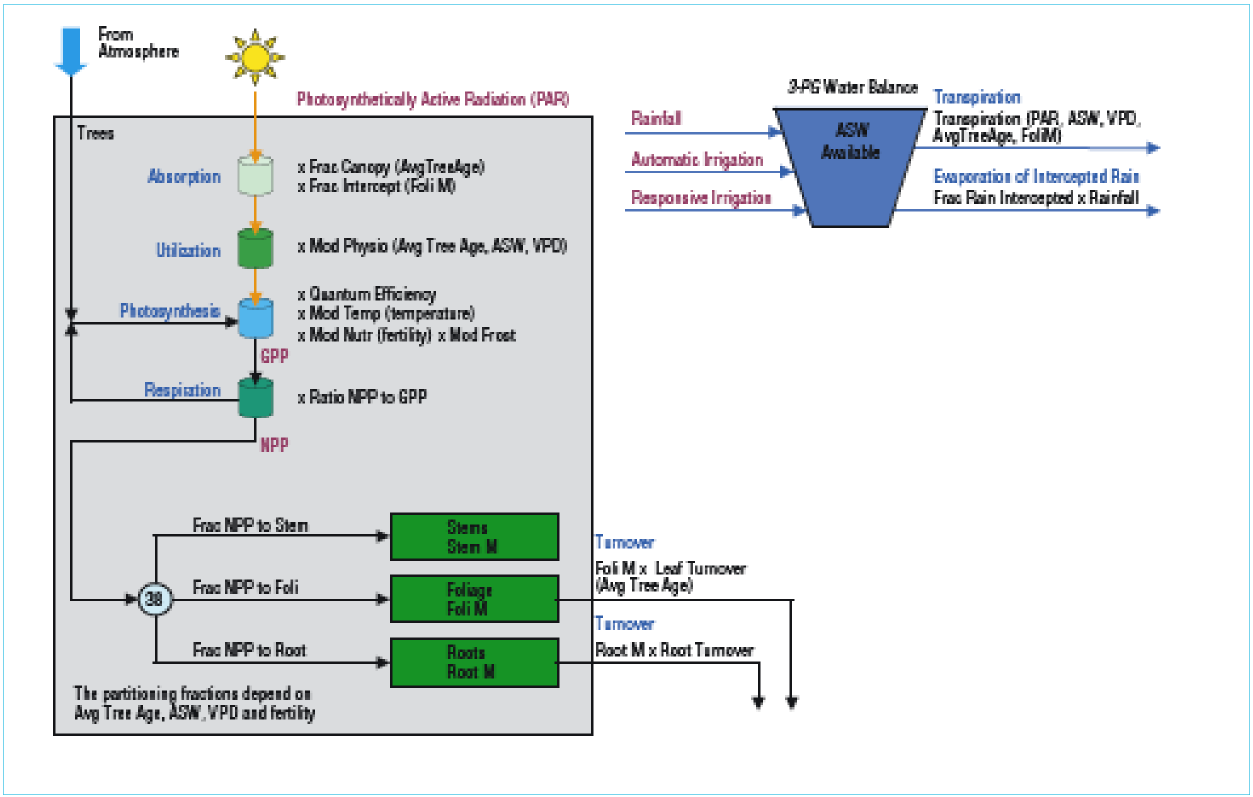
Actv	=	Active soil carbon
Avg	=	Average B = Microbes (dead) (see P, Micr)
Bkdn	=	Breakdown C = Carbon Material whose every atom has six protons
C	=	Coarse (see Dcy, Root)
Cel	=	Cellulose (see Lig, Sol)
CM	=	Carbon mass of material Mass of carbon atoms in the material
Conp	=	Consumption (of fodder by animals,which emits methane)
Cons	=	Construction wood
Dcmp	=	Decomposition
De	=	Decomposable (see Re)
Debr	=	Debris
Dec	=	Decrease (due to)
Decomp	=	Decomposable
Dcy	=	Decay (sloughed off root), either CDcy (coarse decay)or FDcy (fine decay)
Dwd	=	Deadwood
Eff	=	Assimilation efficiency of microbes
Evap	=	Evaporation
F	=	Fine (see Dcy, Root)
Fibr	=	Fibreboard
Fodd	=	Fodder (inside animal stomachs)
Foli	=	Foliage Leaves and twigs of tree
Frac	=	Fraction of a specified part of a whole (a number from 0 to 1, inclusive)
Furn	=	Furniture
Grth	=	Growth (of trees or crops)
Humf	=	Humification Inc = Increase (due to)
Inrt	=	Inert soil carbon
Lig	=	Lignin (see Cel, Sol)
Lit	=	Litter, either LLit (leaf litter) or BLit (bark litter)
M	=	Mass (dry weight)
Micr	=	Microbes (live) (see B, P)
Mod	=	Modifier
N, Nitro	=	(Available) nitrogen
NCRatio	=	Ratio of nitrogen mass to carbon mass
NM	=	Nitrogen Mass
Nutr	=	Nutrition
P	=	Plant matter (dead) (see B, Micr)
Pack	=	Packing wood
Papr	=	Pulp and paper
PB	=	Plant matter and microbial matter
Rel	=	Relative
Resi	=	Residue (from wood product mill)
Root	=	Root, either CRoot (coarse root) or FRoot (fine root)
RotAge	=	Rotation age (years since trees were planted)

Sol	=	Soluble litter (see Cel, Lig)
Tbl	=	Table
Temp	=	Temperature
Turn	=	Turnover
Wall	=	Microbe cell wall

Abbreviated Quantities

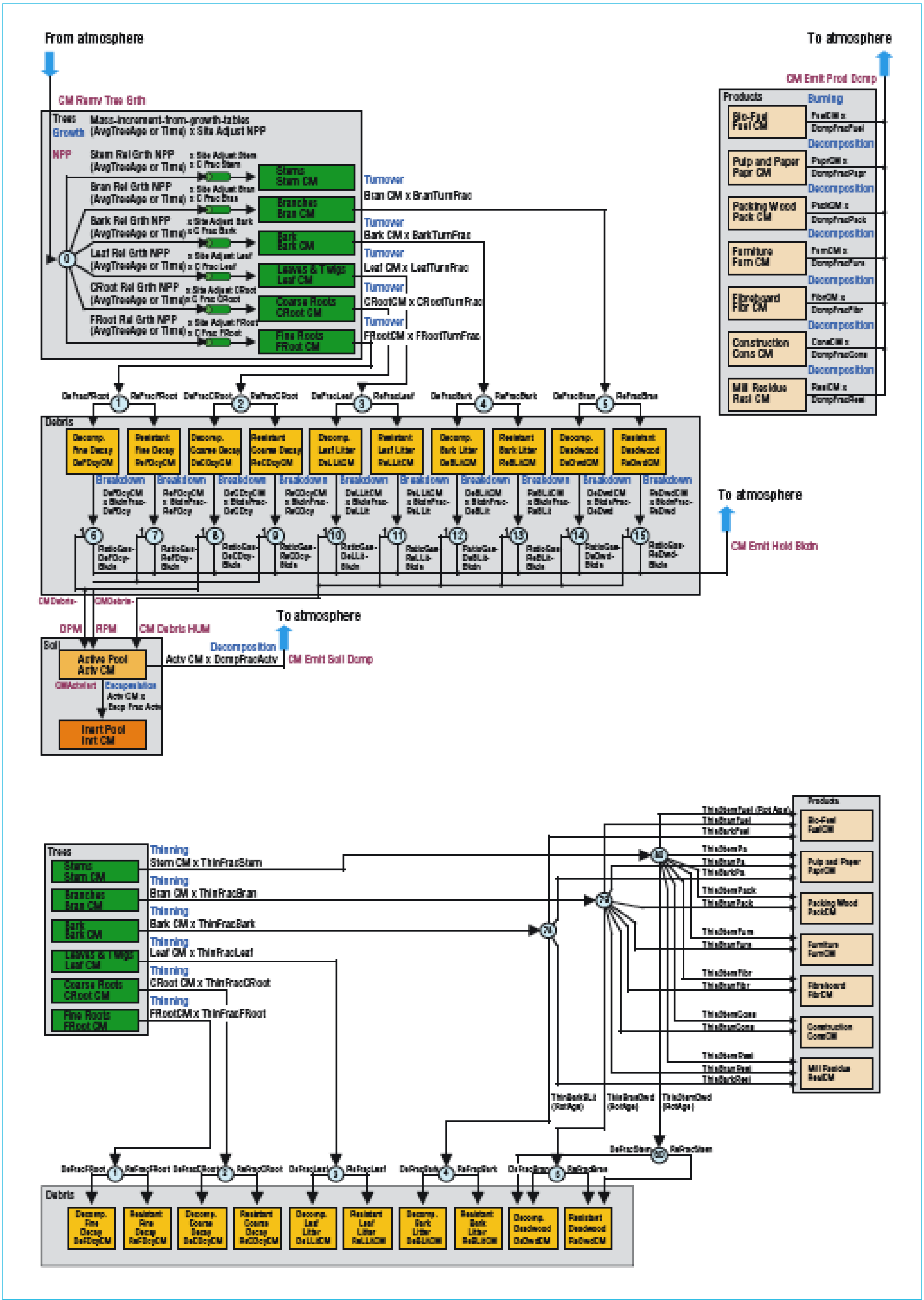
ASW	=	Available soil water (in mm of rainfall or irrigation) (3-PG only)
BIO	=	Microbial biomass = Fast and slow decomposing biomass combined (BIO-F + BIO-S) (Roth-C only)
BIOF	=	BIO-F = Fast decomposing biomass (Roth-C only)
BIOS	=	BIO-S = Slow decomposing biomass (Roth-C only)
CO_2	=	Carbon dioxide
DPM	=	Decomposable plant material (Roth-C only)
GBF	=	Grain, buds, and fruit
GBFP	=	Grain, bud, and fruit products
GPP	=	Gross Primary Production = Overall production of tree or crop biomass in tonnes of carbon
HSS	=	Hay, straw, and silage
HUM	=	Humified organic matter (Roth-C only)
NPP	=	Net Primary Productivity = GPP - carbon lost in respiration
PAR	=	Photosynthetically Active Radiation (3-PG only)
RPM	=	Resistant plant material (resistant to decomposition) (Roth-C only)
TSMD	=	Topsoil moisture deficit
VPD	=	Vapor Presure Deficit (in kPa) (3-PG only)
XXX	=	DPM, RPM, BIO-F or BIO-S (all active soil carbon categories except HUM)

The 3-PG Model

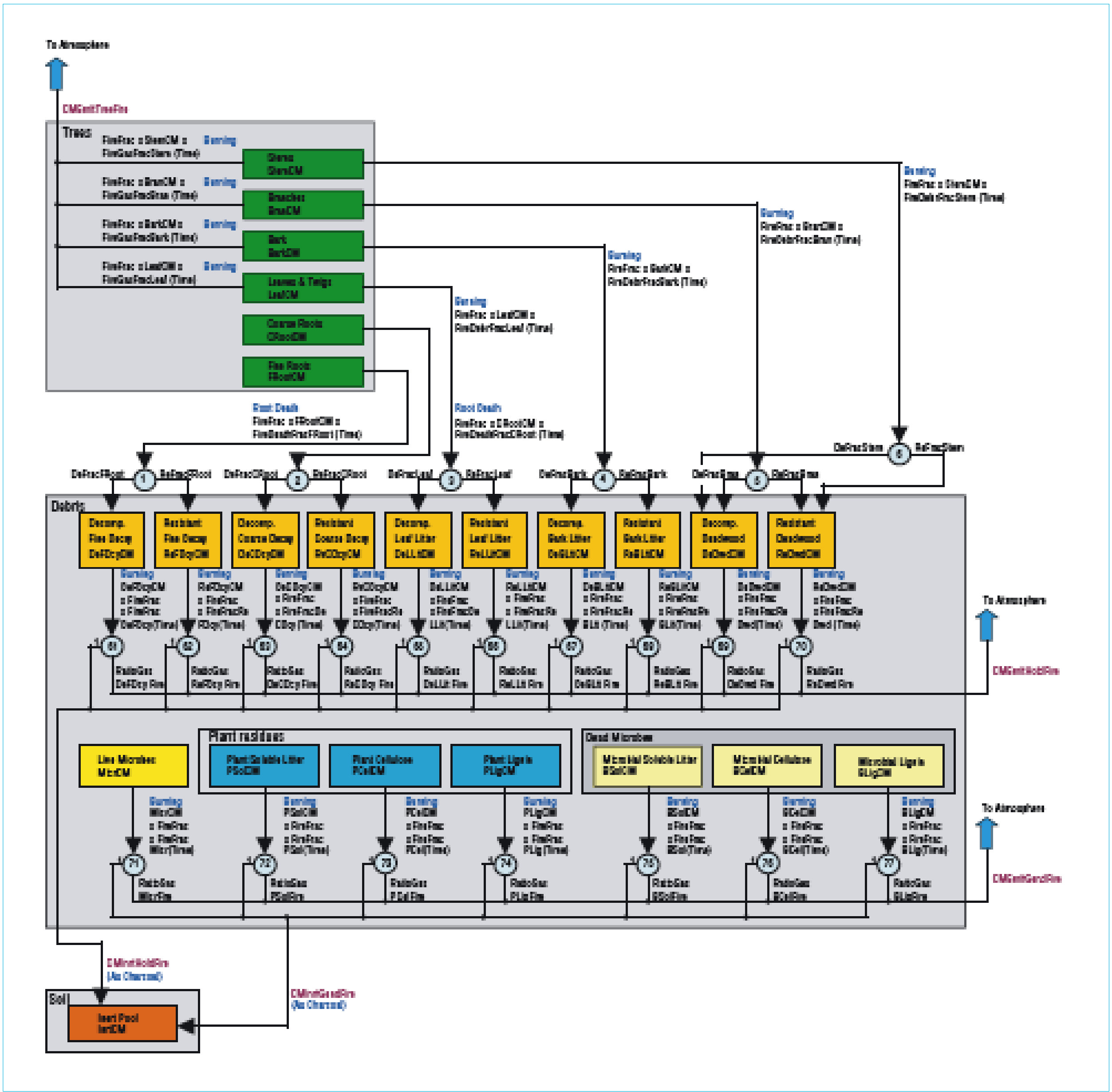


7.A APPENDIX

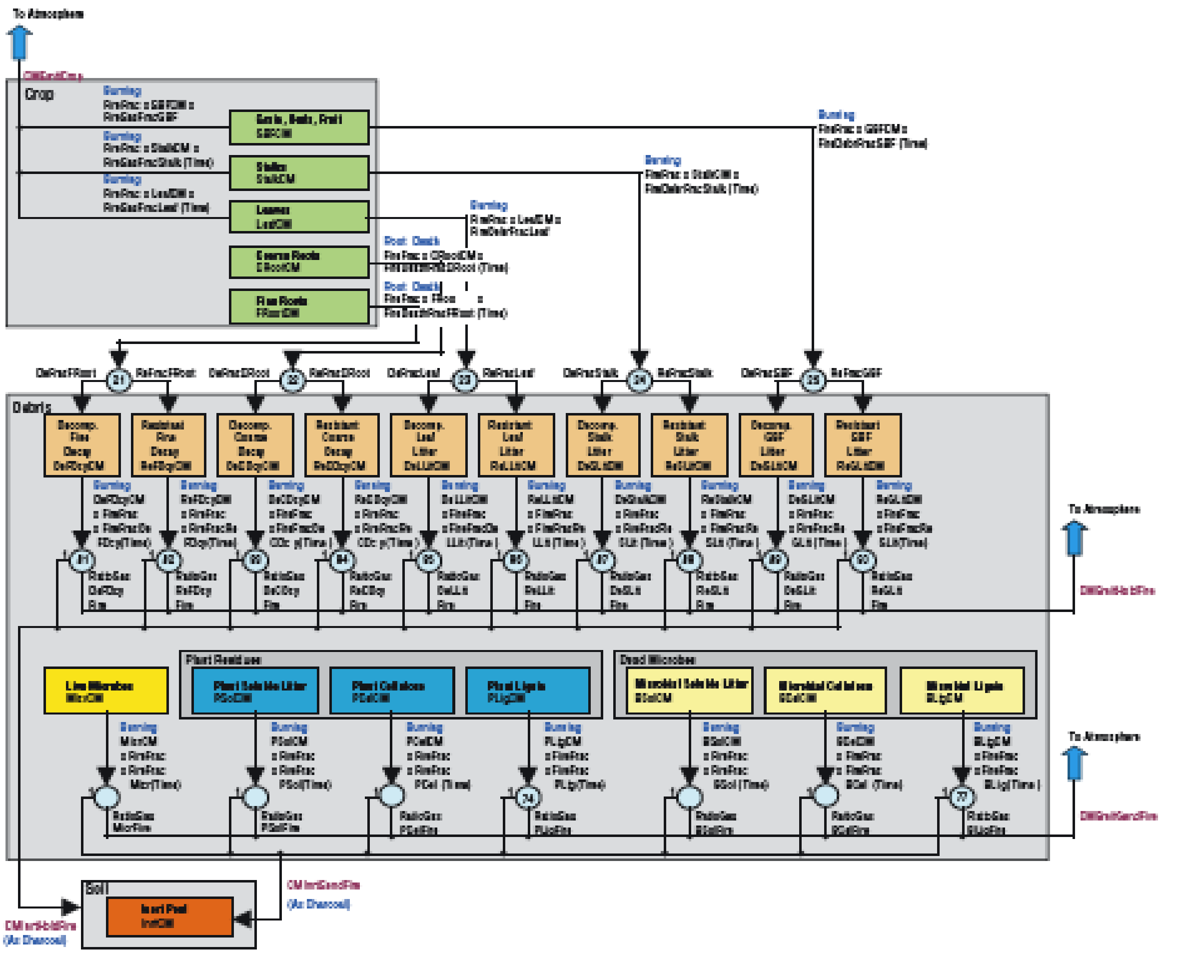
The *CAMFor* Model (a) Thinning



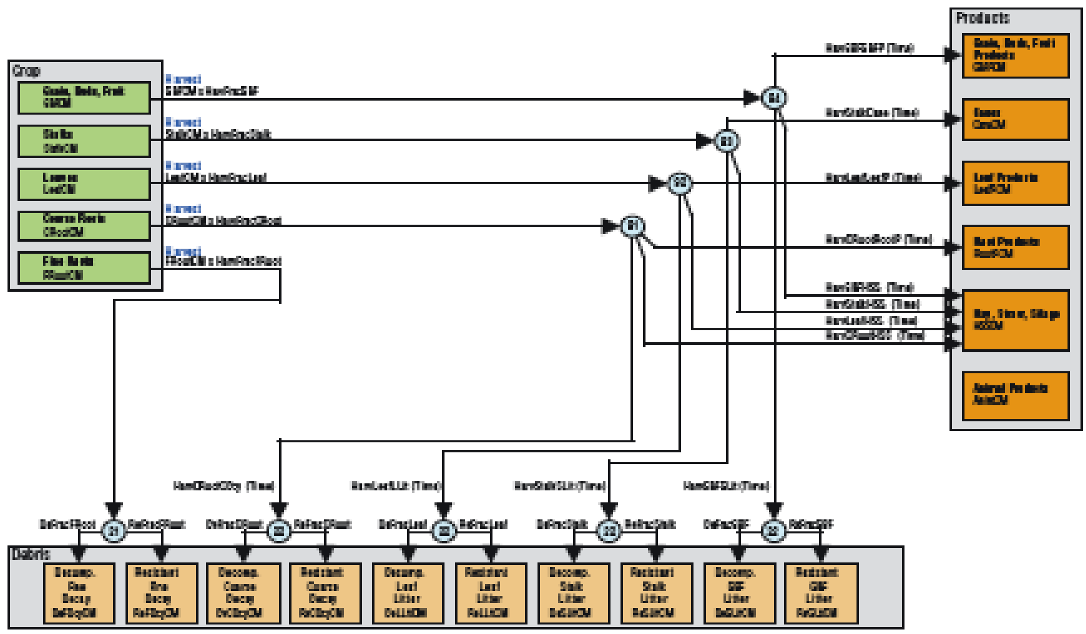
The *CAMFor* Model (b) Fire



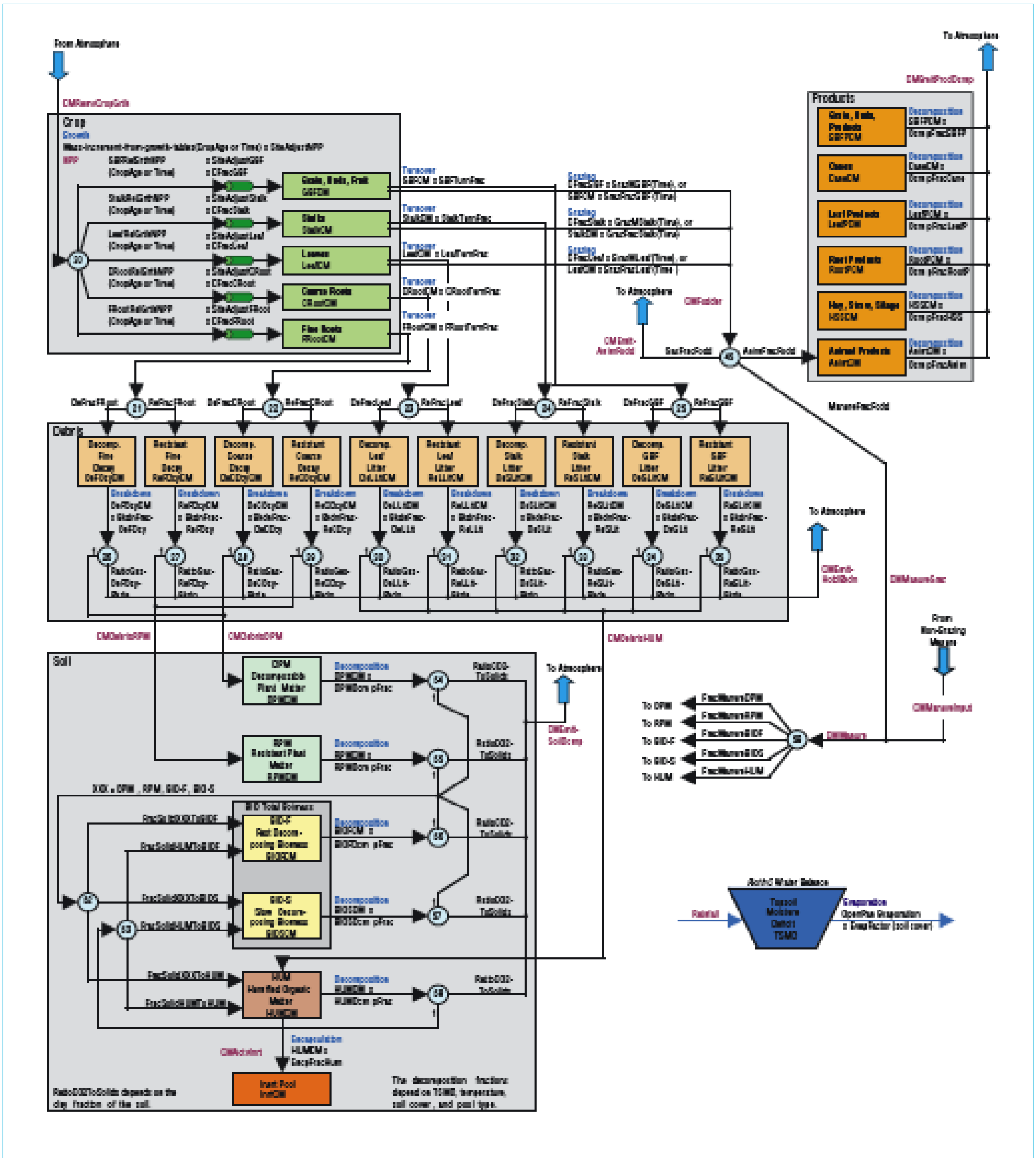
The *CAMAg* Model



The *CAMAg* Model (a) Fire

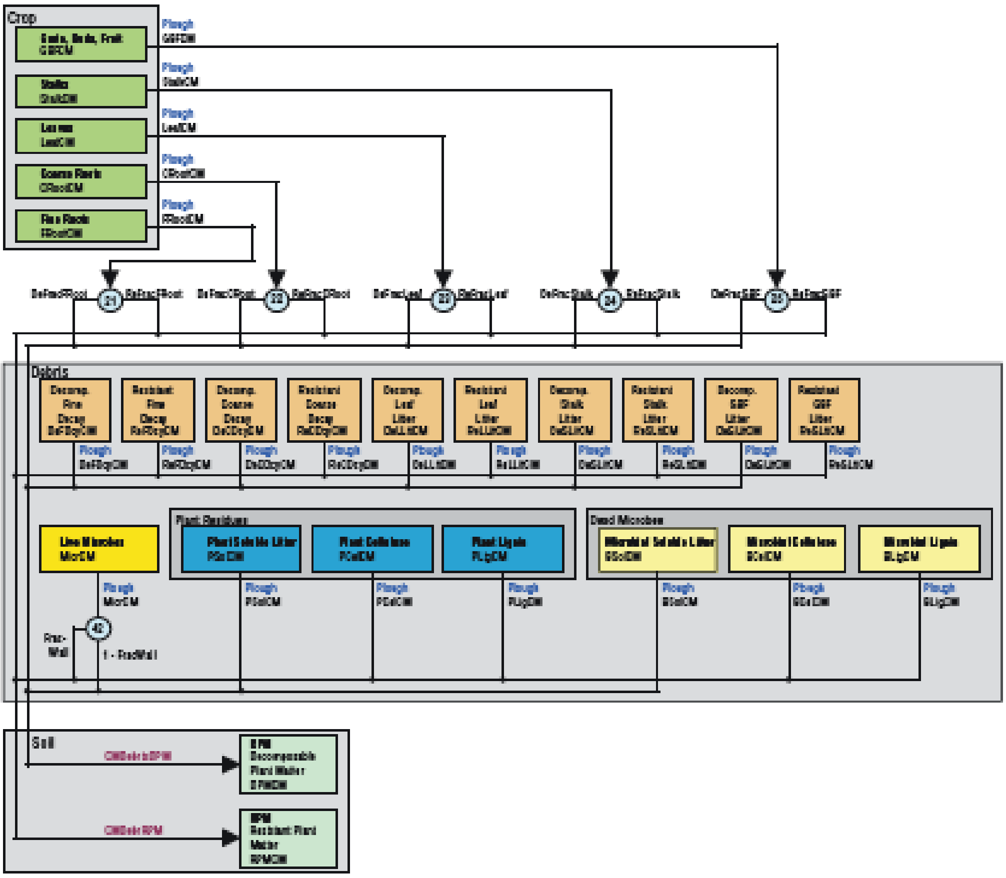


The *CAMAg* Model (b) Harvest

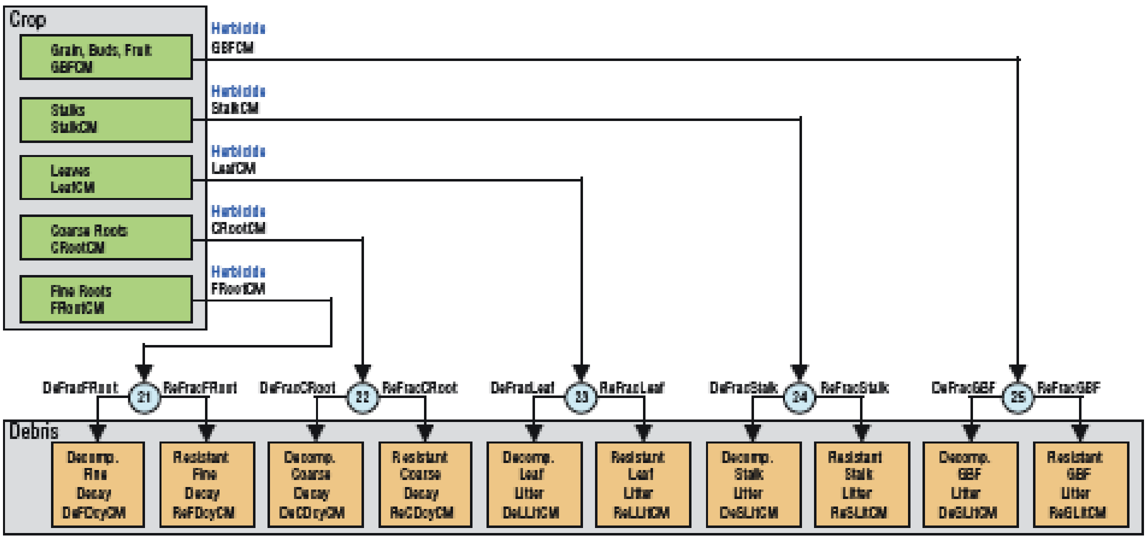


7.A APPENDIX

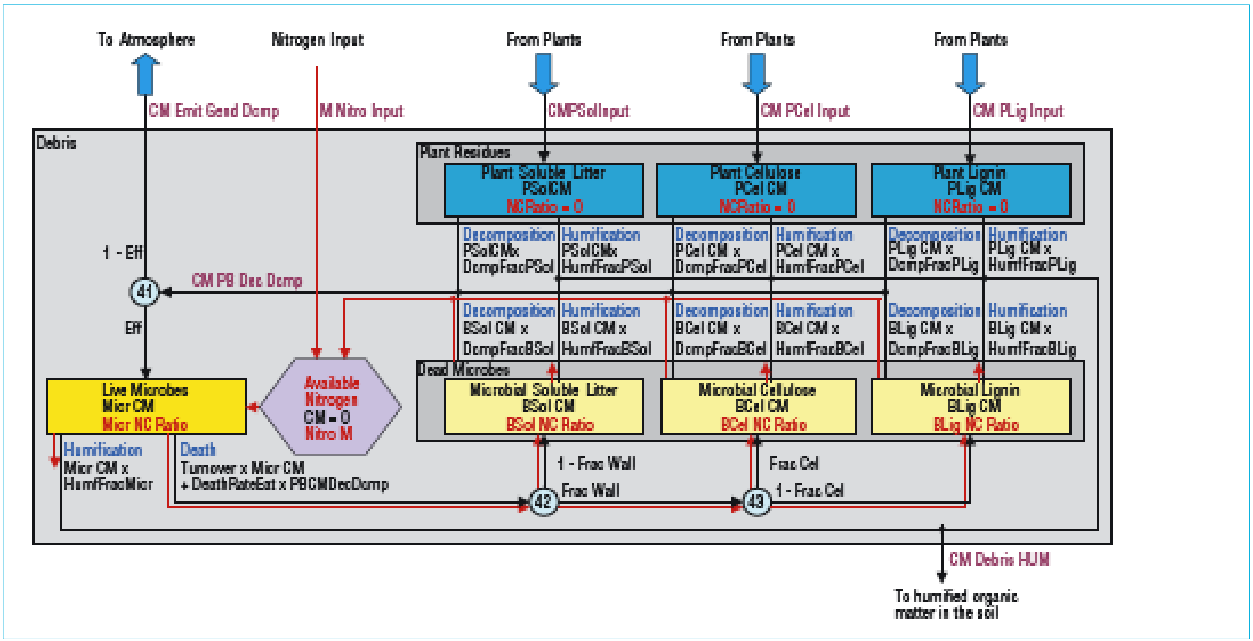
The *CAMAg* Model (c) Plough



The *CAMAg* Model (d) Herbicide



The *Roth-C* Model



7.A
APPENDIX

APPENDIX 7.B: HARVESTED NATIVE FORESTS

Background

As part of the ongoing process of implementing the fully spatially explicit Tier 3 model for all *forest land* sub-categories*,* an interim, Tier 2 model for estimating emissions and removals from *harvested native forests* has been developed. This model represents an important step towards implementing the fully spatially explicit Approach 3, Tier 3 model for reporting emissions and removals from *harvested native forests*.

The *harvested native forests* sub-category is modelled using the non-spatially explicit Tier 2 capabilities of *FullCAM* (see Appendix 7.A). *FullCAM* enables the use of age-based growth data and modelling of dead organic matter accumulation while incorporating the effects of differing silvicultural treatments on the creation and management of harvest residues. The *harvested native forests* model considers living above and belowground biomass and dead organic matter from both turnover and harvest residue. Consistent with the treatment of mineral soils in *forest land remaining forest land* in the IPCC *Good Practice Guidance* (IPCC, 2003) a Tier 1 method is applied for soil carbon. This method assumes that soil organic carbon in mineral soils is stable when averaged over the *harvested native forest* estate through time, with any losses due to harvesting compensated by uptake in areas recovering from previous harvesting.

Australia is continuing to develop capacity to comprehensively report on *forest land remaining forest land*, including the *harvested native forests* sub-category. The spatially explicit methods when applied to all categories will ensure that there are no gaps or overlaps in reporting of either lands or emissions. In the interim, review of areas included in the *forest land converted to cropland* and *grassland*, and of *plantations*, plus review of land tenure, ensures that these lands do not overlap other reporting categories.

Area of Harvested Native Forests

The area of *harvested native forests* in 1990 includes those forests subject to and managed for harvesting, and those regrowing from prior harvest but which may no longer be available for harvest, having been withdrawn from commercial use due to changes in policy, such as new codes of practice and transfer to conservation or recreation reserves. As the removal of greenhouse gases due to recovery from former harvesting continue to be reported in this category, the forest areas do not change with time. The areas of each forest type are shown in Table 7.B1.

Growth Modelling

The growth rates of *harvested native forests* (in t C ha^{-1} yr^{-1}) are modelled based on the broad forest types and age classes (Table 7.B1) reported by Lucas *et al*., (1997). The initial carbon stock in 1990 is calculated based on the area of each forest type and age class. *FullCAM* is then configured to model biomass increments based on the growth rates reported in Table 7.B1 and reset forest age following harvest. To ensure that all forest areas were assigned to an age-based growth curve, forests of unknown age or those which contain two or more age classes were assumed to be 70 years old in 1990.

The growth rate of rainforests was assumed to be constant at 0.58 t C ha^{-1} yr^{-1} as per Lucas *et al*., (1997). The growth rate of Medium sparse Eucalypt forests, Cypress pine forests and 'Other' forests is also assumed to be constant based upon the data in Lucas *et al*., (1997) (see Table 7.B2).

Post-harvest growth is modelled according to the type of harvest that took place. Areas subject to clearfell harvest regrow from age zero. Areas subject to partial harvest continue to grow at the same rate as they were growing prior to the harvest (i.e., there is no thinning effect at the stand level, either positive or negative, on the rate of biomass accumulation) despite the reduction in stem numbers/carbon stock. This assumes that the growth of the remaining trees will increase to utilise the additional resources made available through the removal of some trees and subsequent reduction in competition.

Table 7.B 1 Areas by forest type and age classes in 1990 (ha)

Forest Type	Establishment 1-10 yrs	Juvenile 11-30 yrs	Immature 31-100 yrs	Mature 100-200 yrs	Senescent > 200 yrs	Forests of unknown age (a)	Two Aged	Three or More Aged	Total
Rainforests				1,332,882					1,332,882
Tall Dense Eucalypt Forests	73,919	151,025	371,586	462,067	364,000	1,015,024	183,000	614,077	3,234,698
Medium Dense Eucalypt Forests	23,058	154,619	274,340	1,311,540	266,000	2,625,710	433,000	1,616,923	6,705,190
Medium Sparse Eucalypt Forests					546,000	433,869		1,049,383	2,029,252
Cypress pine Forests						66,848		228,083	294,931
Other Forests						1,064,653		224,134	1,288,787
Totals	96,978	305,644	645,926	2,144,607	1,266,000	5,958,439	616,000	3,852,148	14,885,741

(a) The unknown and mixed age classes were assumed to have an average age of 70 years

Table 7.B 2 Aboveground growth rates by forest type and age class (t C ha^{-1} yr^{-1})

Forest Type	Establishment 1-10 yrs	Juvenile 11-30 yrs	Immature 31-100 yrs	Mature 100-200 yrs	Senescent > 200 yrs
Rainforests	-	-	-	0.58	0
Tall Dense Eucalypt Forests	6.44	4.41	2.23	0.74	0
Medium Dense Eucalypt Forests	4.24	2.80	0.99	0.18	0
Medium Sparse Eucalypt Forests	0.24	0.24	0.24	0.24	0
Cypress pine Forests	0.25	0.25	0.25	0.25	0
Other Forests	0.23	0.23	0.23	0.23	0

Forest debris

FullCAM is a dynamic mass-balance model that allows for the modelling of debris accumulation and decay based on forest growth and management. Debris accumulates from the turnover of dead plant material (e.g., branches, bark, leaves, and roots). In the absence of forest disturbances such as harvest or fire, debris mass increases with age to a steady state where the addition of forest material to the debris pools and loss from decomposition is in balance. Debris pools are also increased by the addition of slash material following harvest and decreased by any residue management techniques, in particular residue burning. The turnover rates applied for each plant component in the model are shown in Table 7.B3. A full description of the *FullCAM* model structure is provided in Appendix 7.A.

Table 7.B 3 Turnover for tree components

Tree component	Turnover yr^{-1}
Branches	0.065
Bark	0.095
Leaves	0.40
Coarse Roots	0.065
Fine Roots	0.73

Table 7.B 4 Decomposition rates for debris pools used in the *harvested native forests* model

Debris component	Breakdown yr^{-1}	
	Decomposable	Resistant
Deadwood	0.05	0.05
Bark litter	0.50	0.50
Leaf litter	0.80	0.80
Coarse dead roots	0.40	0.10
Fine dead roots	1.00	1.00

The initial amount of forest debris for each forest type and age class combination is based upon model simulation, cross checked with published estimates of debris in Australian forests. For each forest type a clearfall event was simulated using initial debris levels. This simulation was then run to equilibrium over 200 years. The final debris pools from this simulation were then used as the initial conditions for a final simulation. The results of the final simulation were used to define the initial debris for each age class for each respective forest type. This method produced debris quantities that are comparable with published estimates of debris in Australian forests (e.g., Woldendorp and Keenan, 2005, Hingston *et al.,* 1981) (Figure 7.B2) as detailed in Appendices 7.A and 7.J.

The decomposition rates for the different debris pools were drawn from available information including Mackensen *et al.,* (2003), Mackensen and Bauhaus (1999), O'Connell (1997) and Paul and Polglase (2004a). The rates used are shown in Table 7.B4. There is limited information on decomposition rates in the *harvested native forests* of Australia. The rates applied are considered to be best estimates based on the available information.

Carbon Fraction of Biomass

Studies of the carbon fractions of above and belowground biomass components for Australian vegetation were used to provide the parameters for the carbon fractions of tree components in the model (Gifford, 2000a and 2000b)(Table 7.B5).

Table 7.B 5 Carbon Fraction of biomass for each tree component based on Gifford (2000a and 2000b)

Tree component	% Carbon
Stems	52
Branches	47
Bark	49
Leaves	52
Coarse roots	49
Fine roots	46

Partitioning of biomass to tree components

The partitioning of biomass to different tree components is important for the amount of harvest slash that is produced relative to harvest products. The partitioning ratios used (Table 7.B6) are drawn from the best available data, largely from the synthesis of data compiled by Snowdon *et. al.,* (2000) and the results of Ximenes and Gardner (2005) and Ximenes *et al.,* (2005).

Table 7.B 6 Partitioning of biomass to each of the tree components

	Fraction of biomass allocated to:					
Forest Type	Stems	Branches	Bark	Leaves	Coarse roots	Fine roots
Rainforest	0.60	0.08	0.09	0.03	0.17	0.03
Tall Dense Eucalypt Forest	0.55	0.12	0.10	0.03	0.17	0.03
Medium Dense Eucalypt Forest	0.50	0.15	0.12	0.03	0.17	0.03
Medium Sparse Eucalypt Forest	0.47	0.15	0.12	0.03	0.20	0.03
Cypress pine Forest	0.47	0.15	0.12	0.03	0.20	0.03
Other forest	0.47	0.15	0.12	0.03	0.20	0.03

Carbon to CO_2 Conversion

The conversion factor used is 44/12 (3.666) which is the IPCC default.

Area Harvested and Type of Harvest

The area of *harvested native forests* harvested in each broad forest type and age class was collated from data provided by state agencies and data collected in Raison and Squire (2008) (Table 7.B7). The availability and quality of this data has vastly improved since 2000. Harvest area data was obtained for the states of Victoria, Tasmania, New South Wales and Western Australia, which produce over 95% of the log volume harvested from native forests in Australia (ABARE, 2009d). Data on the harvest area in Queensland which represents the remaining 5% of log volume was not available for this inventory. The harvest area for Queensland was estimated as 22% of harvest area of New South Wales based on the proportion of roundwood removals between New South Wales and Queensland as provided in the National Forest and Wood Products Statistics (ABARE, 2009d). This assumption was based on Queensland *harvested native forests* being most similar to *harvested native forests* in northern New South Wales and a consistent relationship between the volume of timber harvested in New South Wales and in Queensland (ABARE, 2009d).

Table 7.B 7 Estimated total area of native forest harvested

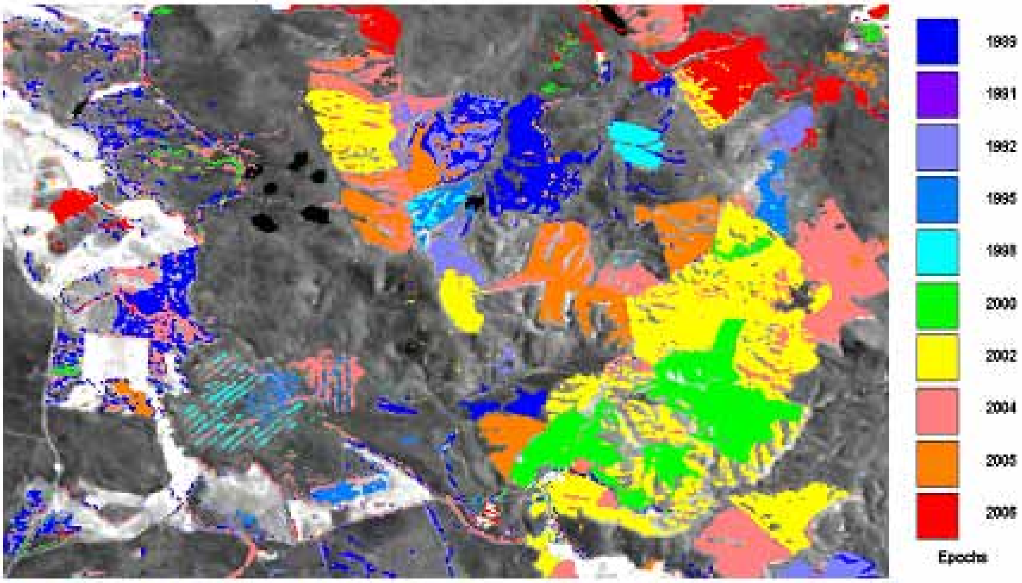
Year	Area harvested (ha)
1990	141,441
1991	135,928
1992	140,734
1993	144,259
1994	152,082
1995	149,306
1996	142,646
1997	137,877
1998	138,709
1999	132,550
2000	136,206
2001	148,557
2002	114,504
2003	111,090
2004	111,620
2005	99,363
2006	100,018
2007	103,722
2008	112,433
2009	81,387
2010	90,522

The actual age class of the forests harvested was not explicitly reported. Information on the forest type and silviculture method applied also varied in the level of detail available with better information available from the states where the greatest amount of harvesting occurs (Victoria, Tasmania and New South Wales) particularly post 2000. Where the information was not explicitly reported, it was inferred from the best available information including information within the state agency reporting, publications from state agencies (e.g., Forestry Tasmania, 2008; FPA, 2007; Forests NSW, 2008; Vic Forests, 2008) and from Raison and Squire (2008). It was assumed that no harvesting occurred in the Establishment (1-10 years) and Juvenile (11-30 years) phases as these are generally too young to produce forest products in Australia's native forests.

Most states began phasing out logging of rainforests in the 1980's and in the most part logging was entirely phased out prior to 1990 (Raison and Squire, 2008). Some rainforest logging has continued in Tasmania. It was not possible to separate cold temperate rainforest logging from logging in wet temperate eucalypt forests in Tasmania. The harvested area for rainforests in Tasmania was therefore modelled as tall and medium dense eucalypt forests, which are closest to cold temperate rainforests spatially and in successional sequence (Hickey, 1994).

As part of the ongoing development of the *harvested native forests* model, new methods utilising Australia's time-series remote sensing data are being developed to detect areas of harvest in the *harvested native forests* sub-category (see example in Figure 7.B1). This approach will greatly improve the quality of the harvested area data in future inventories. The spatially and temporally explicit nature of this data will allow for greater precision in the allocation of management regimes, age class structure and growth rates to harvested areas.

Figure 7.B 1 An example of harvested area detection using Australia's time-series remote sensing data.



Coloured areas represent detected harvest areas in a particular epoch

Silvicultural systems

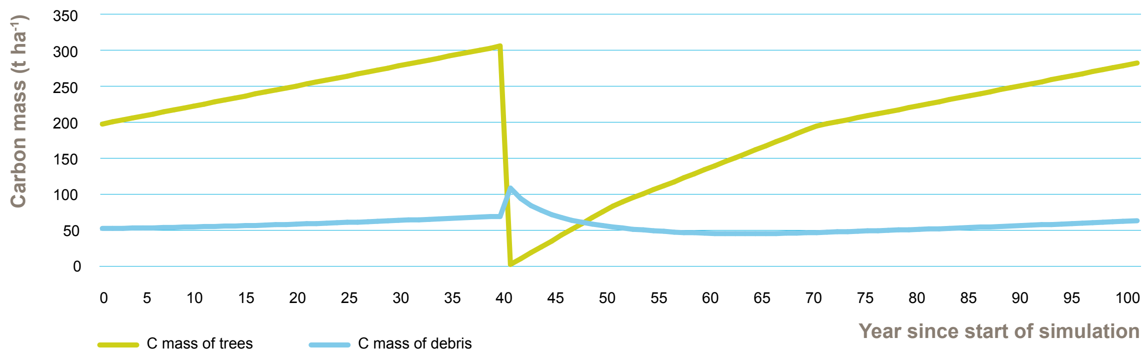
Ten broad silvicultural systems are represented in the model (Table 7.B8). These systems are designed to represent the range of harvesting systems employed in Australia throughout the 1990's and up to present. Each silvicultural system is modelled based on the unique combinations of forest age and forest type (Table 7.B1 and Table 7.B8) to which it is associated. This produces 73 unique silviculture, forest age and forest type combinations. These are simulated annually according to the area that was estimated to occur under each particular combination. Examples of the carbon mass in trees and debris for the models developed for each of the silvicultural systems are presented in Figure 7.B2.

Table 7.B 8 Broad silvicultural systems used in the harvested native forests model

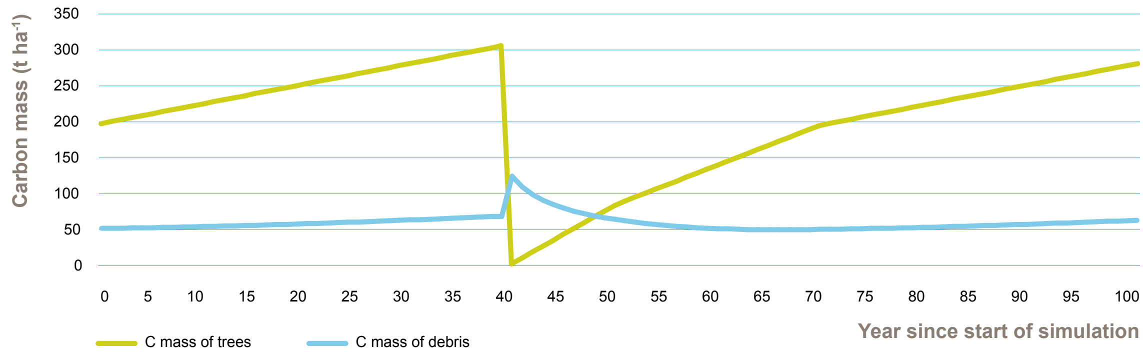
Forest type	Silviculture	% of trees harvested	Post harvest management
Tall dense eucalypt forest	Clearfell with pulpwood	100%	Regeneration burn
	Clearfell without pulpwood	100%	Regeneration burn
	Partial harvest with pulpwood	35-50%	Slash left on-site
	Partial harvest without pulpwood	25%	Slash left on-site
Medium dense eucalypt forest	Clearfell with pulpwood	100%	Regeneration burn
	Clearfell without pulpwood	100%	Regeneration burn
	Partial harvest with pulpwood	35-75%	Slash left on-site
	Partial harvest without pulpwood	40%	Slash left on-site
Medium sparse eucalypt forest	Partial harvest without pulpwood	30%	Slash left on-site
Callitris forest	Partial harvest without pulpwood	40%	Slash left on-site

Figure 7.B 2 Examples of the tree and debris carbon mass change for the ten silvicultural systems.

(a) Tall dense eucalypt forest clearfell with pulpwood



(b) Tall dense eucalypt forest clearfell without pulpwood



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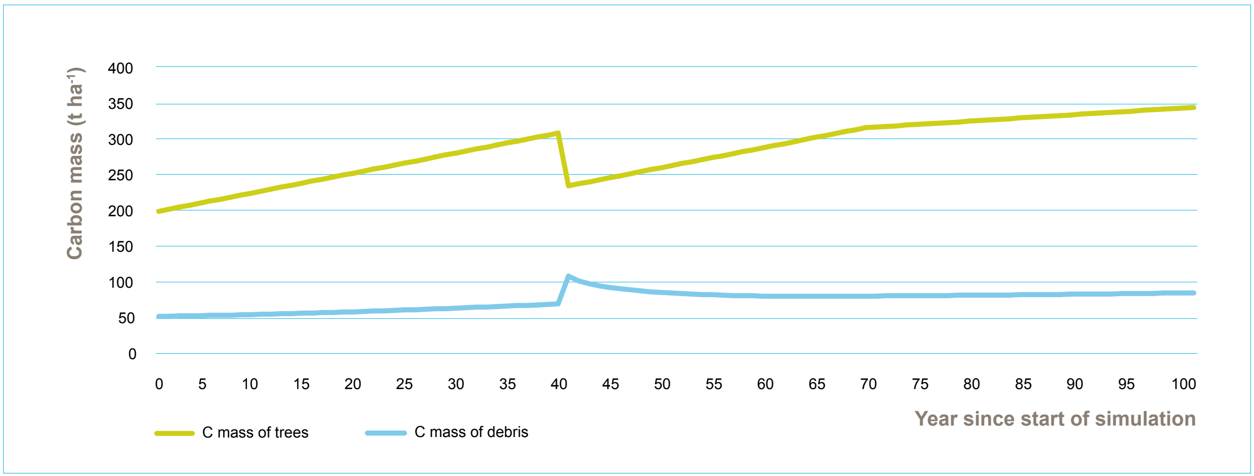
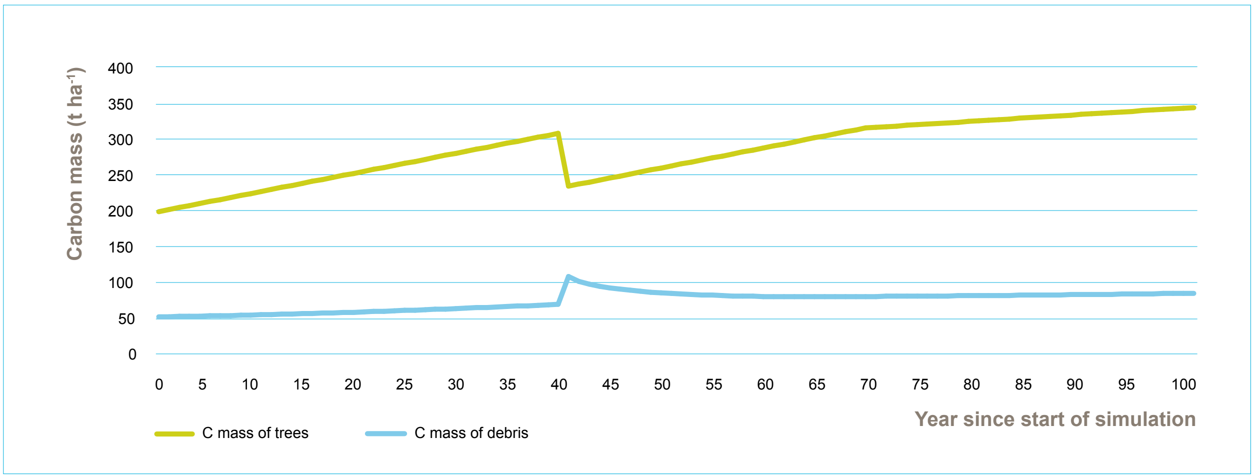
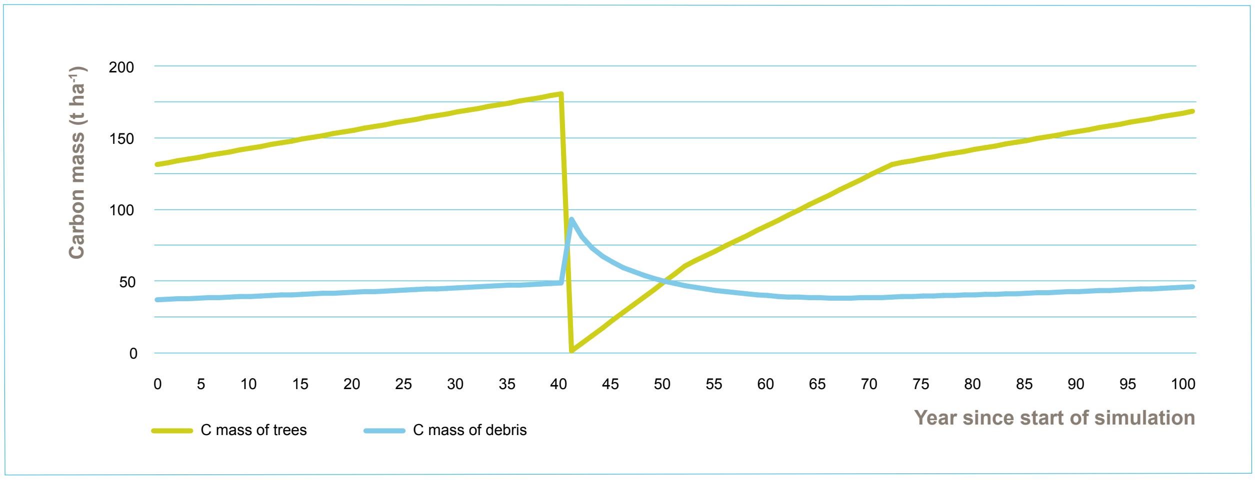
(c) Tall dense eucalypt forest partial harvest with pulpwood



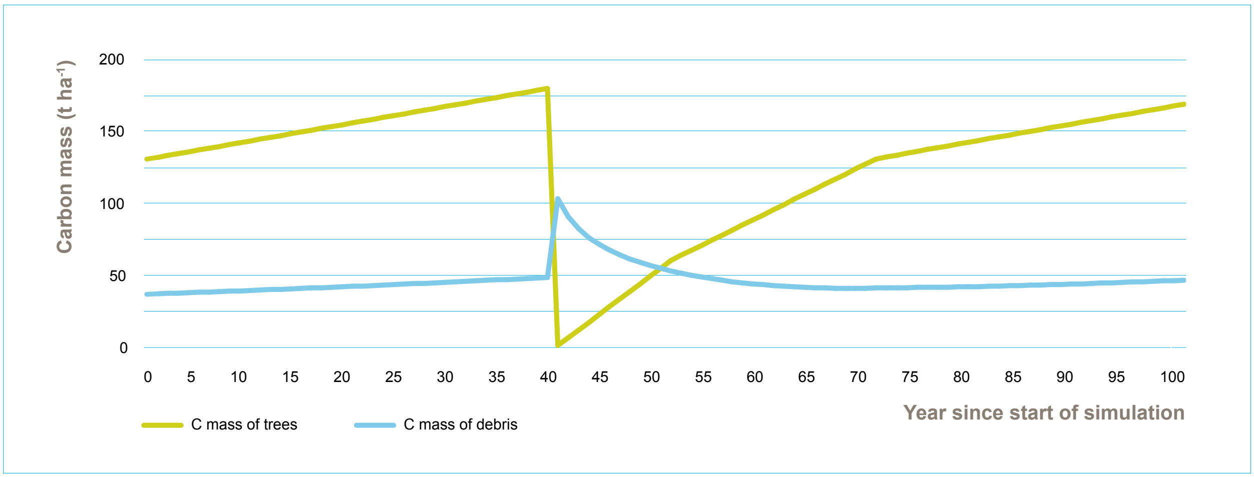
(d) Tall dense eucalypt forest partial harvest without pulpwood



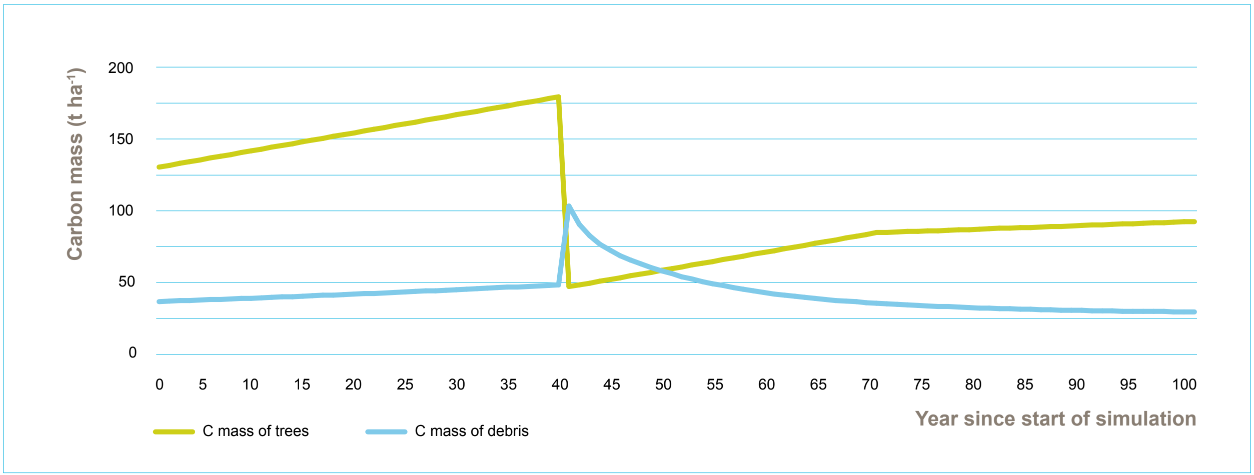
(e) Medium dense eucalypt forest clearfell with pulpwood



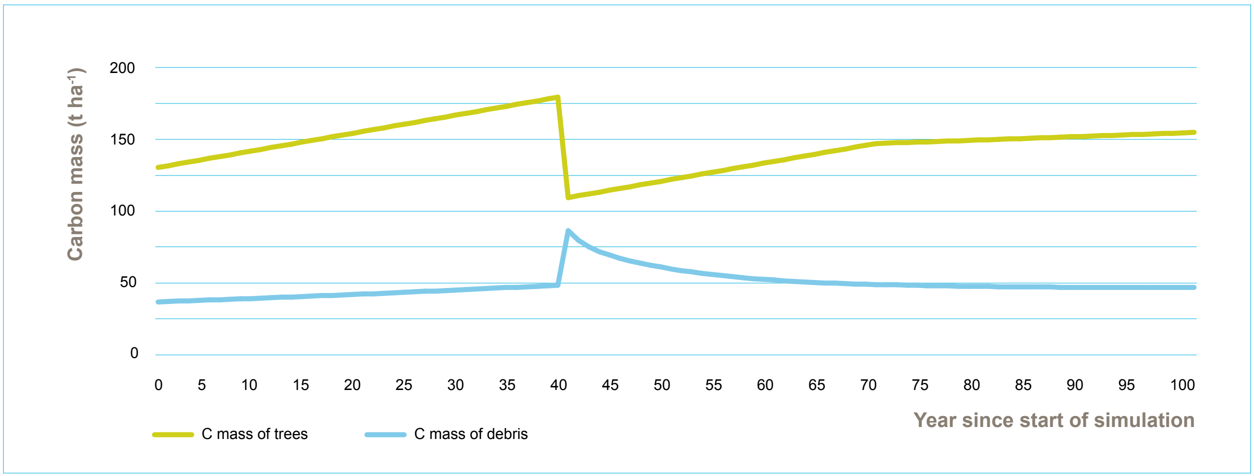
(f) Medium dense eucalypt forest clearfell without pulpwood



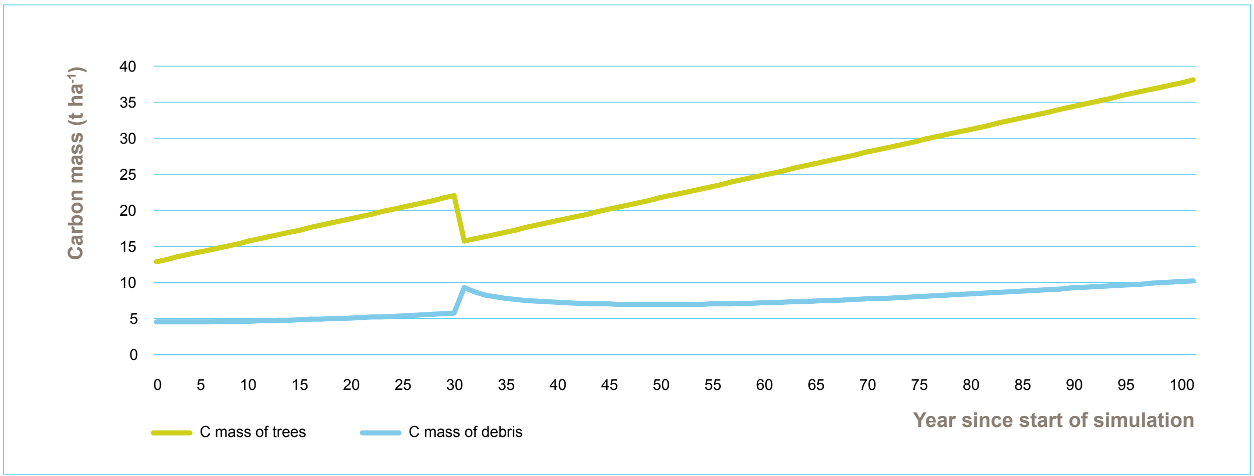
(g) Medium dense eucalypt forest partial harvest with pulpwood



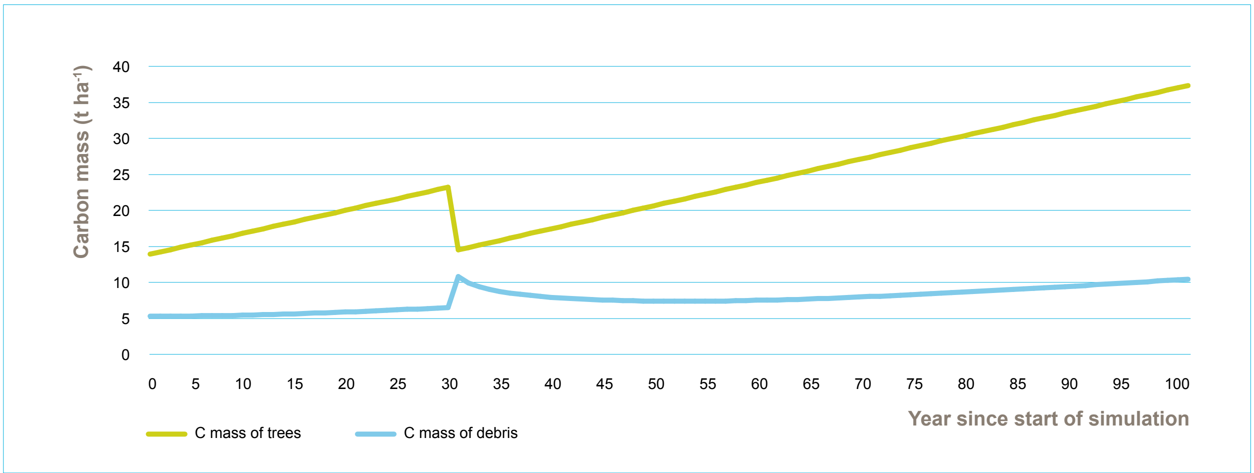
(h) Medium dense eucalypt forest partial harvest without pulpwood



(i) Medium sparse eucalypt forest partial harvest without pulpwood



(j) cypress pine partial harvest without pulpwood



Emissions due to harvest and harvest residue

The amount of carbon removed as products in a harvest is dependent upon age class, forest type and the type of harvest. The harvest events were informed by a comprehensive national review of forest management in Australia (Raison and Squire, 2008). In the model the removal of products at harvest is assumed to result in instant oxidation. Wood products removed from *harvested native forests* are included in the *harvested wood products* modelling (see Appendix 7.I).

The amount of residue produced by a harvest is also dependent upon the harvest type, forest age and forest type. Information on the production of harvest residue by broad forest type, harvest type and forest age was sourced from a comprehensive review of forest management in Australia (Raison and Squire, 2008) and studies of residue production (Ximenes and Gardner, 2005, Ximenes *et al.,* 2005). Following harvest the residue decomposes and is also impacted by management actions taken post-harvest such as regeneration fire treatments.

Calculation of emissions and removals in harvested native forests

The annual change in living biomass in harvested native forests is the net result of uptake due to forest growth (above and belowground as determined from the growth models) and losses due to forest harvesting. Losses occur with the removal of forest products (instant oxidation) and movement of residue material (including belowground biomass) to dead organic matter (DOM). The annual change in DOM in harvested native forests is the net result of additions due to turnover and movement of living biomass to DOM due to harvesting and losses due to decomposition of both natural accumulation and harvest residue, and burning of residues as part of some silvicultural systems (see Figure 7.B2).

Losses from the DOM pool are accounted for emissions in the year in which they occur. As a Tier 1 approach is currently used for soil carbon, assuming a balance between losses due to harvest and re-accumulation following harvest, no transfers occur between the DOM and soil pools. The DOM pool therefore includes the lag emissions due to the ongoing decay and management of residue from harvesting in previous years.

Harvested native forests and Australia's Forest Management reference level

As part of the negotiations for further commitments for Annex I Parties under the Kyoto Protocol, Australia submitted a Forest Management reference level to the United Nations Framework Convention on Climate Change (UNFCCC) Secretariat[10].

The anthropogenic emissions and removals due to the management of Australia's forests are primarily the result of management activities and practices related to the production of wood and wood products. Consequently Australia has defined Forest Management lands as those forests that are managed under a system of practices that include:

- forest harvesting;
- silvicultural practices; and
- the protection of natural resources within the areas of land available for harvest.

Publically owned native forests that fit this definition are identified as Multiple Use Forests (Australia's State of the Forests Report, 2008).

Forest Management activities (harvesting and silvicultural practices) also occur on privately managed native forests. As the management intent on these lands is largely unknown, to ensure balanced and complete accounting for emissions and removals from forest management activities, harvesting on these lands since 1990 has been estimated and included under Forest Management.

The Forest Management reference level thus utilises the most recent data available for delineating areas of land included under Forest Management. Forest Management therefore includes all native timber production areas including public Multiple Use Forests mapped under Australia's State of the Forests Report 2008 and privately owned native forest harvested since 1990. Once fully developed, a remote sensing program will be used to identify the areas of native forests harvested since 1990. This approach provides a clearly delineated and verifiable basis for monitoring and measuring changes in carbon stocks from Forest Management activities in the period to 2020. In contrast, existing national inventory estimates of net emissions from *forest land remaining forest land* are based on areas of land that have not been spatially mapped and which therefore do not provide a basis for delineating Forest Management activity lands in the future.

As part of the development of the Forest Management reference level a reconciliation of *harvested native forests* with the native forests included under Forest Management was developed (Table 7.B9). As the data used to define the area of *harvested native forests* was estimated using non-spatial data almost 20 years ago, it was difficult to accurately reconcile the harvested native forest area with the area of forest included under Forest Management as Multiple Use Forests and Private harvest native forests.

10 Submission of a Forest Management reference level and supporting information as requested by Decision 2/CMP.6 (Land use, land use change and forestry)

Table 7.B 9 Reconciliation of forest areas between UNFCCC *Forest land remaining forest land harvested native forests* and *native forests* considered under Australia's Forest Management reference level as Article 3.4 Forest Management

UNFCCC Forest land remaining forest land	Estimated area in 2009 (Mha)	2012 NIR Disaggregation (bold categories are Forest Management lands)	Estimated area in 2009 (Mha)
Harvested native forests	14.89	**Multiple Use Forests**	9.41
		Private harvest native forests	0.39
		Native forests no longer identified as managed for wood production in 2009 (e.g. new conservation areas, private native forests previously considered as production forests but not harvested since 1990, statistical discrepancy, etc)	5.09

The emissions and removals from *harvested native forests* according to Forest Management sub-categories have been estimated (Table 7.B10). The allocation of historical harvest areas in public native forests between Multiple Use Forests and native forests that are no longer identified as managed for wood production as at 2009 had to be estimated. As there is no information currently available to determine this, the assumption was made that all harvesting on public native forests from 1990 onwards occurred on Multiple Use Forests. While this assumption has little impact on the emissions and removals during the projected forest management reference level period (2013-2020) this is likely to result in an overestimate of removals in the early 1990s for Native Forests no longer identified as managed for wood production in 2009, and a possible overestimate of emissions from Multiple Use Forests in the early 1990s.

Table 7.B 10 Indicative estimate of emissions from UNFCCC *Forest land remaining forest land - harvested native forests* disaggregated by Forest Management native forest sub-category

Year	Multiple Use Forests	Private native forests	Areas not considered to be managed for wood production as at 2009	Harvested native forests total
			Emissions (Mt CO_2)	
1990	-16.8	6.0	-22.4	-33.2
1991	-16.7	7.0	-23.7	-33.5
1992	-15.8	7.7	-24.4	-32.6
1993	-14.0	8.2	-24.9	-30.7
1994	-12.8	8.6	-25.2	-29.4
1995	-11.7	9.0	-25.4	-28.1
1996	-10.2	9.3	-25.5	-26.5
1997	-10.4	9.5	-25.6	-26.5
1998	-10.2	9.7	-25.6	-26.2
1999	-9.9	9.8	-25.6	-25.7
2000	-8.9	10.8	-25.6	-23.8
2001	-6.9	11.5	-25.6	-21.0
2002	-11.0	8.1	-25.7	-28.5
2003	-10.6	8.1	-25.7	-28.2
2004	-10.2	9.5	-25.7	-26.4
2005	-13.0	8.3	-25.8	-30.5
2006	-13.3	8.8	-25.8	-30.2
2007	-14.3	10.0	-25.8	-30.0
2008	-12.6	8.1	-25.8	-30.3
2009	-17.0	9.4	-25.7	-33.3
2010	-17.3	7.5	-25.7	-35.5

APPENDIX 7.C: PRE-1990 PLANTATIONS

Introduction

Pre-1990 *plantations* are commercial plantations (hardwood and softwood) established in Australia up to the end of 1989. Softwood plantations make up the vast majority of pre-1990 *plantations* with hardwood plantations (primarily eucalypt species) making up only a minor part of the plantation estate. Until the mid-1960s most new areas of softwood plantation were derived from clearing of native forest or scrublands and in later years, some of the hardwood plantations were also established after clearing native forest (Snowdon and James, 2008). By the mid-1980s, clearing of native forests for the establishment of plantations had ceased in most States and most new plantations were established on farmland.

The results presented in this Appendix represent an implementation of the Tier 3 emissions estimation and Approach 2 land representation methods. The form of Tier 3 emissions estimation and Approach 3 land representation, as used for the post-1990 *plantations*, will be implemented in future inventory submissions.

Growth Modelling and Management

Plantation growth and the effect of management on emissions and removals for the pre-1990 *plantations* sub-category are modelled using the Full Carbon Accounting Model (*FullCAM*). For the *plantations* category tree growth is modelled using the volume growth increment tables of Turner and James (2002), as developed from the National Forest Inventory wood flow estimates (National Forest Inventory 1997a and 1997b).

For the pre-1990 *plantations* 34 *FullCAM* models representing the key species and management practices within each National Plantation Inventory region were developed. In addition to the growth tables and thinning regimes of Turner and James (2002) the models require parameters for:

- wood basic density;
- stem to whole tree mass conversion;
- carbon contents;
- wood product destinations; and,
- leaf and root turnover and decay rates.

Table 7.C1 and Attachment 7.C1 show the relevant inputs and the resultant carbon balances on a per hectare basis from the representative models for each plantation type.

Growth Tables and Thinning/Harvest Regimes

Turner and James (2002) reinterpreted their previous work for the National Forest Inventory wood flow estimates (National Forest Inventory, 1997b) to provide current annual increments (CAI) of stem volume for the key plantation types and regions in Australia. To determine the CAI, the estimates of total volume produced (from a thin or clearfall) by age, region, species and plantation type were fitted with growth curves that met the annual growth needed to meet the volume harvested (yield). The method of fitting growth curves to the known points of wood yield for each plantation type is described in Turner and James (2002). Thinning and harvesting regimes are also modelled using data on volume production region, species and age as collated by the National Forest Inventory.

The empiricism of the estimates masks the influences of climate variability resulting in estimates which represent average performance over the time of measurement. It has been shown that a variable climate will cause variability in growth over time in these plantations (Waterworth *et al*., 2005). While it is unlikely that the volume at maturity (reflecting the longer term climate average) would be much affected, performance over a shorter period, such as a single inventory year, may yield above or below the expected growth due to the prevailing climate conditions. The potential impact of prevailing climate conditions during the time of reporting is described in Brack and Richards (2002).

Wood Density Estimates

Wood basic density estimates for each plantation species were extracted from the compendium of wood density estimates prepared by Ilic *et al*., (2000). While many native forest species have few, in some instances zero, reported wood density estimates, plantation species are relatively well studied and reported. However, wood density is most commonly measured at the time of harvest, reflecting a mature state.

As it is commonly accepted that wood density increases with tree age (Polglase et al., 2004), there is potential that the adopted wood densities are over-estimates for the early stages of plantation growth. However, as the average age of the pre-1990 *plantations* is much greater than the post 1990 *plantations* the overall effect is unlikely to be significant as lower densities occur when mass is least, that is, during early growth stages. Table 7.C3 and Attachment 7.C1 show the wood density values used for the major plantation species in the plantation types.

Stem to Whole Tree Mass Conversions

Studies on the above and belowground partitioning of biomass (Keith *et al*., 2000, Eamus *et al*., 2000, Snowdon *et al*., 2000) have shown that both above and belowground variability reduces, as do non-stem allocations, as site biomass increases. Greatest uniformity, therefore least variability, tends to occur in older even-aged and productive stands. Attachment 7.C1 provides a synopsis of the non-stem allocations used in each plantation type model.

The ratio of stem (merchantable) quantities to non-merchantable components is particularly important for the calculation of the amounts of forest slash generated by thinning and harvesting activity. The potential accumulation of slash can make a considerable contribution to increased carbon stock, particularly on former pasture sites.

Carbon Contents

Studies of the carbon fractions of above and below ground biomass components for Australian vegetation were used to provide the parameters for the carbon fractions of tree components in the model (Gifford, 2000a and 2000b). Carbon fractions were examined for a range of species and growing conditions which provided a range for the carbon fractions with a recommended estimate. There was little variability in the results and more importantly no cause to suspect bias in any set of environmental conditions or plant groups. These results could be considered as robust and reliable estimates, providing little source of uncertainty in the carbon models. The carbon contents are listed in Table 7.C3.

Turnover and Decomposition Rates

The turnover rates determine the amount of material being added to the debris pool. Decomposition rates determine the rates of loss of carbon back to the atmosphere as the debris breaks down. The balance of these two factors determines the amount of debris on site excluding the effects of management. The amount of carbon moved from living biomass to the dead organic matter pools due to forest harvesting is determined in the model by the age, type of harvest and species characteristics. These are shown in Attachment 7.C1.

The turnover rate of leaves and fine roots affects both the amount of fine litter on the forest floor and subsequently most of the contribution to soil carbon. As this implementation of the model does not include soil carbon (which is estimated using a Tier 2 method), the rates of turnover of both leaves and fine roots are relatively unimportant. The key attributes of the assigned rates are that they are realistic and do not operate at rates that are too high or low enough to either reduce below reasonable expectation, the mass of attached leaves and live roots, or to create unrealistically high or low levels of litter. While leaf turnover rates have been the subject of measurement and can be compared to observations, the difficulty in measuring root turnover means that there are very few reported measures against which to compare. However, as the stock of 'dead' fine root material is accounted for as soil organic matter, this becomes irrelevant until the spatial mass balance soil carbon modelling system is implemented.

Table 7.C 1 Tree component annual turnover rates

Tree Component	Turnover yr^{-1}
Branches	0.03
Bark	0.1
Leaves	0.5
Coarse Roots	0.05
Fine Roots	0.1

The rates of decomposition applied in the model have been guided by the work of Mackensen and Bauhus (1999). Table 7.C2 shows the decomposition rates applied.

Table 7.C 2 Debris decomposition rates

Debris Component	Breakdown Rate yr^{-1}
Deadwood	0.1
Bark Litter	0.5
Leaf Litter	1.0
Coarse Dead Roots	0.5
Fine Dead Roots	1.0

The main focus of this work was on modelling rates that coincided with measures of litter mass when the models were run over extended periods so that a reasonable balance between turnover (input to litter pools) and decomposition of litter pools was achieved.

Table 7.C 3 Plantation types, wood densities, carbon contents and management regimes

Region(s)	Species	Density	CC% Leaf	CC% Branch	CC% Wood	CC% Bark	CC% Fine Roots	CC% Coarse Roots	Regime Description
Green Triangle	Pinus radiata	440	52	51	52	53	46	49	Average Sites - 54% thinning @ 13 years, 25% @ 18, 28% @ 23, CF @ 30
Green Triangle	Pinus (other than radiata)	440	52	51	52	53	46	49	Average Sites - 54% thinning @ 13 years, 25% @ 18, 28% @ 23, CF @ 30
NSW Northern Tableland	Southern Pine (P. elliotti, P. taeda, Araucaria cunninghamii)	440	52	51	52	53	46	49	Average Sites - 27% thinning @ 14 years, 47% @ 20, CF @ 30
NSW	Eucalyptus plantations	550	52	47	52	49	46	49	All Sites - 67% @ 20 years, 47% @ 35, CF @ 45
NSW	Eucalyptus plantations	550	52	47	52	49	46	49	All Sites - CF @ 20
Qld	Eucalyptus plantations	550	52	47	52	49	46	49	All Sites - 67% @ 20 years, 47% @ 35, CF @ 45
Qld	Eucalyptus plantations	550	52	47	52	49	46	49	All Sites - CF @ 20
Qld	Southern Pine (P. elliotti, P. taeda, Araucaria cunninghamii)	440	52	51	52	53	46	49	All Sites - 35% @ 18 years, CF @ 35
South Australia	Eucalyptus plantations	550	52	47	52	49	46	49	All Sites - CF @ 20
South Australia	Eucalyptus plantations	550	52	47	52	49	46	49	All Sites - CF @ 15
South Australia	Eucalyptus plantations	550	52	47	52	49	46	49	All Sites - CF @ 25
South Australia	Pinus (other than radiata)	440	52	51	52	53	46	49	Average Sites - 54% thinning @ 13 years, 25% @ 18, 28% @ 23, CF @ 30
Tasmania	Eucalyptus nitens	550	52	47	52	49	46	49	All Sites - CF @ 30
Tasmania	Eucalyptus nitens	550	52	47	52	49	46	49	All Sites - CF @ 15
Tasmania	Eucalyptus nitens	550	52	47	52	49	46	49	All Sites - CF @ 25
Tasmania	Pinus radiata	440	52	51	52	53	46	49	Average Sites - CF @ 35
Tasmania	Pinus (other than radiata)	440	52	51	52	53	46	49	All Sites - CF @ 35
Victoria (Central)	Pinus radiata	440	52	51	52	53	46	49	Average Sites -34% thinning @ 15 years, 18% @ 22, 24% @ 28, CF @ 35
Victoria (Central)	Pinus radiata	440	52	51	52	53	46	49	Average Sites - CF @ 30
Victoria (Central Gippsland)	Eucalyptus plantations	550	52	47	52	49	46	49	All Sites - CF @ 25
Victoria (Central Gippsland)	Eucalyptus plantations	550	52	47	52	49	46	49	All Sites - CF @ 20
Victoria (Central Gippsland)	Eucalyptus plantations	550	52	47	52	49	46	49	All Sites - CF @ 30
Victoria (Central Gippsland)	Eucalyptus plantations	550	52	47	52	49	46	49	All Sites - CF @ 35
Victoria (Central Gippsland)	Pinus radiata	440	52	51	52	53	46	49	Average Sites - 33% thinning @ 15 years, 37% @ 20, CF @ 30
Murray Valley	Pinus radiata	440	52	51	52	53	46	49	Average Sites - 47% thinning @ 14 years, 35% @ 22, 29% @ 29, CF @ 30
Murray Valley	Pinus radiata	440	52	51	52	53	46	49	Average Sites - 47% thinning @ 14 years, 35% @ 22, CF @ 30

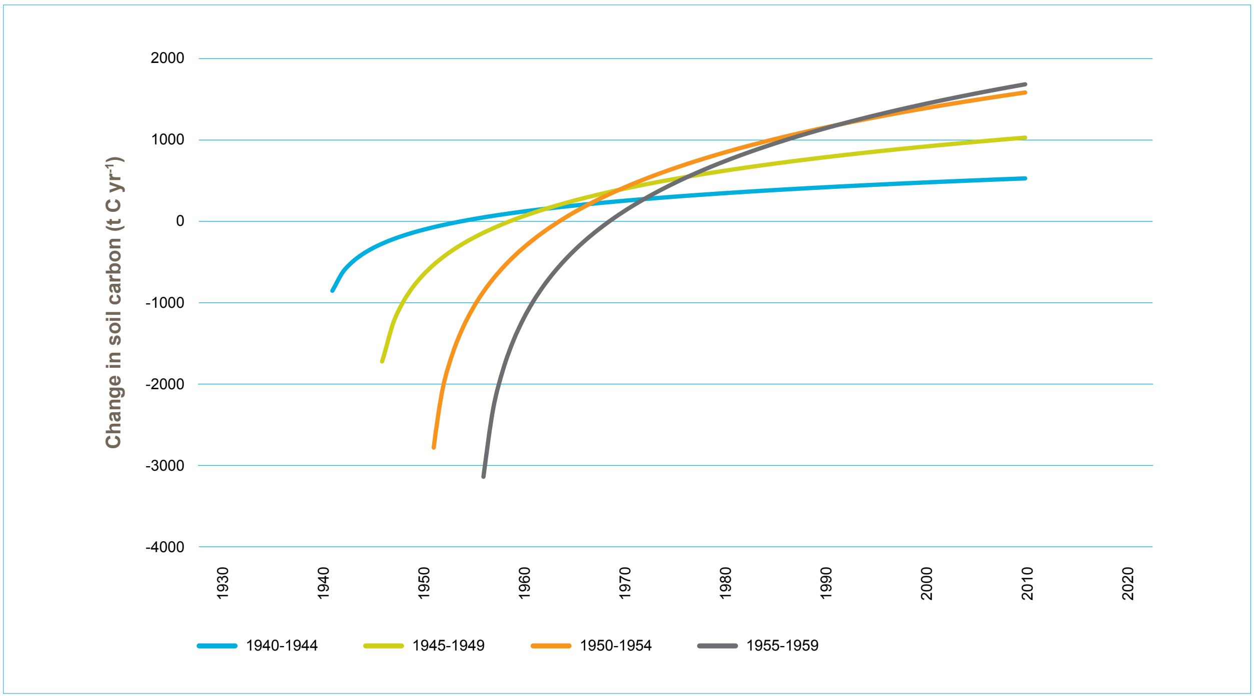
Region(s)	Species	Density	CC% Leaf	CC% Branch	CC% Wood	CC% Bark	CC% Fine Roots	CC% Coarse Roots	Regime Description
Murray Valley	Pinus radiata	440	52	51	52	53	46	49	Very Good Sites - 44% thinning @ 14 years, 31% @ 18, 27% @ 23, CF @ 30
Victoria and NSW	Pinus radiata	440	52	51	52	53	46	49	Average Sites - CF @ 30 years
Victoria and NSW	Pinus radiata	440	52	51	52	53	46	49	Average Sites - 65% thinning @ 16 years, CF @ 30
Victoria and NSW	Pinus radiata	440	52	51	52	53	46	49	Average Sites - 65% thinning @ 16 years, 57% @ 24, CF @ 30
Victoria and NSW	Pinus radiata	440	52	51	52	53	46	49	Average Sites - 65% thinning @ 16 years, 57% @ 24, 27% @ 30, CF @ 35
Victoria and NSW	Pinus radiata	440	52	51	52	53	46	49	Poor Sites - 26% thinning @ 18 years, 32% @ 24, CF @ 30
Victoria and NSW	Pinus radiata	440	52	51	52	53	46	49	Poor Sites - CF @ 30 years
Western Australia	Eucalyptus globulus	550	52	47	52	49	46	49	Clear fall @ 10
Western Australia	Pinus pinaster	470	52	51	52	53	46	49	Average Sites - 65% thinning @ 18 years, 37% @ 25, CF @ 40
Western Australia	Pinus radiata	440	52	51	52	53	46	49	Average Sites - 51% thinning @ 12 years, 39% @ 18, 32% @ 24, CF @ 35

Soil Carbon Modelling

While it has been shown that in the medium to long term, soil carbon does not change for most plantations (Polglase *et al*., 2000), it has also been identified that there are frequently short term losses which are later recovered in most situations and some instances of long term losses or gains (Paul *et al*., 2002b). Work is currently underway to develop the spatial soil carbon modelling capacity for pre-1990 *plantations*. The application of the spatial soil carbon model for the post-1990 *plantations* based on the work of Paul *et al*., (2002b, 2003a and 2003b) shows the potential for the development of this capacity. In the interim, a Tier 2 method for estimating emissions and removals from soil has been developed for plantations.

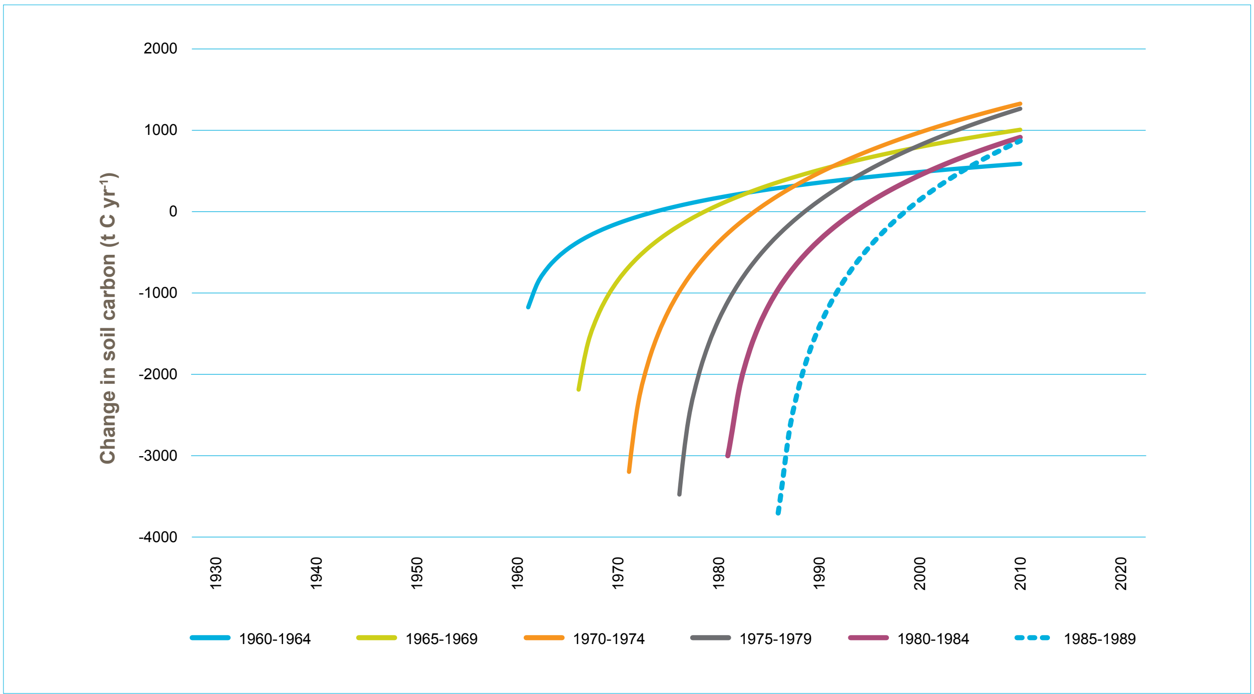
- The soil carbon estimates are based on the model developed by Polglase *et al.*, (2000) covering plantation forests aged from zero to 100 years and to a soil depth of 30 cm. This soil carbon model was used to estimate soil carbon change following the establishment of plantations between 1940 and 1989. An initial soil carbon value of 38.71 t C ha^{-1} (Polglase *et al.*, 2000) was used to convert the change of soil carbon from a percentage change per year (% yr^{-1}) to tonnes of carbon change per year (t C yr^{-1}). The age of the plantation was calculated as the time since plantation establishment. Figures 7.C1 and 7.C2 show the estimated change in soil carbon (t C yr^{-1}) following plantation establishment between 1940 and 1959, and 1960 and 1989, respectively.
- The change in soil carbon was estimated for the total area of plantation established per year; therefore, the large estimated change in soil carbon stock from one year to the next is due to the increase in the area of the plantation estate; by 1985, the total pre-1990 *plantation* estate had expanded to over 40 times the area initially established in 1940. The change in soil carbon following plantation establishment does not explicitly incorporate the effects of factors such as site preparation, previous land use, climate, soil texture, site management and plantation harvesting during the time since planting. However, the data used to develop the model covers a wide range of conditions and management practices and can therefore be considered representative at the national scale.

Figure 7.C 1 Change in soil carbon (t C yr^{-1}) following plantation establishment from 1940 to 1959



APPENDIX 7.C

Figure 7.C 2 Change in soil carbon (t C yr[-1]) following plantation establishment from 1960 to 1989



Activity data

Activity data for plantations is sourced from the National Plantation Inventory (NPI) (Table 7.C4). The area of land converted to plantation is restricted to direct human induced activities, that is, it does not include ephemeral and non-human induced changes in plantation area.

The plantation area data provided by the NFI is reported on the basis of the 14 National Plantation Inventory regions (Figure 7.C3). Three broad classes of forest are defined - Short Rotation Hardwood (SRH), Long Rotation Hardwood (LRH) and Softwood (SW). This data is subsequently annualised (cumulative area divided by number of years) from within the blocks of years reported by Spencer *et al*., (2001).

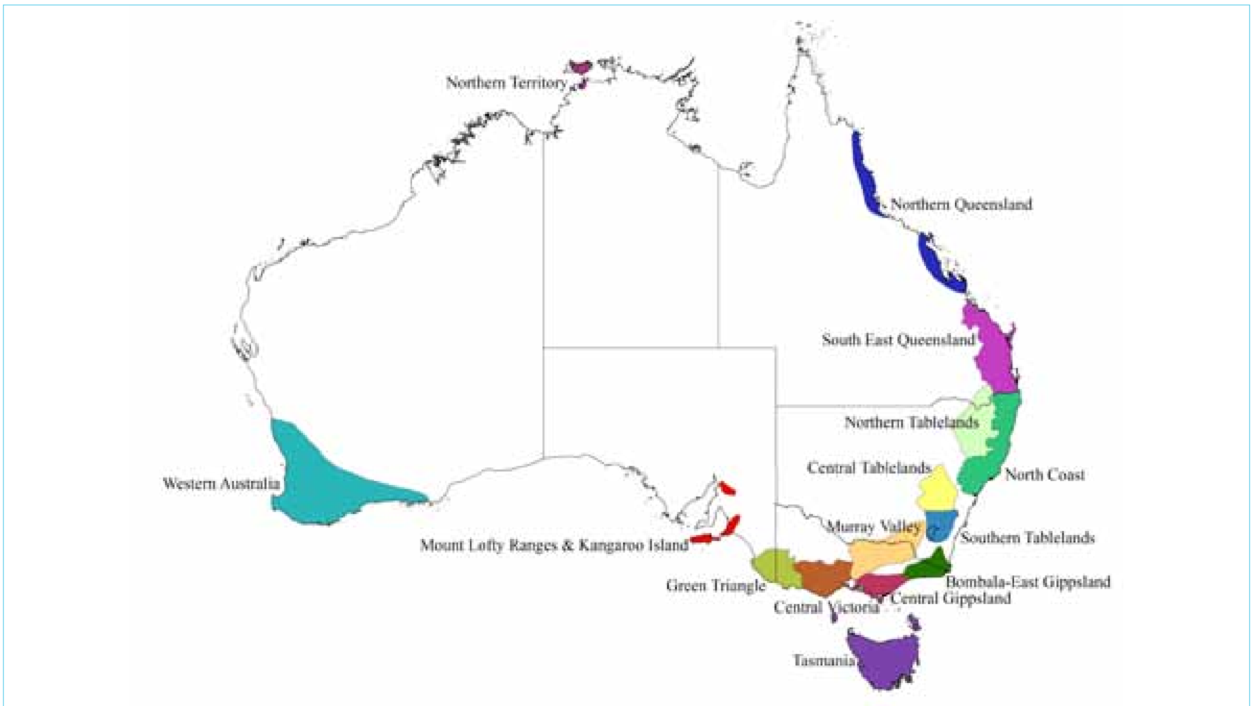
Allocations of the Short Rotation Hardwood (SRH), Long Rotation Hardwood (LRH) and Softwood (SW) classes are made to the region and species specific plantation models as described by Turner and James (2002).

Table 7.C 4 Areas of land converted to plantation from 1940-1989

Year	Area (ha)	Year	Area (ha)
1940	787	1965	20,350
1941	787	1966	20,350
1942	787	1967	20,350
1943	787	1968	20,350
1944	787	1969	20,350
1945	1,596	1970	29,686
1946	1,596	1971	29,686
1947	1,596	1972	29,686
1948	1,596	1973	29,686
1949	1,596	1974	29,686
1950	2,580	1975	32,280
1951	2,580	1976	32,280
1952	2,580	1977	32,280
1953	2,580	1978	32,280
1954	2,580	1979	32,280
1955	2,914	1980	27,852
1956	2,914	1981	27,852
1957	2,914	1982	27,852
1958	2,914	1983	27,852
1959	2,914	1984	27,852
1960	10,987	1985	34,400
1961	10,987	1986	34,400
1962	10,987	1987	34,400
1963	10,987	1988	34,400
1964	10,987	1989	34,400

One of the key improvements planned for the pre-1990 *plantations* sub-category is to identify lands converted to (pre-1990) plantation since the commencement of the Landsat archive in 1972. At present, *land converted to forest land* (post 1990) are identified and classified to plantation type (native forest, hardwood and softwood) using the Landsat TM and ETM+ data (see Appendix 7.A). This capacity is being extended to allow the identification of softwood plantations establishment (which form the vast majority of pre-1990 *plantations*) from 1972 to 1989 using Landsat MSS data.

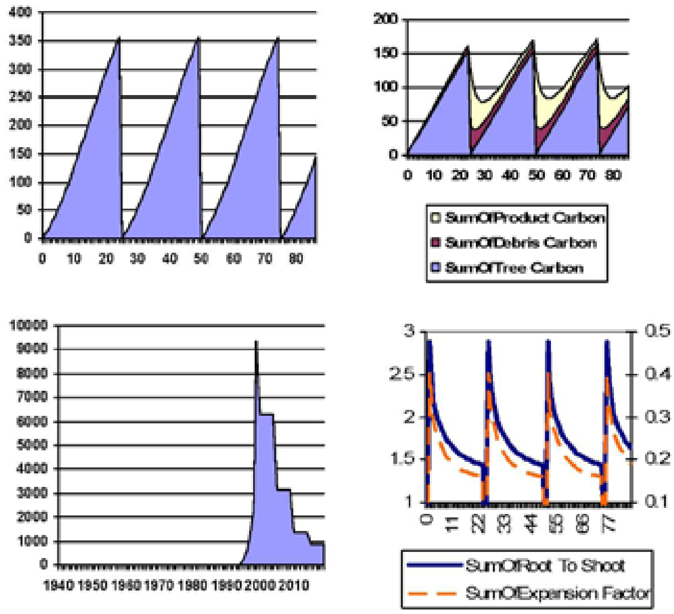
Figure 7.C 3 The National Plantation Inventory regions



Calculations of total emissions and removals

The ‘Estate’ module of *FullCAM* is used to scale each pre-1990 *plantation* model by the areas of each plantation type established over time. To do this the model interrogates the carbon balance for each plantation type at the relevant point in time to derive the overall account. The per hectare outcome of each model, by the relevant age (as determined by the year of planting for each plantation type), is multiplied by the number of hectares planted in the corresponding year to calculate the change for the whole of the estate in any one year. A fuller explanation of the operation of the ‘Estate’ module of *FullCAM* can be found in Richards and Evans (2000a).

Attachment 7.C1: Example Plantation Type Model Parameters and Outcomes



LookUp	Region(s)	Species	Density	CC% Leaf	CC% Twig	CC% Branch	CC% Sapwood	CC% Wood	CC% Bark	Regime Description
SA4 Euc 3	South Australia	Eucalyptus plantations	550	52	52	47	52	52	49	All Sites - CF @ 25

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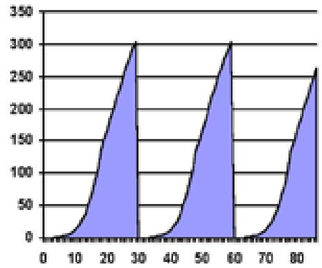
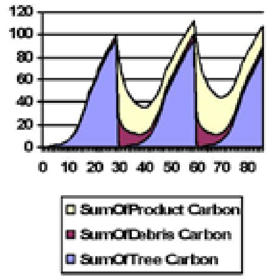
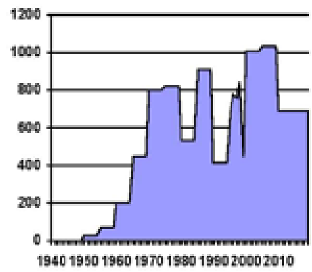
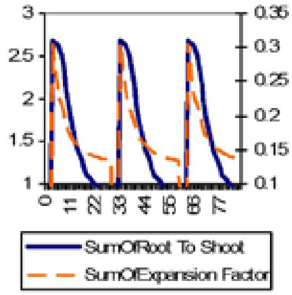
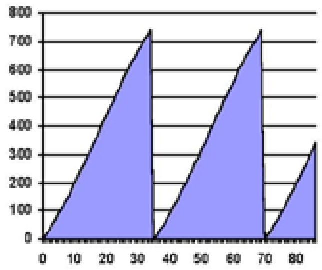


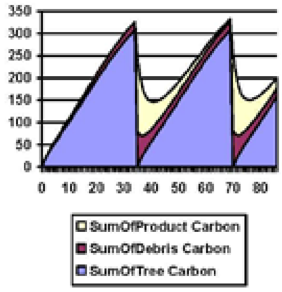


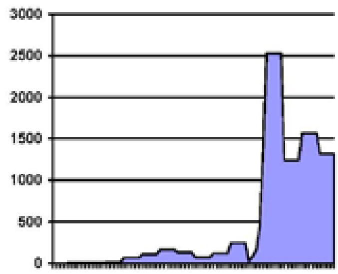


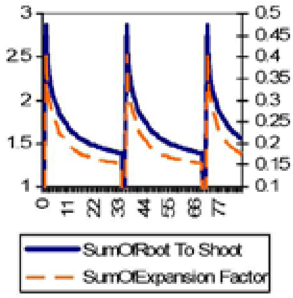


LookUp	Region(s)	Species	Density	CC% Leaf	CC% Twig	CC% Branch	CC% Sapwood	CC% Wood	CC% Bark	Regime Description
VicNSW891011 P.rad 6	Victoria and NSW	*Pinus radiata*	440	52	52	51	51	52	53	Poor Sites - CF @ 30 years









LookUp	Region(s)	Species	Density	CC% Leaf	CC% Twig	CC% Branch	CC% Sapwood	CC% Wood	CC% Bark	Regime Description
Vic7 Euc 4	Victoria (Central Gippsland)	Eucalyptus plantations	550	52	52	47	52	52	49	All Sites - CF @ 35

APPENDIX 7.D: POST-1990 PLANTATIONS

Introduction

Post-1990 *plantations* are plantations (both commercial and non-commercial) that were established, via direct human-induced methods, in Australia since the beginning of 1990.

Model Configuration

The methods used to estimate emissions and removals in post-1990 *plantations* reflect an implementation of the full form of Tier 3 emissions estimation and Approach 3 land representation. The model covers all carbon pools: living biomass, dead organic matter and soil. These pools can be further divided as necessary for reporting under the Kyoto Protocol. A full description of the modelling system is provided in Appendix 7.A. The modelling methods and calibration have been published in the peer-reviewed literature (Waterworth et al., 2007, Waterworth and Richards, 2008)

Growth Modelling and Management

Forest growth model

Understanding spatial and temporal variation in forest growth is important to developing accurate carbon accounts. Rainfall, temperature and soil fertility are significant determinants of the potential total biomass carrying capacity and the rate at which the forest approaches carrying capacity. Growth estimates over short periods (< 5 years) are sensitive to climate variability and forest age. Growth rates are also affected by management, age, forest type and forest structure. It is necessary to account for all of these factors when estimating emissions and removals over short reporting periods (e.g., annual) over an entire continent. Purely empirical modelling methods using methods based purely on yield or increment tables (Richards and Brack, 2004a; Lewis *et al.*, 1976; Turner and James, 2002) do not reflect short-term climate variability and cannot easily account for management effects.

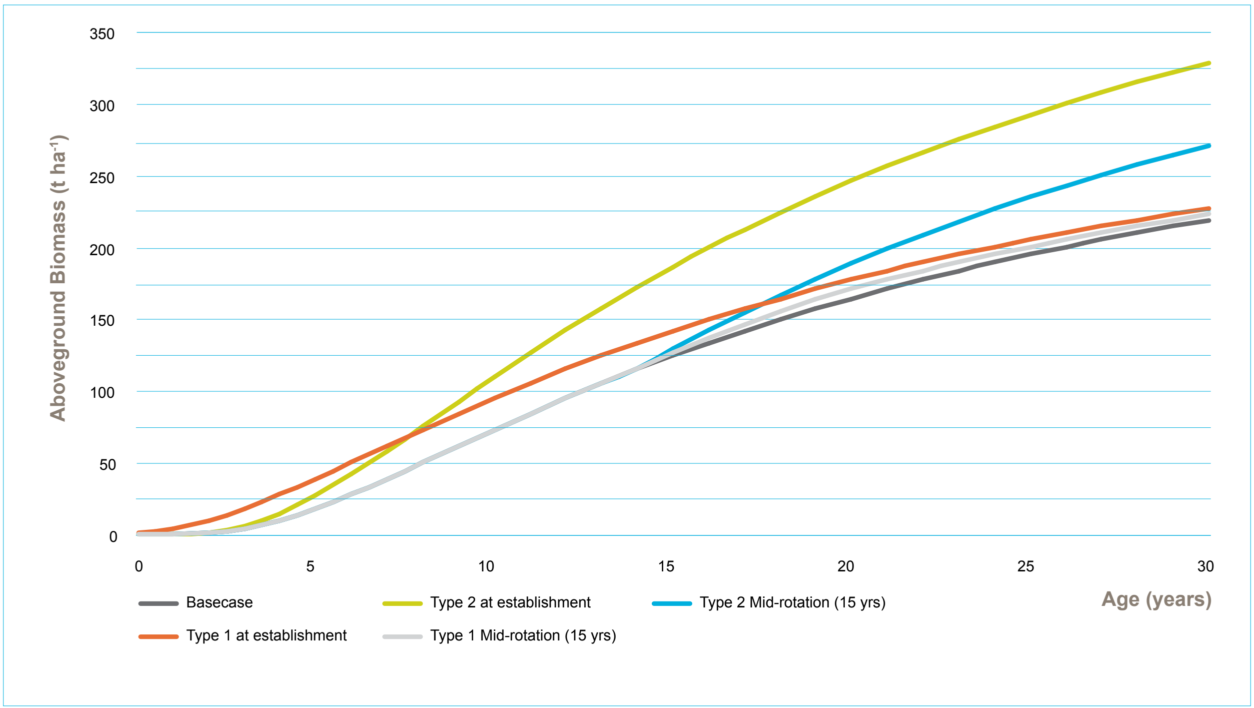
Plantations commonly produce more biomass than native forest systems in Australia, at least in the short to medium term (15-40 years). For example, Baker and Attiwill (1985) showed that *Pinus radiata* achieved 70-100% of the biomass of an 80 year old native forest, grown under similar conditions, in only 20 to 24 years. These growth differences are driven by factors such as nutrient addition, reduction in insect herbivory associated with the use of non-endemic species or through control of pests, site-specific species matching and management, and possibly greater physiological efficiency in utilising site resources by the introduced species.

The initial assumed biomass model and methods to estimate removals due to regrowth post clearing represent forest systems without significant management input and is well suited to the *forest land converted to grassland* and *cropland* sub-categories. However, in plantation systems with significant management inputs, such as fertiliser application or intensive site preparation, and species specific site matching, additional model parameters are needed to accurately estimate forest growth.

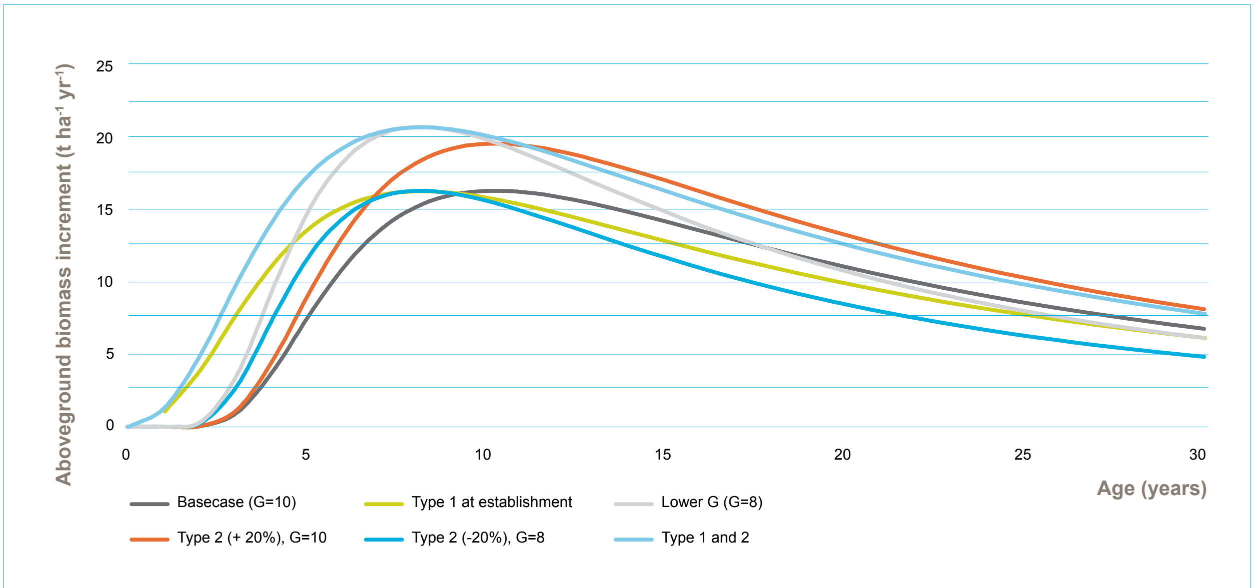
To account for the effects of management practices on growth the native regrowth forest model (Appendix 7.A) is supplemented to include functions that represent Type 1 and Type 2 growth responses (Snowdon and Waring, 1984) (Figure 7.D1). Type 1 management practices advance or retard stand development (effectively age) but do not increase underlying site productivity over the life of the rotation. Weed control at establishment, and nitrogen fertiliser application after thinning are examples of Type 1 responses (Snowdon, 2002). Type 2 treatments increase (or decrease) a site's carrying capacity in the longer term. Phosphorus application, which in Australia can lead to long-term increase in site productivity (i.e., over several rotations) (Snowdon, 2002) is an example of a Type 2 response.

Figure 7.D 1 Effect of Type 1 and Type 2 management practices on

(a) cumulative and



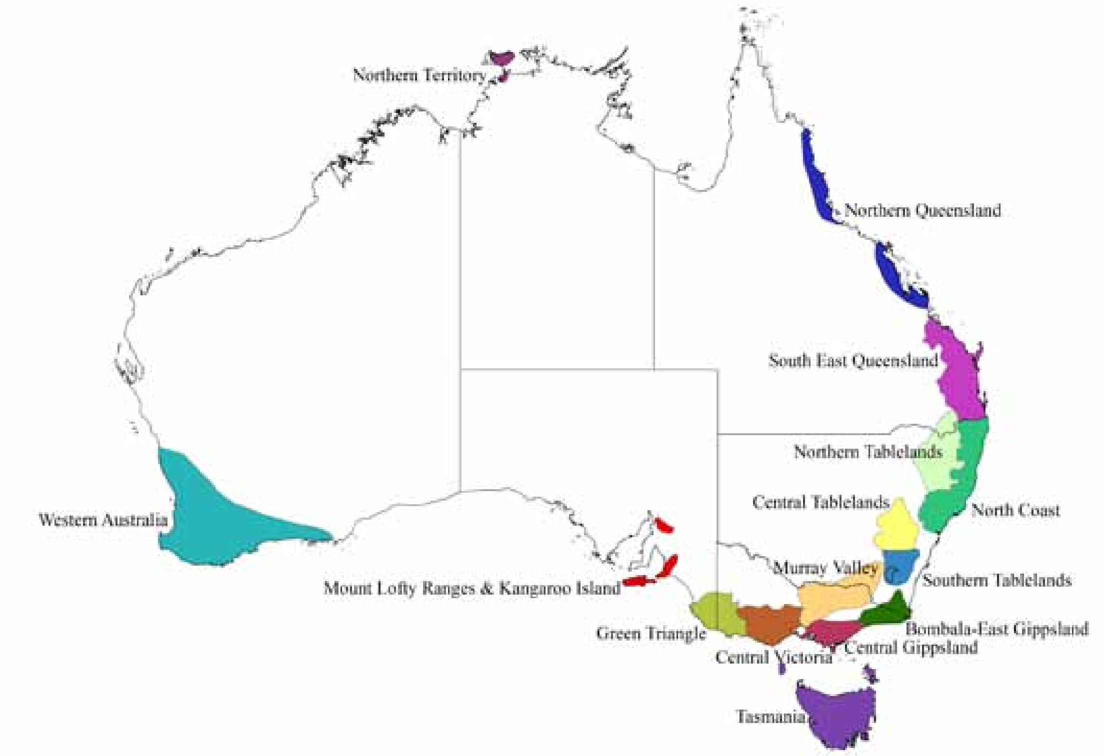
(b) annual growth



Snowdon (2002) developed methods for including Type 1 and 2 effects in hybrid growth models and these have been implemented in the forest growth component of the *FullCAM* model. In the model, Type 1 forest treatment events are simulated by varying the developmental stage or age of the stand, moving the forest back and forth along the growth curve depending on the degree of treatment (see Equation 3). Type 2 treatments simply change the asymptote (i.e., *M*; see Equation 4) from the time the treatment is applied. These methods lend themselves well to application in the hybrid empirical-process based structure of *FullCAM*.

A further effect that must be accounted for is the impact of establishing regionally non-endemic plantation species. This effect is expressed through a plantation species multiplier (*r*; see Equation 1), which is similar to a Type 2 response being applied from the time a species is planted until final harvest. The *r* multiplier is based on the long term average Forest Productivity Index (*P*; see Appendix 7.A) for each point, the type of plantation established and is stratified by State and National Plantation Inventory (NPI) region (Figure 7.D2). This allows the model to account for variations in growth between regions that cannot be accounted for easily from climatic and broad scale site information (e.g., Sheriff *et al.*, 1996; Turner *et al.*, 2001), while still accounting for the significant variation that occurs within each region due to site factors.

Figure 7.D 2 The National Plantation Inventory regions



Calculation of r

The plantation species multiplier (*r*) was determined for each major plantation species on a regional basis. Regional long-term forest productivity index values of plantation areas in each National Plantation Inventory (NPI) region and State were determined by overlaying the long-term Forest Productivity Index (*P*) spatial data, with areas of hardwood and softwood plantation as identified by the plantation type mapping from the remote sensing program. The average Mean Annual Volume Increment (MAVI) data for each plantation species in each state and NPI region was obtained from Turner and James (1997), Turner and James (2002), Snowdon and James (2008) and Ferguson *et al.,* (2002). The values are either based on or represent the data used in Australia's National Forest Inventory (NFI). Minimum and maximum MAVI values that are not available in the NFI data were estimated for each species and NPI region, based on Snowdon and James (2008) and the following assumptions:

1. MAVI values of the NFI are the average for the region, not the most common growth rate;
2. Minimum MAVI values are effectively set by commercial viability. These are generally not lower than 12 m3 ha^{-1} yr^{-1}, (although this may vary for certain species within regions, such as *Pinus pinaster* in dry regions in West Australia); and
3. Maximum MAVI values are unlikely to exceed 30 m3 ha^{-1} yr^{-1} in long rotation systems and 35 m3 ha^{-1} yr^{-1} in short rotation systems.

APPENDIX 7.D

Environmental plantings are considered similar to regenerating native forest and assigned an *r* value of 1 (no management/species effect). The distribution of plantations according to plantation typing was mapped to the *P* data to verify that the minimum and maximum values were reasonable given the assumptions applied. For the calculation of *r*, the minimum and maximum *P* values were assumed to be the 5% and 95% of the total distribution of area for each plant type. As species is not identified in the plantation type data, where a plantation type (i.e., hardwood/softwood) consisted of different species with distinct productivity ranges (e.g., *P. pinaster* and *P. radiata* in Western Australia are both softwoods but *P. pinaster* is commonly established in low rainfall areas), the *P* for the dominant species was set values from regions with similar species and conditions, with the other species ranging from the minimum P value to the lowest P value of the dominant species. The MAVI and *P* data used for calibrating *r* are shown in Table 7.D1.

The *r* value required to adjust the base case native forest growth model to the documented plantation MAVI growth rates and the estimated minimum and maximum MAI's for each state, NPI region and species was calculated based on assumptions of species characteristics and forest management (Equation 1). As the MAVI growth data is not spatially explicit it was assumed that low *P* values represent low MAVI values and high *P* values represent high MAVI values. This is justified through the strong relationship between *P* data and native forest biomass stocks (see Appendix 7.A), and studies using the productivity data in plantation systems that show relationships between *P* and stand height and basal area, but with significant regional variation (Ford, 2004). Expansion factors at final harvest were calculated using the equations from Snowdon et al (2000) and the average rotation length. While the expansion factor data show considerable variability at young ages, there is little variation in older stands, providing a high degree of certainty in these values. Species specific basic wood density values at maturity were obtained from Illic *et al.,* (2000) and Polglase *et al.,* (2004). Similar to the expansion factors, the range of density values decreases as the stands mature. For species in which management typically includes a thinning prior to final harvest, typically longer rotation sawlog plantations, the basic density value was reduced by 10% to account for the age-related effects and the thinned volume added to the final total harvest biomass. The percentage of maximum potential biomass achieved by final harvest was calculated based on estimates of age of maximum biomass increment, described in the next section.

Table 7.D 1 Range of FPI (P) values on which plantation types occur, the minimum, average and maximum growth rates (Mean Annual Volume Increment, m^3 ha^{-1} yr^{-1}) and rotation length.

NPI	Plantation type	Species	FPI low	FPI mean	FPI high	Min MAI	Average MAI	Max MAI	Rotation length
Western Australia	Softwood	Pinus radiata	5.0	7.0	11.2	12	20	30	30
Western Australia	Softwood	Pinus pinaster	3.8	5.5	8.0	6	11	16	35
Western Australia	Hardwood	Eucalyptus globulus SR	4.0	6.7	11.9	12	17	30	12
Western Australia	Hardwood	Eucalyptus globulus LR	5.0	7.0	11.9	12	18	27	25
Tasmania	Softwood	Pinus radiata	5.3	10.0	15.3	12	19	30	30
Tasmania	Hardwood	Eucalyptus globulus SR	6.0	11.5	15.5	14	23	30	10
Tasmania	Hardwood	Eucalyptus nitens SR	5.3	10.0	14.5	12	15	27	15
Tasmania	Hardwood	Eucalyptus nitens LR	6.0	11.5	15.5	14	19	27	25
Green Triangle	Softwood	Pinus radiata	4.8	7.4	11.5	12	21	30	35
Green Triangle	Hardwood	Eucalyptus globulus SR	4.8	7.7	11.5	12	17	27	12
Green Triangle	Hardwood	Eucalyptus globulus LR	6.0	8.2	11.5	14	20	25	25
South Australia - Lofty Block	Softwood	Pinus radiata	5.3	6.6	10.6	12	21	27	35
South Australia - Lofty Block	Hardwood	Eucalyptus globulus SR	4.3	6.5	10.4	12	17	27	12
South Australia - Lofty Block	Hardwood	Eucalyptus globulus LR	5.0	7.5	10.4	12	20	25	25
Central Victoria	Softwood	Pinus radiata	5.5	8.0	14.1	12	18	27	35
Central Victoria	Hardwood	Eucalyptus globulus SR	5.3	7.3	13.9	12	18	27	12
Central Victoria	Hardwood	Eucalyptus globulus LR	6.0	8.0	13.9	14	18	25	25
Murray Valley	Softwood	Pinus radiata	5.3	9.4	12.4	12	20	27	30
Murray Valley	Hardwood	Eucalyptus globulus SR	5.3	8.6	13.0	12	16	25	13
Murray Valley	Hardwood	Eucalyptus globulus LR	6.5	9.0	13.0	12	18	25	25
Central Gippsland	Softwood	Pinus radiata	5.9	9.0	16.6	12	20	30	30
Central Gippsland	Hardwood	Eucalyptus globulus SR	5.8	10.4	16.9	12	18	27	12
Central Gippsland	Hardwood	Eucalyptus nitens LR	7.0	13.0	16.9	12	18	27	25
Bombala-East Gippsland	Softwood	Pinus radiata	6.4	11.0	14.9	12	16	27	35
Bombala-East Gippsland	Hardwood	Eucalyptus globulus SR	6.4	9.5	15.1	12	19	27	12
Southern Tablelands	Softwood	Pinus radiata	5.1	7.0	12.4	12	16	27	30
Central Tablelands	Softwood	Pinus radiata	5.3	9.0	11.7	12	16	25	30
Northern Tablelands	Softwood	Pinus radiata	6.2	9.9	16.6	12	16	25	30
Northern Tablelands	Hardwood	Eucalyptus globulus SR	4.7	8.4	16.1	12	16	25	14
Northern Tablelands	Hardwood	Nth Coast Eucs LR	7.4	11.7	16.1	12	14	20	30
North Coast	Softwood	SouthernPines	8.1	12.5	22.3	12	15	25	30
North Coast	Softwood	Hoop pine	8.1	12.5	22.3	9	13	20	40
North Coast	Hardwood	Nth Coast Eucs SR	7.6	10.8	19.6	12	18	27	12
North Coast	Hardwood	Nth Coast Eucs LR	8.0	10.8	19.6	12	18	25	35
South East Queensland	Softwood	SouthernPines	6.3	11.1	21.2	12	13	25	30
South East Queensland	Softwood	Hoop pine	6.3	11.1	21.2	8	13.4	20	40
South East Queensland	Hardwood	Nth Coast Eucs SR	6.0	9.0	21.0	12	18	27	12
South East Queensland	Hardwood	Nth Coast Eucs LR	7.0	11.5	21.0	12	18	25	35
Northern Queensland	Softwood	SouthernPines	6.7	10.4	17.5	12	13	25	30
Northern Queensland	Softwood	Hoop pine	6.7	11.8	25.0	8	13.4	20	50
Northern Queensland	Hardwood	Nth Coast Eucs SR	6.6	10.2	20.9	12	18	27	12
Northern Queensland	Hardwood	Nth Coast Eucs LR	9.0	15.0	20.9	12	18	25	35
Northern Territory	Hardwood	Acacia	6.4	8.4	11.0	20	25	35	8
Northern Territory	Hardwood	NT eucs	6.4	8.5	11.0	8	12	20	30

r = (MAVI x Rotation Length x Basic Density x Expansion Factor) / M............................(Equation 1)

A $\log_e$-$\log_e$ (ln-ln) model was then fitted to the r and P data by plantation type (hardwood/softwood) (Figure 7.D3) (Equation 2). Residuals were homogenously distributed. P, NPI region and rotation length (short or long) were found to be significant effects. A separate model based on state was also developed using the same regression to allow predictions for the small area (< 5%) of hardwood and softwood plantations identified outside the NPI regions. There was no significant interaction between NPI and rotation length and no apparent bias in the results.

$\ln(r) = b_0 + b_1 * \ln(P_{av})$ ....(Equation 2)

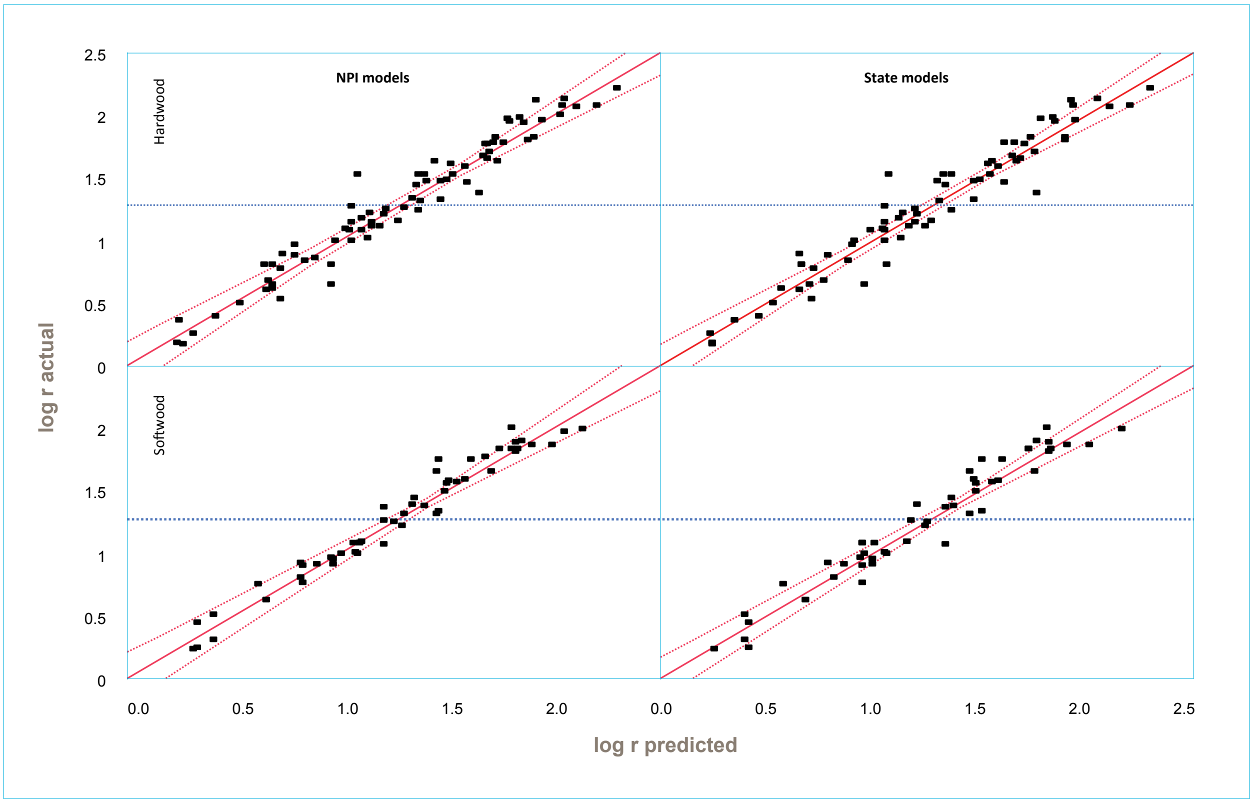
where r = non-endemic species multiplier

b_0 = value based on NPI region and rotation length (long or short)

b_1 = value based on if the plantation occurs in an NPI region or a state.

P = long-term average FPI value.

Figure 7.D 3 Actual vs predicted *r* values for hardwood and softwood plantations by State and National Plantation Inventory



The analysis showed that plantation forests established on sites with high *P* values require lower *r* values than those on sites with lower *P* values. This was expected, as plantations on low quality sites will often respond better, in percentage response, to good site preparation methods and adequate fertilizer addition (Turner, 1984; Snowdon and James, 2008), leading to a more 'even' range of carbon uptake rates compared with native systems.

The age of maximum biomass increment

The age and magnitude of maximum current annual biomass increment (Max I_B) varies with species, site productivity and management. The age of Max I_B is not typically reported in forest growth studies as it generally occurs before the age of first commercial thinning when direct measurements of stem volume are less commercially important and, hence, less frequent. However, it is generally considered that the age of Max I_B occurs at or around the time of canopy closure (Gower *et al.*, 1994; Ryan *et al.*, 1997; Law *et al.*, 2003). For the purpose of calibrating the model this was assumed to be the case.

In addition to underlying site conditions (soils and climate), fertilisation and improvements in establishment techniques over the past 30 years have reduced the age of canopy closure and promoted early growth in long-rotation plantation systems (Boomsma and Hunter, 1990; Snowdon and James, 2008). Management systems which aim for high biomass outputs with a lower concern for stemwood quality and form (i.e., short rotation pulpwood plantations) will also tend to lower the age of maximum biomass increment through high stocking rates and more intensive initial management.

In *FullCAM* the age of maximum biomass increment can be modified through direct manipulation of *G* or through applying Type 1 effects prior to *G* (see Appendix 7.A; Equation 5). Varying *G* affects both the age and magnitude of Max I_B. Where a Type 1 response is applied prior to *G* (i.e. between ages 0 and *G*), the effective age of Max I_B is lowered without affecting the magnitude of growth. The majority of management effects on early age growth, such as weed control and good site establishment methods, are modelled by applying Type 1 effects at planting. This also provides extra flexibility in adjusting stand growth based on specific management regimes. Hence, the unaffected *G* value (i.e., that with little or no management) can be calculated based on the actual age of Max I_B and the sum of Type 1 effects on early age growth due to management (Equation 3):

$G = G_{man} + T1_{pre\text{-}g}$ .... (Equation 3)

G_{man} = age of maximum biomass increment with management
G = age of maximum biomass increment assuming no management
$T1_{pre\text{-}g}$ = sum of the Type 1 age advance events applied prior to G

For native ecosystems an age of maximum current annual growth increment (CAI) of ten years is applied. Many commercial plantations are managed for aggressive early growth that shortens the period to harvest. This is most evident in short rotation (approximately ten year) pulpwood plantations. Silviculture, in particular a dense stocking rate of trees per hectare, is used to supply this early growth. In some instances this can bring the age of maximum current annual increment to being as low as 2-3 years after establishment. Each plantation type/management regime combination is assigned a specific age of maximum current annual increment based on location.

Calibration of G

Values for G were calibrated for each species within each NPI region based on rotation length and the approximate sum of Type 1 effects at planting. Canopy closure (effectively G_{man} in the model) in *P. radiata* plantations established over the last 20 years generally occurs between the ages of seven and 12 years depending on site quality and management (Snowdon and James 2008). On poor quality sites with little management or site improvement it may take even longer. Improved establishment and early age management practices adopted in the last 20 to 30 years, in particular after the late 1970's, have reduced the age of canopy closure by about two to three years (Boomsma and Hunter, 1990; Snowdon and James, 2008) and were modelled as Type 1 effects. Equation (4) was calibrated based on 'unaffected stands' by adding two years of Type 1 effect to the current age of canopy closure (Equation 3), resulting in a range of nine to 14 years for G. Regionally specific data for G and G_{man} was not available so this range was applied for all long rotation systems. However G_{man} does vary by region and time depending on management practices. Long-rotation eucalypt plantations are still relatively uncommon and little is known about their future management and prospects. Given the paucity of data it was assumed that long-rotation eucalypt plantations are similar in management to other long rotation systems, although they may reach canopy closure slightly earlier depending on growth conditions, as discussed below. To account for the effect of site productivity on G a simple linear relationship between G and M was included (Equation 4). The results of the calibration are shown in Waterworth *et al.,* (2007).

Canopy closure tends to occur much earlier in short rotation plantations due to species characteristics, higher stocking rates, more intensive management and better site/species matching. *Eucalyptus* species tend to reach canopy closure much more quickly than *Pinus* species given suitable conditions, and hence increase in mass much faster during the early stages of development (Myers *et al.*, 1996). Therefore G for short rotation plantations was set two to three years earlier than for long rotation systems.

Final model form used for post-1990 plantations

$G = s * M + c$ .... (Equation 4)

Where G = age of maximum biomass increment of unaffected stand

s = multiplier to account for site productivity

M = unadjusted maximum biomass value

c = region/species dependant intercept

The modified tree yield formula that is used to calculate forest growth for the post-1990 *plantations* sub-category is therefore:

$I_a = r * M * ((y_2 * e^{-k/d}) - (y_1 * e^{-k/d-1})) * (P/P_{av})$ .... (Equation 5)

Where

I_a =Aboveground mass increment of the trees, in t DM ha^{-1}

a = Age of trees

r = non-endemic species multiplier

M = maximum aboveground biomass (calculated from P)

y_1 =Type 2 site multiplier at age, a

y_2 = Type 2 site multiplier at age, a^{-1}

$k = 2 * G$

where G = Tree age of maximum growth

d = Adjusted age of the trees, in years
= a + sum over each treatment of

0	if $a <= W$
$v * (a – W) / U$	if $a >= W$ and $a <= W + V$
v	if $a > W + U$

where, for each Type 1 treatment,

v = the age advance due to the treatment, either positive or negative, in years

U = the advancement period, in years

W = the age, a, at which the treatment was applied, in years.

P= the actual FPI over the period d_a to d_{a-1}

P_{av}=Long term average FPI value

Stem to Whole Tree Mass Conversions

Studies on the above and belowground partitioning of biomass (Keith *et al*., 2000, Eamus *et al*., 2000, Snowdon *et al*., 2000) have shown that both above and belowground variability reduces, as do non-stem allocations, as site biomass increases. Greatest uniformity, and therefore least variability, tends to occur in even-aged and productive stands.

The ratio of stem (merchantable) quantities to non-merchantable components is particularly important for the calculation of the amounts of forest slash generated by thinning and harvesting activity. The potential accumulation of slash can make a considerable contribution to increased carbon stock, particularly on former pasture sites. Fortunately, only limited variability has been identified around age based partitioning of aboveground biomass to tree components in forest plantations, even with varying species and stocking rates. As part of the calibration process we developed an empirical approach for calculating partitioning based on the current aboveground biomass and the expansion factors of Snowdon *et al.,* (2000).
This method allows allocation to vary between sites and species within set ranges based on age, site productivity and level of stand development.

As the carbon increment estimates are based on aboveground biomass, there is a need to correct for increment in belowground biomass (roots) to provide an estimate of total live biomass. This is completed within *FullCAM*, largely using data provided in a synthesis report provided by Snowdon *et al.,* (2000) and data from a global review by Mokany *et al.,* (2006).

Carbon Contents

Studies of the carbon fractions of above and belowground biomass components for Australian vegetation were used to provide the parameters for the carbon fractions of tree components in the model (Gifford, 2000a and 2000b). Carbon fractions were examined for a range of species and growing conditions which provided a range for the carbon fractions with a recommended estimate. There was little variability in the results and more importantly no cause to suspect bias in any set of environmental conditions or plant groups. These results could be considered as robust and reliable estimates, providing little source of uncertainty in the carbon models.

Table 7.D 2 Carbon percentage (%) of tree components

Tree Component	Hardwood carbon content %	Softwood carbon content %	Other (environmental plantings) carbon content %
Stems	50.0	51.0	50.0
Branches	46.8	51.4	46.8
Bark	48.7	53.3	48.7
Leaves	52.9	51.1	52.9
Coarse roots	49.2	50.4	49.2
Fine roots	46.1	48.4	46.1

Turnover and Decomposition Rates

The turnover rates determine the amount of material being added to the debris pool. Decomposition rates determine the rates of loss of carbon back to the atmosphere as the debris breaks down. The balance of these two factors determines the amount of debris on site excluding the effects of management. The amount of carbon moved from living biomass to the dead organic matter pools due to forest harvesting is determined in the model by the age, type of harvest and species characteristics. These are shown in Attachment 7.C1.

The turnover rate of leaves and fine roots (Table 7.D3) affects both the amount of fine litter on the forest floor and subsequently most of the contribution to soil carbon. The key attributes of the assigned rates are that they are realistic and do not operate at rates high or low enough to either reduce below reasonable expectation, the mass of attached leaves and live roots, or to create unrealistically high or low levels of litter. While leaf turnover rates have been the subject of measurement and can be compared to observations, the difficulty in measuring root turnover means that there are very few reported measures against which to compare. The tree component turnover rates applied in the model were guided by work by Paul et al., (2004).

Table 7.D 3 Tree component annual turnover rates

Tree Component	Softwood Turnover yr^{-1}	Hardwood Turnover yr^{-1}
Branches	0.03	0.05
Bark	0.05	0.07
Leaves	0.3	0.5
Coarse Roots	0.07	0.1
Fine Roots	0.8	0.85

The rates of decomposition applied in the model have been guided by the work of Mackensen and Bauhus (1999). Table 7.D4 shows the decomposition rates applied.

Table 7.D 4 Debris decomposition rates

Litter Component	Breakdown Rate yr^{-1}
Deadwood	0.1
Bark Litter	0.5
Leaf Litter	1.0
Coarse Dead Roots	0.4
Fine Dead Roots	1.0

The main focus of this work was on modelling rates that coincided with measures of litter mass when the models were run over extended periods so that a reasonable balance between turnover (input to litter pools) and decomposition of litter pools was achieved.

Soil carbon

Soil carbon is estimated using the fully spatially explicit approach described in Appendix 7.A with some modifications to the base input data to suit the modelling for post-1990 *plantations*. The initial soil carbon map used for the *forest land converted to cropland* and *grassland* analyses is based on pre-clearing conditions. While this is suited to modelling the effects of clearing forest on soil carbon stocks, it is not suitable as a starting condition for lands that have been under agricultural management for some time. To account for the effects of agricultural management on initial soil carbon stocks prior to reforestation a new initial soil carbon map was derived. This map was created by assuming that all post-1990 *plantation* areas had been cleared 20 years prior to re-establishment. The Tier 3 spatial model was then run for 20 years assuming that the land was managed as grassland. At the end of the 20 years the total soil C was then calculated by the model and converted into a reforestation initial soil carbon map. On average the new initial soil carbon was lower than the initial values used for *forest land converted to cropland* or *grassland*, but the actual change varied across the country with some regions increasing and others decreasing.

Activity data

The activity data for post-1990 *plantations* is drawn from the remote sensing program (see Appendix 7.A). The remote sensing data allows the location, plantation type and time of establishment to be determined with a high degree of accuracy. The methods applied also ensure that the post-1990 *plantations* modelled in the account are directly human induced, that a conversion from another land use (grassland) has occurred (i.e., not simply recovers from previous harvest) and that only plantings after 1989 are included. This is achieved by:

- application of three pixel clusters and spatial and temporal analysis;
- applying the 1989 forest extent data as a mask (i.e., no area that was forest in 1989 is modelled);
- attribution of the plantation typing to exclude scattered natural regrowth from plantation typing, thus ensuring that only direct human induced plantations are included in this sub-category; and
- use of the *FullCAM* model to allocate pixels between years to ensure a non-biased estimate of the area of plantation established between 1989 and 1991.

A full description of the quality assurance, quality control, calibration, validation, verification and sensitivity and uncertainty analyses are reported in Appendix 7.J.

Table 7.D 5 Annual plantation area from the remote sensing program 1990 – 2010

Year	Area (ha)
1990	51,574
1991	47,520
1992	50,846
1993	54,068
1994	51,193
1995	35,125
1996	37,163
1997	34,245
1998	42,667
1999	45,770
2000	72,119
2001	81,818
2002	77,416
2003	81,709
2004	79,541
2005	55,935
2006	49,302
2007	63,065
2008	63,505
2009	47,692
2010	19,363

Management information

Forest management practices affect carbon sequestration and greenhouse gas emissions in forests and therefore need to be considered when estimating emissions and removals in forests. While remote sensing can identify some management actions, such as time of establishment and harvest (clear-cut and heavy thinning) it is less able to detect site preparation methods and continuing management actions such as weed control and light thinning, including pruning.

Forest management has varied with both time and location, depending on site and climate, species selection, market availability, desired products, research and technology developments, and political factors (Raison and Squire, 2008). The impact of management practices on greenhouse gas emissions and removals depends on their intensity, timing and on tree species characteristics. For example, the ratio of product to slash at harvesting determines how much is removed to products offsite, and how much remains on-site. The relative quantities of products and slash depend on stand age, species, available markets and products (Snowdon and James, 2008). Slash may be retained intact on-site to decay, be crushed and incorporated into the soil to promote decay, or burnt. Within each of these broad management practices, various finer scale differences also apply, for example differences in slash consumption between broadcast burning or windrow and burning.

There are few publications documenting the history of forest management in Australia (exceptions being Florence, 1996 and Boomsma *et al.*, 1997). Most information is either in literature such as annual reports, technical reports (e.g., Lewis *et al.*, 1976), or held as corporate knowledge. While a valuable qualitative resource, little of this information has been available for a quantitative analysis, especially at the continental scale. A recent report by Raison and Squire (2008) details the history of native and plantation forest management in Australia since 1945, and makes available quantitative information such as previous land use, thinning intensity and establishment methods.

For each plantation species, Raison and Squire (2008) detail information on the types of management practices applied and where and when they were applied. This includes information on site establishment methods, weed control, pruning and the number, timing and intensity of thinnings. The report also outlines time-series information for each region, detailing when and why changes in management occurred (e.g., improved silviculture and changes in available markets) and how this affected the destination of forest products. Information on new plantation types not covered by Raison and Squire (2008) were obtained through annual reports or direct contact with forest management organisations (e.g., state agencies and plantation companies).

To allow the effects of ongoing management to be represented within the Tier 3, Approach 3 modelling system a comprehensive database of the plantation management practices used in Australia since 1970 was implemented (Waterworth and Richards, 2008). The plantation management database contains information on management practices for each tree species within each region. It then creates full management regimes based on known practice. These management regimes are spatially and temporally referenced to allow them to link to the spatially explicit identification of plantations and vary with region, species, site productivity and previous land-use. The management regimes are assigned frequencies relative to the frequency of the range of plantation regimes within each region (Figure 7.D4). This allows time series management regimes to be developed for each plantation pixel through time (Figure 7.D4 (b)). The range of possible management actions is shown in Table 7.D6.

Table 7.D 6 Management actions, the *FullCAM* events used to represent them and the choices available through parameterisation of the *FullCAM* event

Management action	FullCAM event type	Effect in model	Standard event options
Mechanical weed control	Plow (agriculture)	Moves herbaceous species carbon to debris, mulch and soil	Spot Strip Broadcast
Chemical weed control	Herbicide event (agriculture)	Kills herbaceous species cover, moving it to debris	Spot application Strip application Broadcast application
Chopper roll	Chopper roll (forest)	Transfers woody debris to faster decaying 'chopped wood' pool	Chopper roll
Management fires	Forest fire (forest)	Transfers carbon from trees to debris and atmosphere, and debris to the atmosphere or soil pools.	Prescribed burn Broadcast burn Windrow and burn
Wildfire1	Forest fire (forest)	Transfers carbon from trees to debris and atmosphere, and debris to the atmosphere or soil pools.	Trees killed Trees not killed
Grazing	Graze (agriculture)	Removes aboveground herbaceous species mass and varies root slough	Normal Heavy
Plant trees	Plant trees (forest)	Establishes trees on a site	Different initial masses depending on stocking
Cultivation	Plow (agricultural)	Moves herbaceous species carbon to debris, mulch and soil	Spot cultivation Strip cultivation Broadcast cultivation
Forest thin and harvest and pruning	Forest thin (forest)	Moves tree components to products or debris, debris to bioenergy	Varies by time, species and region.
Fertiliser application2	Type 1 or 2 event (forest)	Varies tree growth based on the type and intensity of fertilisation (see Snowdon, 2002).	Normal N fertilisation Applied to any treatment that affects tree growth
Fertiliser application3	Fertiliser application (forest and agriculture)	Adds N to the mineral N pool	Different levels of N addition (kg ha^{-1})

[1] Although not a management practice, wildfire events allow for the future spatial modelling of their effect on carbon stocks. See the discussion for more details.

[2] *FullCAM* only requires kg N ha^{-1} when using the nitrogen cycling model capacity.

[3] Applies only when using the nitrogen cycling model capacity.

Source: Waterworth and Richards, 2008

Figure 7.D 4 (a) Each regime is assigned a relative frequency

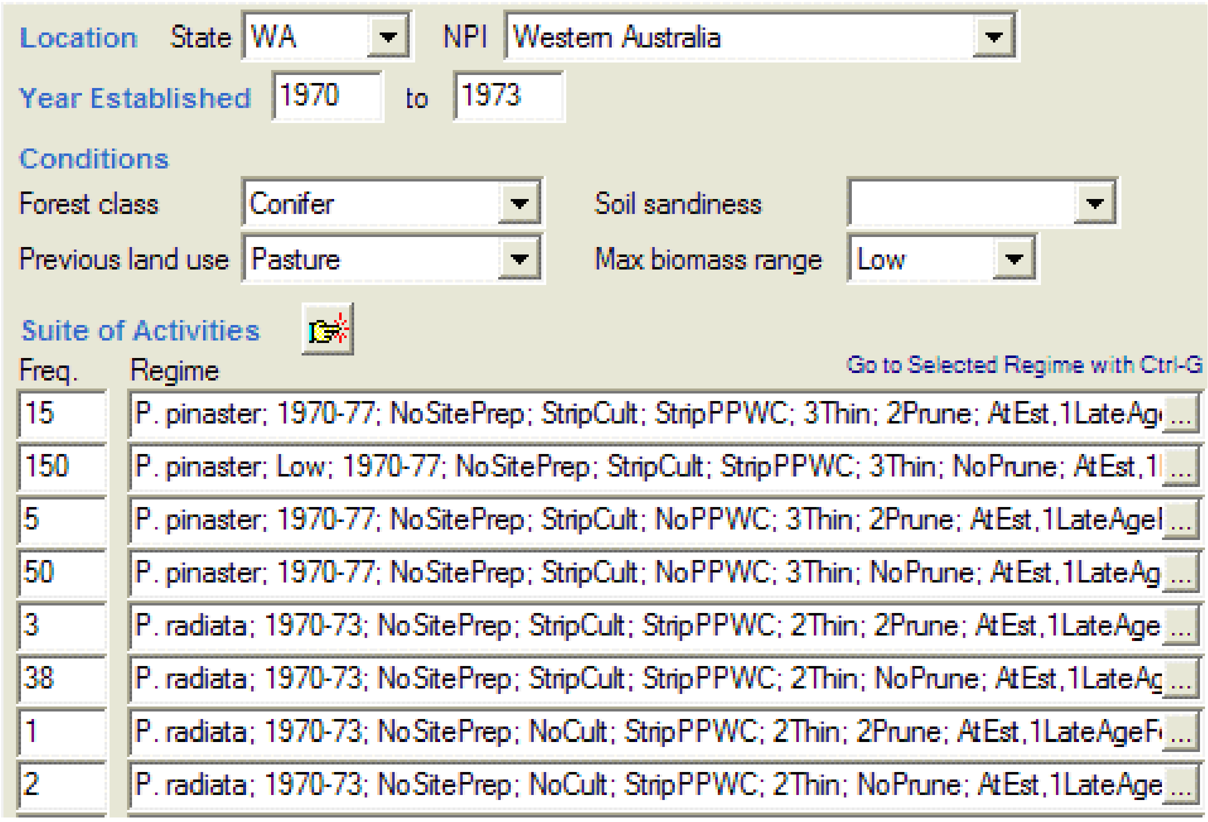


Figure 7.D 4 (b) time series of management regimes to be developed.

Year	Day	Species	Management action	FullCAM event
0	152	Agricultural species	Cultivation: Strip plow	Plow
0	166	Agricultural species	Weed control initial: Blanket herbicide	Herbicide
0	196	Pinus radiata	Plant trees: seedlings normal stocking	Plant trees
0	196	NA	Forest percentage -> determined by tree yield formula	Forest percentage Change
0	196	Pinus radiata	Weed control - Standard (All 1980-present)	Type 1 Forest Treatment
0	196	Pinus radiata	Starter fertiliser - normal	Type 1 Forest Treatment
1	196	Agricultural species	Weed control post planting: Strip herbicide	Herbicide
10	196	Pinus radiata	Thin 1 (SthnTbl ACT 1978-1996)	Forest Thin
10	196	Pinus radiata	Fertilisation: Mid-rotation (Medium)	Type 1 Forest Treatment
10	197	Pinus radiata	Prune (Selective 33%)	Forest Thin
20	196	Pinus radiata	Thin 2 (SthnTbl ACT 1978-1996)	Forest Thin
20	196	Pinus radiata	Fertilisation: Mid-rotation (Medium)	Type 1 Forest Treatment
30	196	Pinus radiata	Thin 3 (SthnTbl ACT 1987-1996)	Forest Thin
40	196	Pinus radiata	Thin clearing Pa (SthnTbl ACT 1987-1996)	Forest Thin

Source: Waterworth and Richards, 2008

The species table contains information on tree species characteristics including forest growth model parameters, carbon allocation to tree components over time, biomass carbon percentages, basic wood density, turnover rates for each tree component, decay and product use data. These data allow *FullCAM* to model forest growth for any point based on the site and climate data using the methods described previously.

Each species has a series of uniquely parameterised management practices (standard events) that affect plant growth, carbon stocks and greenhouse gas emissions. The standard event parameters may be either similar, within and between species, or different, where management varies. When, and in what order, standard events occur is determined by the management regime as discussed previously (Figure 7.D4).

The plantation management database currently consists of around 5,000 regimes each comprising 10-30 events. To be comprehensive for management regimes, many regimes are described that may only occur rarely.

Fertiliser Use

Nitrous oxide released from the application of N fertiliser on forests is reported as IE (agriculture). The amount of N applied to lands in Australia is obtained from national statistics of the amount of N purchased. It is not possible to split the use of N fertiliser between agriculture and forests.

Nitrogen fertilisation of native forests is very rare, if occurring at all. There is a limited amount of N fertiliser applied to forest plantations in Australia. Fertiliser application in plantations is typically done to correct for nutrient deficiencies and trace element correction at establishment. N may be applied on sites where it is shown that it is a significant limiting nutrient, but as most establishments are on pasture systems, background nutrient levels are typically sufficient.

Calculation of emissions and removals

Each individual 25 m x 25 m pixel identified as being a post-1990 *plantation* is modelled through time from the time of establishment. Each 25 x 25 m model takes into account the age, plantation type, management and site conditions to estimate emissions and removals. The national account for any one year is the sum of all the pixels being actively modelled. A full description of this form of spatially explicit modelling is provided in Appendix 7.A.

APPENDIX 7.E: OTHER NATIVE FORESTS

Background

The *other native forests* sub-category includes all areas of forest that are not *plantations* (see Appendix 7.C), not *harvested native forests* (see Appendix 7.B) and have not been subject to deforestation (*forest land converted to cropland* and *grassland*; Appendix 7.F). The *other native forests* sub-category includes protected areas (such as Wilderness areas and National Parks) not previously subject to harvesting and areas of extensive forests and woodlands. Australian vegetation is adapted to frequent disturbances, such as recurrent fires, and the effects of extreme climate variability (in particular, droughts). The influences on annual emissions and removals that are likely to affect *other native forests* include:

- fire;
- thickening and dieback;
- annual climate variability;
- selective extraction of forest products;
- grazing; and,
- recovery from pre-1972 land use change.

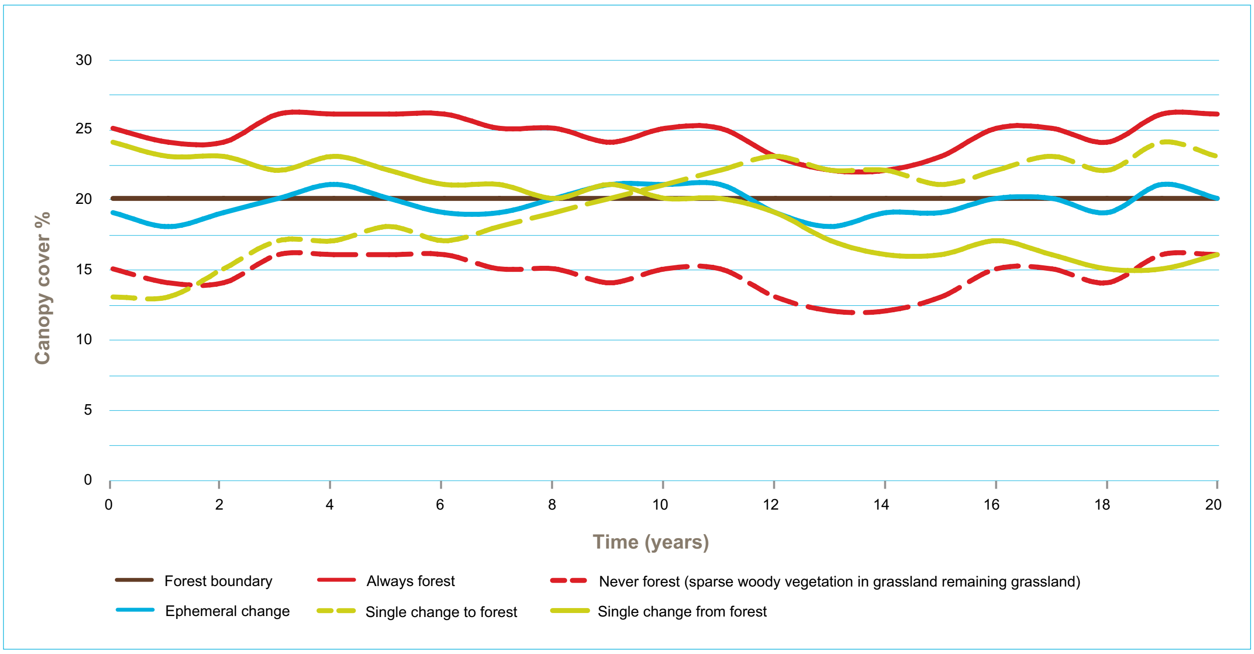
As most of the emissions and removals from these activities are driven by natural variability and natural disturbance, the effects are:

- generally cyclic in terms of disturbance and recovery patterns over time;
- typically regionally specific because differences in climate and ecosystem type imply different stages of disturbances and recovery at different times; and,
- not expected to exhibit consistent trends toward either emissions or removals over the longer term, but will be highly variable over shorter time periods.

Trends in Forest Vegetation Cover in Other Native Forests

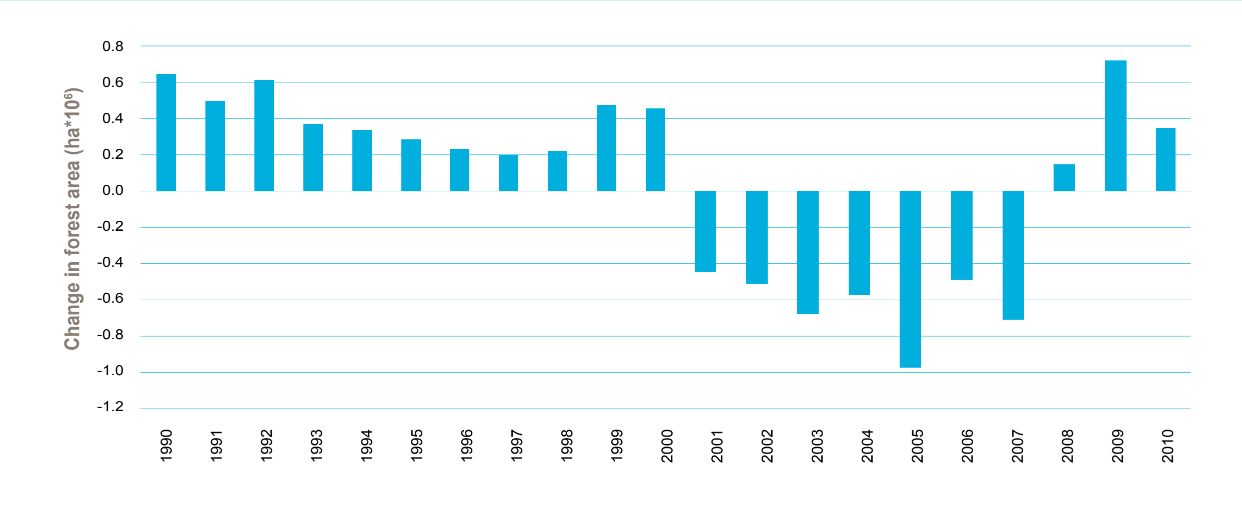
The mixture of climate effects, grazing, fire and recovery from land use change, and the regional differences in these processes gives rise to variability in forest cover over time. Figure 7.E1 shows the typical fluctuations in forest cover that occur around the prescribed canopy cover definition of a forest (20% in Australia).

Figure 7.E 1 Patterns of change in forest cover in areas of *Other Native Forest*



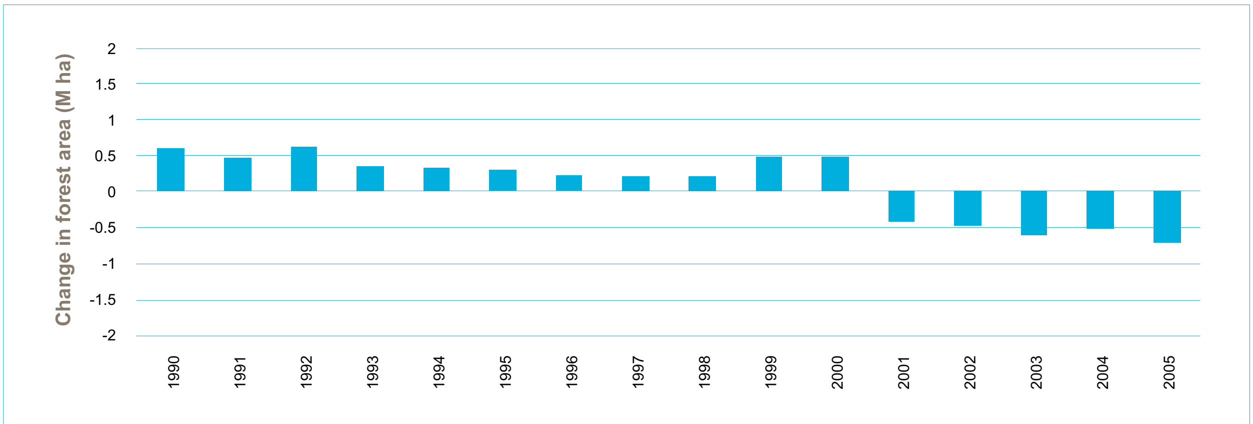
For the areas that exhibit a loss or gain in the area of forest, it is possible to extract these data from the time-series of remotely sensed data. Figure 7.E2 below shows the net national gains and losses in forest cover in *other native forests* since 1972. This represents the areas of forest cover change not assessed as being a land use change.

Figure 7.E 2 Change in forest area (Mha) not attributable to land use change and included in *Other Native Forests*, since 1990

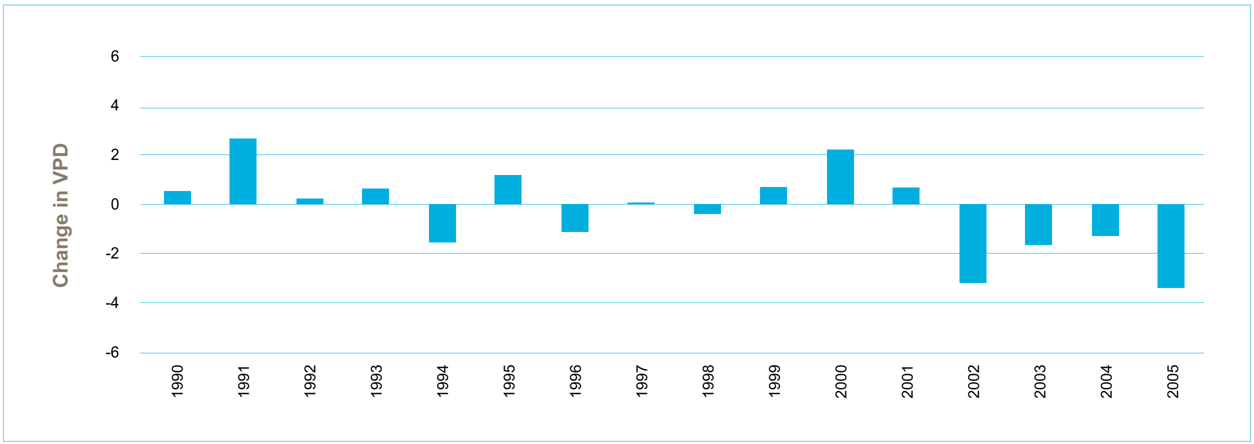


One of the first ways to contemplate attribution to a 'cause' for loss or gain is to look at the correlation of change with climate variation. This can be done at a national scale by comparing the gains and losses of forest area not attributable to anthropogenic land use change with a key climate variable of tree stress, such as vapour pressure deficit. Notably, at this coarse national scale there is a statistically significant ($p < 0.01$, $r^2=0.67$) association between vapour pressure deficit and change in forest cover (Figure 7.E3).

Figure 7.E 3 (a) Annual change in forest area.

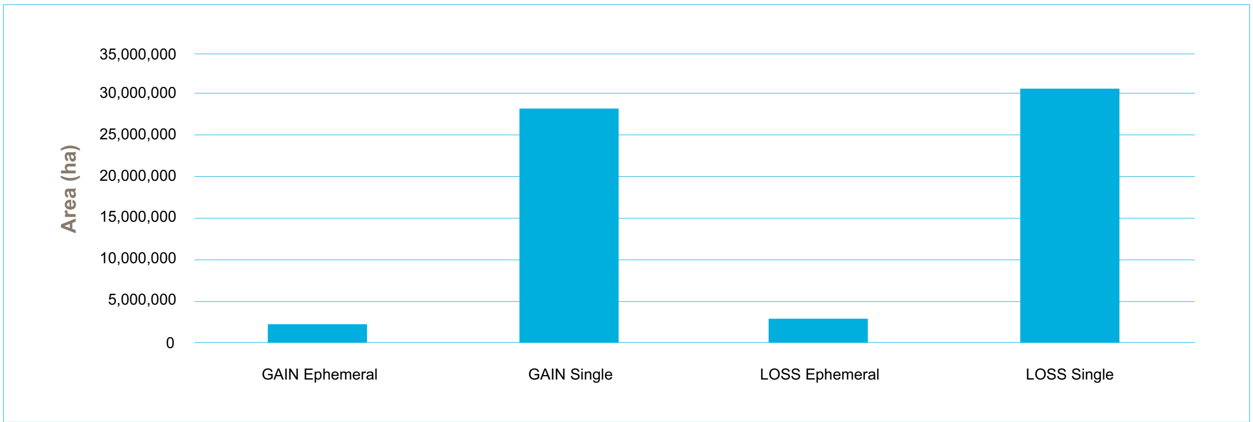


(b) Variation of Vapour Pressure Deficit (VPD) from long term average



To estimate emissions, it is of significance whether these changes in forest cover are persistent changes on different areas of land, or whether they are intermittent and ephemeral changes on the same areas of land. To resolve this question, the areas affected by non-anthropogenic change in forest area were analysed to determine the proportion that were impacted by a single observed change in the remote sensing time series, or intermittent change. The process used to separate the human caused land use change areas from natural cycles in forest cover change is described in Appendix 7.A. Figure 7.E4 shows that the proportion of areas affected by a single change (a single transition in either direction) compared to intermittent and ephemeral change (more than one transition) is around 8%.

Figure 7.E 4 Areas of forest to non-forest transitions and non-forest to forest transitions that are single (one transition only) and ephemeral (more than one transition) at some time in the time series of remotely sensed data



The importance of the information on the number of transitions to the estimation of emissions is that:

- a single transition (loss or gain) usually indicates the longer-term (e.g., not seasonal) loss or establishment of a long-term forest system unless it occurs at the end of the time series; and,
- multiple transitions are indicative of ephemeral changes, likely affecting only leaf mass and with negligible emissions or removal consequences.

For the second component of *other native forests*, (those that have continuously been forest since 1972) the process of emissions and removals is determined by the combination of variation in patterns of densification and degradation. This must be accounted for using both the temporal and spatial approaches.

Methodology

The estimates of emissions and removals in *other native forests* consist of several sub-models. The five components of the estimate of emissions and removals are:

- ephemeral, intermittent changes in forest cover (i.e., forest and non-forest transitions) due to changes in leaf area;
- changes in leaf area in areas of continuous forest cover (i.e., no change in forest status);
- single changes in forest cover (i.e., forest and non-forest transitions) through dieback and regrowth;
- woody thickening; and,
- emissions and removals of CO_2 through wildfire and prescribed burning.

Annual changes in foliage mass

The thinning and flushing of tree crown cover with climate fluctuation is a common feature of Australian forests. As the change is not persistent, it is presumed that there is no significant tree mortality or seedling recruitment beyond normal levels. With extensive areas of forest just at the lower crown cover threshold, annual climate variability can move substantial areas of forest under and over the forest threshold (2 metres height and 20% crown cover density) value, with only a small loss or gain of leaf mass. In areas of thicker forest, changes in leaf mass will not lead to changes in forest cover, but will still lead to small amounts of emissions and removals. These two processes, although driven by the same factors, are modelled separately as ephemeral, intermittent changes in forest cover, and changes in leaf area of continuous forest cover.

Ephemeral, Intermittent Change in Forest Cover

The proportion of forest cover that is subject to ephemeral, intermittent change is around 8% of the total non-anthropogenic change identified using the forest extent data obtained from the Landsat analysis (Appendix 7.A). For these lands a Tier 2 model is used to estimate emissions and removals due to changes in forest cover. The method assumes a total change of 0.15 t DM ha^{-1} yr^{-1} for both losses and gains, and a carbon content of 50%. The estimate of 0.15 t DM per hectare is based on an estimated aboveground biomass of 30 t DM for dry forests at the edge of the forest/non-forest boundary (based on Raison *et al*., 2003), with 2% of the aboveground mass being leaf, and a total potential loss or gain of 25% of the leaf mass with climate variability.

Changes in Leaf Area of Continuous Forest Cover

In many areas of *other native forests* there are intermittent changes in forest cover, largely attributed to changes in leaf area with climate variability. Despite the change, the forest crown cover may not move to a level below the lower threshold used to define a forest condition, i.e., the area remains a forest.

As the change is due to fluctuations in leaf area (and leaf mass) but not the woody component of trees, the effect on emissions and removals is short-lived and sporadic, as the carbon stock losses are small and recovery rapid. For this class of change in forest cover, both losses and gains are considered to take place within the one year. The parameters used in the Tier 2 model developed are shown in Table 7.E1. This method assumes a maximum change in leaf mass of 0.2 t C ha^{-1} between the maximum and minimum leaf area index (LAI) values. When the average LAI declines, leaf mass is lost and when LAI increases leaf mass also increases. The amount of loss or gain depends on the change in LAI.

Table 7.E 1 Parameters used to estimate emissions and removals from changes in leaf mass in areas of forest cover

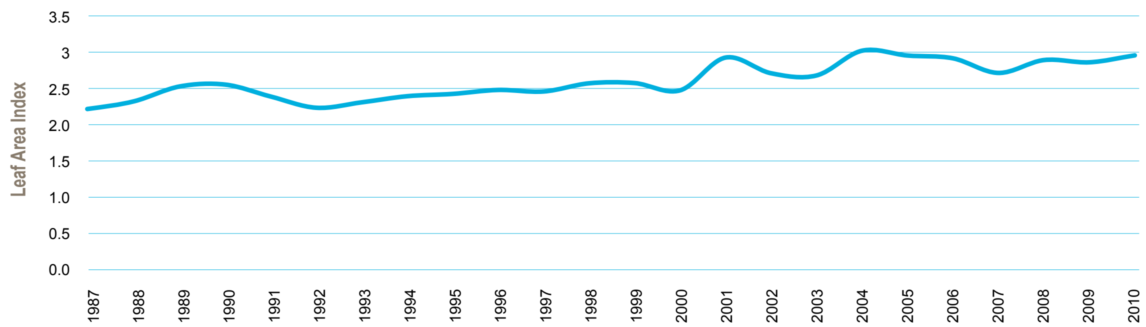
Parameter	
Max LAI	3.05
Min LAI	2.23
LAI range	0.82
Leaf mass range (t C ha^{-1})	0.20

Australia is working on the development of methods for the time-series mapping of forest crown cover density that can be extracted from the existing Landsat data archives. However, until the development of the methods is complete, the best estimate of changes in forest crown cover through time can be obtained by:

- calculating Leaf Area Index (LAI) from the time-series of Normalised Difference Vegetation Index of the AVHRR, NOAA satellite sensor using equation (10) presented in Kesteven *et al.*, (2004);
- intersecting the LAI data with forest extent (that is, only include areas of continuous forest cover as determined from the 25 m Landsat data); and,
- summing and averaging the monthly LAI values to give annual, national LAI value.

The time-series trend in LAI for areas of continuous forest cover is shown for the period where the LAI data series is available (i.e., since 1987) (Figure 7.E5).

Figure 7.E 5 Time-series national annual leaf area index



Permanent loss and gain of forest cover

This category is for areas where there is a single change in forest extent, as either a loss or a gain throughout the observed time-series. This represents either a gain or loss of forest cover in independent areas. The emissions and removals for these areas reflect a change in forest cover, even in the absence of a land use change. A long term effect is more likely to result from changes in woody biomass than the ephemeral changes that affect only leaf mass as reported in the previous section. The Tier 2 model developed for the estimation of emissions of change from these sustained effects uses the parameters shown in Table 7.E2. A carbon increment value of 0.5 t C ha^{-1} yr^{-1} (Lucas *et al.*, 1997) is used, as most of these changes are occurring in drier, degraded woodland systems. The model assumes that carbon is lost or gained for 20 years following inclusion or removal of the forest from the national forest area. This reflects both the slow uptake of carbon in regrowing systems and continuing decline and emissions from areas which fall below the forest threshold.

Table 7.E 2 Parameters used in the model of single change in forest cover

Parameter	
Total C loss/gain from single change (t C ha^{-1})	10
Years over which C is lost	20
Years over which C is gained	20
Effective growth rate (t C ha^{-1} yr^{-1})	0.5
Effective loss rate (t C ha^{-1} yr^{-1})	0.5

Woody thickening

Some studies in Australia have indicated a trend towards 'woody thickening' in some Australian forests (e.g. Burrows *et al.*, 2002; Gifford and Howden 2001). Where this thickening is occurring it is likely to lead to carbon uptake. Conversely, other studies have found evidence of widescale dieback and degradation (Fensham *et al.*, 2008), which would lead to decreasing carbon stocks and increased emissions.

An estimate of the area subject to woody thickening was derived based on the results of both Burrows *et al*., (2002) and Fensham *et al*., (2008). The regional coverage of the Burrows *et al.,* (2002) study is limited and is only considered representative for 71% of the 27 Mha of south east Queensland woodlands (19.1 Mha). Based on the work of Fensham *et al*., (2008), this area estimate was reduced by 50% to account for dieback and degradation. The total area used in the woody thickening model is therefore 9.55 Mha.

Burrows *et al*., (2002) estimated an average aboveground biomass increment of 0.25 t C ha^{-1} for areas subject to woody thickening. This was adjusted to include belowground biomass by applying a root:shoot ratio of 0.4 based on Snowdon *et al*., (2000). This results in a total growth of 0.35 t C ha^{-1} per year, which is equivalent to 1.28 t CO_2 ha^{-1} yr^{-1}.

The calculation for the woody thickening component of *other native forests* (that have always been forest) is therefore 9.55 Mha * 1.28 t CO_2 ha^{-1} yr^{-1} = 12.2 Mt CO_2 per year. This value is applied for each year in the inventory.

Fire

The *other native forests* category includes CO_2 emissions from both prescribed burning and wildfire. Prescribed burning includes managed fires that aim to reduce debris loads in *other native forests* and is typically low intensity, only removing fine litter from the forest. Wildfires are uncontrolled fires and can range from low intensity burns which remove fine litter through to high intensity wildfire which can remove most debris as well as foliage and small branches. While it is rare in Australian native systems for a fire to be 'stand-replacing', even in instances where this occurs, carbon from live biomass is typically transferred to coarse woody debris. High levels of combustion are typically confined to 'fines' such as grasses, leaves and twigs. Even under the most intense fire, most stems will remain.

The emissions caused by fire are affected by the areas burnt, the combustion efficiency of fires and micro-scale climate condition (e.g., wind, local temperatures and topography). The rates of recovery (removals) after fire vary with climate, ecosystem type, previous fire history and site conditions. As fires often remove only fine debris and leaves from live biomass, the recovery can be quite rapid. The estimation of CO_2 emissions from forest fires and CO_2 removals from recovery in *other native forests* is based on the areas burnt (Figure 7.E6), and parameters and input data developed for the estimation of non-CO_2 emissions from *forest land* in section 7.12.1.1. The debris mass recovers within five years, with a typical rapid input of scorched leaf and bark material.

For forest fires the total mass of fuel burnt is calculated as:

$$M_{jk} = A_{jk} * FL_{jk} * Z_{jk} * 10^{-3} \quad \text{.......} \quad (1)$$

Where: A_{jk} = area of category burnt annually (ha),

M_{jk} = mass of fuel burnt annually (Gg),

FL_{jk} = fuel loading (dry weight) (Mg ha^{-1}) (Table 7.12 and 7.14),

Z_{jk} = burning efficiency (Table 7.14).

Annual CO_2 emissions are calculated as:

$$E_{ijk} = M_{jk} * CC_{jk} * C_i \quad \text{.......} \quad (2)$$

Where: E_{ijk} = annual emission of gas *i* from biomass burning (Gg),

M_{jk} = mass of fuel burnt annually (Gg yr^{-1}),

CC_{jk} = carbon mass fraction in vegetation (Table 7.15,

C_i = 3.67 factor to convert from elemental mass of gas species *i* to molecular mass.

Annual CO_2 removals are calculated as:

$$R_{ijk} = \sum(M_{jk} * CC_{jk}) / t * C_i \quad (3)$$

Where: R_{ijk} = annual removals of CO_2 following biomass burning *(Gg),*

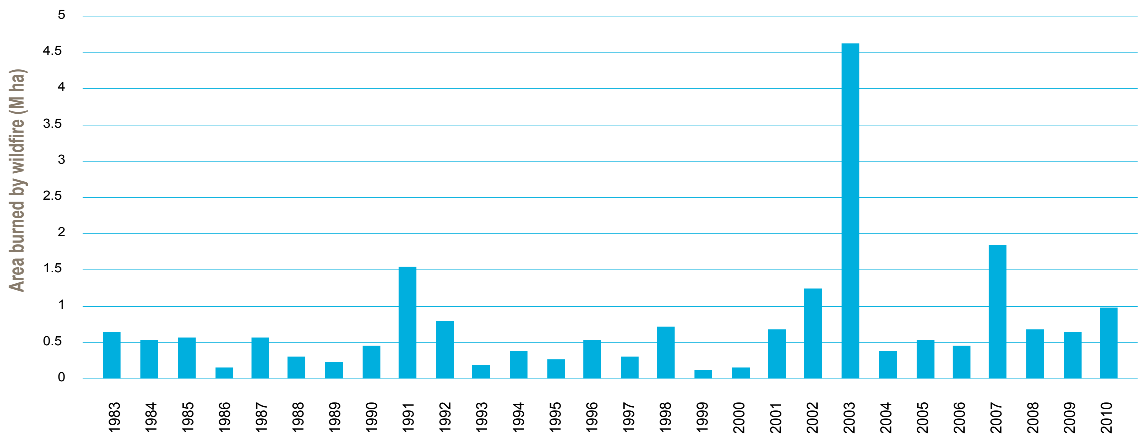
$\sum M_{jk}$ = mass of fuel burnt over period t,

t = time required for carbon lost due to fire to be recovered (assumed to be 5 years),

CC_{jk} = carbon mass fraction in vegetation (Table 7.11),

C_i = 3.67, factor to convert from elemental mass of gas species *i* to molecular mass.

Figure 7.E 6 Areas burned by wildfire 1983-2010



Results

The annual emissions and removals from *other native forests* are highly variable due to the effects of natural variability and disturbance (Table 7.E3). Emissions and removals from the change in leaf area (leaf mass) of continuous forests are highly variable, responding on annual timescales to climate variability. For the period 1990 to 2010 emissions estimation for the single change in forest cover, the model indicates a net removal (sink) due to the increase in new forest area from the late 1970s until 2000 (Figure 7.E2). The decrease in forest area since 2000 is yet to offset the area gains of the previous 20 years. Emissions from fire are highly variable and contribute the majority of variation in emissions and removals for the *other native forests* category.

Table 7.E 3 Results of the estimates of annual emissions and removals in *other native forests*

Year	Emissions (Mt CO_2)					
	Ephemeral change in forest	Leaf mass change in continuous forest	Single change in forest	Woody Thickening	Fire	Total
1990	-0.01	-2.19	-4.11	-12.20	4.63	-13.89
1991	-0.01	14.38	-4.88	-12.20	58.91	56.20
1992	-0.01	13.50	-5.85	-12.20	5.60	1.04
1993	-0.01	-6.53	-6.94	-12.20	-23.63	-49.31
1994	-0.01	-7.37	-7.20	-12.20	-10.79	-37.57
1995	-0.01	-2.78	-7.61	-12.20	-18.37	-40.97
1996	0.00	-4.77	-8.55	-12.20	-4.88	-30.41
1997	0.00	1.86	-9.62	-12.20	-3.04	-23.01
1998	0.00	-9.84	-9.86	-12.20	14.47	-17.43
1999	-0.01	-0.29	-10.56	-12.20	-16.01	-39.06
2000	-0.01	8.79	-10.94	-12.20	-11.17	-25.53
2001	0.01	-39.12	-10.01	-12.20	13.45	-47.87
2002	0.01	18.54	-8.86	-12.20	39.36	36.85
2003	0.02	2.61	-7.51	-12.20	188.60	171.51
2004	0.01	-28.66	-6.42	-12.20	-46.89	-94.15
2005	0.02	5.47	-4.94	-12.20	-42.88	-54.53
2006	0.01	3.13	-3.82	-12.20	-51.48	-64.36
2007	0.02	16.32	-2.41	-12.20	20.10	21.83
2008	0.00	-14.33	-2.35	-12.20	-46.84	-75.72
2009	-0.01	2.51	-1.43	-12.20	-2.96	-14.10
2010	-0.01	-7.80	-0.93	-12.20	10.31	-10.63

APPENDIX 7.F: FOREST CONVERSION TO CROPLAND AND GRASSLAND

Introduction

Emissions estimates from *forest land* converted to a non-forest land are based on the use of a mass balance, process-based ecosystem model (Tier 3) in a fully spatially explicit land representation (Approach 3). The areas and timing of forest conversion are identified through a national time-series of Landsat satellite data.

The data used for *forest land converted to grassland* and *forest land converted to cropland* are reported below. The descriptions are framed around the program areas of Australia's land sector emissions reporting capabilities that provide the required input data. A full description of the methods used is provided in Appendix 7.A.

Model configuration

The *FullCAM* model is used for estimating emissions from the *forest land converted to grassland* and *forest land converted to cropland* sub-categories. For these sub-categories *FullCAM* operates in its fully spatially explicit (Approach 3) mode using Tier 3, mass-balance modelling. The model runs in a mixed configuration (i.e., both forest and agricultural systems) using the *CAMFor, CAMAg* and *Roth-C* sub-models as shown in Table 7.F1. Initial biomass and tree growth is established using the approaches outlined in Appendix 7.A. A description of the sub-models, how they are linked to ensure mass balance, and their performance is also provided in Appendix 7.A.

Consistent with the treatments of *forest land* conversion under the IPCC *Good Practice Guidance* (IPCC, 2003), only areas that have been affected by a relevant land cover change are accounted for. This includes land cover change in previous years (since 1972) which can have a 'lagged' impact on carbon stock. Once an area of land is identified as being subject to conversion its status is subsequently tracked through time.

To support this form of *FullCAM* model implementation, a series of tabular and spatial databases are used, including:

Maps

i. nineteen sequences of both clearing and regrowth 1972-2010 (25 m);
ii. an initial 1972 forest/non-forest mask (25 m);
iii. monthly rainfall maps of Australia since 1968 (1 km);
iv. monthly average temperature maps of Australia since 1968 (1 km);
v. annual top-soil moisture deficit maps of Australia since 1970 (1 km);
vi. a long-term average productivity (index) map of Australia (250 m);
vii. annual productivity maps of Australia since 1970 (1 km);
viii. a soil clay content map of Australia (250 m);
ix. a pre-disturbance soil carbon content map of Australia (250 m);
x. a maximum forest biomass (biomass at maturity) map of Australia (250 m); and,
xi. a forest type (MVG) map of Australia (200 m).

Tabular Data (from the FullCAM relational database)

i. forest type attributes (e.g., partitioning and density);
ii. forest litter amounts and characterisation;
iii. land use allocations (to allocate cleared land to an agricultural land use based on the time of clearing, soil type and region);
iv. soil fractionation scheme for each soil type;
v. crop type attributes (e.g., harvest index and yield); and,
vi. crop management (activities, sequencing and timing for land use systems).

Table 7.F 1 *FullCAM* configuration used for the *Forest Land* to *Cropland* and *Grassland* sub-categories

Component	Forest	Agriculture
Living biomass	CAMFor – Forest Productivity Index and Tree Yield Formula	CAMAg – Crop yield tables
Dead organic matter	CAMFor	CAMAg
Soil carbon	Roth-C	Roth-C
Offsite products	NA	NA

Data used

Land Cover Change

The area of land that is converted from forest to crop and grassland is obtained from Australia's remote sensing programme described in Appendix 7.A. These data provide the timing and location of change since 1972. The spatially explicit nature of these data allow for the pixel by pixel (Approach 3) modelling of *forest land converted to cropland* and *grassland* across the landscape. The long time-series of data also allows for the identification of cyclic clearing/regrowth cycles that are common across much of Australia's drier inland regions (AGO, 2000a).

Climate and Soil Inputs

Climate variation has a significant effect on emissions in the short term, and as many management and reporting issues also relate to short term changes, it is important to be able to account for this variability. The process-based models integrated into *FullCAM* (e.g., *Roth-C*) use the climate data described in Appendix 7.A. to reflect this variability. The methods used to develop the climate surfaces are detailed in Kesteven *et al*., (2004). Soil inputs to the model are soil type (for fractionation), clay content and the initial topsoil moisture deficit. These affect the amount of carbon in each soil fraction (e.g., RPM, DPM) and the subsequent rates of loss or gain in soil.

Crop Growth and Plant Parameters

Crop Yield and Residue (CAMAg)

The amount of plant residue input to litter and soil carbon pools is a significant determinant of total site carbon and trends in soil carbon over time (Janik *et al*., 2002) (Figure 7.F1). Therefore, reliable crop growth information (supported by management practice information as management practice affects residue generation) is important for robust soil carbon estimation. The crop growth data used in the model are based on crop yield statistics obtained annually from ABARES and collated by CSIRO. The available crop data are usually expressed in terms of the mass of the saleable product component of growth (e.g., tonnes of grain, cane, leaf yield per hectare or tonnes of total aboveground yield per hectare). Available data have been reviewed to develop the appropriate corrections for each plant type to enable conversion from mass of saleable product to total plant mass. The crop types and plant partitioning used in the modelling are shown in Table 7.F2. Where crop yield data are not readily available the crop yield data are estimated using plant growth model outputs.

The crop yield data are updated annually by CSIRO. The data are then incorporated into the *FullCAM* relational database so that it can be accessed during modelling for each cropping system at the relevant time, IBRA region and soil type.

Figure 7.F 1 Overview of the Crop Growth and Plant Parameters Program

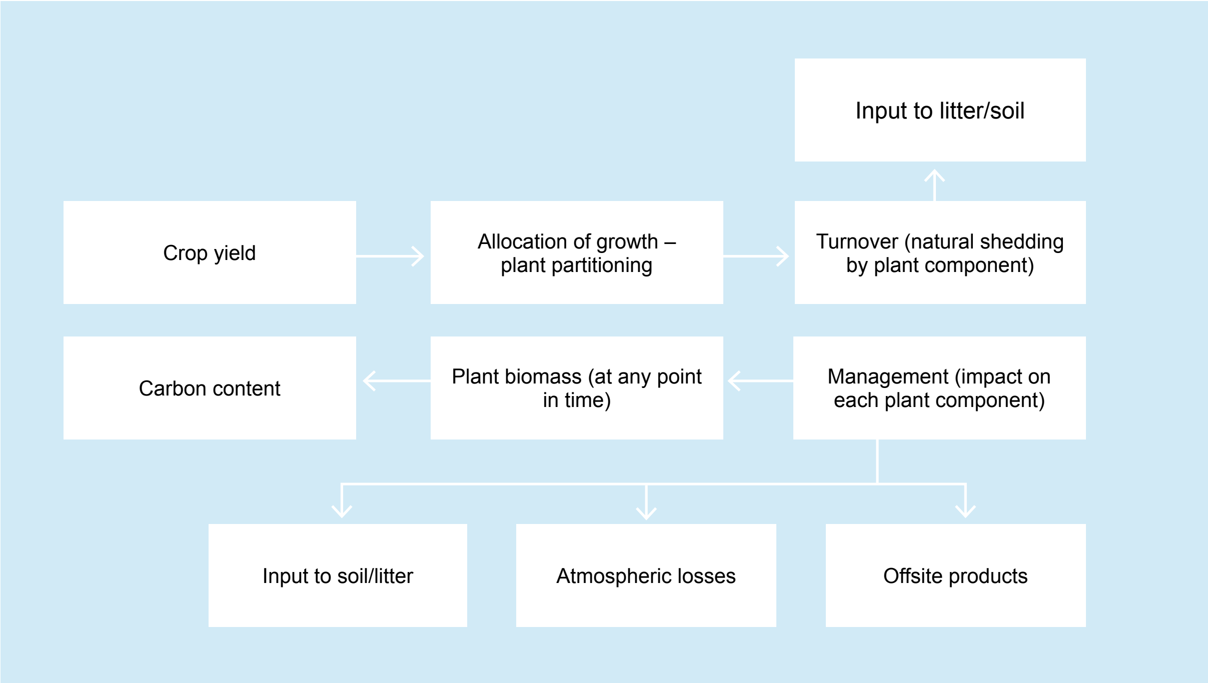


Table 7.F 2 Plant partitioning by crop type

Name	Yield Allocation to Grains, Buds or Fruit (fraction)	Yield Allocation to Stalks (fraction)	Yield Allocation to Leaves (fraction)	Yield Allocation to Coarse Roots (fraction)	Yield Allocation to Fine Roots (fraction)
Agricultural crops	0.28	0.00	0.42	0.00	0.30
Annual pasture	0.00	0.00	0.50	0.00	0.50
Annual pastures	0.00	0.00	0.50	0.00	0.50
Barley	0.30	0.00	0.40	0.00	0.30
Canola	0.27	0.00	0.51	0.00	0.22
Cereal	0.27	0.00	0.43	0.00	0.30
Cereal forage	0.00	0.00	0.60	0.00	0.40
Cereals	0.26	0.00	0.43	0.00	0.31
Cleared improved pasture	0.00	0.00	0.50	0.00	0.50
Continuous pasture	0.00	0.00	0.50	0.00	0.50
Crop	0.27	0.00	0.43	0.00	0.30
Cropping (e.g. barley)	0.24	0.00	0.46	0.00	0.30
Fallow	0.20	0.20	0.20	0.20	0.20
Grain sorghum	0.29	0.00	0.41	0.00	0.30
Grass pasture	0.00	0.00	0.50	0.00	0.50
Horticulture	0.00	0.00	0.30	0.60	0.10
Improved pasture	0.00	0.00	0.50	0.00	0.50
Irrigated cotton	0.25	0.25	0.30	0.10	0.10
Legume	0.00	0.00	0.50	0.00	0.50
Legume crop	0.30	0.00	0.48	0.00	0.22
Lucerne	0.00	0.00	0.50	0.00	0.50
Lupins	0.23	0.00	0.55	0.00	0.22
Maize	0.34	0.32	0.09	0.00	0.25
Pasture	0.00	0.00	0.50	0.00	0.50
Pasture permanent	0.00	0.00	0.50	0.00	0.50
Peanut	0.35	0.00	0.35	0.00	0.30
Poppies	0.25	0.20	0.35	0.00	0.20
Pulse	0.30	0.00	0.48	0.00	0.22
Root vegetables	0.00	0.00	0.30	0.60	0.10

Name	Yield Allocation to Grains, Buds or Fruit (fraction)	Yield Allocation to Stalks (fraction)	Yield Allocation to Leaves (fraction)	Yield Allocation to Coarse Roots (fraction)	Yield Allocation to Fine Roots (fraction)
Roughly cleared pasture	0.00	0.00	0.50	0.00	0.50
Sugar cane	0.00	0.75	0.15	0.00	0.10
Sugarcane	0.00	0.75	0.15	0.00	0.10
Sunflower	0.32	0.39	0.20	0.00	0.10
Unimproved or native pasture	0.00	0.00	0.50	0.00	0.50
Wheat	0.26	0.00	0.44	0.00	0.30
Winter grain (wheat)	0.28	0.00	0.42	0.00	0.30

The amount of plant residue generated by a crop or grass is dependent on both the crop growth and management practice. As well as containing the crop growth and species data, the relational database describes the agricultural management practices, (e.g., use of fire and harvesting methods) applied to each crop. These data are used to determine how much of the crop mass becomes residue for incorporation and decomposition to litter and soil carbon pools, how much is taken offsite and how much is burnt.

Carbon Contents of Crop and Grass Species

Little data were available on the carbon content of various components of each crop type. To determine a robust general value, various plant materials were obtained from around the country and, using a dry combustion method, the materials were analysed for carbon content. This analysis established an average crop carbon content value of 0.45 (expressed as a fraction of dry matter).

Initial Crop Litter Mass and Decomposition Rates

Given both the rapid rates of decomposition of onsite crop material (compared to woody material) and the active management of litter in most agricultural systems, only small initial litter pools have been used in the model initialisation. The decomposition rates applied acknowledge that the crop residues that form the litter generally decompose within 12 months. The initial mass of litter assigned and their decomposition rates are shown in Table 7.F3.

Table 7.F 3 Initial litter mass and decomposition rates for crop systems

Plant Component	Initial Mass t ha^{-1}	Decomposition Rate yr^{-1}
Grains, Buds, Fruit (Resistant)	0.10	1
Grains, Buds, Fruit (Decomposable)	0.00	1
Stalks (Resistant)	0.01	1
Stalks (Decomposable)	0.01	1
Leaves (Resistant)	0.01	1
Leaves (Decomposable)	0.01	1
Coarse Roots (Resistant)	0.01	1
Coarse Roots (Decomposable)	0.01	1
Fine Roots (Decomposable)	0.01	1

Crop Turnover Rates

Turnover (natural shedding of material) rates for crop and pasture species are generally low for each monthly simulation step given that the pasture is growing for a minimum of nine months. Within this annual cycle, the litter and soil carbon modelling is relatively insensitive to turnover rate. For continuous (perennial) systems, such as grazed pastures, root sloughing in response to grazing is included in the model which maintains the relative ratio of aboveground to belowground plant mass with grazing. The turnover rates used are shown in Table 7.F4.

Table 7.F 4 Turnover rates applied to the crop systems

Plant Component	Turnover Rates yr^{-1}
Grains, Buds, Fruit	0.4
Stalks	0.4
Leaves	0.4
Coarse Roots	0.4
Fine Roots	0.4

Forest growth and tree parameters

Forest growth in the *forest land converted to cropland* and *forest land converted to grassland* category is modelled using the fully spatial, hybrid process-empirical method described in Appendix 7.A and detailed in Richards and Brack (2004a) and Waterworth *et al*., (2007).

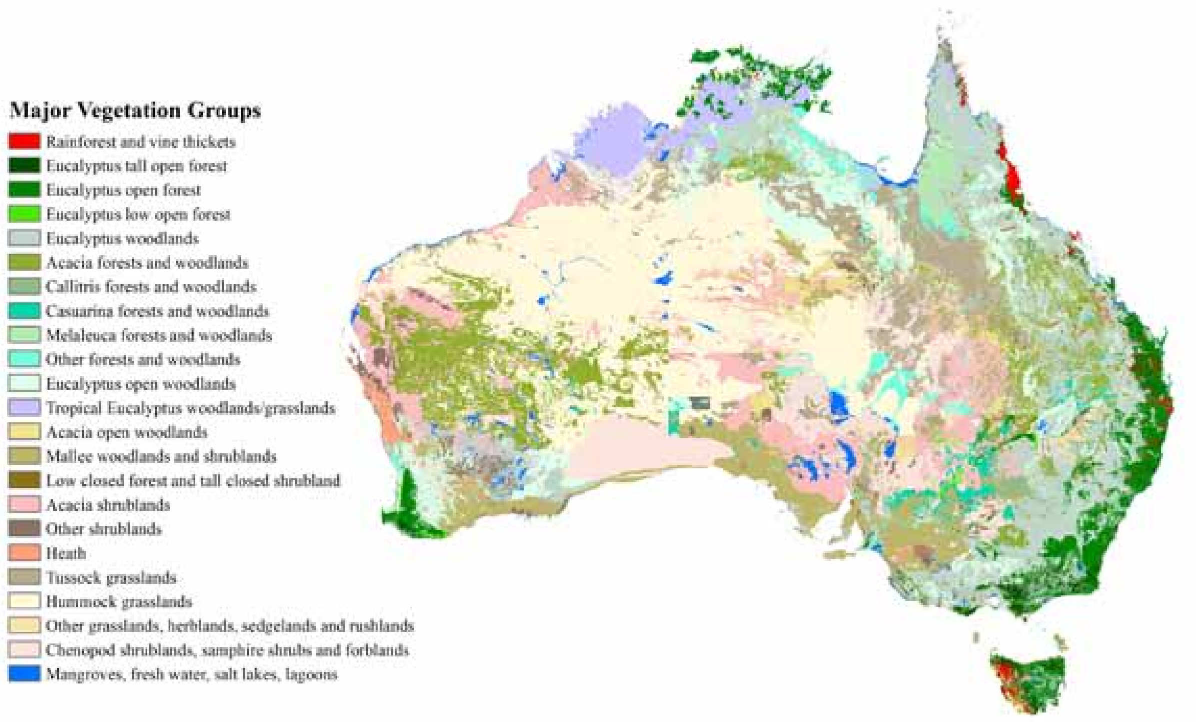
Forest Type Mapping

The National Vegetation Information System (NVIS, see NLWRA, 2001) provides a composite of the best available vegetation mapping in Australia. For the *forest land converted to cropland* and *forest land converted to grassland* category, various forest characteristics (e.g., forest floor coarse woody debris and litter) are associated with the forest types extracted from the NVIS. The NVIS collates and provides, in a consistent taxonomy and classification, the best available vegetation maps from all available sources. Six levels of information are available (Table 7.F5). For the purposes of carbon accounting the Level III Major Vegetation Grouping (MVG) categories were applied. These vegetation types are described in Attachment 7.F1.

Table 7.F 5 National Vegetation Information System (NVIS) hierarchical classifications

Hier-archical Level	Description	National Vegetation Information System structural/floristic components required
I	Class	Dominant growth form for the ecologically dominant stratum
II	Structural Formation	Dominant growth form, cover and height for the ecologically dominant stratum.
III	Broad Floristic Formation	Dominant growth form, cover, height and broad floristic code usually dominant land cover Genus for the upper most or dominant stratum.
IV	Sub-Formation	Dominant growth form, cover, height and broad floristic code usually dominant Genus and Family, for the three traditional strata.(i.e. Upper, Mid and Ground)
V	Association	Dominant growth form, height, cover and species (3 species) for the three traditional strata. (i.e. Upper, Mid and Ground)
VI	Sub-Association	Dominant growth form, height, cover and species (5 species) for all strata.

Figure 7.F 2 Major vegetation groups



In addition to the 'current' vegetation mapping which represents a composite of recently collected data, the NVIS also modelled forest distributions to infer a pre-European settlement (i.e., pre 1770) vegetation map. Some of the land clearing identified by Australia's land cover change program pre-dated the current vegetation mapping (which was generally based on data from 1990 onwards). This meant that areas identified as cleared land in the NVIS could have been forested between 1972 and the date used in the NVIS mapping. In these instances, the vegetation type allocation was drawn from the 1770 modelled (inferred) vegetation map.

While the forest potential maximum (at maturity) biomass and growth rates are largely independent of forest type, other tree characteristics are specific to forest type. Wood density, partitioning of mass to different tree components, the belowground to aboveground biomass ratios and the initial debris stocks are forest type dependent. These are described in the sections below.

Wood Basic Density

One of the key benefits of the direct biomass (rather than volume) modelling approach used in the *forest land converted to cropland* and *forest land converted to grassland* sub-categories, is that the considerable uncertainty in wood basic density values for various forest types and species does not affect the model results, as would be the case for volume based inventories. Although volume, and hence basic density, is not used in the carbon modelling, it is back calculated during the analysis to assist in comparisons between modelled estimates and measured plot data for verification purposes.

The wood basic density information used for the back calculation of wood volume was drawn from Ilic *et al.*, (2000), a national compendium of wood basic density information. The data of Ilic *et al.*, (2000) are presented on a species basis. The wood basic density assigned to each forest type is an approximate average of the values for species typically represented in each class. The wood basic density values used are shown in Table 7.F6.

Table 7.F 6 Wood basic density values for the major vegetation group (MVG) classes

MVG Class	Wood Density (Basic) (kg dry matter m-3)
Rainforest and Vine Thickets	500
Eucalypt Tall Open Forest	550
Eucalypt Open Forest	625
Eucalypt Low Open Forest	550
Eucalypt Woodland	890
Acacia Forest and Woodland	940
Callitris Forest and Woodland	650
Casuarina Forest and Woodland	860
Melaleuca Forest and Woodland	660
Other Forests and Woodland	800
Tropical Eucalypt Woodland/Grassland	830
Eucalypt Open Woodland	890
Acacia Open Woodland	940
Mallee Woodland and Shrubland	1,060
Low Closed Forest and Closed Shrubland	1,000
Acacia Shrubland	940
Other Shrubland	940
Heath	900
Chenopod Shrub, Samphire Shrub and Forbland	900
Unclassified Native Vegetation	780

Age of maximum biomass increment

Where an area that has previously been cleared begins to re-grow to forest, the forest biomass increment is modelled using the simple empirical growth model described in Appendix 7.A. and Richards and Brack (2004a), Brack *et al*., (2006) and Waterworth *et al*., (2007). One of the key parameters in this model is the age of maximum aboveground biomass increment (BI_a).

Available national data and literature sources were analysed to estimate BI_a for regrowth forests (i.e., those identified by remote sensing as recovering from clearing since 1972). This work was conducted by the Australian National University and was based largely on the work of West and Mattay (1993). This was a challenging task due to the lack of growth data for Australia's native forests, in particular for the drier woodlands. This was noted by Richards and Brack (2004a) who suggest that understanding *"... growth patterns in lower productivity (generally non-commercial forest types….)."* could be enhanced by further sampling because *"... Few yield tables are available for these types of forests*".

Available data, such as that reported by West and Mattay (1993), suggest that the age of maximum current annual increment (CAI) for stem volume is within a small range (12-20 years) for most species and is largely independent of site productivity. For the *forest land converted to cropland* and *forest land converted to grassland* sub-categories the age of maximum aboveground biomass increment is set to ten for all species based on the following:

- available data for production native forests which yields a central estimate of 14 years for maximum volume increment (range 12-20);
- the age of maximum volume increment is reduced by one to two years to account for increased allocation of biomass growth to non-stem (wood volume) components as trees are establishing, in particular just before canopy closure;
- the age of maximum volume increment is further reduced by one to two years to allow for the lag in detection of regrowth by remote sensing data (i.e., accounting for the time until detection of trees becomes possible); and,
- a final reduction is applied to account for the rapid site occupancy of woodland species which regenerate from root stock left after clearing, allowing more rapid growth following the removal of grazing pressures.

The effect of these adjustments is that a BI_a of ten is equivalent to an effective age of maximum current annual increment in stemwood volume of around 14 years. A BI_a of ten is higher than that found in most eucalypt plantations, which reach this peak between two to seven years. Plantation management aims to achieve maximum growth rates as quickly as possible and probably represent the best achievable early age growth rates when compared to natural forests.

Tree Partitioning

The partitioning of mass to different tree components has limited effect on the carbon modelling for forest conversion, but robust data are required for model accuracy. A number of studies have been completed to collect data relevant to partitioning (Keith *et al*., 2000, Eamus *et al*., 2000, Grierson *et al*., 2000 and Burrows *et al*., 2001). Snowdon *et al*., (2000) provides a synthesis of the available data. While in harvested forests, tree components will likely be treated independently (e.g., stemwood being removed from the site as wood product and crowns burnt or left to decay onsite); such differential management does not occur in land clearing activity to any degree of significance, except for some removal of firewood. A national study on firewood collection indicated that limited activity is associated with forest conversion (Driscoll *et al*., 2000).

The most important attribute in partitioning is the ratio of belowground biomass to aboveground biomass (the root:shoot ratio), which is estimated using available data (Snowdon *et al*., 2000). There is also a need to apportion materials to different decomposition pools from aboveground components. As land cover change is frequently cyclic (including removal of regrowth), any over- or underestimates in growth due to the root-to-shoot ratio applied will be largely compensated for by an equivalent over– or underestimate in amounts of regrowth removed. The partitioning ratios used are drawn from the best available data, largely taken from the synthesis of data compiled by Snowdon *et al*., (2000). The partitioning used for each forest type is shown in Table 7.F7.

Table 7.F 7 Partitioning of biomass by major vegetation group (MVG) class

Name	Yield Allocation to Stems (fraction)	Yield Allocation to Branches (fraction)	Yield Allocation to Bark (fraction)	Yield Allocation to Leaves (fraction)	Yield Allocation to Coarse Roots (fraction)	Yield Allocation to Fine Roots (fraction)
Rainforest and vine thickets	0.78	0.06	0.06	0.01	0.06	0.03
Eucalyptus Tall Open Forest	0.67	0.09	0.10	0.02	0.08	0.04
Eucalyptus Open Forest	0.45	0.12	0.10	0.02	0.25	0.06
Eucalyptus Low Open Forest	0.45	0.12	0.10	0.02	0.25	0.06
Eucalyptus Woodland	0.44	0.15	0.10	0.02	0.23	0.06
Acacia Forest and Woodland	0.42	0.15	0.10	0.02	0.25	0.06
Callitris Forest and Woodland	0.42	0.15	0.10	0.02	0.16	0.15
Casuarina Forest and Woodland	0.42	0.15	0.10	0.02	0.25	0.06
Melaleuca Forest and Woodland	0.42	0.15	0.10	0.02	0.25	0.06
Other Forests and Woodland	0.42	0.15	0.10	0.02	0.25	0.06
Eucalyptus Open Woodland	0.41	0.18	0.10	0.02	0.23	0.06
Tropical Eucalyptus woodland/ grassland	0.41	0.18	0.10	0.02	0.23	0.06
Acacia Open Woodland	0.22	0.165	0.10	0.025	0.42	0.07
Mallee Woodland and Shrubland	0.22	0.165	0.10	0.025	0.42	0.07
Low Closed Forest and Closed Shrubland	0.22	0.165	0.10	0.025	0.42	0.07
Acacia Shrubland	0.22	0.165	0.10	0.025	0.25	0.24
Other Shrubland	0.22	0.165	0.10	0.025	0.25	0.24
Heath	0.00	0.3	0.18	0.03	0.25	0.24
Chenopod Shrub, Samphire Shrub and Forbland	0.00	0.3	0.18	0.03	0.25	0.24
Mangrove, tidal mudflat, samphire and bare areas, claypan, sand, rock, salt lakes, lagoons, freshwater lakes	0.167	0.167	0.167	0.167	0.167	0.167
Unclassified Native vegetation	0.39	0.14	0.09	0.02	0.25	0.11

Tree Carbon Contents

The carbon content of the estimated biomass (dry matter) is needed to derive a carbon mass equivalent from the biomass modelling. Studies by Gifford (2000a) and Gifford (2000b) considered the carbon content of various tree components, for a range of species and across a range of environments. Drawing on this work, the carbon contents used in this analysis are shown in Table 7.F8.

Table 7.F 8 Carbon content of tree components

Tree Component	Carbon Content (fraction of dry matter)
Stems	0.50
Branches	0.47
Bark	0.49
Leaves and Twigs	0.52
Coarse Roots	0.50
Fine Roots	0.48

Tree Component Turnover Rates

Tree component turnover rates determine the inputs to litter, while soil organic matter is largely derived from root turnover (the balance coming from litter decomposition). The tree component turnover rates have little effect on the *forest land converted to cropland* or *forest land converted to grassland* categories except for areas under trees that are part of the cyclic regrowth cycle. Litterfall (leaf), branch and bark shed and root turnover have been determined from available literature. The rates applied are in Table 7.F9. These draw heavily on the rates determined by Paul *et al*., (2002b) in a model calibration study.

Table 7.F 9 Tree component turnover rates

Tree Component	Turnover rate yr^{-1}
Leaf	0.50
Branch	0.05
Bark	0..07
Coarse Roots	0.10
Fine Roots	0.85

Forest Litter

Initialisation of the forest litter stock in the model (coarse woody debris and fine litter) draws upon work by Murphy *et al*., 2002; Griffin *et al*., 2002; Harms and Dalal, 2003; Harms *et al*., 2005 and Mackensen and Bauhus, 1999). Sites used in these studies were widespread throughout the areas primarily cleared for agricultural purposes. Additional data were drawn from literature where available. The values used are shown in Table 7.F10. Debris mass is converted to carbon assuming a carbon fraction of 0.45.

Forest Residue Management

The principal methods of land cover change for forest conversion involve the extraction of root material (e.g., tree pulling) to allow for subsequent cultivation for pasture and cropping. Limited use of tree poisons, with subsequent standing decomposition (by microbial and invertebrate activity) also occurs.

Table 7.F 10 Initial forest litter values (t dry matter ha^{-1})

Major Vegetation Group (MVG) Class	Decomposable Fine Decay	Resistant Fine Decay	Decomposable Coarse Decay	Resistant Coarse Decay	Decomposable Leaf Decay	Resistant Leaf decay	Decomposable Bark Decay	Resistant Bark Decay	Decomposable Deadwood Decay	Resistant Deadwood Decay
Rainforest and Vine Thickets	30	18	14	10	5	2	0.5	2	18	100
Eucalypt Tall Open Forest	30	18	14	10	12	5	1	5	18	100
Eucalypt Open Forest	20	9	7	5	10	4	1	5	9	56
Eucalypt Low Open Forest	10	5	4	3	7	3	0.75	3	5	30
Eucalypt Woodland	5	2	1	1	4.5	2	0.5	2	2	12
Acacia Forest and Woodland	5	2	1	1	4.5	2	0.5	2	2	12
Callitris Forest and Woodland	5	2	1	1	4.5	2	0.5	2	2	12
Casuarina Forest and Woodland	5	2	1	1	4,5	2	0.5	2	2	12
Melaleuca Forest and Woodland	5	2	1	1	4.5	2	0.5	2	2	12
Other Forests and Woodland	5	2	1	1	4.5	2	0.5	2	2	12
Tropical Eucalypt Woodland/ Grassland	6	3	2	1.5	4	2	0.5	2	2	15
Eucalypt Open Woodland	5	2	1	1	4.5	2	0.5	2	2	12
Acacia Open Woodland	1	0.2	0.1	0.1	3	1	0.2	1	1	2.5
Mallee Woodlandand Shrubland	1	0.2	0.1	0.1	3	1	0.2	1	1	2.5
Low Closed Foresand Closed Shrubland	1	0.2	0.1	0.1	3	1	0.2	1	1	2.5
Acacia Shrubland	1	0.2	0.1	0.1	3	1	0.2	1	1	2.5
Other Shrubland	1	0.2	0.1	0.1	3	1	0.2	1	1	2.5
Heath	1	0.2	0.10.	3.1	1	0.2	1	1	2.5	
Chenopod Shrub, Samphire Shruband Forbland	1	0.2	0.1	0.1	3	1	0.2	1	1	2.5
Unclassified Native Vegetation	8	4	3	2	5	2	0.5	2	2	25

Tree pulling usually involves forming ‘wind rows’ for subsequent burning. Burning of wind rows follows a period of curing (drying), but combustion is still not always complete. *FullCAM* has been developed to accommodate these processes by implementing a delayed burning, with subsequent decomposition of residual material. The residual decomposing pool also includes ‘standing dead’ material from treatments such as poisoning. The proportion of biomass potentially affected by burning is set at 98 %, leaving 2 % of all biomass unaffected by burning. Further residue is left to decompose following incomplete combustion, with combustion efficiencies set at 90 % for stems, 95 % for bark, 95 % for leaf litter, 80 % for coarse dead roots and 70 % for fine roots.

Litter decomposition rates have been extracted from available information including the study undertaken by Mackensen and Bauhus (1999). The rates applied are shown in Table 7.F11. There are few studies in Australia of litter decomposition rates with most work being focused on wood product longevity trials. The data were supplemented with some limited chronosequence work on paired sites. However, the main focus of this work was on modelling rates that coincided with measures of litter mass when the models were run over extended periods so that a reasonable balance between turnover (input to litter pools) and decomposition of litter pools was achieved.

Table 7.F 11 Litter decomposition rates for tree components

Plant Component	Decomposition Rate (yr^{-1})
Decomposable Leaf	1.0
Resistant Leaf	1.0
Decomposable Deadwood	0.1
Resistant Deadwood	0.1
Decomposable Bark	0.5
Resistant Bark	0.5
Decomposable Coarse Root	0.4
Resistant Coarse Root	0.1
Decomposable Fine Root	0.3
Resistant Fine Root	0.4

Soil Carbon parameters

A full description of the soil carbon model (*Roth-C*) and the parameterisation of the model are provided in Appendix 7.A.

Attachment 7.F1: Major Vegetation Groupings Classified by the National Vegetation Information System

Group 1. Rainforest and Vine Thickets

Rainforest communities in Australia are mostly confined to the wet and cooler areas or climatic refuges in eastern Australia, apart from the semi-evergreen vine thickets of the Brigalow Belt and the monsoonal vine thickets that are found in the tropics in Western Australia and the Northern Territory. Community types include cool temperate rainforest, sub-tropical rainforest, tropical rainforest, vine thickets, and semi-deciduous and deciduous vine thickets. Rainforests were cleared extensively in the late 19th or early 20th centuries for high value timbers, dairying, tobacco/sugar cane or other agricultural production. The best known examples of this are the “Big Scrubs” of Illawarra and northern New South Wales and the Atherton Tableland in north Queensland.

Group 2. Eucalyptus Tall Open Forest

These communities are restricted to all but the wetter areas of eastern Australia from the margins of the wet tropical rainforests of north Queensland to Tasmania, and the south west of Western Australia, often in rugged mountainous areas. At their maximum development in Tasmania and parts of Victoria, they contain the world’s tallest flowering plants, with some trees rising to heights in excess of 100 m. These communities are typified by a well-developed often broad-leaved shrubby understorey or sometimes tree ferns and are mostly found adjacent to, or in association with, rainforest communities. Extensive areas of these communities were cleared for agriculture and grazing early in the 20th century, particularly where they occurred in association with rainforests. Major areas remain today in crown reserves as State Forests or National Parks.

Group 3. Eucalyptus Open Forest

This group is widespread along the sub-coastal plains, foothills and ranges of the Great Dividing Range in eastern Australia and the sub-coastal ranges of the south west of Western Australia. Generally this group has a shrubby understorey which is low to moderate in height, but in drier sites they may have a grassy understorey with scattered shrubs and/or cycads. There has been widespread clearing of these communities for grazing and agriculture in the major agricultural zones of eastern Australia and the south west of Western Australia. The rate of clearing in these communities by the early 20th century saw the development of crown reserves for the protection of forests, either as national parks or as production forests, and the establishment of forestry departments within several jurisdictions.

Group 4. Eucalyptus Low Open Forest

This group contains a series of montane communities of the Great Dividing Range such as Snow Gum, Red Stringybark and Scribbly Gum, and the drier Jarrah communities in the south west of Western Australia. Extensive areas of these communities have been cleared principally for grazing.

Group 5. Eucalyptus Woodland

This group is widespread throughout the mountain ranges and plains west of the divide in Eastern Australia and east of the sub-coastal ranges of south west Western Australia. This group includes a series of communities, which have come to typify inland Australia. For example the box (poplar box, white box, yellow box etc.) and ironbark woodlands of eastern Australia are included in this group. The Eucalyptus woodlands have been extensively cleared and modified, particularly in the agricultural zones of eastern Australia and in south west Western Australia. In many regions only small isolated fragments remain today, in many instances found only along creeks and road verges.

Group 6. Acacia Forest and Woodland

Brigalow (*Acacia harpophylla*) and Mulga (*A. aneura*) dominate this group with mulga covering large parts of the arid interior of the continent. A series of other acacias such as Lancewood (*A. shirelyii*) and Myall (*A. pendula*) are also included. Mulga is one of the most widespread species on the continent, occurring on a series of forest, woodland and shrubland communities. The Mulga and Brigalow communities of eastern Australia have been extensively cleared for grazing and agriculture and in many regions only scattered remnants are found today. Mulga communities in the arid interior have not been subject to clearing to the same degree but many areas have been subject to modification by grazing pressures from cattle/sheep and feral animals, and increased macropod populations supported by the increased availability of water from bores.

Group 7. Callitris Forest and Woodland

Cypress Pine forests are found mostly in a series of discrete regions, notably in the Brigalow Belt, but also in the arid areas in South Australia and in association with mallee communities near the South Australia – Victoria border. Extensive areas have been cleared for grazing in the Brigalow Belt and in the Mallee bio-regions in particular, but major areas are included in State Forests and other crown reserves in Queensland and New South Wales.

Group 8. Casuarina Forest and Woodland

Containing both Casuarina and Allocasuarina genera, these occur in a series of quite distinct communities, notably foredune (*C. equisetifolia*) communities, swamp (*C. glauca*) communities, riverine (*C. cunninghamiana*) and desert (*C. cristata*) communities. These communities have been extensively cleared in many coastal areas for agriculture, or for industrial uses or urban developments. Areas in the arid zone are subject to modification by grazing of domestic stock and from feral herbivores.

Group 9. Melaleuca Forest and Woodland

These cover substantial areas in the tropical north, but are also found in temperate climates most often in or adjoining coastal or montane wetlands. These communities have been extensively cleared in many coastal areas for agriculture or housing near major cities. Extensive areas remain in the tropical north, in particular southern Cape York Peninsula.

Group 10. Other Forest and Woodland

This is a diverse group of communities, some of which such as Banksia woodland are comparatively restricted in their extent, but may be locally abundant. It also includes a series of mixed communities of the arid zone, which are not dominated by any particular species. These communities have been extensively cleared in many coastal areas for agriculture or urban uses. Extensive areas remain in the arid zone but are subject to modification by grazing of domestic stock and from feral herbivores.

Group 11. Eucalyptus Open Woodland

These cover extensive areas of the arid zone or drier tropical north mostly with a shrubby or grassy ground layer. Little of this group has been cleared. Many areas have been subject to modification by grazing of domestic stock and from feral herbivores.

Group 12. Tropical Eucalyptus Woodland/Grassland

This group contains the so-called tall bunch-grass savannas of north Western Australia and related Eucalyptus woodland and Eucalyptus open woodland communities in the Northern Territory and in far north Queensland, including Cape York Peninsula. They are typified by the presence of a suite of tall annual grasses, notably *Sorghum spp*, but do not include communities in more arid sites where *Triodia spp* becomes more dominant. The fundamental difference between how Western Australia and the Northern Territory and Queensland describe these vegetation communities, necessitated their separation into a separate MVG.

Group 13. Acacia Open Woodland

These also cover extensive areas of the arid zone or drier tropical north mostly with a shrubby or grassy ground layer such as Blue Grass (*Dicanthium sericeum*). Eucalyptus species such as the Yapunyah (*E. thozetiana*) may also be present. Little of this group has been cleared but many areas have been subject to modification by grazing of domestic stock and from feral herbivores.

Group 14. Mallee Woodland and Shrubland

Multi-stemmed eucalyptus trees in association with a broad range of other shrubs or grasses cover extensive areas of the southern arid zone from Victoria to the south west of Western Australia. The mallee communities in Victoria and parts of South Australia have been extensively cleared, with only isolated remnants remaining in some areas, but these communities are still widespread in the arid zone of South Australia and Western Australia. These are subject to modification by grazing of domestic stock and from feral herbivores.

Group 15. Low Closed Forest and Closed Shrubland

These dense communities are found mostly in coastal environments, for example Kunzea and Leptospermum scrubs, or sub-coastal plains e.g., Banksia scrubs, and can cover significant areas. They also occur in rugged mountainous areas, such as sub-alpine areas in Tasmania. They have been extensively cleared in many coastal areas for agriculture or urban development.

Group 16. Acacia Shrubland

Mulga, Gidgee and mixed species communities of the central Australian deserts dominate this group, but it also includes a series of other desert acacia communities. Little of this group has been cleared outside of the major agricultural zones, but they have been subject to modification by grazing from domestic stock and from feral herbivores.

Group 17. Other Shrubland

This is a diverse group containing a series of communities dominated mainly by genera from the Mrytaceae family. Kunzea, Leptospermum and Melaleuca shrublands are important components of this group, but it also includes a suite of mixed arid zone communities and other communities dominated by typical inland genera such as Eremophila and Senna. This group has been extensively cleared in the agricultural regions and in coastal areas adjoining major cities. In the arid zone, little of this group has been cleared but many areas have been subject to modification by grazing of domestic stock and from feral herbivores.

Group 18. Heath

This group includes the stunted (< 1 m tall) vegetation of the coastal sand masses, typified by the family Epacridaceae and also other dense low shrublands in sub-coastal or inland environments, mostly on drainage impeded soils or natural hollows or depressions. The communities have been cleared for sand mining, agriculture and urban development.

Group 19. Tussock Grassland

This group contains a broad range of native grasslands from the Blue Grass and Mitchell Grass communities in the far north to the temperate grasslands of Southern New South Wales, Victoria and Tasmania. The group contains many widespread genera including Aristida, Astrebla, Austrodanthonia, Austrostipa, Crysopogon, Dichanthium, Enneapogon, Eragrostis, Eriachne, Heteropogon, Poa, Themeda, Sorghum and Zygochloa and many mixed species communities. Extensive areas of this group have been cleared and replaced by exotic pasture species and most other areas have been subject to modification by grazing, weed invasion and land management practices associated with grazing domestic stock, such as frequent fire and the application of fertilisers.

Group 20. Hummock Grassland

The spinifex (*Triodia spp.* and *Plechrachne spp.*) communities of the arid lands are quintessential to the Australian outback. These cover extensive areas of the continent either as the dominant growth form with the occasional emergent shrub or small tree (either acacia or eucalypt). They are also a conspicuous element of other communities such as open woodlands. Little of this group has been cleared but many areas have been subject to modification by grazing of domestic stock and from feral herbivores.

Group 21. Other Grassland, Herbland, Sedgeland and Rushland

This diverse group contains a series of communities, some of which are restricted within the landscape, some of which occur as mosaics and others that are otherwise too small or diffuse across the landscape to be easily discerned at a continental scale.

Group 22. Chenopod Shrub, Samphire Shrub and Forbland

The chenopods such as Saltbush (*Atriplex spp.*) and Bluebush (*Maireana spp.*), cover extensive areas of the arid interior on saline soils. They are also associated with the ephemeral salt lakes of these arid areas, often in association with samphires such as *Halosarcia* species. Similarly, some forbland communities contain a mix of species including samphires and chenopods. Other forblands containing Asteraceae species are found in Queensland.

Group 23. Mangrove, Tidal Mudflat, Samphire, Claypan, Salt Lakes, Bare Areas, Sand, Rock, Lagoons and Freshwater Lakes

Mangroves vary from extensive tall closed forest communities on Cape York Peninsula to low closed forests or shrublands in southern regions. Samphires are found in the coastal mudflats and marine plains, adjoining mangrove areas in many instances, but they also cover extensive marine plains inland from the southern Gulf of Carpentaria and other parts of the tropical north. In the harsh environments of the arid interior extensive areas devoid of vegetation can be found as bare ground, either sand dune, claypan or salt lakes. Similarly, the coastal sand masses can often contain extensive areas of bare sands, mostly as active dunes. In mountainous areas, large areas of bare rock or scree may be a feature of the landscape. This is particularly the case where large rocky outcrops dominant the landscape, such as Uluru and the Olgas in central Australia, Bald Rock in northern New South Wales and many examples of large monadnocks in the south west of Western Australia. There can be widespread clearing or infilling of mangroves and tidal mudflats in coastal areas near urban major centres for industrial uses or urban developments.

APPENDIX 7.G: CROPLAND REMAINING CROPLAND

Background

Cropland by definition is land on which crops are grown and harvested. The *cropland remaining cropland* sub-category covers an area of over 20 million hectares and includes lands that are cropped in rotation with pastures, systems that change between grassland and cropland on a regular basis. Land that is categorised as *cropland remaining cropland* has been subject to regular cropping since prior to 1972 and has remained in a cropping land use state. *Croplands* are considered to be of high land value with a high return on production and of moderate to high soil nutrient status and are therefore not generally converted to *forest land* or *grassland* but remain as *cropland*.

Australian croplands range over a longitude of 40º and latitude of 25º resulting in significant geographical variation in the types of crops grown and climatic conditions (Unkovich *et al*, 2009). Climate variability is an important factor affecting changes in Australian crop production, with rainfall variation the main contributor to changes in crop yields from one year to another (ABARE, 2009e). Croplands are generally located along a broad inland fringe across the southern and eastern areas of Australia, with the highest yields commonly obtained in the south west and eastern regions. In the southern regions, cropland is dominated by wheat production, with barley, oats, lupins and canola being the other dominant crops. In the north; wheat, sugarcane, sorghum and cotton production dominate.

Pasture and grass systems that have never been cropped (annual, perennial, improved, native, permanent and lucerne) are reported under the *grassland remaining grassland* sub-category. Pasture and grass systems that are incorporated as part of a crop-pasture rotation, are reported under the *cropland remaining cropland* sub-category.

Methodology

The *cropland remaining cropland* sub-category includes emissions and removals due to the effect of climate, the effects of management regimes (including residue burning), and the effect of grazing on crop-pasture rotation systems. The key drivers of the emissions and removals in *cropland remaining cropland* are:

- Annual variability (gains or losses) in biomass due to climate variability, particularly rainfall and frost;
- Management practices (in particular fertiliser application and residue management);
- Crop-pasture rotations; and
- Grazing of stubble or pasture within crop-pasture rotations.

FullCAM estimation of carbon emissions from *cropland remaining cropland* includes all on-site carbon pools (living biomass, dead organic matter and soil), as described in Appendix 7.A. For reporting purposes the soil carbon masses only are used to calculate the annual change in soil emissions from the *cropland remaining cropland* category.

For this sub-category, it is presumed that land in the *cropland remaining cropland* area entered this category following forest clearing between1924 and 1971. The date of forest clearing of each pixel is randomly allocated between these years. The model is initially equilibrated from 1800 to stabilise the soil carbon pools before it is calibrated against regionalised cropping practices from 1972 to 1989, for the initial reporting year of 1990, to stabilise the soil carbon stocks therefore reflecting soils under long term cropping management. As the lands in the *cropland remaining cropland* sub-category are retained under a similar land use for several years (i.e., the land has been *cropland* since 1972), changes in carbon stocks are affected primarily by land management practice and climate. These two factors largely determine the amount of live biomass and therefore the residues in dead organic matter that subsequently become incorporated into the soil carbon (Janik *et al*, 2002).

For the current *cropland remaining cropland* estimates, management is not varied as comprehensive, spatially and temporally explicit management data for all of Australia's croplands is not yet available. Hence variation in the live biomass, dead organic matter and soil pools is largely driven by crop production, which varies due to climate and improved breeding. Therefore emissions and removals from this sub-category follow climate effects on crop production.

Non-CO_2 emissions from *cropland remaining cropland* are reported in the Agriculture sector.

Crop biomass change (transitions)

The variability in gains and losses in cropping systems are highly affected by climate variability, particularly the variability in rainfall. Rainfall variability in Australia is very high relative to global patterns and often results in lengthy periods without rain (ABS, 2008e). Most recently in 2002-03 and 2006-07, Australia experienced two of the worst droughts on record and in some regions the drought has lasted several years. These drought conditions resulted in highly variable (mostly losses) crop productivity levels, which are reflected in the degree of variation in emissions and removals of CO_2 (ABS, 2008e; Swift & Skjemstad, 2002). In general terms the impact on soil emissions is low as the increases in biomass stocks in a single year are equal to the biomass losses from harvest and mortality.

Cropland management practices

The climate in Australia has a strong influence on agricultural land use. For example, the tropical north is suited to extensive grazing (principally cattle) as well as, in some areas, intensive production of fruit, sugarcane and grain crops which are grown during the summer wet season (Dec – Apr), but also include regions where winter crops can also be grown. The temperate regions support grain cropping and livestock production. In the drier central regions, low-density grazing (mostly cattle) is found (Swift & Skjemstad, 2002). In the southeast of Australia, the Murray-Darling Basin has a large irrigation infrastructure to support the production of fruit, vegetables, rice, and other intensive agricultural activities including irrigated broadacre crops (DAFF, 2005).

Irrigation

The nature of Australian cropping systems is predominantly rain fed whereby the amount and distribution of rainfall are important determinants of crop selection, growth and yield. The majority of crops grown in Australia are winter dominant given that they are predominantly reliant on winter rainfall with 55% of the cropping area receiving winter dominant rainfall (southern Western Australia, South Australia and Victoria), 40% receiving equiseasonal rainfall (New South Wales), and 5% receiving summer dominant rainfall (Queensland) (Unkovich *et al.*, 2009). In addition, crop yields vary according to the annual distribution of rainfall and the types of crops grown within a region. Irrigation of cropping systems only accounts for approximately 1 million hectares of field crops (approximately 5% of the total cropped area), most of which (92%) occurs in New South Wales and Queensland.

Some farmers in Australia use irrigation water, where available, to supplement rainfall in agricultural production systems, largely due to Australia's variable and unpredictable rainfall; however, irrigation practices differ between farms according to water availability, soil type, topography, state legislation and water costs, to name a few (ABS, 2008e). Some crops are almost totally dependent on irrigation, while for others irrigation water supplements natural rainfall or provides moisture at critical periods of plant growth (ABS, 2007).

Water sources for irrigation are mostly drawn from surface water, such as rivers, lakes, weirs and dams with most water used for irrigation originating from Australia's major river systems, the Murray-Darling system in eastern Australia and the Ord River in the Kimberley region of Western Australia together with other significant river and dam systems in Queensland, Western Australia and Victoria (ABS, 2008e). Another large source of water is sub-surface or "ground" water from the Great Artesian Basin which provides irrigation water for agriculture in regions of north-eastern Australia (ABS, 2008e).

Fertiliser application

Australian soils are geologically old, highly weathered, fragile and naturally nutrient deficient and need extra nutrients to maximise crop yields. The application of nitrogen and phosphorus-based fertilisers to Australian soils aid in increasing soil fertility and hence agricultural productivity. The most common types of fertiliser used in Australia are urea and single superphosphate, however ammonium phosphates (MAP and DAP) and manufactured fertilisers are also commonly used and coated fertilisers are becoming more common especially where canola is grown (ABS, 2009d).

Crop residue management

The crop residue management practices used in Australia include leaving crop residue intact, removing crop residue by baling or heavy grazing, burning crop residue, ploughing crop residue into the soil, and mulching crop residue (ABS, 2009d). The burning of crop residue was a widespread practice in Australia in the early 1970s generally occurring just prior to sowing of the next year's crop and after fire restrictions had been removed (Swift & Skjemstad, 2002). Although there has been a widespread move away from burning, it is still practised in some regions to control weeds. Nowadays, there is a tendency to retain crop residue for soil protection over the summer months (i.e., retention of soil water and minimise erosion). Subsequent crops are sown directly into the stubble residues which help to retain soil moisture. This requires the use of specialised sowing equipment or precision farming techniques. In the Western Australia cropping region more than 86% of growers now adopt this practice (Llewellyn *et al.*, 2009). However, burning of crop residue is still used as a strategy to control weeds, diseases and pests, and to remove bulky straw that is difficult to sow into.

Mapping of Cropland remaining Cropland systems

The mapping of the extent of *cropland remaining cropland* systems is estimated using the National Land Use 2001/2002 (Version 3) Summary Statistics provided by the Bureau of Rural Sciences (http://nlwra.gov.au/). The area of cropping includes areas of both continuous cropping and areas under crop-pasture rotations.

Estimation of CO_2 emissions and removals

Carbon dioxide (CO_2) emissions and removals from *cropland remaining cropland* are estimated using the Tier 3 *Full Carbon Accounting Model* (*FullCAM*). When configured for *cropland remaining cropland FullCAM* use the same climate, site and management data as that used in the *forest land converted to cropland* estimates as described in Appendix 7.F.

APPENDIX 7.H: GRASSLAND REMAINING GRASSLAND

Background

The *grassland remaining grassland* sub-category covers around 440 million hectares of land. The vast majority of this area occurs in inland Australia and is used for extensive grazing of both sheep and cattle. In Australia, grazing occurs across very diverse climate, ecosystem and management systems. The pasture types and associated management intensities range from highly improved and sometimes irrigated pastures to extensive rangeland systems in the semi-arid and arid regions of Australia. Native or naturalised pastures are the major pasture type, occupying approximately 17% of Australia's land area with sown and fertilised pastures occupying only 4% of the land area. Sown pastures are represented by mixed annual grasses and legumes as well as mixed perennial grasses and legume species depending upon rainfall and regional location. Irrigated pastures represent about 1% of all pastures and are generally confined to the dairy and feedlot industries.

Pasture productivity determines the amount of live biomass that is produced, while the effects of grazing and fire determine transition of the living biomass into carbon stock pools over a reporting period. In addition, the dead organic matter and soil carbon pools will be influenced by pasture utilisation (grazing management), and interventions such as burning. The introduction of an improved pasture system may lead to a moderate increase or decrease in soil carbon, and this may vary (increase or decrease) on an annual basis according to annual climate variability.

Methodology

The *grassland remaining grassland* sub-category includes emissions and removals in both shrub (non-forest forms of perennial woody vegetation) and grass systems, including the effects of grazing, grass and shrub transitions and the effects of fire. This comprehensive approach therefore also captures the losses and uptake of carbon associated with savanna burning, both anthropogenic and natural. The key drivers of the emissions and removal in *grassland remaining grassland* are:

- grazing intensity;
- annual variability in biomass due to climate variability;
- land management (in particular burning practice);
- natural disturbances (wildfire); and,
- shrub and grass transitions (due to both natural effects and anthropogenic cause).

The distribution and area of land in *grassland remaining grassland* was estimated using the National Land Use 2001/2002 (Version 3) Summary Statistics prepared by the Bureau of Rural Sciences (**www.nlwra.gov.au**). The subset of areas of *grassland remaining grassland* that were shrub vegetation was established by the methods described below. The area that was only grasses was established by removing the areas of shrubland from the total *grassland remaining grassland* area.

Grass component

The estimates of emissions for all grass components include all on-site carbon pools (living biomass, dead organic matter and soil). Emissions and removals are estimated using the *FullCAM*, as described in Appendix 7.A. Reporting of emissions from the *grassland remaining grassland* category uses the emission outputs for the soil and below ground masses only, as per IPCC *Good Practice Guidance* (2003 and 2006). The calibration and verification of this model, along with the associated quality assurance and quality control program are described in Appendix 7.J. The data used in the model runs include plant growth rates, grazing intensity and pasture management practices such as burning. These data are described in Appendices 7.A and 7.F.

For the *grassland remaining grassland* sub-category, there are three main agro-ecological categories; native arid and semi arid which occupy about 340 M ha and the high rainfall improved pastures that occupy about 60 M ha. Historical data on land use from early European settlement identifies that extensive grazing practices (primarily sheep) commenced in the late 1700's and continued to expand to a maximum sheep flock of more than 180 M head by 1900 (Henzell 2007). It is therefore presumed that land in the grass component of the arid and semi-arid regions, which comprised of sparse woody vegetation and woodlands, remained as native pastures with some introduced species transitioning over this entire period from settlement. Soil carbon pools were stabilised for the semi-arid and arid regions from 1500 to remove the influence of above and belowground masses from forest soil inputs. For the high rainfall pastoral regions grazing was stabilised from 1800 to 1971 to reflect the gradual clearing of native forest soils for grazing purposes. The date of forest clearing of each pixel is randomly allocated in the period between these two years with the amount of clearing approximately evenly distributed in each year. The model is then equilibrated using typical grazing practices at the Iterim Biogeographical Regionalisation of Australia (IBRA) scale from 1972 to 1989, for the initial reporting year of 1990, which is used to stabilise the soil carbon stocks therefore reflecting soils under long-term grazing management, i.e., soil carbon is not significantly affected by the initial pasture establishment or former land use. This equilibration allows the model to represent both areas which have always been grassland and those cleared for grazing since 1972.

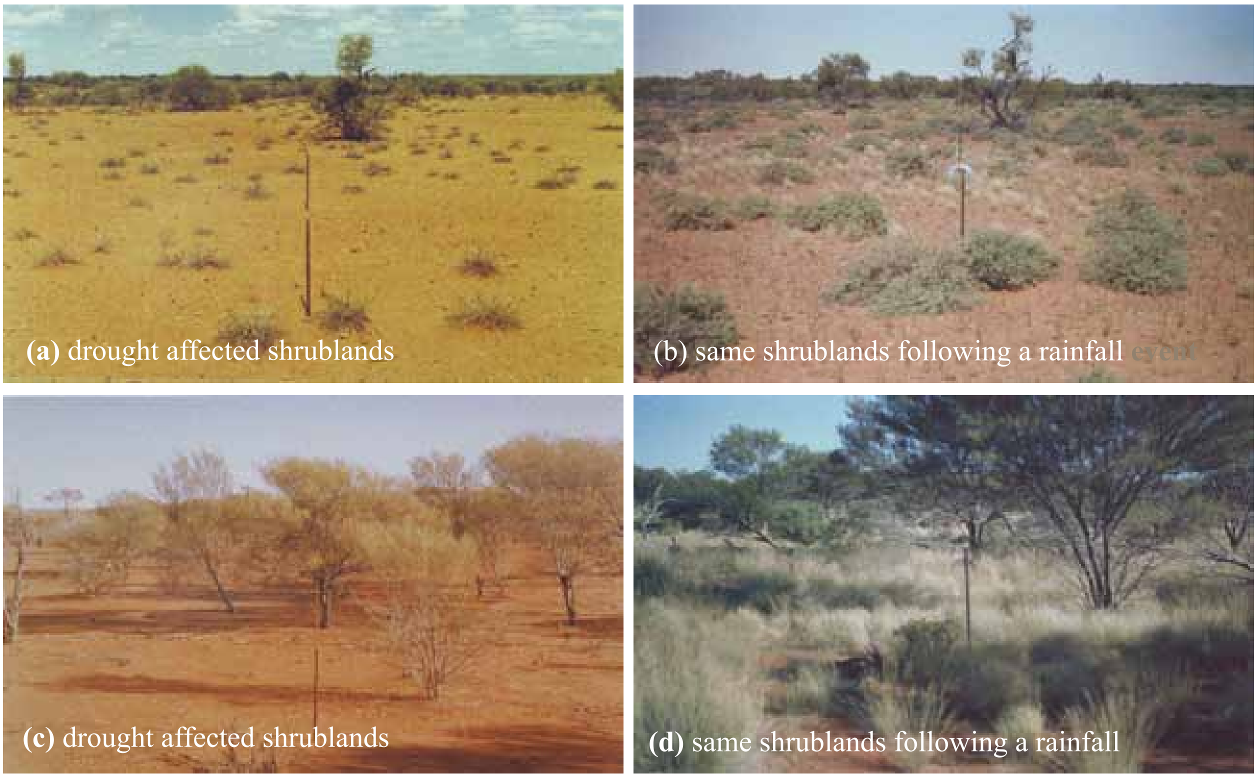
For the current *grassland remaining grassland* grass component estimates, several generic management practices have been identified for the arid, semi-arid, and improved pasture systems prior to 1972. Post 1972 more specific regionalised grazing practices were applied and modelled across all pasture regions to better reflect the differences in stocking rate (grazing pressure), pasture growth and climate (B. Henry, Meat and Livestock Australia, 2011, *pers. comm*. 2011). Hence variation in the live biomass, dead organic matter and soil pools are largely driven by variations in pasture yield, grazing pressure and climate.

Grass and Shrub Transitions

There are many processes that lead to transitions between shrubs and grasses in Australian ecosystems. These processes are driven by factors that include how palatable the shrubs are to herbivores, and whether they are resistant or susceptible to fire, drought and waterlogging. The species concerned may be endemic, native (but not endemic), or introduced.

The direct anthropogenic transitions between shrub and grass systems, such as land clearing and the subsequent establishment of shrub plantations (e.g., saltbush for grazing and tea-tree for oils), are readily the 'cause' for the transition. Equally, losses due to natural and managed fires are also straight forward to interpret. Another natural phenomenon that impacts carbon stocks and transitions between grasses and shrubs is climate driven changes in the shrub condition. While the climate driven process is well understood, quantifying its effects is not straight forward. Figure 7.H1 highlights how the presence of shrubs can be affected by climate variability with 'flushing' in standing plants following a rainfall event.

Figure 7.H 1 The impact of climate variability on woody shrubs.



Source: Watson et al., 2004

Transitions that are not in response to a direct human intervention are difficult to assign a cause to, although they may occur in response to the combination of past or current land management and climate. These transitions are predominately a shift from grass to shrubs in a process often described as 'woody weed invasion'. Woody weed invasion has been reported in many areas of Australian rangelands and savannas. Woody weed invasion is often associated with changed fire regimes (lower frequency and less intensive) that have accompanied the introduction of grazing.

A range of land management practices are used to treat woody weed invasion and include:

- prescribed burning;
- mechanical control (e.g. ploughing); and,
- chemical control.

Mapping of Extent and Change in Shrubs

Mapping of the extent, and change in extent in forest systems (as reported in other forest related emissions categories) is now relatively straight-forward using data from the Landsat satellite data archives (see Appendix 7.A). To supplement the forest mapping a national mapping program is currently underway to assess both the extent, and changes in extent, of sub-forest forms of woody vegetation. The results of the program to date are that:

- reliable extent and change mapping is possible (Caccetta and Furby, 2004) by supplementing the techniques applied to forest mapping to deal with the impact of low signal (proportion of woody vegetation of interest) to noise (other vegetation) ratio;
- the low signal to noise ratio leads to a variable lower detection limit. 'False change' (i.e., change only in the lower detection limit threshold) can occur and this must be addressed by enforcing a constant lower limit, which is in the order of 5-7% woody cover; and
- the analysis can only be applied to the more recent (since 1988) Landsat TM and ETM+ data. Data from the earlier Landsat MSS sensors is not able to deal with the low signal to noise ratio in these systems.

This inventory has seen the completion of a national coverage of shrubland extent 'base' maps (see Figure 7.H2) for a single point in time (2002). A further subset of areas (see Figure 7.H3) includes change analysis which has been applied and verified for the period 1991 to 2004.

Figure 7.H 2 Extent of sparse vegetation

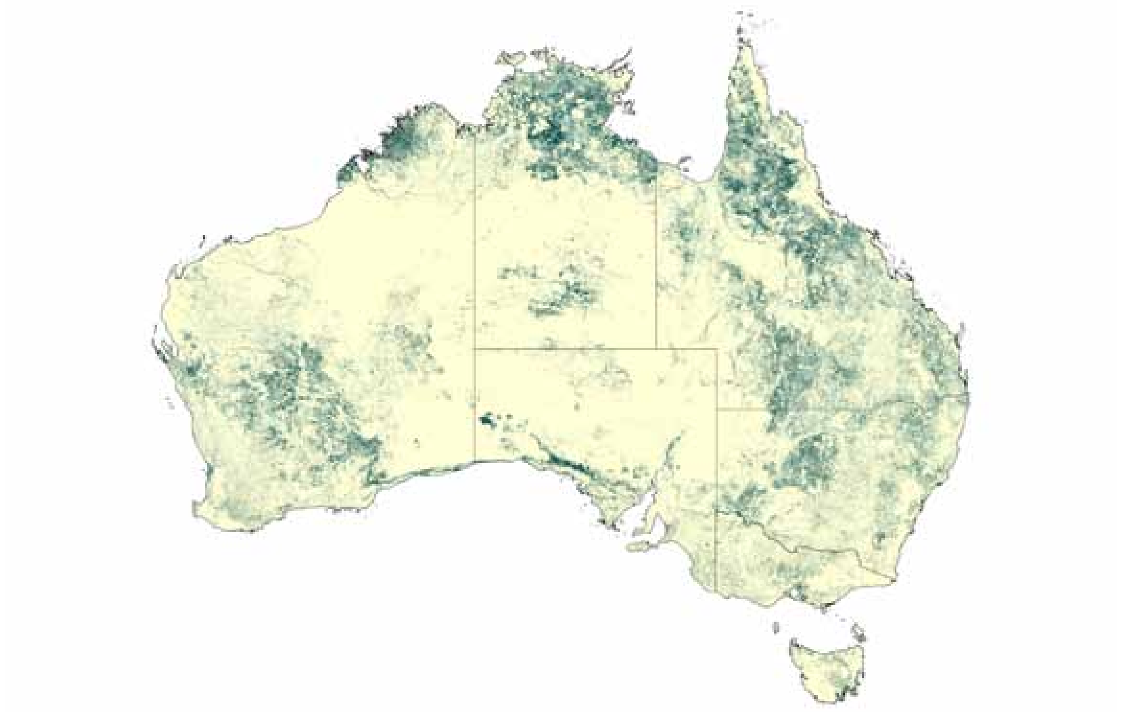
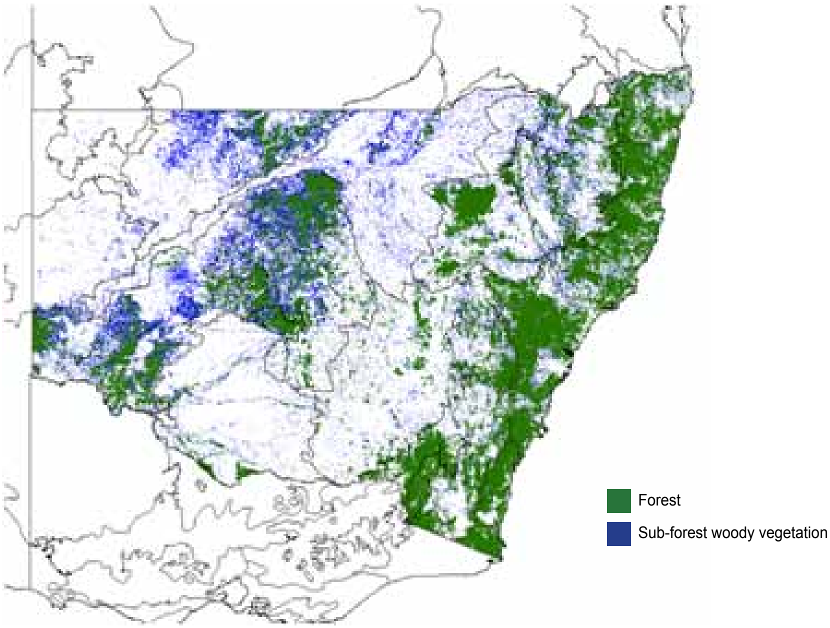


Figure 7.H 3 Map of forest and sub-forest woody vegetation for the area where the sparse change analysis has been verified



To use these preliminary data to derive an estimate of the emissions from grass to shrub transitions Australia has:

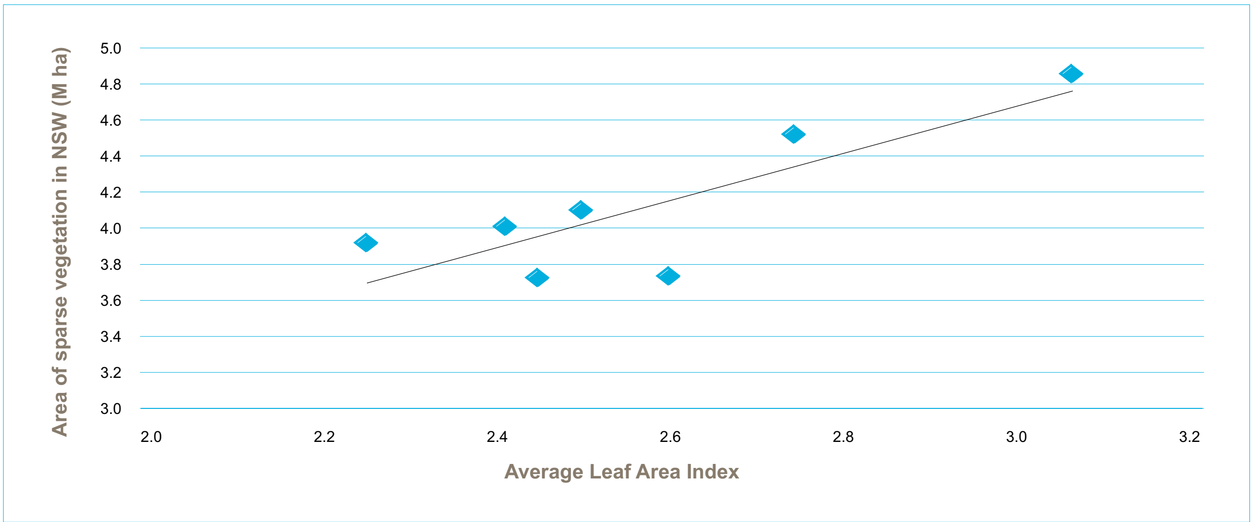
- used the recently completed shrubland extent base maps to determine the sub-forest woody vegetation extent; and
- used the time-series trends for change in areas where change is available (see Figure 7.H3) and applied this to the national extent.

As the data on the transitions between shrubs and grasses were only available for a sample of the country since 1991, it was necessary to extrapolate the data so that an emissions estimate for 1990 could be derived. To do this, a relationship between the observed transitions (change) in the sample area and the national trends in leaf area index (derived from satellite data) was developed (Figure 7.H4; $r^2 = 0.65$). The robustness of this relationship allows for extrapolation of the observed shrub and grass transitions to the date of the first leaf area index (LAI) data in 1987. Prior to 1987 no net change in extent of shrub vegetation is assumed.

Estimation of emissions and removals

To estimate the change in shrub biomass due to the change in shrub area, the net annual change in area was placed in a simple Tier 2 model. The model uses an average woody biomass of 10 t DM ha^{-1} (Raison *et al*., 2003) and presumes a linear loss of that amount over a period of 20 years. Where the area of shrubland increases it is assumed that these will regrow to 10 t DM ha^{-1} over 20 years (i.e. a growth rate of 0.5 t DM ha^{-1} yr^{-1}).

Figure 7.H 4 The relationship between leaf area index and woody vegetation change



Fires

Fires are the major natural disturbance in grasslands, and area burned varies from year to year. Fire in grass areas of the *grassland remaining grassland* sub-category are modelled as part of the Tier 3 *FullCAM* analysis. Fires in the shrubland component of the *grassland remaining grassland* sub-category are modelled using a Tier 2 method, based on empirical data, disaggregated spatially and with country-specific parameters.

For mass of fuel burnt the method uses the relevant equations and parameters used for the estimation of non-CO_2 gases from the *prescribed burning of savannas* (4.E). Estimations are made only for those vegetation communities that meet the definition of shrubland, being the following savanna woodland vegetation classes:

- Eucalypt Open Forest;
- Eucalypt Woodland;
- Melaluca Woodland;
- Sandstone Heath;
- Sandstone Woodland; and
- Shrub.

Consistent with UNFCCC CRF tables for source category 5C, *grassland remaining grassland*, the fuel load in these communities is the perennial live biomass only (i.e. the *shrub* fuels size class in 4.E). In accordance with 4.E fuel load is assumed static with years since last burnt (YSLB).

For these vegetation communities there is insufficient published live fuel accumulation data of satisfactory statistical significance to assume that fuel recovery follows any particular curve. Thus following burning, biomass is presumed to recover linearly over a four year period. The four year recovery period was used as this first time step following the average number of years since the last fire (YSLB) of 3.85 years. This average YSLB was calculated from all data and weighed to the mass of fuel burnt in each combination of fire season, vegetation class, seasonality and state.

Activity data for the period 1989-2010 is the savanna woodland area burnt data used for the *prescribed burning of savannas* (4.E) for the aforementioned six vegetation classes.

APPENDIX 7.I: HARVESTED WOOD PRODUCTS

Introduction

Harvested wood product CO_2 emissions are considered under the 1996 (Revised) IPCC *Guidelines* for the United Nations Framework Convention on Climate Change (IPCC 1997) and associated *Good Practice Guidance* (IPCC 2003) and are reported in the *land use, land use change and forestry* component of Australia's National Greenhouse Gas Inventory where they arise from the service life of products. Emissions from landfill are reported under the *waste* sector of the inventory.

A national database of domestic wood production, including import and export quantities, has been maintained in Australia since the 1930s. This consistent and detailed collection of time-series data provides a sound basis for the development of a national wood products model. The model developed and implemented to model *harvested wood products* is reported in detail in Jaakko Pöyry Consulting (1999) and Jaakko Pöyry Consulting (2000). Updates and model refinement were subsequently undertaken by MBAC Consulting. The refined model and its sensitivity analysis are reported in Richards *et al*., (2007).

Accounting Approaches

Accounting approaches for carbon emissions from timber harvesting and wood products include emissions from wood products in Australia (wherever the source). This approach accounts for emissions from all wood products within Australia, regardless of their country of origin. Exported wood products are not accounted for and are the responsibility of the importing country. The amount of material exported is deducted from the total production, with total imports added, to derive the amount of material available for emissions within Australia. The origin of imported wood products is not tracked. However, the total flow of imported wood products into various pools within Australia is monitored.

Model Components

Information has been obtained and examined under the following components of the model:

- log flow from the forest: current annual production data were obtained by species groupings, and product classes, e.g., sawlogs, veneer logs, pulp logs, roundwood and other, e.g., sleepers;
- fibre flow from processing: data on the intake of raw materials to the various processing options and the output of products and by-products have been used in the model to estimate the total tonnes of carbon produced each year under various end product classes;
- import and export quantities of wood products;
- recycling;
- entry and decomposition in landfill;
- use for bioenergy; and,
- other losses to atmosphere.

Life Cycles and the Wood Products Carbon Pool

Estimates of the life cycles appropriate for each class of wood product have been made and methods for estimating the initial pool of carbon, as represented by wood products in use since 1943, have been proposed. Annual log removals data are available through the Australian Forests Products Statistics published quarterly by the Australian Bureau of Agricultural and Resource Economics (ABARE 2009c). Data are also available through the Levies Management Unit of the Department of Agriculture, Fisheries and Forests, on behalf of the Forest and Wood Products Research and Development Corporation (FWPRDC). Log removals data are also published by the relevant State Forest Services and these provide a valuable crosscheck on ABARE data.

Cypress pine removals are included under the total for coniferous logs and a separate figure is not provided. It is necessary to extract cypress pine volume and analyse separate from softwood sawmilling because:

- Cypress pine is a significant source of wood products;
- Cypress pine is a native conifer and softwood sawmilling largely refers to exotic species plantations; and,
- Cypress pine is a denser wood than exotic pines and is used by a totally separate industry supplying different products to the market.

A Cypress pine figure can be developed from the ABARE information by applying a conversion factor to sawn-wood consumption and applying a conversion factor to calculate equivalent log removals.

Wood Flow

The model develops wood flows separately for each sector and these are integrated to account for cross-linkages. This is particularly important in the accounting for waste or by-products which are themselves used as resources for other segments of the industry. In conjunction with the carbon pool and life cycle of timber products, this model enables the total and projected carbon pools to be estimated.

In broad terms, the components of the models developed for each sector are similar, using:

- an estimate of raw materials input, whether of sawlogs, woodchips ex-sawmill, or pulp logs;
- an estimate of the products of processing, e.g., "x" percentage sawdust, shavings or sander dust for on-site energy generation or compost, "y" percentage woodchips for other manufacturing processes, "z" of sawn timber products, panel products and paper;
- an estimate of the proportion of products by product categories, depending on whether their expected end use is long-term or short-term; e.g., framing timber, dry dressed boards, cases and pallet stock, panel products for use in house construction, panel boards for use in furniture and cabinets, newsprint paper, and writing and printing paper;
- a final figure for total Australian consumption by end use categories, converted to wood fibre content (oven-dry weight) and to tonnes of carbon; and
- import and export data obtained from the ABARE (2009c) by end use categories.

Details of the flows are shown in Attachment 7I.1.

Treatment of Bark

There has been no accounting for bark in this study. All bark is regarded as being a component of logging slash (harvesting residue) and accounted for under in-forest logging operations, for the following reasons:

- logs are sold with log volumes recorded on an underbark basis;
- in most hardwood operations, logs are debarked in the field;
- in softwood operations, it is estimated that some bark is lost prior to the logs reaching the mill. Most of this loss occurs during the mechanised de-limbing and log docking operations; and,
- most softwood bark recovered at the mill is used for garden mulch which it is considered would have decay characteristics similar to that of logging slash.

Softwood bark is a significant source of carbon with total bark varying from about 35% of underbark log volume (not oven dry weight) in Caribbean pine to 20% in radiata pine and hoop pine. It is likely that, in the future, an increasing proportion of softwood bark will be used in the co-generation of energy and it may be reasonable to review this proposal should the situation change.

Basic Density and Carbon Content

Basic wood density and carbon content estimates are relevant to all of the processing options and the choice of values adopted has a significant bearing on the final outcome. In the case of all sawn timber, and treated softwood and hardwood poles, weighted basic densities for the species involved have been applied across each category. Basic density is defined as oven dry weight divided by green volume and the values adopted have been based on Ilic *et al.,* (2000). For board products and paper, however, the situation is different because all have been subjected to varying amounts of compression during manufacture and to compensate for this, their basic densities have been adjusted accordingly from the air-dry density of the finished products.

Carbon content is defined variably throughout the literature with values ranging from 0.4 to 0.53 of the oven dry (bone dry) weight. A figure of 0.5 has been adopted for use in the model as a median value extracted from Gifford (2000a).

Apart from the assumptions concerning basic density and carbon content, the other manufacturing assumptions were developed from interviews with representatives from the various industry associations and individual sawmilling companies. The issues addressed included:

- recoveries of green sawn timber, sawdust and chip;
- actual sawn sizes and corresponding dressed sizes; and,
- the range and proportions of products produced.

For the softwood sawmilling industry, for example, weighted averages of the information received have provided realistic assumptions. The same applies to the other species/industry sectors, with the exception of hardwood sawmilling.

Table 7.I 1 Basic densities, moisture and carbon contents

Carbon Fractions	
Description	**Value**
Fraction of softwood sawmilling dry matter that is carbon, by weight	0.50
Fraction of particleboard dry matter that is carbon, by weight	0.40
Fraction of MDF dry matter that is carbon, by weight	0.40
Basic Densities (a)	
Description	**Value kg m^{-3}**
Density of softwood sawmilling	460
Density of hardwood sawmilling	630
Density of cypress sawmilling	600
Density of plywood (softwood and hardwood) and veneer	540
Density of particleboard	520
Density of MDF	600
Density of hardboard	930
Density of softboard	230
Density of pulp and paper: Paper	1,000
Density of pulp and paper: Softwood	430
Density of pulp and paper: Hardwood	500
Density of pulp and paper: Waste paper	1,000
Density of pulp and paper: Pulp	1,000
Density of paper and paperboard imports and exports, on average	1,000
Density of chips and logs for export: Softwood logs	415
Density of chips and logs for export: Hardwood logs	630
Density of hardwood poles, sleepers and miscellaneous	790
Moisture Content of Green Wood	
Description	**Value**
Ratio of weight of water to weight of wood substance in softwood chips	1.10
Ratio of weight of water to weight of wood substance in hardwood chips	0.90

(a) Basic density = (mass of oven dry wood in kg) / (volume of green wood in m^3)

Wood Flows from Processing

Wood flows in the various wood products produced in Australia have been developed under the following species/industry headings:

- Softwood sawmilling;
- Hardwood sawmilling;
- Cypress sawmilling;
- Plywood;
- Particleboard and medium density fibreboard (MDF);
- Pulp and paper;
- Preservative treated softwood;
- Hardboard;
- Hardwood poles, sleepers and miscellaneous; and,
- Export of woodchips and logs.

Softwood Sawmilling

The softwood sawmilling industry in Australia is largely based on plantations of exotic pines, although the native pine, hoop pine, is grown in southern Queensland. Most plantations were initiated around the 1930s. Early development was slow, but momentum was gained in the 1960s and 1970s.

Softwood processing has become very efficient, highly mechanised and a well integrated industry, comparable with any of its overseas counterparts. Most softwood mills are large, with up to 500,000 m^3 yr^{-1} log intake. Most of the sawn timber is seasoned and dressed. Value-adding options such as machine stress grading, glue lamination and finger jointing are common.

Nearly all softwood mills are now operating on zero waste, with all slabs and edgings being chipped for paper pulp or panel board feedstock and the sawdust and shavings being used for boiler fuel to provide energy for kiln drying. In some cases, some of this material is sold for composting, but this is unlikely to continue if the co-generation of electricity becomes more financially attractive.

A basic density of 415 kg m^{-3} is used. This is sourced from Ilic *et al*., (2000) and Gardner and Ximenes (*pers. comm.*); and is based on a weighted average of the respective densities of radiata pine, slash pine, Caribbean pine and hoop pine that are harvested.

The destinations of sawlogs and sawn timber products were sourced from representative sawmills in South Australia, Tasmania, Queensland and the Australian Capital Territory and from Pine Australia. Import and export figures were derived from ABARE (2009c).

Hardwood Sawmilling

The hardwood sawmilling sector is quite different from the softwood sector being characterised by a large number of small mills; even the very few large hardwood mills are much smaller than the average softwood mill. In recent years, the hardwood industry has undergone considerable change in response to reductions in their traditional resource base and to the impact that softwood framing has had on the traditional green hardwood framing market and also due to growing restrictions in the utilisation of native hardwood forests.

As indicated earlier, the hardwood plantation resource is expanding and removals from hardwood plantations have been included in the total hardwood removals. Most of this material is currently of pulp log quality, but more sawlogs will be harvested as the resource matures. There is a reasonable degree of integration in the hardwood industry; however integration is difficult for the smaller more remote mills.

The hardwood sawmilling industry is far more complex and varied than any of the other sectors. There are at least 10 major species throughout the country, all having different densities and shrinkage rates, and to a great extent having different end uses. This sector has not been addressed in nearly the same detail as was applied to the softwood sawmilling sector and the outcome should be regarded as indicative only.

Assumptions on the product out-turn from hardwood sawmilling were sourced from the Victorian Association of Forest Industries and a large sawmilling company operating mills in Queensland, New South Wales and Tasmania. Sawlog volumes produced and import/export data have been sourced from ABARE (2009c).

A basic density of 630 kg m^{-3} is assumed for hardwood sawlogs. This is an average of the following ten commonly logged hardwoods: spotted gum (*Corymbia maculata*), blackbutt (*Eucalyptus pilularis*), rose gum (*E. grandis*), jarrah (*E. marginata*), karri (*E. diversicolor*), mountain ash (*E. regnans*), alpine ash (*E. delegatensis*), silvertop (*E. sieberi*), brown barrel (*E. fastigata*) and messmate stringybark (*E. obliqua*). The basic density assumed for poles and sleepers is 790 kg m^{-3}. This is an average of spotted gum, ironbark and blackbutt - the main species used.

Hardwood chips are lower in average density than either sawlogs or poles and sleepers as they contain a wider range of species as well as younger regrowth and plantation material. An average basic density of 570 kg m^{-3} is assumed. This is sourced from Chin (*pers. comm.*) of CSIRO.

Cypress Sawmilling

The Cypress sawmilling industry is restricted to the native cypress pine forests in Queensland and New South Wales. The quantity of logs removed is small and the data are currently included in the coniferous forest information in the ABARE quarterly reports (ABARE 2009d).

The industry consists of several relatively small, low technology mills operating on a scattered resource. Because of the distances involved, integration with other processing sectors is difficult; however some Cypress pine chips are being used in panel board manufacture. The products are principally green framing and high value flooring and dressed panelling.

Plywood (Softwood and Hardwood) and Veneer

The Australian plywood industry is based principally on plantation grown softwoods and about 8% hardwoods, both native and plantation grown. Large, high quality logs, for which premium prices are paid, are preferred. In volume terms, the plywood industry is small, but it uses high technology and produces a variety of products.

In addition to plywood veneer, sliced or rotary peeled decorative veneer is produced in small quantities for furniture, door and panel overlays. This production is not recorded separately by ABARE. Jaakko Pöyry Consulting (2000) estimated annual production is less than 10,000 m^3. Data sources used in the model for plywood was from ABARE (2009c) and the Plywood Association of Australia.

Particleboard and Medium Density Fibreboard (MDF)

The characteristics of these two wood panel boards are different, but their feedstock and end use product categories are similar. Their densities are, however, different. Particleboard and MDF plants are large-scale operations and they are usually located close to their resource. Both require low cost material as input using either small logs unsuited to sawmilling, or woodchips produced as a by-product of sawmilling. Most of the feedstock is from softwood plantations, although some regrowth hardwood is being used in a plant in Tasmania and some cypress pine is being used in a plant in Queensland. In terms of trade, Australia is a net exporter of particleboard and MDF. The industry source used for information on processing assumptions in the model was the Australian Wood Panels Association.

Pulp and Paper

Pulp and paper plants are very large-scale industries requiring large volumes of low cost resource. Plantation grown softwood fibre provides the major resource but hardwood and recycled fibre is also important. Accounting for this sector is complicated by the fact that recycled fibre is exported and pulp is imported. Australia has five pulp and paper mills. Production data is sourced from ABARE (2009c).

A complicating factor in the assumptions on waste with the pulp and paper stream is the fact that mills vary dramatically in their recovery according to type. Kraft pulp mills typically have a low yield of fibre (at 50%) whereas thermo-mechanical mills have a high yield (at 95%). The manufacture of recycled paper also results in a lower yield of fibre. Based on weighted inputs, a yield of 70% has been adopted.

Preservative Treated Softwood

Both hardwood and softwood can be preservative treated, but only softwood has been allocated a separate category. This is because treated sawn softwood has some use categories which are different to untreated softwood, whereas hardwood is usually treated so that the sapwood can be protected against borer attack and its use is then the same as for untreated hardwood.

Treated softwood poles and posts have also been included with sawn softwood, but treated hardwood poles and piles have been included with sleepers and other miscellaneous hardwood products. The ABARE statistics do not list treated timber of any description. The information used in the model has been obtained from the Timber Preservers Association of Australia.

Hardboard

The hardboard industry in Australia is quite small, with only two plants in operation. One is at Ipswich (Queensland) and the other is at Raymond Terrace (New South Wales). Hardwood is used for feedstock, sourced from pulp logs and sawmill residue.

The technology is quite old, but the products are unique and have niche markets that are likely to endure the competition from other panel products. Both hardboard producers were contacted during the study for manufacturing assumptions.

Hardwood Poles, Sleepers and Miscellaneous

The existing stock of hardwood transmission poles in Australia is reputed to number about 6,000,000 and production is estimated to be about 100,000 poles per annum, equivalent to about 75,000 m^3 of log. Railway sleepers also represent a considerable resource, and although concrete sleepers are now used for all new work, timber sleepers will continue to be used for the maintenance of secondary lines. 'Miscellaneous' includes a range of products such as mining, fencing and landscaping timbers. The log removals information for this group is conflicting and difficult to uncover. A provisional constant of 184,400 m^3 has been proposed for use in the model and further work is recommended.

Log and Woodchip Exports

Woodchip Exports

Export woodchips constitute a significant proportion of the annual harvest from Australian forests. The ABARE quarterly forest products statistics report both bone dry tonnes (BDt) of softwood chips and BDt of hardwood chips exported. The model uses the ABARE reported export figures directly in bone dry tonnes.

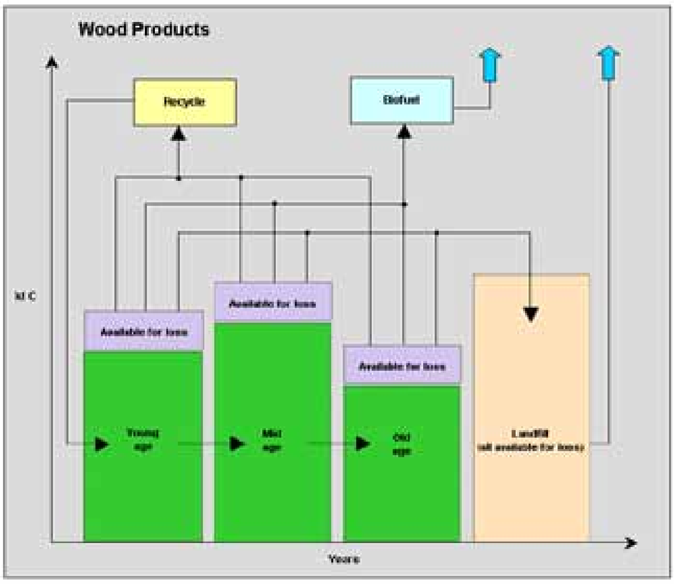
Log Exports

Total exports of coniferous logs reported by ABARE (2009c) consist of both sawlog and pulp log. New South Wales exports approximately 7,000 m^3 of short length poles per year.

Life Span of Timber Products (Recycling and Landfill)

The life span of wood products must be taken into account when ascertaining the quantity of carbon stored in timber products. Considerable attention has been given to subdividing the various timber products pools into different classes based on product and decay rates. The decay rates used assume that losses of material from service life will increase with product age. Therefore the entry and exit of material from production to loss from each product pool is tracked and aged according to three age classes; young, medium and old. The proportion of material lost from each pool may vary (e.g., there may be little loss from young pools (excluding those to the medium age class)). Material is lost at a constant rate and may be placed in landfill, recycled, used for bioenergy or lost to the atmosphere (e.g., burnt with no energy capture) (Figure 7.I1).

Figure 7.I 1 Structure of the Wood Products Model



For shorter-term products, the impact of the size of previous stocks is fairly slight as the recent additions to the pools have the major impact. For long-term products, an estimate of the size of the initial pool is essential, but difficult. The size of the housing pool uses housing starts data. Other pools are also only estimates. The proportion of the pool that has been derived from Australian-grown wood is required in order to implement an approach that separately deals with imported wood products. However, this component is difficult to estimate and estimates should be treated with some caution.

Life Span Pools Assumed for the Carbon Model

Very short-term products – Pool 1

- Paper and paper products.
- Age: young = 1; medium = 2; old = 3

Short-term products – Pool 2

- Hardwood – pallets and palings.
- Softwood – pallets and cases.
- Particleboard and MDF – shop fitting, DIY, miscellaneous.
- Plywood – form board.
- Hardboard – packaging.
- Age: young = 3; medium = 6; old = 10

Medium-term products – Pool 3

- Plywood – other (noise barriers).
- Particleboard and MDF – kitchen and bathroom cabinets, furniture.
- Preservative treated pine – decking and palings.
- Hardwood – sleepers and other miscellaneous hardwood products.
- Age: young = 10; medium = 20; old = 30

Long-term products – Pool 4

- Preservative treated pine – poles and roundwood.
- Softwood – furniture.
- Hardwood – poles, piles and girders.
- Age: young = 20; medium = 30; old = 50

Very long-term products – Pool 5

- Softwood – framing, dressed products (flooring, lining, mouldings).
- Cypress – green framing, dressed products (flooring, lining).
- Hardwood – green framing, dried framing, flooring and boards, furniture timber.
- Plywood – structural, LVL, flooring, bracing, lining.
- Particleboard and MDF – flooring and lining.
- Hardboard – weathertex, lining, bracing, underlay.
- Preservative treated pine – sawn structural timber.
- Age: young = 30; medium = 50; old =90

A specified proportion of material may be lost annually (an exponential loss) from each age class of each product pool. The amount lost from each age class for each product pool can be capped and different proportions can be lost according to age. This feature of the model provides for 'steps' in product loss rather than functioning on either a simple linear or exponential loss applied to a whole product pool, irrespective of the average age of the pool. If inputs vary over time the average age of products will vary, and this is represented by the amounts of material in each age class of each product pool.

Initial Stock Assumptions

Input data is available for the model since 1944 and this has the benefit of allowing the model to establish new equilibrium pools as the input material may be 'turned-over' several times prior to an equilibrium stock being reached for recent years. Initial stock estimation (for 1944) is more important for Pool 5 as this material may remain in use.

Model Calibration

Once the data on production inputs, processing flows and initial stocks is determined other model calibration requirements include:

- the age at which material moves from young to medium and medium to old pools;
- the amount of each age class for each product pool exposed to loss;
- the rate of loss from each age class in each product pool; and,
- the fraction of losses from each age class in each product pool to each of landfill, recycling, bioenergy and the atmosphere.

The model estimates used are presented in Tables 7.I2 and 8.5 (in Chapter 8).

Table 7.I 2 Decomposition rates and maximum possible loss

Pool	YOUNG		MEDIUM		OLD	
	Loss Yr^{-1}	Max. Possible Loss (%)	Loss Yr^{-1}	Max. Possible Loss (%)	Loss Yr^{-1}	Max. Possible Loss (%)
1	1.0	0.60	0.500	0.65	0.333	0.90
2	0.333	0.30	0.167	0.50	0.100	0.90
3	0.10	0.15	0.050	0.65	0.033	0.45
4	0.05	0.25	0.033	0.65	0.020	0.80
5	0.033	0.20	0.020	0.55	0.011	0.95

To understand the impact of uncertainties, *Monte Carlo* analyses using the Palisade @Risk software (Palisade 1997) was applied. This approach is also able to identify model sensitivities. Through this, it is possible to identify where uncertainty in parameter estimation may be most significant in terms of a probability distribution of expected outcomes, and to focus future data collection on areas that will have greatest impact on reducing uncertainties.

Model Results

By integrating the carbon pools and life cycles of wood products, the model enables the total carbon pools and emissions to be estimated. In broad terms, the components of the models as described for each sector are similar, using:

- an estimate of raw materials input, whether of sawlogs, woodchips ex-sawmill, or pulp logs;
- an estimate of the products of processing, e.g., "x" percentage sawdust, shavings or sander dust for on-site energy generation or compost, "y" percentage woodchips for other manufacturing processes, "z" percentage of sawn timber products, panel products and paper;
- an estimate of the proportion of products by product categories, depending on whether their expected end use is long-term or short-term;
- a final figure for total Australian consumption by end use categories, converted to wood fibre content (oven dry weight) and to tonnes of carbon; and
- import and export data obtained from the ABARE (2009c) by end use categories.

Table 7.I3 shows the annual additions and losses and carbon pool sizes.

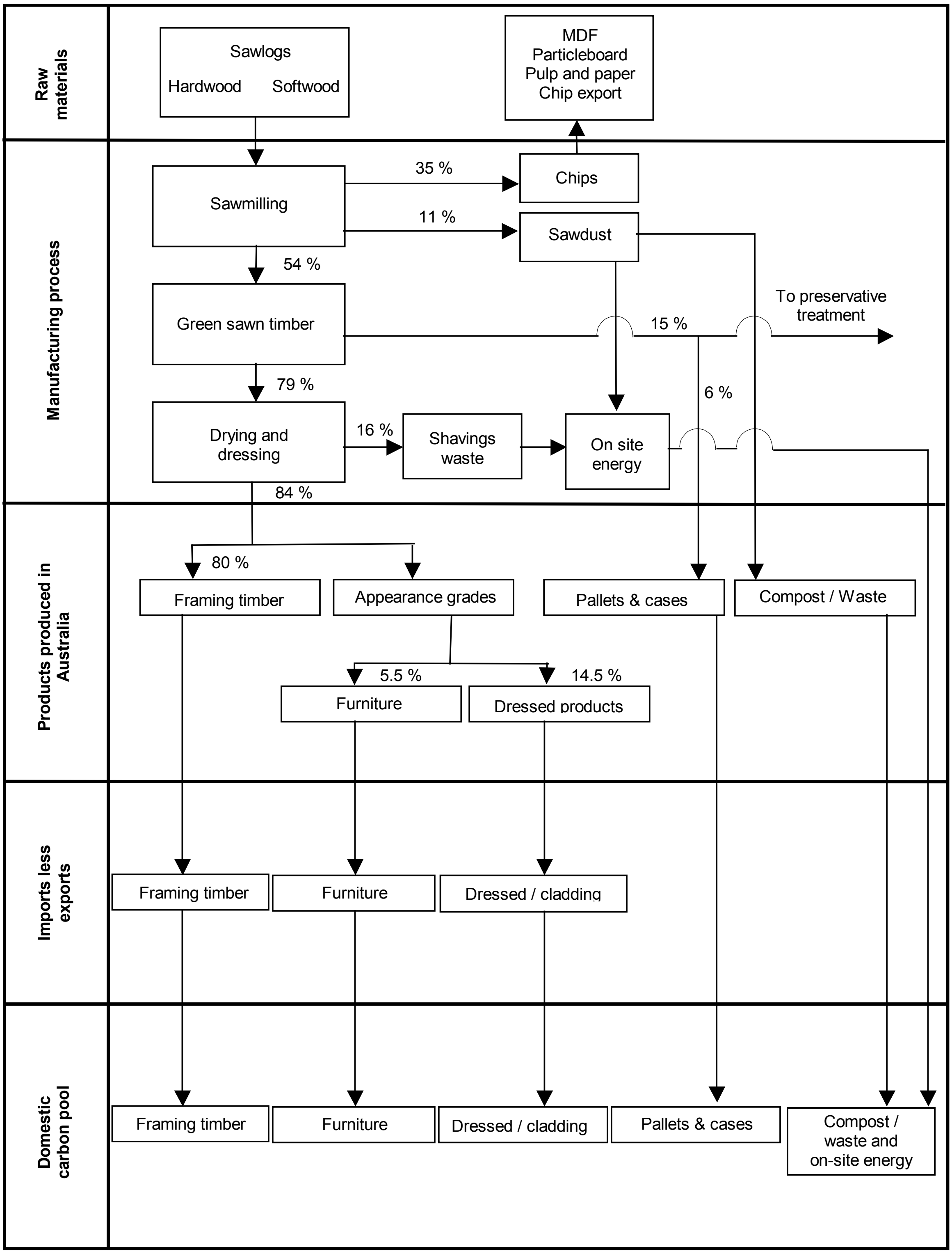
Table 7.I 3 Carbon stock and emissions outcomes (kt C)

Year	Domestic Production of Wood Products[a]	Imports of Wood Products	Exports of Wood Products[a]	Increase Due to Wood Products	Carbon Pool (excl. landfill)
	kt C	kt C	kt C	kt C	kt C
1990	3,307	730	80	3,957	79,454
2000	3,791	920	315	4,396	91,760
2005	4,249	1005	481	4,773	98,295
2006	4,232	960	493	4,699	99,653
2007	4,114	985	500	4,599	100,903
2008	4,179	1056	468	4,767	102,301

(a) Exports of wood products excluded exports of woodchips

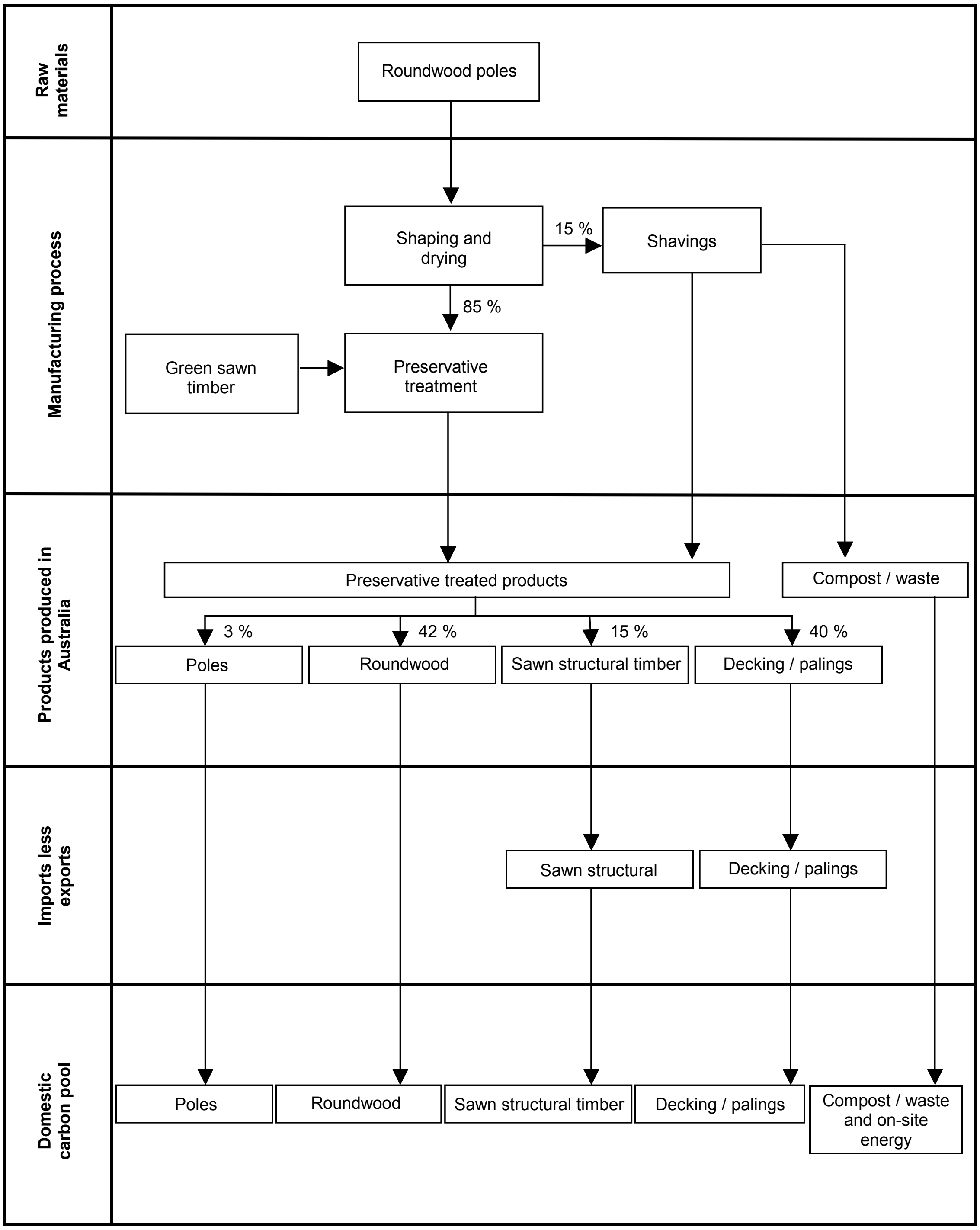
Attachment 7.I1: Wood Flows by Sector

Figure 7.I2: National Carbon Accounting Model for Wood Products – Sawmilling wood flows *



* percentages shown for softwood sawmilling, refer to model for hardwood and cypress pine

Figure 7.I3: National Carbon Accounting Model for Wood Products – Wood flows in preservative treated products



7.I APPENDIX

Figure 7.I4: National Carbon Accounting Model for Wood Products – Wood flows in plywood production

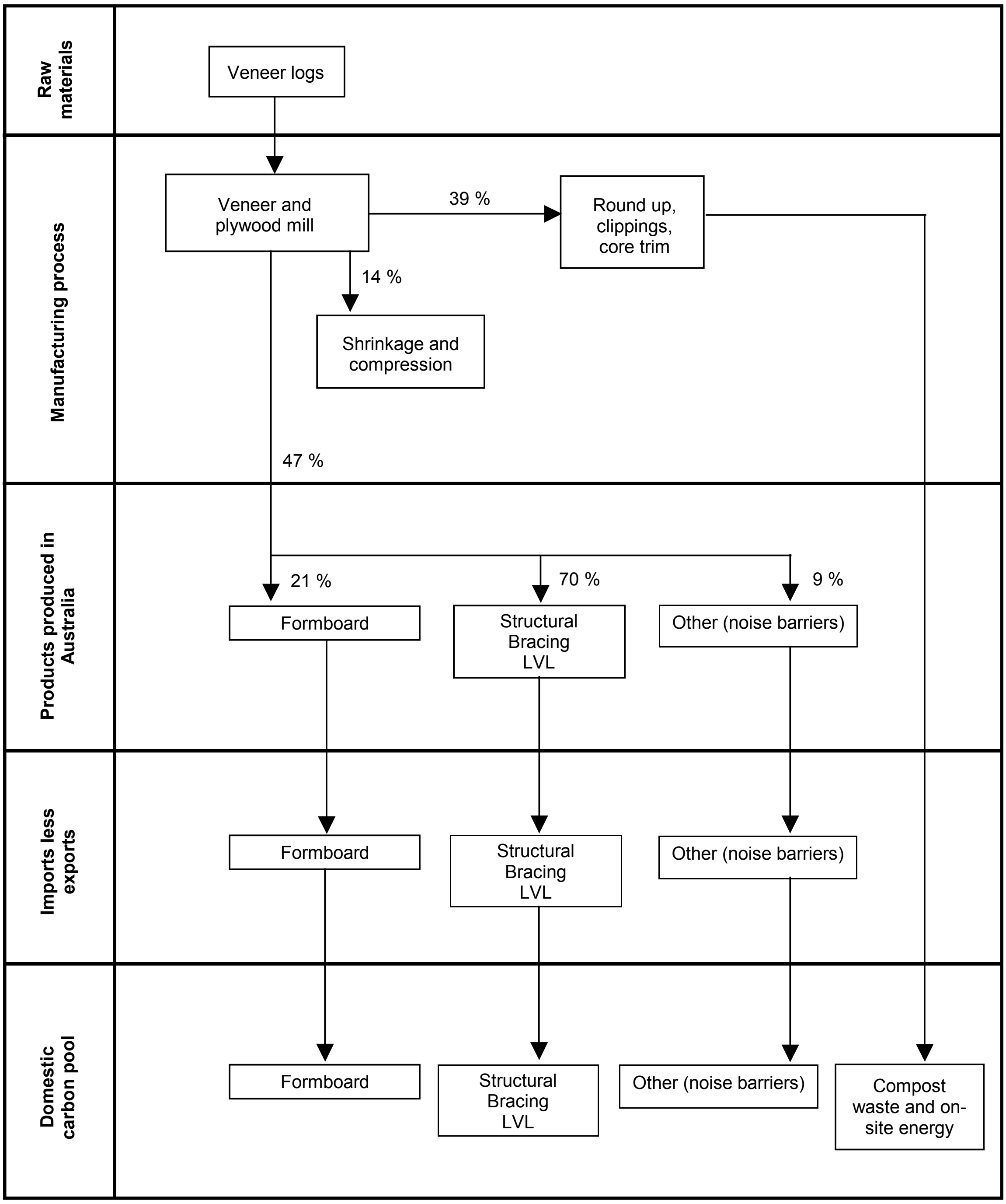
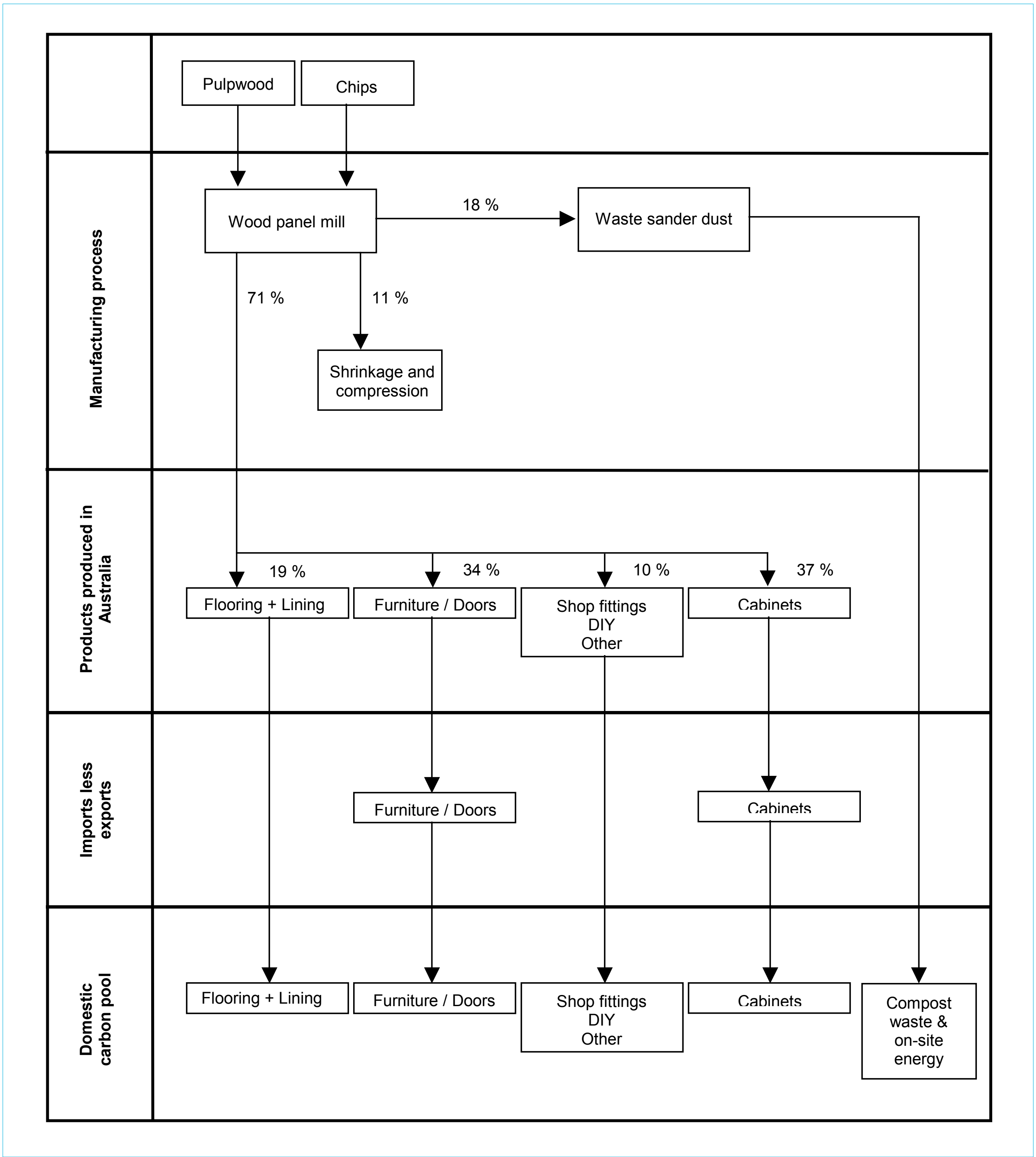
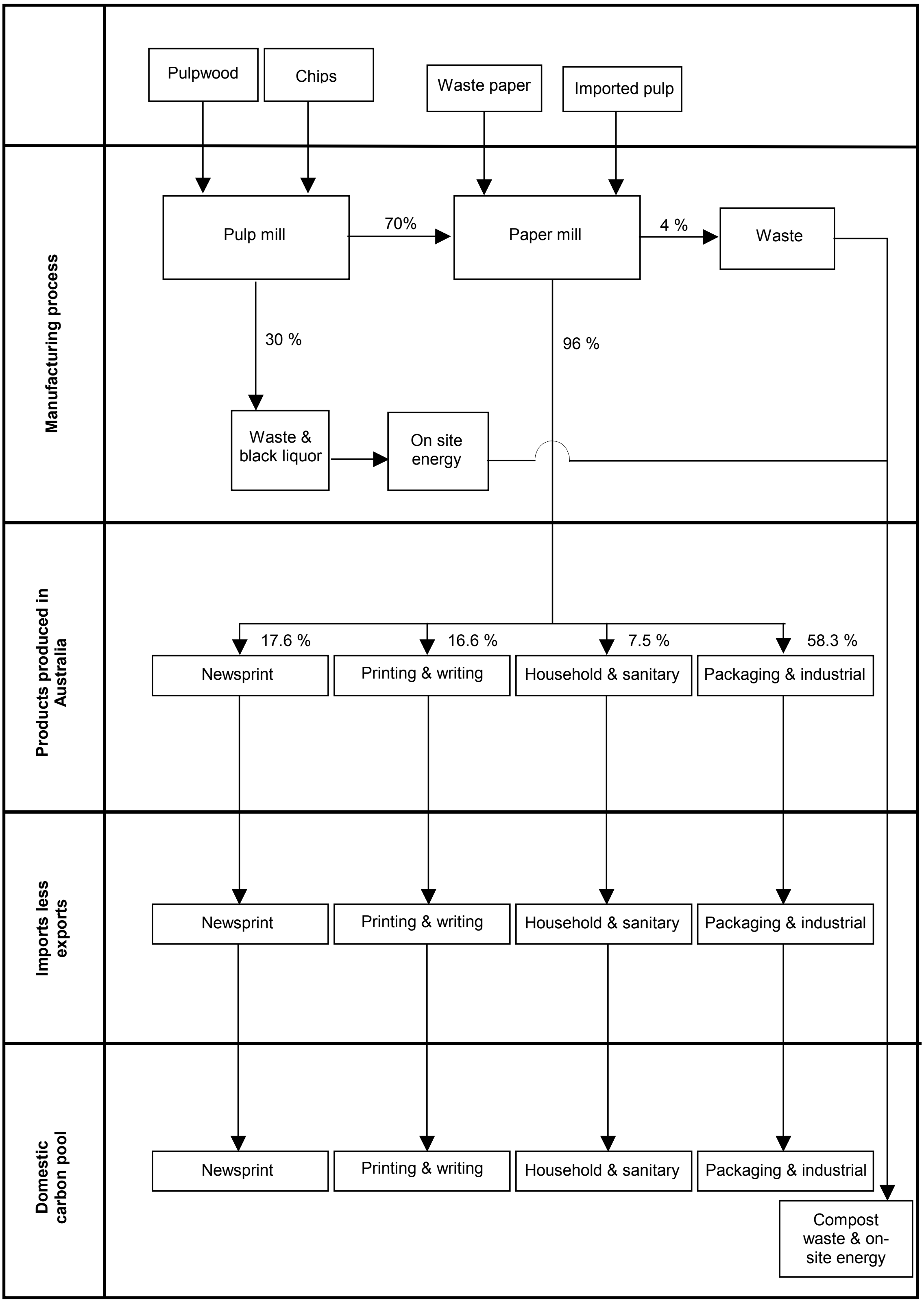


Figure 7.I5: National Carbon Accounting Model for Wood Products – Wood flows in MDF and particleboard manufacture *



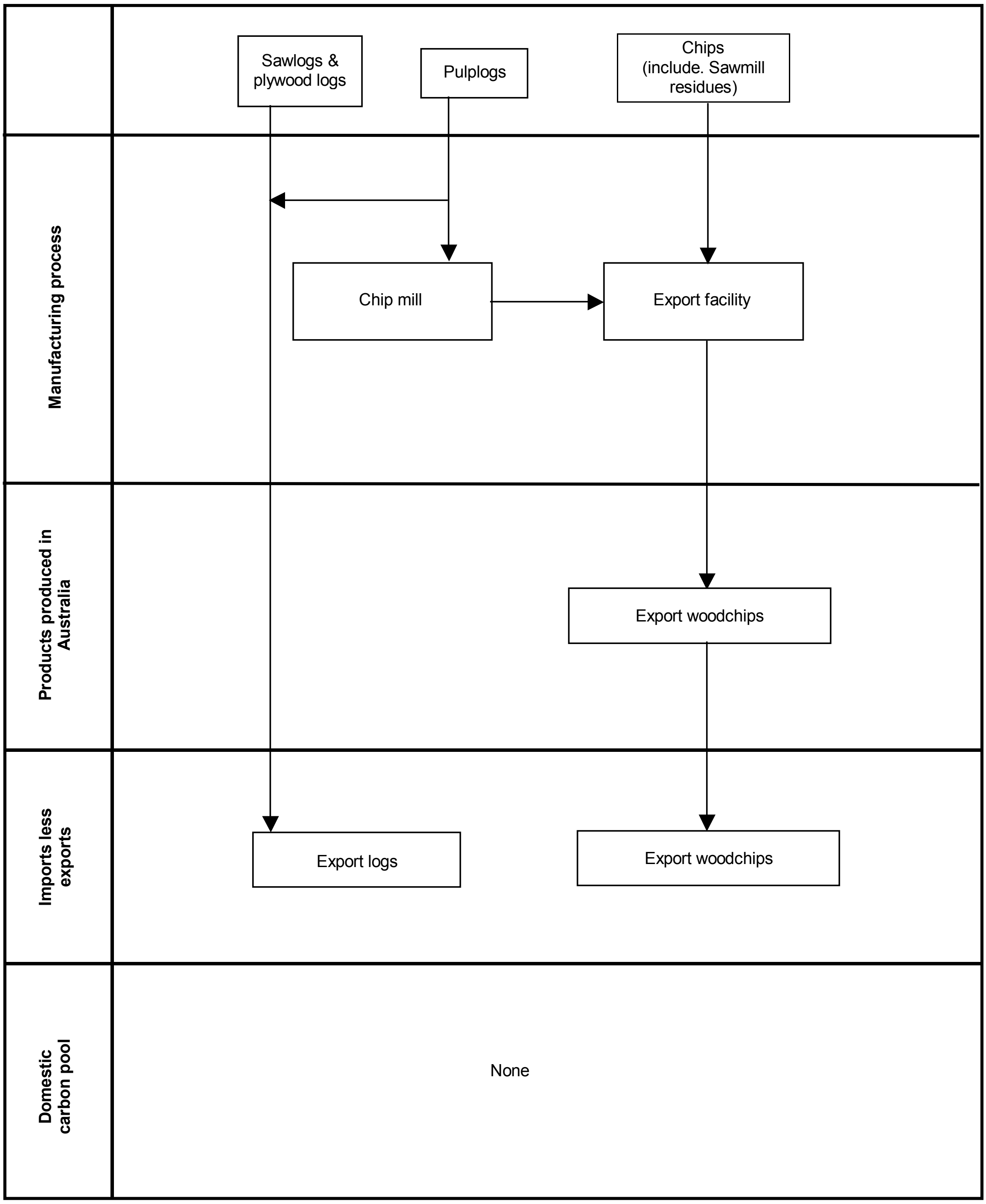
* percentages shown for particleboard manufacture – see model for details on MDF

Figure 7.I6: National Carbon Accounting Model for Wood Products – Wood flows in pulp and paper manufacture



APPENDIX 7.I

Figure 7.I7: National Carbon Accounting Model for Wood Products – Wood flows in export woodchips and logs



APPENDIX 7.J CROSS-CUTTING ISSUES (QA/QC)

7.J.1 Introduction

The land sector components of Australia's National Inventory System use a combination of Tier 2 and Tier 3 methods to estimate emissions and an Approach 3 method to represent most land categories.

This appendix defines and details the calibration, validation, verification, quality assurance, quality control, sensitivity and uncertainty analyses, and transparency and review applied to the calculation of Australia's greenhouse gas emissions from *Land-Use, Land-Use Change and Forestry* (LULUCF) (Section 7.J.6). These activities ensure that Australia's estimates are in line with the IPCC Guidelines and Guidance. It also describes the roles and responsibilities of the various organisations and agencies involved in each of the processes required to estimate and deliver the LULUCF emissions estimates and the National Inventory Report. The appendix is divided into the following sections:

Section 7.J.1 – Roles and responsibilities;

Section 7.J.2 – Input data and model development;

Section 7.J.3 – Source category;

Section 7.J.4 – Model and data management;

Section 7.J.5 – Transparency and Review; and,

Section 7.J.6 – Definition of key terms.

7.J.1.2 Roles & Responsibilities

Many organisations external to DCCEE are involved in the development, testing and maintenance of *FullCAM* and geospatial systems which support land sector reporting. Table 7.J1 summarises these external organisations and their roles and responsibilities.

External organisations (contributors) are generally engaged on a fee for service basis. The processes undertaken to check the accuracy of data and information supplied by external contributors are detailed in later sections.

Table 7.J 1 Roles and responsibilities of organisations involved with the development and maintenance of the land sector reporting in the National Inventory System.

Category	Sub-category	Activity	Quality Task	Responsibility	Frequency	Reports
Input data	Remote sensing for land cover and land use	Satellite data acquisitions				
			Data (scene) selection	DCCEE	Annual	Technical specifications for image selection
			QA/QC of selected scenes for consistency with specifications	External , CSIRO)	Annual	Technical specifications for image selection
			Data order	DCCEE	Annual	DCCEE Geospatial Analysis Unit
			Data generation and internal QA	External (GA)	Annual	DCCEE Geospatial Analysis Unit
			Data delivered to DCCEE	External (GA)	Annual	Entry to image database
		Satellite data processing	Registration and calibration	External (various contractors)	Annual	Technical specifications for registration and calibration
			Registration and calibration QA	DCCEE & CSIRO	Annual	Manual for registration and calibration
			QA/QC pass for registration and calibration	External (CSIRO)	Annual	Naming standards for registration and calibration products
			Cloud cover masks generated	External (various contractors)	Annual	DCCEE Geospatial Analysis Unit
			QA on cloud cover masks	External (CSIRO)	Annual	DCCEE Geospatial Analysis Unit
			Image mosaic analysis of new data	External (various contractors)	Annual	Technical specifications for mosaicing
			QA on mosaicing	External (CSIRO)	Annual	Manual for mosaicing Naming standards for mosaic products and cloud masking
			QA/QC for mosaicing	External (CSIRO)	Annual	DCCEE Geospatial Analysis Unit
		Satellite data classification	Thresholding	External (various contractors)	Annual	Technical specifications for thresholding

Category	Sub-category	Activity	Quality Task	Responsibility	Frequency	Reports
			QA/QC for thresholding	External (CSIRO)	Annual	National standards for thresholding products
			CPN analysis	External (CSIRO)	Annual	DCCEE Geospatial Analysis Unit
			Forest extent product QA	External (CSIRO)	Annual	DCCEE Geospatial analysis Unit
			Final products	DCCEE	Annual	DCCEE Geospatial analysis Unit
	Climate	Data are obtained from the Australian Bureau of Meteorology	QA and QC Checks on data integrity and spatial accuracy	External (ANU)	Annual	NCAS Technical report 23
		Check of data library	QA and QC on data entries	External (ANU)	Annual	NCAS Technical report 23
		Generation of initial surfaces	QA and QC on data outputs	External (ANU)	Annual	NCAS Technical report 23
		Accuracy checking of surfaces against individual station data	Validation of surfaces	External (ANU)	Annual	NCAS Technical report 23
		Checks include data integrity and that the data for each pixel in each time epoch conforms with expectations of normal data ranges		DCCEE	Annual	Data only enters national system when integrity checks passed
Input data	Yield	Collate and validate annual crop yield data for all IBRA regions	Develop QA and QC methods of entry of yield to data base	External (CSIRO)	Received Annually	CSIRO reports and research papers (Unkovich et al., 2009; Unkovich et al., 2006)
			Collection of new yield data	External (CSIRO)	Annual	Annual reports to DCCEE
		Crop yield data is checked against previous years of data	QA/QC for the new crop yield data	DCCEE	Annual	Protocols for data entry
			New crop yield data is checked against previous years	DCCEE and External (CSIRO)	Annual	QA report on data integrity
		Enter crop yield data into FullCAM database	QA/QC for data entries	DCCEE	Annual	QA/QC checks against the original data

Category	Sub-category	Activity	Quality Task	Responsibility	Frequency	Reports
			New yield data are entered into the FullCAM database	DCCEE	Annual	Data integrity checks on updated database
		Checks include the integrity and completeness of the relational database, and that data conform with expected ranges	Validation of data inputs	DCCEE and External (CSIRO)	Annual	DCCEE Agriculture Inventory Unit
Input data	Wood and Wood Products	Obtain data on forest product statistics published by the Australian Bureau of Agricultural and Resource Economics	QA/QC of forest product data	External (MBAC consulting, Jaakko Pöyry consulting, ANU, WebNet land resource services Pty Ltd)	Annual	NCAS Technical reports 8 and 24
		Enter data into model	QA/QC for data entry, check data for consistency with previous estimates	External, DCCEE and MBAC Consulting	Annual	DCCEE internal process
			Enter new data into wood products model	DCCEE	Annual	DCCEE internal process
Model validation	Tree growth	Checks include the integrity and completeness of the relational database, and that data conform with expected ranges		DCCEE and External (CSIRO)		Published papers (Waterworth et al., 2007; Brack et al., 2006)
	Litter		Ensure that estimates are within expected ranges	DCCEE and External		NCAS Technical reports 14, 40 and Woldendorp & Keenan, 2005
	Soils	Checks include the integrity and completeness of the relational database, and that data conform with expected ranges	Test FullCAM output for soil C stocks against measured soil C values. Validation and verification of data outputs.	DCCEE and External (CSIRO)	Periodic	NCAS Technical Report 30 NCAS Technical reports 34, 36, 37 and 38
Emissions estimates	Emissions categories	Grassland remaining grassland	Validation of outputs checked against previous annual runs	DCCEE	Annual	NIR
		Cropland remaining cropland	Validation of outputs checked against previous annual runs	DCCEE	Annual	NIR
		Plantation forests	Validation of outputs checked against Tier 2 models	DCCEE	Annual	NIR

Category	Sub-category	Activity	Quality Task	Responsibility	Frequency	Reports
		Harvested native forests	Validation of outputs checked against independent data	DCCEE	Annual	NIR
		Spatial inputs to FullCAM	Undertake QC of spatial inputs to FullCAM	DCCEE	Annual	NIR
		Uncertainty analysis of FullCAM outputs	Provide uncertainty analysis of FullCAM for national estimates	DCCEE	Annual	NIR
			Provide national trends with uncertainty analysis for carbon stock changes	DCCEE	Annual	NIR
		Uncertainty analysis of carbon stocks	Validation of the impacts of climate parameters on carbon stocks	DCCEE	Annual	NIR; Waterworth et al., 2005 and 2007; Brack and Richards, 2002

7.J.1.1.1 Input data collection & preparation

Input data are obtained from a range of agencies external to DCCEE by either purchasing the data directly from the agency or using publicly available databases. Table 7.J2 lists these data and the sources of these data. Analysis and preparation of data for use is conducted by both the external agencies and DCCEE.

Table 7.J 2 Public and private sector agencies contributing to tasks associated with the collection and preparation of input data for *FullCAM*.

Task	Contributing agencies
Calculation of land cover change from remotely sensed imagery	CSIRO Mathematics, Informatics and Statistics Geoscience Australia (GA) DCCEE Geospatial Analysis Unit Various private sector firms
Collection and collation of current and historical land use data	Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES) Australian National University (ANU) CSIRO Land and Water CSIRO Sustainable Ecosystems Department of Sustainability, Environment, Population and Communities (SEWPaC)
Collection of climate data and derivation of modelled climate surfaces	Australian Bureau of Meteorology (BOM) Australian National University (ANU)
Derivation of an Australia-wide soil type map	CSIRO Land and Water State and Territory Governments
Collection and collation of crop yield and management data	Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES) Australian Bureau of Statistics (ABS) CSIRO Land and Water Various agricultural industry bodies
Collection and collation of forest growth and management data	Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES) Australian National University (ANU) CSIRO Sustainable Ecosystems DCCEE Forests Inventory Unit
Collection and collation of wood and wood products data	Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES)

7.J.1.1.2 *FullCAM*

FullCAM is developed internally by code developers and testing is undertaken by a dedicated *FullCAM* tester in conjunction with the DCCEE teams responsible for the various aspects of the emissions inventory. Models are developed and improved in line with policy settings required for reporting to the UNFCCC and accounting under the Kyoto Protocol and tested for operability. The development of the conceptual and functional specifications of *FullCAM* is conducted by the DCCEE staff in collaboration with various external agencies. Table 7.J3 lists the agencies responsible for and that contribute to the development and testing of *FullCAM*.

Table 7.J 3 Public and private sector agencies contributing to tasks associated with the development, maintenance, documentation and testing of *FullCAM*, and the scientific development of *FullCAM* functions

Task	Contributing agencies
Software development	FullCAM Code Developers
Software testing	FullCAM tester
Business Analysis and defect management	FullCAM Business Analyst
Scientific guidance	DCCEE Forests Inventory Unit
	DCCEE Geospatial Analysis Unit
	DCCEE Agriculture Inventory Unit
	Australian National University
	CSIRO Land and Water
	CSIRO Livestock Industries
	CSIRO Sustainable Ecosystems
	NSW Department of Agriculture and Fisheries
	Queensland Department of Environment and Natural Resources and Water.
	University of Western Australia
	Victorian Department of Primary Industries

7.J.1.1.3 Emissions estimates and the National Inventory Report

DCCEE is responsible for delivering emissions estimates from the land sector (LULUCF) for both UNFCCC reporting and KP accounting. DCCEE is also responsible for the production of Volume 2, which pertains to the LULUCF sector, of Australia's National Inventory Report. The NIR is subject to annual internal review prior to release. DCCEE also uses independent experts to review the NIR.

7.J.1.1.4 Co-ordination with the National Inventory Team

Consolidation of Australia's greenhouse gas emissions estimates is conducted by the National Inventory Systems and International Reporting (NISIR) Branch within DCCEE. The NISIR branch includes the three land sector teams (Geospatial Analysis, Agriculture Inventory and Forests Inventory Units) the National Inventory Team who jointly operate the National Inventory System. The National Inventory Team is responsible for collating emissions estimates across all sectors and delivering Australia's National Inventory Report (NIR) to the UNFCCC. Teams within the National Inventory Systems and International Reporting (NISIR) Branch work closely to ensure that Australia's emissions inventory is in line with international guidelines and guidance.

7.J.2 INPUT DATA & MODEL DEVELOPMENT

7.J.2.1 Land cover change

Australia maintains an extensive archive of Landsat ETM+, TM and MSS satellite data collected since the first Landsat sensor delivered data in 1972. A review of the data archive in 1998 showed that there was sufficient continental coverage to derive a time-series of land cover change commencing in 1972, with satellite imagery now collected annually.

The use of remote sensing imagery to calculate land cover change requires that an exact spatial location be followed through time. Consistent methods are also required to reveal real change through time, and not that arising from methodological artefact (Furby and Campbell, 2001) which can occur because of mis-registration, where the same areas on both images are not comparable because one or both are geographically mis-positioned (Furby and Campbell, 2001). Mis-calibration can also occur where images are processed to different spectral qualities (e.g., brightness from sunlight and greenness from seasonal conditions) which lead to false detection of spectral change.

To ensure consistency of methods, and the provision of spatially accurate land cover change data through time, a detailed protocol of remote sensing specifications for land cover change was developed by Furby (2002) through extensive pilot testing (Furby and Woodgate, 2002). These specifications determine the exact way that images are acquired, processed and classified. The three primary QA/QC items associated with the use of satellite imagery to calculate land cover change are:

1. Acquiring and selecting satellite imagery;
2. Satellite data processing, including registration, calibration and mosaicing; and,
3. Satellite data classification, to identify forest cover.

The QA/QC and data validation procedures for each of these items in the Australia's land cover change methods are summarised below and in Figure 7.J1, and are described in full in Furby (2002).

7.J.2.1.1 Acquisition & selection of satellite imagery

Data (scene) selections and raw data quality are thoroughly checked and reviewed by the CSIRO and DCCEE to ensure that:

1. the images purchased overlap to prevent gaps in the coverage;
2. optimal, spatially and temporally consistent image dates are purchased;
3. cloud in overlap areas is covered by cloud-free data in adjacent images whenever possible;
4. when the first selection is identified as having a high proportion of cloud cover, image searches are repeated to ensure that better images have not been overlooked; and,
5. image problems are correctly entered into a scene selection database.

7.J.2.1.2 Year 2000 Australian mosaic

A Year 2000 Australia mosaic serves as the rectification (geographical registration) and calibration (spectral consistency) base for the images from other years. The mosaic is formed from 369 Landsat 7 ETM+ scenes taken from July 1999 to September 2000. The following steps were undertaken in the process of creating the base image:

1. Rectification (registration) base
2. A viewing-geometry approach was used to ortho-rectify the Landsat 7 ETM+ images for the year 2000, specifically the viewing-geometry and block adjustment model incorporated in the PCI software (PCI OrthoEngine). The viewing-geometry approach also required a height from a digital elevation model (DEM) as well as a map coordinate for each control point. Map coordinates for the ground control points are obtained from two sources: the Queensland Department of Environment and Resource Management (DERM; formerly known as Queensland Department of Natural Resources) and raster versions of the AUSLIG 1:100,000 map series.
3. Calibration to create a radiometrically (spectrally) consistent base
4. After all Landsat scenes were ortho-rectified, calibrated images were produced by applying correction to scaled top-of-atmosphere reflectance and correction for surface reflectance properties. The aim was to produce a radiometrically consistent base. Resulting individual images were mosaiced and inspected for edge effects. The results indicate that the majority of differences between images (with similar seasonal conditions) were systematic and were removed by this radiometric correction method.
5. Mosaicing into 1:1,000,000 map sheet tiles to form a seamless base
6. The final step in producing the Year 2000 Australia mosaic for use as the rectification and calibration base image was to mosaic the individually calibrated images. The individual images were mosaiced into 1:1,000,000 map sheet tiles. The mosaiced 1:1,000,000 map sheet tiles were then compared to the individual images to check for consistency within the registration and calibration.

7.J.2.1.3 Land cover resolution

To deal with the change in pixel size of the various Landsat sensors over time, and the need for spatially and temporally consistent integration with other spatial data used in the model, the 'natural' pixel size of the 1972 to 1988 Landsat MSS (57 m x 79 m) is re-sampled to a 50 x 50 m pixel. The 30 x 30 m native resolution of the Landsat TM and ETM+ data available after 1988 is produced as 25 x 25 m pixels.

To apply the pixel-by-pixel analysis over the period where the pixel size changed from 50 m to 25 m (in 1988), a 50 m MSS equivalent (in both spatial and spectral resolution) is derived from the 1989 TM (25 m) data, and then forest extent is calculated separately from both the 50 m and 25 m data sets. Differences in the extents of forest between these two outputs are due to "sensor change". An overlap technique, as recommended by the IPCC (2003), is used to ensure time-series consistency such that the assessment of land cover change for 1988-89 is then based on a 50 m to 50 m comparison, while the 1989-1991 data is a 25 m to 25 m comparison. This permits the use of best available data while maintaining time series consistency.

All Landsat derived data are used at a consistent 25 m resolution for the full time series analysis by re-sampling the 50 m pixels (1972-1988 information products) into four 25 m pixels. The spatial-temporal model (see the Conditional Probability Network described below in the *Time Series Consistency* section) is important at this time, as it reduces the effect of "mixed" isolated and edge pixels in the overlap period. The period of the transition to the true 25 m data takes place prior to the period where it would have any significant effect on the first reported year of emissions (1990). The 50 m data resolution is effectively only used to run-in the model to establish forest age (if the forest is regrowth from non-forest land or in response to a forest removal since 1972) as lagged effects are small from all years except those immediately prior to 1990. The ability to determine, from 1990 onwards, the effects of land use change to 0.2 ha minimum areas is robust, given that this area is greater than the pixel resolution and the approach used removes mixed and other pixels which are temporally and spatially inconsistent.

Re-sampling Landsat TM and ETM+ data to 25 m pixels is common practice. Using a 50 m re-sample to provide consistency over the multiple resolutions of Landsat sensors also provides for uniformity in the time series. Quality assurance and validation processes confirm that accurate results are achieved with this re-sampled data.

Particular attention is paid to ensure that there is no evidence of methodological artefact in the transition period by observing cover change maps. Any identifiable effects that are clearly not a cover change are manually edited during the subsequent 'attribution' processing stage.

7.J.2.1.4 Registration & Calibration

Registered and calibrated images are returned to DCCEE after both processes are complete. The assessment of each registered and calibrated image is performed in three stages:

1. the information and data provided to the DCCEE is checked for completeness and the registration assessed, based on the summary information provided to the DCCEE;
2. if the registration accuracy appears doubtful, unacceptable or cannot be determined from the information provided, it is further investigated so that the exact nature of any problem can be described to the contractor for correction; and,
3. a Registration/Calibration Quality Assurance form is completed, the processing status of the image updated in the DCCEE Image Catalogue, and the image returned to the contractor for reprocessing if required.

7.J.2.1.5 Mosaicing

All mosaiced images (quadrants and time slices) for a particular map sheet tile are assessed at the same time. The assessment of each image is performed in two stages:

1. the information and data provided by the contractor is checked for completeness and the consistency of the mosaiced image assessed; and,
2. the processing status of the mosaic image is updated in the Image Catalogue, and the images were returned to the contractor for reprocessing if required.

The individual steps involved in the assessment of the image are listed in Furby (2002).

7.J.2.1.6 Thresholding

Two review processes are applied to the thresholding products. A quality assurance process is applied during and at the end of the thresholding stage of the processing. The aim of this quality assurance process is to ensure that the methodology has been correctly applied and that the intermediate and final products are consistent with the supplied ground data and with each other across stratification zone and map sheet boundaries. The assessment of the thresholding products is performed in several stages:

1. The information and data provided by the contractor after the single-date probability images are created (Step 8; see Furby, 2002) is checked for completeness. The adequacy and consistency of the analyses and the accuracy of the probability images is also assessed by CSIRO.
2. If the analyses or probability images appear doubtful or inconsistent, further investigations are carried out so that the exact nature of any problem can be reported to the contractor.
3. An Initial Assessment report is completed and the contractor advised of the results of the assessment and the actions required (either review of the analyses or continuation of the processing sequence).
4. The plausibility of the change images produced by the contractor is checked by CSIRO.
5. If the accuracy appears doubtful, images are further investigated so that the exact nature of any problem can be reported to the contractor.
6. A Change Image Assessment report is completed by CSIRO and the contractor advised of the results of the assessment and the actions required (either review of the analyses or continuation of the processing sequence).
7. The final products supplied by the contractor are checked for completeness and the remainder of the processing by the contractor is assessed.
8. A Final Assessment report is completed and the contractor advised of the results of the assessment and the actions required (either review of the analyses or continuation of the processing sequence).

The first three steps are performed during the thresholding processing (step 8 of Furby, 2002), based on preliminary information provided by the contractor. The next three steps are performed during the thresholding processing (step 11 of Furby, 2002). The final two steps are performed after the final products had been delivered.

7.J.2.1.7 Time-series consistency

Remote sensing pilot testing demonstrated the need for time-series consistency in image data pre-processing, analysis, and subsequent formation of time-series forest/non-forest labels. The operational standards (Furby, 2002) give explicit emphasis through documented rule sets to each of these areas. For instance, although the processing is performed by different companies, all images are oRtho-rectified using a standard algorithm (PCI Orthoengine) with standard inputs (a consistent digital elevation model). For time-series classification, these standards also include the use of a joint spatial-temporal model, in this case a conditional probability network (Caccetta, 1997; Caccetta *et al.*, 2003; Kiiveri *et al.*, 2001, 2003), for determining time-series of forest/non-forest labels. This process produces superior forest extent and change results compared to a process reliant on pair-wise differencing of image pairs. The use of pair-wise differencing methods can lead to change estimates that are affected by errors due to seasonally changing land management effects (introducing large contiguous areas of false change), or by subtle sampling differences where mixed pixels have varying composition of forest/non-forest from year to year (producing many isolated false change pixels or edge effects at forest boundaries).

The conditional probability network uses a series of spatial and temporal rules for determining forest/non-forest and forest change (forest and non-forest conversions). The temporal rules bias against unlikely events such as multiple one year conversions between forest and non-forest. The rules are particularly effective when the time between observations is less than that of a forest growth and harvest cycle. This is one of the reasons for having a relatively dense time-series sampling.

The spatial rules consider the labelling of a pixel in the context of its spatial surroundings, where labels that are consistent with the neighbouring labels are reinforced as opposed to those that are inconsistent (e.g., isolated pixels). The spatial and temporal rules work together providing spatial and temporal consistency, minimising temporally varying "mixed pixel" effects (due to spatially varying sampling from independent satellite overpass from year to year) and subsequent error in pixel and change labelling.

7.J.2.1.8 Attribution

Once the quality assurance processes have been applied, land cover change maps are created. Changes identified in cover change maps are then attributed for the determination of change as either human induced or natural effect/methodological artefacts. These include green flushing in images due to climate, terrain illumination variability, irrigation, water bodies and fire scars. Contractors use visual image backdrops in time-series for this discrimination. Results of this discrimination are then quality assured by DCCEE. This process provides for an additional independent process of checking the land cover results.

7.J.2.1.9 Plant typing

Validation of plantation type mapping accuracy was carried out against specifically collected field data showing plantation species, stocking, condition, age and extent. This validation data was collected during a national program of site visits. The recently completed plantation mapping achieved an accuracy of 91% in terms of both species and spatial referencing for plantations identified as post-1990 *plantations* (MBAC Consulting, *in prep*.). Incorrect forest typing (e.g., labelling hardwood as softwood and vice versa) contributed 5% of the error, with only 4% being incorrect for both location and type. These results provide considerable confidence in the methodology applied and allow for a spatial-temporal analysis of Australia's plantation estate (see Appendix 7.D).

Methods for plantation typing of pre-1990 *plantations* are being developed. Similarly to post-1990 *plantation* typing (into hardwood and softwood plantations), softwood plantations pre-1990 are being distinguished from native forests using the Landsat MSS data from 1972-88. Validation of softwood plantation type mapping pre-1990 is currently being carried out by validating (and calibrating) against collected field data.

7.J.2.1.10 Improvement & Verification

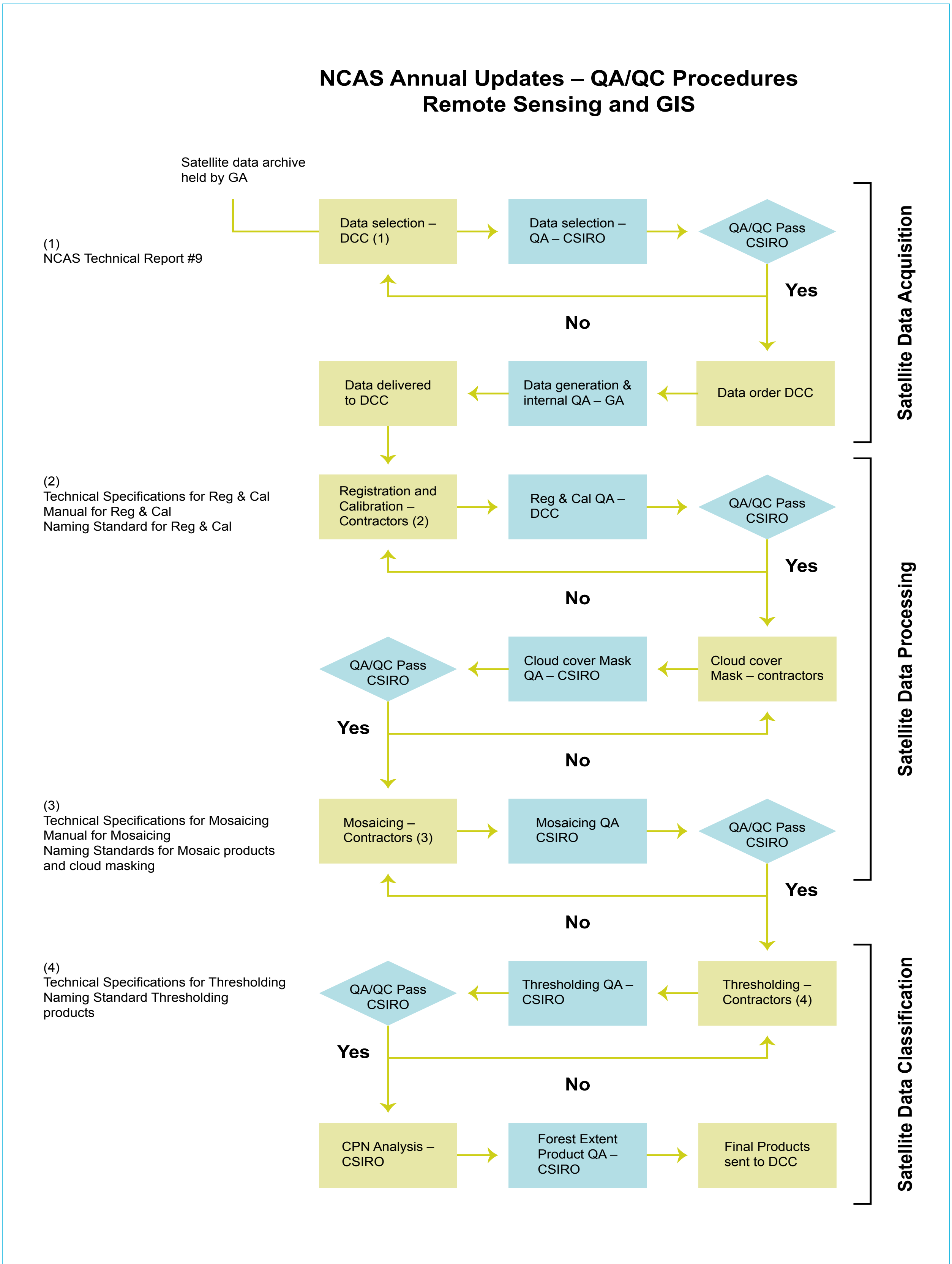
The verification of the remotely sensed land cover mapping is conducted within a continuous improvement and verification program. An independent program of checking the Landsat results is conducted by external agencies, both to verify the method (and hence the accuracy of the product) and to identify areas for improvement. This program involves checking the results of the land cover mapping against high resolution satellite and air photograph interpretation using a stratified sampling technique.

The first verification considered the initial time-series of change data from 1972-2000 and was done using air photograph comparisons. When the recommended improvements were implemented, with the update for the 2002 data, the full time-series was re-analysed to reflect the improvements (Lowell *et al.*, 2003; Jones *et al.*, 2004; Lowell *et al.*, 2005). Subsequent analysis has led to further improvements being implemented during the 2004 and 2005 updates. Since 2005, the verification of the change analyses has been done using very high resolution satellite data which has significantly improved the quality of the verification. Recently, DCCEE has engaged researchers from the Cooperative Research Centre for Spatial Information (CRC SI) to undertake verification of forest extent and change products for the period from 2000 to 2010. This work is expected to be completed by April 2012.

The initial independent assessment of the "raw" accuracy of the classification of forest and non-forest areas across the continent and over the period of 1972 – 2000 indicated that 94-98% of forest and 85-96% of non-forest vegetation was correctly classified (Jones *et al.*, 2004). Accuracy in the data used for estimated rates of change (afforestation/regrowth or deforestation) was higher than the above, because the process of manual attribution, described previously, was used to confirm or reject changes in cover in the final dataset.

Incremental method development beyond that described in Caccetta *et al.*, (2003), and applied throughout the current time-series, includes the implementation of terrain illumination correction (Wu *et al.*, 2004), and the use of 'texture'-based analysis to map sparse vegetation extent and change (Caccetta and Furby 2004).

Figure 7.J 1 Overview of QA/QC procedures associated with Land Cover Change calculations



7.J.2.2 Land use & land management

Land use and land management information is used to determine lagged emissions following land use change as well as the emissions from *cropland remaining cropland* and *grassland remaining grassland* and the effects of silviculture on emissions in the pre- and post-1990 *plantations*.

7.J.2.2.1 Land use mapping

Areas of *grassland remaining grassland* and *cropland remaining cropland* are obtained from the National Land Use 2001/2002 (Version 3) Summary Statistics provided by the Australian Bureau of Resource Economics and Sciences (ABARES) (formerly the Bureau of Rural Sciences, BRS) (http://adl.brs.gov.au/mapserv/landuse/docs/2001_02_Nat_Luse_Summary_Stats.pdf). This mapping combines remotely sensed data with regionally specific information on land use collected by the Australian Bureau of Statistics (ABS). As such the QA/QC procedures are implemented by ABARES and ABS. Prior to use in the national inventory, the data are checked to ensure that they are consistent with previous years' mapping. The data are also checked against areas of land use change as identified via the remote sensing program to ensure that no double counting of land areas occurs.

7.J.2.2.2 Land management

Regionally specific information on land management practices was collated from a large range of sources. Swift and Skjemstad (2002) provided detailed information on agricultural land use and management in Australia (NCAS technical report 13) and Raison and Squire (2008) reported in detail forest management in Australia (NCAS technical report 32).

The land management data represent a composite of the best available and most comprehensive national information. A high degree of confidence can be placed in the data obtained owing to the various sources of information and direct regional knowledge of agency experts involved in collating the data. This confidence is furthered by the concurrence given during State-based workshops used for reviewing the data, thus providing a measure of quality assurance through expert review. Publication of the results has provided transparency and the opportunity for ongoing review. Any concerns about the veracity of the information were not identified throughout peer review or publication.

7.J.2.2.3 Crop yield & management

Crop yield data are used to calculate emissions and removals in all agricultural (*cropland remaining cropland* and *grassland remaining grassland*) and conversion (*forest land converted to cropland* and *forest land converted to grassland*) sub-categories. The crop yield data is used in the Tier 3 model to calculate inputs to debris and soil carbon from turnover and post-harvest residues. The key QA/QC issue associated with crop yield is to obtain a consistent national time series of the best available crop yield data.

The CSIRO Land and Water is contracted by the DCCEE to supply a comprehensive annual crop and pasture yield database. The majority of the available data that is imported into the database is obtained from ABS and ABARES, of which both agencies had collected annual crop and pasture yield data through national statistical surveys at the statistical local area (SLA) for the grains, grazing and dairy industries. These national surveys also provide detailed information on farm inputs (e.g., fertiliser, irrigation, sowing rates, and crop species), production (e.g., crop yields and pasture cut for hay) and economic performance for the grains, grazing and dairy sectors, which comprise more than 70 % of Australian farm business units. In addition, data is also obtained from industry bodies (e.g. Australian Sugar Milling, Peanut Company of Australia) research papers and reports, and farming systems annual reports (e.g., Birchip Cropping Group, Mingenew and Minnepa Farming Group, Central West Farming Services) for the major crops and pastures in Australia (Unkovich *et al.,* 2009).

These data are disaggregated to the Interim Biogeographical Regionalisation of Australia (IBRA, Version 4, Thackway & Cresswell, 1995) scale, and also differentiate between stubble management practices, crop species, crop rotations and crop distribution according to soil type (Swift and Skjemstad, 2002). Quality control for consistency of yield against previous years, constrained by climate, is conducted at the sub-IBRA scale by comparing the current year's yield against the previous year's yield. All data are checked for consistency from the previous year and any values exceeding a variance of greater than 10% of upper and lower limits are checked against industry databases where there is available data. If data are unavailable for any given region a calculation of yield is derived using a growth function (Unkovich *et al.,* 2009) using regionally specific climate data and again checked for a 10% variance.

The inputs of crop yields by region and IBRA in any single year are validated against industry yield data in following years. Yield data are aligned with crop and pasture management practices as they are identified in the database and validated against industry specific data as recorded by ABS and verified by CSIRO (Unkovich *et al.,* 2009). For example, burning of crop residues or no-tillage management, pasture improvement or native (unimproved) pastures would display different yields generally within each IBRA and soil classification and are recorded accordingly.

7.J.2.2.4 Forest growth & management

CSIRO Sustainable Ecosystems (formerly Forestry and Forest Products) was engaged to compile a database of existing biomass measurements from published and unpublished studies. Research studies were only included if they had adequately reported methods, because this information is required to establish confidence in the robustness of the data (Richards and Brack, 2004a). Quality control of the data-set included the stipulation that measurements had undergone scientific peer review prior to publication (Raison *et al.*, 2003). Included data are representative of Australia's major vegetation types, ranging from savannahs to rainforests (Richards and Brack, 2004a). The biomass data was accompanied with information on the site (location, IBRA region, climate and soil type), the vegetation (tree age, vegetation type and management) and the methods for deriving allometric equations (biomass measurement, variables, tree number and DBH) developed for the tree plot. The calibration data covers the range of age classes from regrowth to senescent (old-growth) and therefore the potential variation in field biomass conditions.

In addition to compiling biomass measurements, CSIRO Sustainable Ecosystems was also engaged to review forest management practices in Australia (Raison & Squire, 2008). Forest management activities reported on included site preparation, weed control, stocking rates, thinning, pruning, fertiliser application and irrigation impact on forest carbon stocks, growth rates and total site carrying capacity.

7.J.2.3 Climate

The DCCEE engages the Australian National University (ANU) to provide robust climate data for the modelling period (1970 to present). The attributes of climate data provided include mean monthly rainfall, vapour pressure deficit, pan evaporation, average temperature, minimum temperature, maximum temperature and frost days all of which are obtained or directly derived from the Australian Bureau of Meteorology (BOM). A Digital Elevation Model (DEM) is also used for the production of climate surfaces. Monthly climate surface maps of each attribute are derived using the ANUCLIM (McMahon *et al.*, 1995) climate modelling software (Kesteven *et al.*, 2004) developed by the ANU.

The QA/QC process associated with the climate data, particularly the derivation of monthly climate surfaces, is to minimize errors arising from the data used in the spline functions that produce the output climate surfaces by ensuring that the best available, highest quality input data is used. This is achieved by validating the input data used to generate monthly climate surfaces produced in ANUCLIM, and validating the output climate surfaces.

Three quality control aspects are associated with the production of climate surfaces. The first is examination of the completeness and quality of input monthly average climate data obtained from the BOM. Daily BOM data are accompanied by a quality control flag indicating whether or not the data have been quality controlled by the BOM. The minimum requirement for the calculation of monthly statistics is a 20-day record of quality controlled data for the average, maximum and minimum temperature variables, and a 25-day record of quality controlled data for rainfall and the number of frost day variables. Furthermore, only those years with a full 12 months of data are used to calculate the climate surfaces.

The second quality control aspect is to obtain a DEM with sensible drainage properties, stream lines, contour lines and cliff lines. Version 2 of the nine second (approximately 250 m) national digital elevation model (AUSLIG 2001) is used to provide terrain (elevation and aspect) mapping to support the spline functions used in the ANUCLIM software. Version 2 is based on the ANUDEM 5.0 elevation gridding program developed by the Fenner School of Environment and Society, Australian National University.

The source elevation data used to produce this DEM are taken from 1:100 000 scale topographic mapping. Errors in the DEM are closely related to terrain complexity. Theoretical estimates and tests of the DEM against trigonometric data distributed evenly across the continent indicate that the standard elevation error of the DEM varies between about 7.5 metres and 20 metres for most of the continent. Standard errors are larger in upland areas with steep and complex terrain where the largest errors can exceed 200 metres (Hutchinson *et al.*, 2001; Kesteven *et al.*, 2004).

The third quality control aspect associated with climate data is to examine spatial location of weather stations, and the influence that errors in these data have on fitting the climate surfaces. For example, an error of 200 m altitude in a station location can equate to several degrees of temperature in a mountainous region. To fit multivariate climate surfaces the values of independent variables need to be known at the data point, and meteorological stations should be accurately located in position and elevation. However, the BOM have used various methods to geo-locate weather stations, with older locations being the least accurate. The BOM provided a base station dictionary (23 May 2001) with the supplied monthly climate data (Kesteven *et al.*, 2004). The station dictionary provided site number, latitude and longitude, elevation, location description and the start and finish year of operation (Kesteven *et al.*, 2004). This version of the BOM station dictionary was compared with a 1998 dictionary held by the Fenner School of Environment and Society at the Australian National University. Any station with a difference greater than 0.1° in position or 50 m in elevation was checked by visually locating the station using any available satellite imagery, topographic maps or aerial photographs. The correct geo-location of the station is then used in the model. The effect of the geo-location of weather stations on modelled climate surfaces is examined using variance statistics. The climate surface modelling output includes variance statistics of model residuals (RMSE) that are used to assess the extent of difference between the modelled result and actual weather station data. These residuals indicate how well the predicted climate measurement matches the actual climate measurement for a month and location. The highest 100 residuals are extracted and examined further. If these residuals indicate a geo-location error, then the location of that weather station is corrected and the model re-run. If there is no geo-location error associated with the climate surface then the station is included in the model. The climate surfaces, including all model results, have been submitted to the Australian National University's Fenner School of Environment and Society for independent QA/QC. Detailed checking of procedures and output statistics led to the conclusion that the development of the models represented application of best practice and yielded robust results.

7.J.2.4 Soils

FullCAM requires maps of soil type and pre-cleared soil carbon to calculate soil carbon stock changes due to land use change, ongoing management and climatic conditions. These maps provide: i) pre-clearing soil carbon stocks at a 250 m spatial resolution; and, ii) soil type description that are used to derive water holding capacity and soil clay content that determines the rate of decomposition of plant residues and the allocation of carbon to the different soil pools (Richards, 2001; Webb, 2002).

Data for the development of soil type maps was extracted from the best available resource inventory information held by state and territory governments and was subject to expert review prior to being incorporated. Initially, a comprehensive data search was conducted to determine the extent of existing chemical and physical information for sites that had not been cleared. Organic carbon contents were determined for soil profiles then averaged for each of the Soil Orders, Principal Profile Forms or Groups within each IBRA region. Where site data were scarce or non-existent, data from similar soils in the same or neighbouring IBRA region were used (Webb, 2002). Soil clay content was also taken from these inventories and supplemented with available research data. Soil carbon content was corrected to methodological standards where the initial method of measurement was known; otherwise the data were considered unusable and were not included in the final product.

In deriving the soil carbon map the comparability among existing soil carbon measurements arising from the use of different analytical methods needed to be resolved. Soil organic carbon measurements are normally derived from combustion in a LECO furnace. However, the method historically used to derive soil carbon values for many sites is the Walkley and Black (1934) wet oxidation method. This method has evolved over time in the major laboratories, such as by including a heating step during oxidation (Heanes, 1984) and, thus, has produced results that have varied over time. In a separate study, the relationships between the Walkley and Black method and the LECO method was examined through time across the major laboratories in each state and territory. These relationships provide adjustment factors that are applied to the reported soil carbon values (Wang *et al.,* 1996; Skjemstad *et al.,* 2000; Griffin *et al.,* 2003).

The application of standardised field and laboratory protocols (McKenzie *et al.* 2000) ensures that robust and consistent data are obtained from all validation sampling undertaken for the National Inventory. Extensive field calibration and independent site validation is used to develop and confirm model performance. Use of paired sites and long-term trial data over a wide range of systems ensures that spatial applications are interpolated within well understood and field-verified ranges.

7.J.2.4.1 Soil type

Spatial soil coverage for all Australian states and territories are identified through the Atlas of Australian Soils and broad scale land system mapping together with regionally specific data to produce high resolution (>1:50,000) coverage that could be overlayed on to IBRA regions (Webb, 2002). Where possible the use of land-based soil surveys and geomorphic maps were used to validate the broader scale soil type maps within an IBRA region. In addition, regional expertise was obtained at the state and territory level for the major soil types within each of the IBRA regions. This provided an estimate of the major soil types within an IBRA region and the extent of different land uses for each of these soil types. The process of developing the maps is described in Webb (2002), which was supported by the development of soil sampling protocols and standardised laboratory methods (McKenzie *et al.*, 2000).

7.J.2.4.2 Initial soil carbon

The distribution and extent of soil carbon is not uniform in the Australian landscape, and is influenced by factors such as soil type, soil moisture, climate, land cover and land use. Spatially explicit information about the underlying soil carbon potential in the top 30 cm of soil is required to accurately model soil carbon flux using *FullCAM* (Skjemstad and Spouncer, 2003, Skjemstad *et al.*, 2000). In particular, a key input is the level of soil carbon prior to land use change, that is, soil carbon under pre-cleared conditions.

The Australian Government has invested in an on-going research program that in partnership with industry and research organisations (universities, state government departments, and CSIRO), obtains high quality data to support the development, verification and validation of its inventory. This research program is administered by the Department of Agriculture, Forestry and Fisheries (DAFF) and provides data from research projects to DCCEE for on-going inventory improvement.

There are a number of key areas of soil research activity that provide data to DCCEE, these include research and development activities related to soil carbon stock changes and soil nitrous oxide fluxes under different crops, management practices, soil types and climate. These activities are spread across Australia with more than 2,500 individual soil sampling sites located in four major agro-ecosystems.

7.J.2.5 FullCAM

FullCAM is a hybrid process-empirical model that calculates emissions and removals using a mass-balance approach for both forest and agricultural systems, and transitions between them.

FullCAM is used to calculate emissions and removals for the *forest land converted to grassland*, *forest land converted to cropland*, *grassland converted to forest land*, *cropland remaining cropland* and *grassland remaining grassland* sub-categories. This model utilises data from a variety of sources and accounts for the effects of climate, site, species and management on growth.

7.J.2.5.1 Initial assumed above ground biomass regression model

A Forest Productivity Index to aboveground forest biomass regression model developed for Australia's National Inventory System (Richards and Brack, 2004; Brack *et al.,* 2006) is a fundamental component of Australia's spatial and temporal modelling approach (IPCC Tier 3 Approach 3) to the Land Use, Land Use Change and Forestry Sector (LULUCF).

The *assumed initial biomass surface* produced from this regression underpins the model estimation of emissions and removals for UNFCCC *forest land converted to cropland and grassland* and Kyoto Protocol Article 3.3 *deforestation* (NIR, 2009). The surface also underpins the growth and biomass calibrations developed for UNFCCC *land converted to forest land* and Kyoto Protocol Article 3.3 *Afforestation/Reforestation.*

The forest growth model in *FullCAM* is calibrated for use in both native forest systems and plantation systems. It includes the effects of management on growth, climate, soil type and water holding capacity, and fertility and forest productivity.

As part of the development of the forest growth model, a Forest Productivity Index (index of biomass productivity) was developed which expresses the variability that is both spatial and temporal. The Forest Productivity Index (FPI) is based on monthly climate surfaces (Kesteven *et al* 2004), CSIRO's national soil moisture holding capacity and fertility mapping, the nine second (250m) digital elevation mapping version 2.0, and Normalised Difference Vegetation Information Index data of the environmental resources information network (Waterworth *et al*, 2007). The products from this include monthly 1 km grids of FPI from 1970 presented as an index ranging from 0 to 30 on an annualized basis, and 250 m grids of long-term average FPI that also includes slope and aspect effects (Waterworth *et al* 2007).

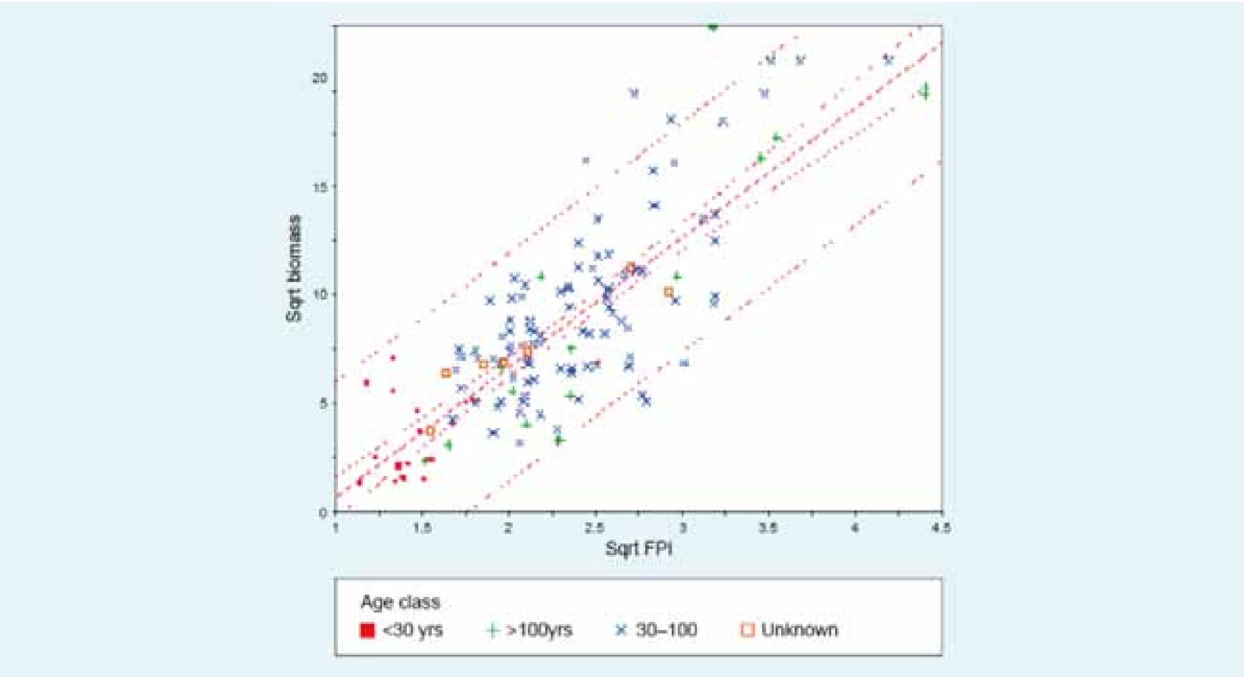
The FPI was then correlated with available aboveground biomass measurements reflecting a range of potential forest conditions and prior disturbance histories (except those with visible evidence of recent disturbance). That is, biomass data for sites with no reported recent disturbance were plotted against the calculated long-term average productivity (Figure 7.J2).

The relationship between aboveground biomass and FPI was used to derive a map of potential site biomass at maturity (Richards & Brack, 2004). The potential (site) biomass estimate represents the biomass which growth will generally approach. The regression, which considers biomass accumulated against the long-term average productivity of the site, was found to have a significant correlation ($P < 0.01$, $r^2 = 0.68$) (Equation (1)) (Richards & Brack, 2004). A square root transformation was required to meet assumptions of normality and homogeneity (Figure 7.J3).

$$M = (6.011 \times \sqrt{P} - 5.291)^2 \quad \text{.......} \quad (1)$$

Where P is the long-term average forest productivity index and M is the above-ground biomass in t dry matter ha^{-1}.

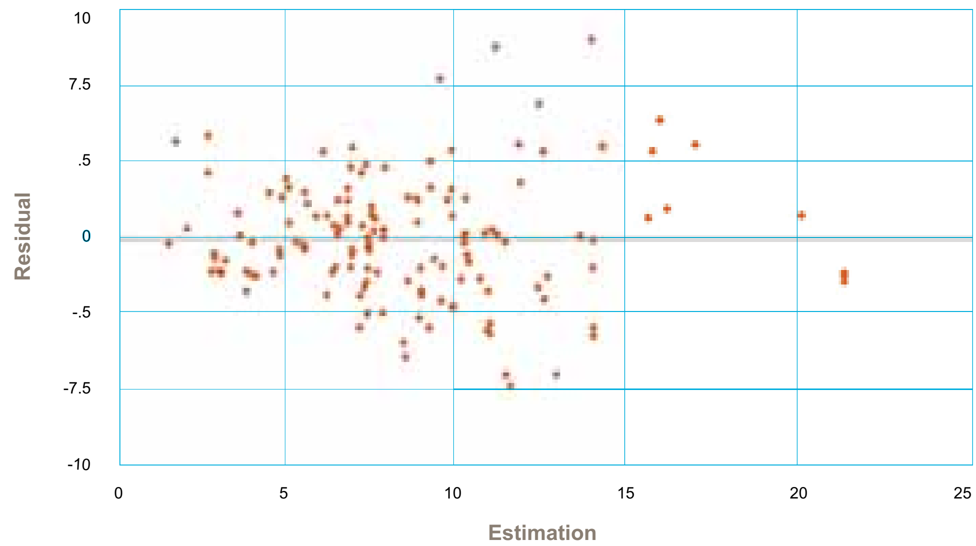
Figure 7.J 2 Initial assumed above ground biomass regression model (square-root-transformed data)



The goodness of fit of Equation (1) to the measured data confirms that a robust relationship exists between the productivity mapping and measured aboveground biomass estimates. The outer 95% confidence limits (outer pair of dotted lines) show the reliability for predicting biomass at any individual site. The inner 95% confidence intervals (inner pair of dotted lines) show the high degree of confidence in the line of best fit being able to represent the variability in the field data at the national scale. It applies throughout the continuum of productivity across the forest estate as a whole. The model shows that the potential (site) biomass estimates is an accurate and unbiased representation of the forest estate (excluding young regrowth) as can be gauged from available data. A key benefit of the hybridisation of process modelling (through the productivity mapping) and empiricism (through known measures), is that estimates will be constrained to actual conditions (measured biomass estimates) and actual growth, not that of optimal growth.

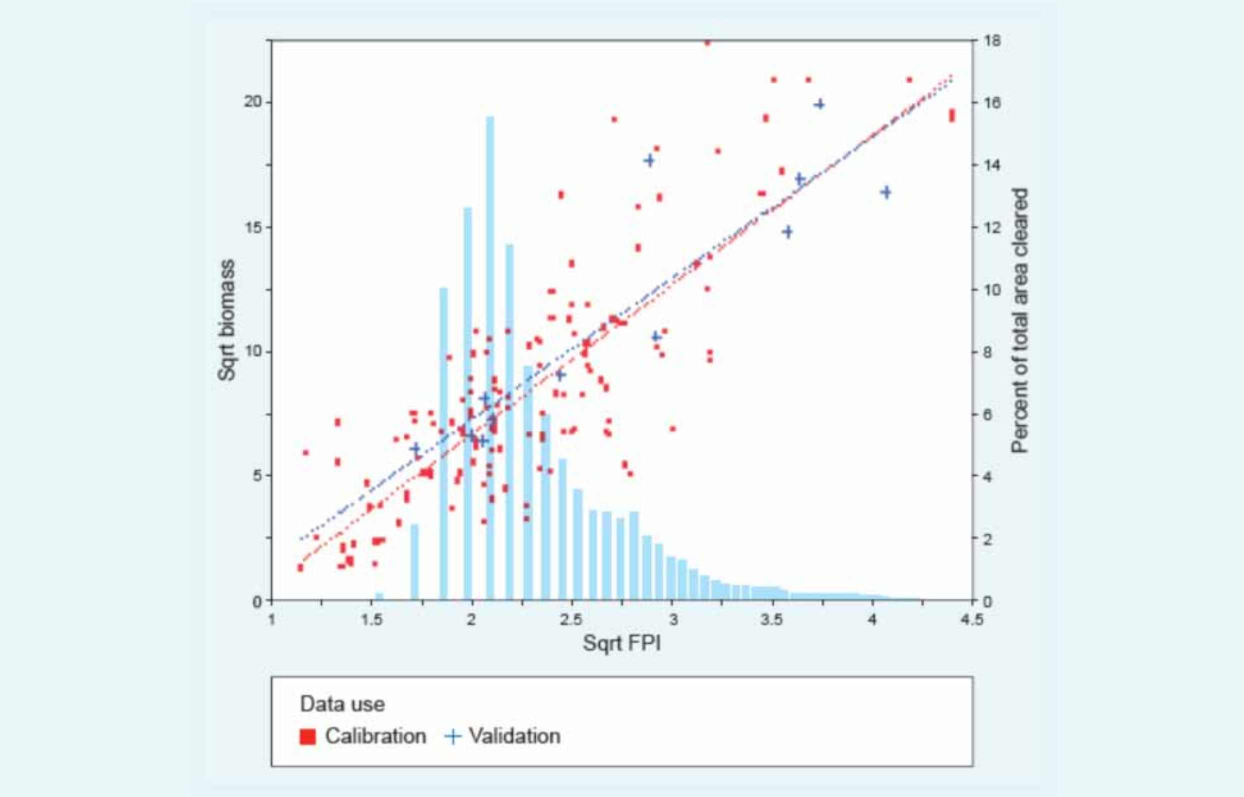
While the goodness of fit and lack of bias in error estimates (Figure 7.J3) provides confidence in the application of Equation (1) as a model to predict biomass at maturity, there is an obvious scatter in the data. This is attributable to the range of age classes and forest histories used in the model, the differing methods used in the field estimation and to an inherent variability between the 'plot' locations used to scale to one hectare mass estimates compared to the average condition reflected in the 250 m resolution productivity estimation.

Figure 7.J 3 Error distribution for equation 1



Calibration of the initial assumed aboveground biomass regression model has been validated by using independent research and field studies of biomass estimates, excluding forest areas with young regrowth. For example, the DCCEE commissioned a research project to weigh all trees at three forest sites of varying productivity but with similar disturbance histories (Ximenes *et al.*, 2005, 2006). Since the model was first developed, data collection from 15 new field sites has since been completed (Snowdon *et al.*, 2002) and are available for validation. These data points cover a wide range of forest types and represent forests that are either near maturity or at maturity with little evidence of recent disturbance. Validation tests show no significant difference between the validation and calibration data (Figure 7.J4). The validation data yielded slightly higher biomass estimates within the range of forest that was most frequently cleared (when comparing the calibration data sets with the more recent validation data sets). This was not a statistically significant difference.

Figure 7.J 4 Calibration and validation data for the initial assumed biomass estimates



Note: The background histogram represents percentage of the area reported under forest land converted to cropland and grassland by forest productivity index.

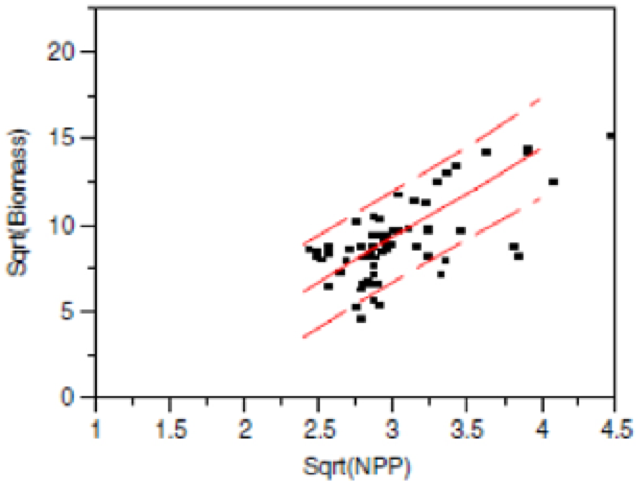
The DCCEE also utilises data collected by other agencies for verifying the biomass relationship. This data is typically of a lower quality (i.e., no direct biomass measurements) that precludes its use in calibration or validation. A key example of this verification approach is outlined in Brack *et al*. (2006). As part of a separate study funded by the Bureau of Rural Sciences (BRS) to estimate stem volume, MBAC Consulting conducted a field inventory of south-east Queensland. Brack *et al*. (2006) converted this basic inventory data to biomass estimate using a generalized allometric equation from Snowdon *et al* (2002) to verify the biomass relationship. The biomass data had several limitations:

1. the disturbance history of the plots was unclear and many appeared to be younger regrowth;
2. many of the plots had large gaps where no trees existed, which would lead to an underestimation of biomass;
3. the applicability of the allometric equation to the sites was not tested; and
4. the sites only covered a small range of the FPI values.

Despite these limitations, there was still a significant relationship between the FPI and biomass (Figure 7.J5). The equation produced lower initial biomass estimates than the biomass equation defined by Richards and Brack (2004) but this is likely a function of the points listed above.

Further verification work is planned and DCCEE is actively working with state agencies and research agencies to collect and collate additional data.

Figure 7.J 5 Regression of FPI and biomass (t ha^{-1}) with 90% confidence interval.



Biomass estimated from Snowdon et al. (2000) allometrics and MBAC Consultants (2003) inventory data.

Source: Brack et al. (2006)

7.J.2.5.2 Agricultural growth

The agricultural growth model component of *FullCAM* reflects the impacts of management on carbon accumulation and allocates masses to various product pools within plants and to decomposable and resistant organic residues (Richards, 2001). The model uses the crop yield data and the proportional allocation of dry matter to different plant components to estimate annual dry matter accumulation in agricultural ecosystems. The proportional allocation of dry matter to plant components were determined from estimates by expert field agronomists and include allocation to roots (above and belowground), GBF (grains, buds and fruit), stalks and leaves.

Fixed harvest indices have been used to estimate total crop biomass of croplands from statistical data on crop yields in both the USA (Prince *et al*., 2001) and Canada (Bolinder *et al.,* 2007). Their harvest indices are given in Table 7.J4, along with the average values from the Australian database for dryland crops. With the exception of grain sorghum and sunflower, the values in the Australian dataset tend to be lower than those indicated by both Prince *et al*., (2001) and Bolinder *et al.,* (2007). A review of the harvest index under Australian conditions indicates that a higher quantity of residues would be returned per unit of production than noted in other regions of the world. In addition, none of the abovementioned studies considered variation in harvest index or included such an exhaustive assessment of crop harvest index as the Australian study (Unkovich *et al*., 2010).

Table 7.J 4 Conversion factors to estimate crop dry matter (DM), harvest indices (HI), and root:shoot ratios for crops

Crop	Conversion to proportion DM	Root:shoot ratio	HI in US literature	HI in Australia database	HI in Canadian literature
Corn grain	0.871	0.18	0.53	0.52	0.50
Soybean	0.920	0.15	0.42	0.24	0.40
Oats	0.923	0.40	0.52	0.30	0.53
Barley	0.904	0.50	0.50	0.38	0.53
Wheat	0.894	0.20	0.50	0.36	0.40
Sunflower	0.931	0.06	0.27	0.40	-
Sorghum		0.08	0.44	0.45	0.25

Study of (Prince et al., 2001) in the USA and compared with Canadian harvest index data (Bolinder et al., 2007), and mean values from the Australian database

The yield data used for Tier 3 inventory estimates to date has been collected from the Australian Bureau of Agricultural Resource Economics and collated by CSIRO for the Department of Climate Change and Energy Efficiency for each of the IBRA regions. This yield data already includes some of the impacts of management practice on soil carbon stock change as they relate to overall plant growth. For example the introduction of no-till cropping in Australia has increased substantially over the past decade (Llewellyn 2009) with some positive effects on plant production and residue return in some regions, which has been reflected in plant production and yield. In future developments of *FullCAM* for national inventory a further disaggregation of the IBRA regions is planned together with improved disaggregation of crops and yield estimation through a growth function in line with suggestions made by the Expert Review Team in 2011. These improvements will provide spatially disaggregated yield for different crops under different management practices across a wider range of climatic regions and together with the disaggregated climate inputs assist in producing a smoother relationship between time and soil carbon emissions.

Current improvements in the data for the 2012 *grassland remaining grassland* category for the inventory submission include the following key areas:

1. Everforest mask;
2. Model simulation for *grassland remaining grassland* at 25m x 25m resolution;
3. Grazing of crop debris rather than crop;
4. Equilibration of soil carbon pools prior to grassland and cropland modelling;
5. Turnover percentage and decomposition rate constants;
6. Adjustment of crop and pasture cycles now include a harvest kill in each annual cycle; and,
7. Removal of remapped data to better reflect low productivity arid and semi-arid regions.

Everforest mask

In line with expert review team recommendations for greater transparency the grassland that had already moved from forest land and converted to grassland has now been spatially mapped and masked so as to preclude the estimation of emissions under the grassland remaining grassland category. As a QC procedure on this mapping exercise the total area of land estimated by both accounts are reconciled to ensure that all grasslands are accounted for in these categories.

Model simulation for grassland remaining grassland at 25m x 25m resolution

Model simulations for the *deforestation and cropland remaining cropland* accounts have been run at a 25m x 25m resolution since 1990. For reasons of server space and length of run time it has not been possible to run the *grassland remaining grassland* account for consistency at the 25m x 25m resolution until this year. This differs from previous runs for this account which were at a 100m x100m resolution.

Grazing of crop debris rather than crop

Within the *FullCAM* development plan there was a need identified to include a function that allowed crop residues to be grazed after harvest as this is a common practice used by farmers to obtain some forage value over the summer months. In developing this function it was identified that pre-existing grazing activities on cereal crops were incorrectly grazing the growing crop prior to harvest. Although this was a common practice in the 1970's and early 80's with oat crops in particular, this practice has largely been disbanded due to the high yield penalty incurred by grazing a grain crop. To align with the improved functioning of the model all grazing of crops has been adjusted in the 2012 inventory submission as an event that occurs only as a post harvest activity.

Equilibration of soil carbon pools prior to grassland and cropland modelling

For the *grassland remaining grassland* sub-category, there are three main agro-ecological categories; native arid and semi arid which occupy about 340 M ha and the high rainfall improved pastures that occupy about 60 M ha. Historical data on land use from early European settlement identifies that extensive grazing practices (primarily sheep) commenced in the late 1700's and continued to expand to a maximum sheep flock of more than 180 M head by 1900 (Henzell 2007). It is therefore presumed that land in the grass component of the arid and semi-arid regions, which comprised of sparse woody vegetation and woodlands remained as native pastures with some introduced species transitioning over this entire period. Soil carbon pools were stabilised for the semi-arid and arid regions from 1500 to remove the influence of above and belowground masses from forest soil inputs. For the high rainfall pastoral regions grazing was stabilised from 1800 to 1971 to reflect the gradual clearing of native forest soils for grazing purposes. The date of deforestation of each pixel is randomly allocated in the period between these two years with the amount of clearing approximately evenly distributed in each year. The model is then equilibrated using typical grazing practices at the Iterim Biogeographical Regionalisation of Australia (IBRA) scale from 1972 to 1989, for the initial reporting year of 1990, which is used to stabilise the soil carbon stocks therefore reflecting soils under long-term grazing management, i.e., soil carbon is not significantly affected by the initial pasture establishment or former land use. This equilibration allows the model to represent both areas which have always been grassland and those cleared for grazing since 1972.

For the current *grassland remaining grassland* grass component estimates, several generic management practices have been identified for the arid, semi-arid, and improved pasture systems prior to 1972. Post 1972 more specific regionalised grazing practices were applied and modelled across all pasture regions to better reflect the differences in stocking rate (grazing pressure), pasture growth and climate as identified from more recent industry and ABARES data. Hence variation in the live biomass, dead organic matter and soil pools is largely driven by variations in pasture yield, grazing pressure and climate.

Turnover percentage and decomposition rate constants

Allocation of turnover percentage for the plant biomass to debris pool for pastures and crops is based on limited data linked to forest soil turnover percentages. This is recognised as a deficiency in the modelling of crops and pastures and has been set at a low rate of turnover of 40 % at each monthly simulation in the *FullCAM* model. Whilst this value is consistent with current understanding within the science community (Baldock *pers. comm.*) there is a requirement to obtain crop and pasture specific data for Australian agro-ecosystems. In addition, the decomposition rate constants will also be investigated to obtain crop and pasture specific data for Australian climatic regions. These tasks are reflected in the development plan for 2012/13.

Adjustment of crop and pasture cycles to include a harvest kill in each annual cycle

In addressing the expert review teams requirement for greater disaggregation of crops the analysis of yield data for crop and pasture rotations was more extensively dealt with in the QC process. This investigation led to the re-evaluation of several crop and pasture regimes and the finding that some of the herbaceous crops had growth cycles longer then the annual cycle. These crop and pasture rotations have now been rectified to include a harvest kill in the rotation to thus ensure that they align with an annual cycle of crop growth.

Removal of remapped data to better reflect low productivity arid and semi-arid regions

Large areas of poorly producing arid and semi-arid agricultural land in central Australia had previously, in the 2011 inventory submission, been remapped from high productivity regions due to the similarity of landuse and the use of a generalised map of net primary productivity. New data from industry (B. Henry, Meat and Livestock Australia, 2011, *pers. comm* 2011) on pasture production for these arid and semi-arid regions has identified that these original estimates were too high and required an adjustment based on these data and other unpublished recent research findings (Carter and Hunt – pers. comm. ACEAS workshop 2011). These changes in yield allocation for arid and semi-arid grass pastures have been applied across the central grazing lands of Australia in the 2012 inventory submission.

These improvements to data and model function are indicative of the on-going development of the *FullCAM* model. As more regionalised data on plant production, soil characteristics and grazing management is supplied to DCCEE through research programs this new information will be incorporated into the databases as part of the national inventory improvement plan. It is expected that the current research activities funded through the Department of Agriculture, Forestry and Fisheries will provide substantive outputs for inventory development in 2012 due to a number of three year projects reaching completion.

7.J.2.5.3 Debris

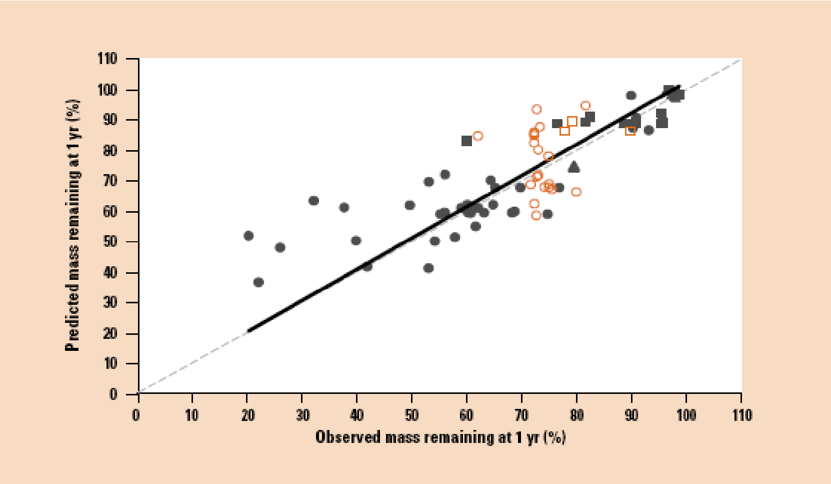
To estimate debris accumulation and loss, *FullCAM* was calibrated and validated using litter decomposition rates taken from studies conducted around the world, representing a range of environmental settings within forest and agriculture. Half the dataset is used to calibrate algorithms and the other half is used to validate decomposition predictions (Paul *et al.*, 2004).

To calculate the decay rate of plant material before it enters the soil pool two groups of parameters used are calibrated: i) decomposable fraction of plant residues, and ii) rate constants for decomposition of decomposable and resistant debris pools of plant residues. The model was set-up to run using field measured rates of plant residues and observed climate conditions. For forest systems the model was run for one year, then for the number of years corresponding to field measured published data. For agriculture, the model was run for a number of pilot agricultural systems over several years, then for the number of years corresponding to field measured and published data (Jeff Baldock, CSIRO Land and Water, *pers. comm.*). The simulated mass of aboveground dry matter available to enter the soil pool as plant debris is compared to that observed in published studies. Rates of decomposition in the model are then adjusted so that the simulated mass remaining best matches the field measured data from similar environmental settings.

A model efficiency index (EF) is calculated as the difference between the field-measured and model-simulated mass of litter remaining. Values of EF can be positive or negative with a maximum and minimum value of 1 and -1, respectively. A positive value indicates that the simulated values describe the trend in the measured data better than the mean of the observations, with a value of 1 indicating a perfect fit. A negative value indicates that the simulated values describe the trend in the measured data to a lesser extent than a mean of the observations. Deviations of predicted mass remaining, or predicted litter accumulation, are assessed using the mean square error (MSE). The smaller the MSE the better the model explains the data.

Once calibrated, the model predicted the observed mass remaining after one year of decomposition with an EF of 0.65 and a MSE of 117 g^2 100 g^{-2} (Paul *et al.*, 2004). The line of best fit between field measured and simulated data had a slope near unity (1.03) with an R^2 of 0.57 (Figure 7.J6).

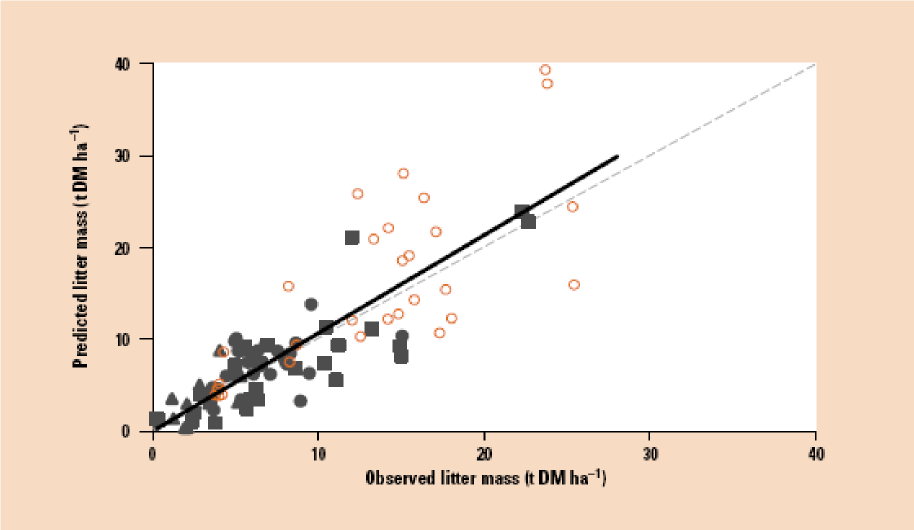
Figure 7.J 6 Relationship between observed mass remaining after one year of decomposition. Model EF and MSE were 0.65 and 177 g^2 100 g^{-2}, respectively.



Eucalypt leaf (l), eucalypt bark (p), eucalypt dead wood (n), pine needles (m) and pine dead wood (q) from the calibration dataset, and that predicted using CAMFor. Dashed line represents the 1:1 line. Solid line represents the linear function of best fit when forced through the origin (Slope=1.03, R2=0.57, n=80).

Using the validation data, the model predicted mass remaining with an EF of 0.70 and an MSE of 80 g^2 100 g^{-2}. The line of best fit between field measured and simulated mass remaining after one year had an R^2 of 0.60 (Figure 7.J8).

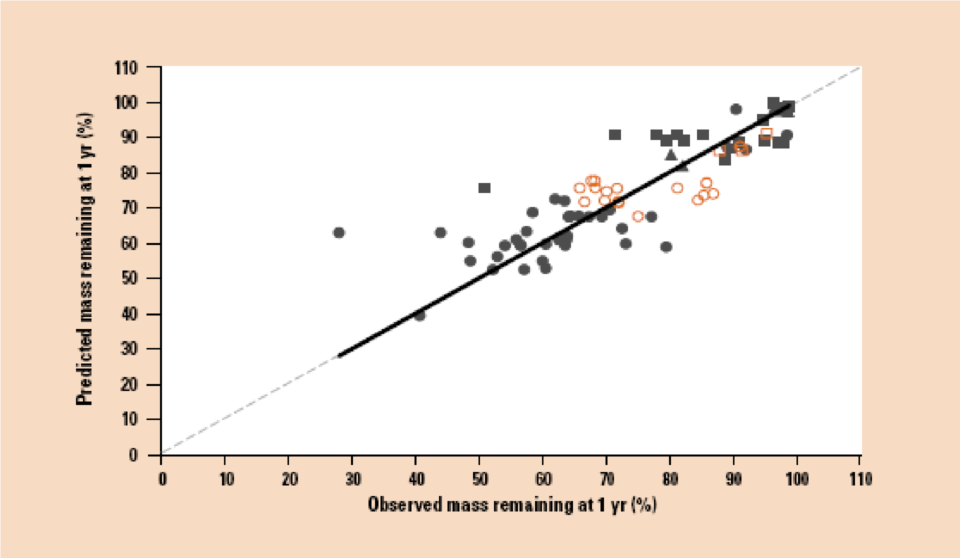
Figure 7.J 7 Relationship between observed mass remaining after one year of decomposition. Model EF and MSE were 0.70 and 80 g^2 100 g^{-2}, respectively



Eucalypt leaf (l), eucalypt bark (p), eucalypt dead wood (n), pine needles (m) and pine dead wood (q) from the validation dataset, and that predicted using CAMFor. Dashed line represents the 1:1 line. Solid line represents the linear function of best fit when forced through the origin (Slope=1.00, R2=0.60, n=83)

Validation of simulated data outputs were also performed using field measured data on long term litter accumulation (Paul *et al.*, 2004). The model predicted litter accumulation between four and 100+ years with an EF of 0.65 and a MSE of 15 t^2 ha^{-2} (Paul *et al.*, 2004). The line of best fit between measured and simulated litter mass had a slope near unity (1.06) and an R^2 of 0.67 (Figure 7.J9).

Figure 7.J 8 Relationship between observed mass and that predicted using *CAMFor*. Model EF and MSE were 0.65 and 15 t^2 ha^{-2}, respectively



Eucalypt leaf (l), eucalypt bark (p), eucalypt dead wood (n) and pine needles (m) Dashed line represents the 1:1 line. Solid line represents the linear function of best fit when forced through the origin (Slope=1.06, R2=0.67, n=95)

7.J.2.5.4 Soils

Calibration

After an extensive search for existing sites that met the requirements of time-series data collection for model calibration, two agricultural and seven forestry sites were selected. One agricultural site was located on a monsoonal subtropical environment with heavy clay soil and the other was located in a temperate Mediterranean climate with a light textured soil. At each agricultural site, archival soil samples (0-30 cm depth) collected throughout the life of the trials were fractionated into particulate organic carbon (POC), charcoal (char-C) and humic (HUM) pools (Skjemstad and Spouncer, 2003). These pools were then used to initialise the model (RPM set to POC, IOM set to char-C, HUM set to TOC minus POC minus char-C) at the first time of sampling. It was found that at both sites, adjusting the default resistant plant matter (RPM) pool decomposition rate constant modifier from 0.3 to 0.15 rectified any divergence in the results. No other changes were necessary. Following the agriculture model calibration, the forestry model calibration was completed using seven forestry sites:

1. *Eucalyptus globulus* in the low rainfall region, south-west of Western Australia;
2. *E. globulus* in the high rainfall region, south-west of Western Australia;
3. *Pinus radiata* in the Green Triangle region of South Australia and Victoria;
4. *E. grandis* in south-eastern Queensland and north-eastern New South Wales;
5. *P. radiata* in the south-eastern highlands New South Wales;
6. *E. globulus* in south-eastern Gippsland, Victoria; and
7. *E. nitens* in the Tasmanian highlands.

Testing of the seven forestry sites and two agricultural sites confirmed the model calibrations for soil carbon pool allocations for both forestry and agricultural sites. Details of the calibration and testing of the model are provided in Paul *et al*., (2002b and 2003b).

Validation and verification

The soil carbon model used to predict changes in soil carbon caused by shifts in agricultural practice was independently calibrated and validated (Skjemstad and Spouncer 2003). The results were found to be sensitive to the partitioning of carbon between the various soil fractions (Janik *et al.,* 2002; Skjemstad *et al.,* 2004; Paul and Polglase, 2004b).

Model validation used existing time-series data and new paired-site comparisons to test model predictions of change. Calibration of the model demonstrated that the measured soil carbon fractions (POC, HUM and Char-C pools) fitted well with the modelled carbon pools (RPM, HUM and IOM) as defined in *FullCAM*, provided that the decomposition rate constant (*kRPM)* of the POC pool was reduced from 0.3 to 0.15. From the calibration sites and using this single rate modification, the model performed equally well in subtropical and Mediterranean climates and for crops and pastures (Sjkemstad and Spouncer, 2003). A full description of the model calibration and validation results for agriculture can be found in Skjemstad and Spouncer (2003).

For long-term rotation trials and other sites sampled from the same location on a temporal basis, validation of the model was found to be very good. For new paired sites, validation of the model was more variable. In many cases, apparent poor performance of the model could be attributed to spatial heterogeneity and inadequate pairing of the sampling sites. Overestimation of modelled plant inputs at the paired sites was also identified as a possible issue. For Tier 3 methods that model soil carbon changes over time due to land use change, the associated errors in sampling are minimised, but remain an issue for the development of the spatial soil data inputs to the model. In general terms the coefficient of variation for modelled outputs of soil carbon is around 5% (Janik *et al.,* 2002), whereas the coefficient of variation for measured soil carbon is 15-40% (McKenzie *et al.,* 2000; Janik *et al.,* 2002). Further details are provided in Murphy *et al.,* 2003, Harms and Dalal, 2003 and Griffin *et al.,* 2003.

The spatial pre-cleared soil carbon map used in *FullCAM* was verified against measured soil carbon values at 53 sites in New South Wales (Murphy *et al.,* 2003), Western Australia (Griffin *et al.,* 2003), and Queensland (Harms and Dalal, 2003). These measured values consist of paired sites containing both a native vegetation site and another site on the same soil type that had been subject to land use change.

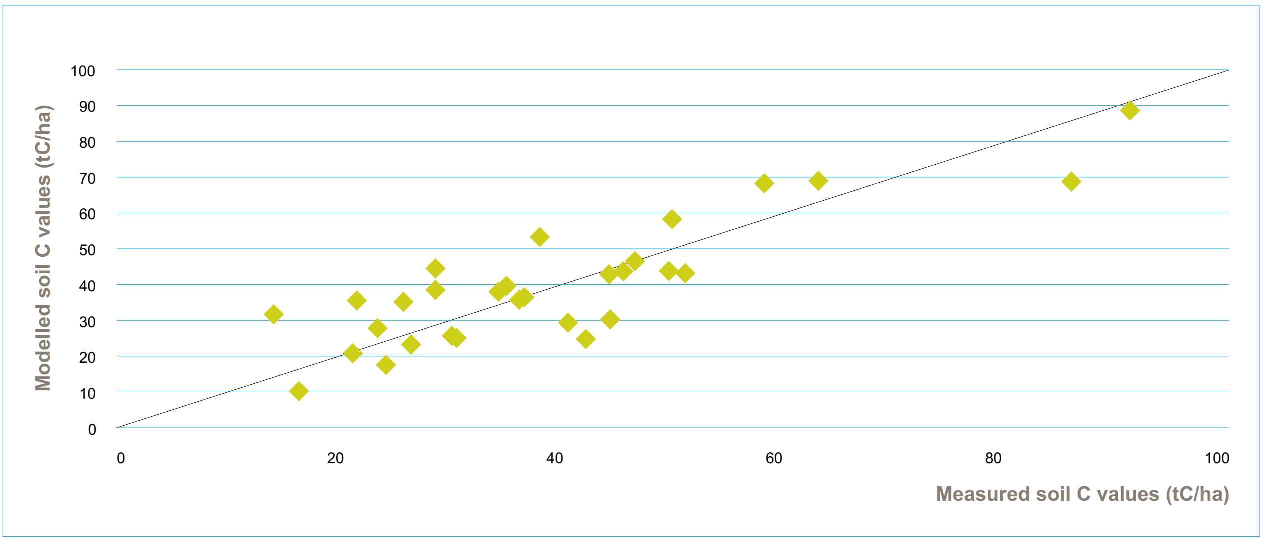
To validate the soil carbon model, the initial soil carbon measurements from 32 of the 53 paired sites (average of 29.5 t C ha^{-1}) were compared to the pre-clearing soil carbon values used by *FullCAM* (average of 29.6 t C ha^{-1}). In addition to the 53 paired sites, another 22 soil pairs (an undisturbed native vegetation site paired with a cleared site) were sampled to provide a range of verification targets for model testing. Sites were established in collaboration with state agencies in New South Wales and Western Australia, in the areas of major forest conversion activity. Sites were selected to cover a variety of crop types, soil types and times since change (i.e., time since clearing) in areas subject to most intensive activity. Sampling of sites was completed according to a standardised soil sample protocol (McKenzie *et al.*, 2000).

Calibration data were drawn from a series of both forestry and agricultural research sites, which although sparse, are ideally suited to model calibration having comprehensive data records and time-series consistent measurements of key soil and management parameters.

An independent assessment of measured soil carbon values from 29 paired sites, representing a subset of all the paired sites, were compared with *FullCAM* outputs using site history as a means of modelling the soil carbon change after land clearing. A regression (Figure 7.J9) found a significant correlation ($r^2 = 0.73$) between the measured soil carbon values of the 29 sites and modelled soil carbon values. These data showed a higher level of variance between measured and modelled values (25%) compared to the validation analysis performed by Sjkemstad and Spouncer (2003), but a lower level of variance than would be expected from a field measurement due to sampling error alone (up to 40% CV; McKenzie *et al.* 2000).

The regression analysis of measured and modelled data (Figure 7.J9) demonstrates that the logic used to establish a pre-clearing soil carbon layer for Australian soils as a basis for modelling under different management practices can be used with a high degree of confidence to estimate current soil carbon values. Therefore, for national inventory reporting requirements *FullCAM* provides data of equal or better accuracy than would a measurement program, especially considering the errors associated with sampling and temporal variability.

Figure 7.J 9 Measured versus modelled soil carbon data collated from 29 sites across a range of soil types in northern and southern Australia



7.J.2.5.5 Sensitivity & Uncertainty

Method development, data compilation, remote sensing and field measurement programs for Australia's land sector reporting methods have been undertaken using sensitivity testing as a component. The sensitivity analysis has been targeted at providing an understanding of the key factors in carbon stock change estimation. Priorities in program development have been established around improvement of the specific inputs identified though sensitivity testing. Sensitivity analyses have mostly been undertaken using *Monte Carlo*-type analyses. These analyses were carried out using the @Risk (Palisade Corporation 1997) software which was applied to both the Excel-based developmental and test models and in direct application in *FullCAM*. The various results of the uncertainty and sensitivity analyses are reported in Brack and Richards (2002), Brack (2001a), Paul *et al.*, (2002a), Paul *et al.*, (2003a) and Janik *et al.*, (2002).

Brack and Richards (2002) have provided the basis for the uncertainty analysis using the @Risk *Monte Carlo* capabilities attached to *FullCAM*. The analysis undertaken took advantage of the progression from treating all parameters as 'uncertain' with ranges of potential values, to describing the potential 'variance' within many parameters in terms of a probability distribution.

Dealing with quantified variance rather than constrained uncertainty within *Monte Carlo* analyses in *FullCAM* makes it possible to consider the correlation between variables and parameters and the likelihood of any single or interacting circumstance occurring. When the *Monte Carl*o analysis runs all statistical variants of possible inputs in combination, unrealistic biophysical scenarios may be induced. For example, under high rainfall, growth rate and decomposition rates will likely increase. If the *Monte Carlo* analysis is not informed that these parameters are positively correlated then the random selection of high growth values may be incorrectly associated with decreased decomposition rates.

If correlations are not prescribed, combinations such as increased growth and decreased decomposition rates (a negative correlation) are as likely to be selected as a positive correlation, yet they are not likely in reality. This inclusion of unrealistic scenarios will considerably increase perceived uncertainty in model outcomes. The result is that a simple multiplicative array of potential (yet unrealistic) extreme results increases uncertainty ranges, as the generally ameliorating impacts of correlated inputs are not acknowledged.

Biomass analyses

Variability in growth over time and wood density are the most sensitive factors in biomass estimation using *FullCAM* (Richards and Brack, 2004a). The method used in the Tier 3, Approach 3 application of *FullCAM* to estimate biomass and biomass increment directly provides a measure of aboveground mass, so no measure of wood density is required to convert volume into mass greatly reducing uncertainty (Richards and Brack, 2004a).

As shown in Snowdon *et al.*, (2000) there is limited information available on root-to-shoot ratios for tree species. The ratios adopted in the National Inventory System represent the best estimates from the available data. There is no cause, from the data available, to presume that there is any bias introduced, despite the evident lack of precision in the data. The low sensitivity of model results to the root-to-shoot ratio is largely due to the compensatory effects of regrowth. As regrowth is accounted for in the modelling, over- or under-estimates in losses due to forest conversion will be compensated for by a symmetrical over- or under-estimate in regrowth.

The sensitivity of *FullCAM* to changes in BI_a was tested by Richards and Brack (2004a). The sensitivity testing showed the value of BI_a=10 years produced yield curves that moderated the patterns to a similar shape to those produced if a higher value of 15 was used. To test the sensitivity of the *forest land converted to cropland* and *forest land converted to grassland* sub-categories to BI_a the model was re-run applying a value of BI_a=15 for all forests. The increase in BI_a from ten to 15 caused little change in the results (1.0 Mt increase in CO_2–e in 1990, less than 1% of emissions). The minimal effect of this parameter on the model results is due to the balancing of reduced emissions from cyclic regrowth clearing by the slower growth rate of regrowth areas that were not cleared in 1990.

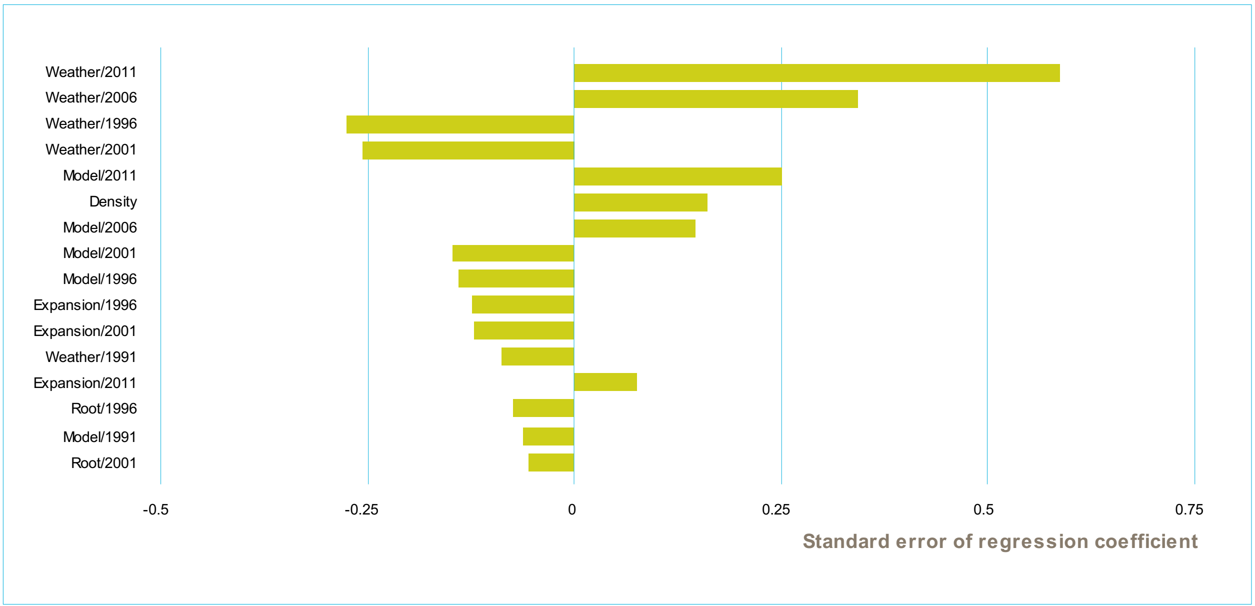
Brack and Richards (2002) modelled the performance of an individual stand using growth rates determined according to the observed growth variance around rainfall variability, error in allocating a growth index for the relevant growth model, and known variance or uncertainty in other key parameters. The key output for consideration is shown in Figure 7.J10.

The tornado graph (Figure 7.J10) shows the sources of uncertainty of model parameters and variables in order of their importance to uncertainty in the model outcome. On an individual stand basis and in this instance, predictions are more prone to climate based variation than any other influence.

Figure 7.J11 provides the mean and standard deviations for projected performance, providing the logical conclusion that stands aged around their maximum potential growth rate would be most affected (largest standard deviation) by variability largely driven by climate.

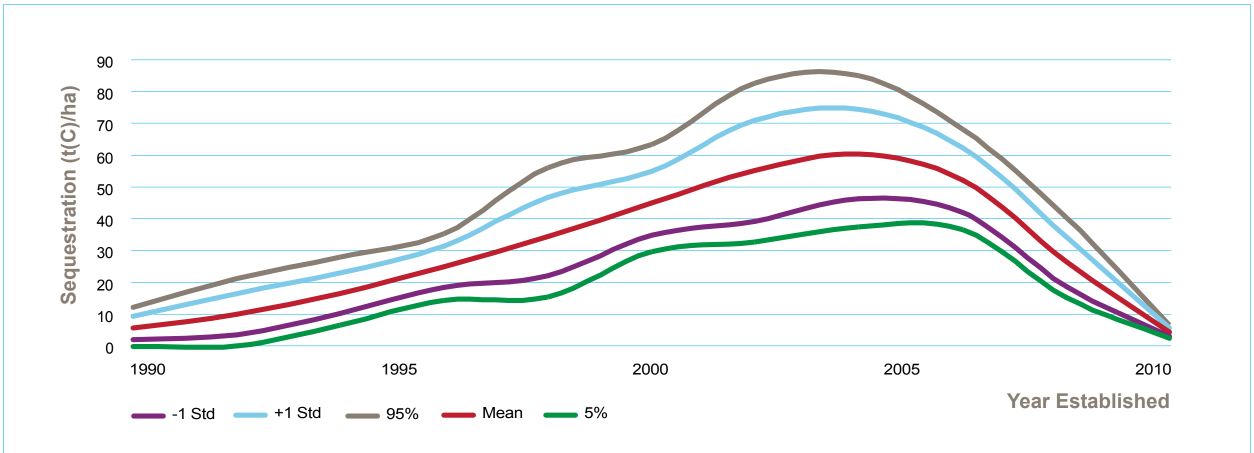
To take such individual stand-based uncertainty analyses to a national scale by simplistically extrapolating high and low outcomes would yield unrealistic results. The use of a 'low' base and the lower standard deviation is founded on the unlikely potential for below average rainfall for all plantation areas across the whole continent. Given the vast areas covered by *plantations*, it is a reasonable expectation that across the continent, 'more average' conditions will be achieved at the national level.

Figure 7.J 10 Tornado diagram derived from @ Risk simulations of the correlation between uncertainty of the inputs and distribution of sequestration estimates between 2008 and 2012 for a plantation established in 1990



Weather/xxxx denotes the variation in weather during 5-year period commencing xxxx. Model/xxxx denotes the variation in the modelled site index during the 5-year period commencing xxxx. Expansion/xxxx denotes the variation in the expansion factors (caused as a result of the variation in increment of bark, branches, twigs and leaves) during the 5-year period commencing xxxx. Roots/xxxx denotes the variation in root increment and decay during the 5-year period commencing xxxx.

Figure 7.J 11 Variability in stand performance by age of stand



Source: Brack and Richards (2002)

Soil analyses

The most extensive sensitivity testing of *FullCAM* was undertaken for the soil carbon sub-model calibration and verification program. The multi-faceted testing included reviews of model performance against measured chronosequence soil pairs and long-term trial data. The model calibration and verification as reported in Skjemstad and Spouncer (2003) gives no cause to suspect that there is any bias from model over- or under-estimation. Under the spatially and temporally disaggregated approaches taken, variance in input data for each grid (25 m) of the model run (presuming it is without skew in the variability in inputs) will, over a large sample, provide a robust and stable central estimate. In terms of uncertainty and potentially biased estimates, this is a significant advance on the default approaches which use constants (emissions factors) to define the change in stock as suggested under Tier 1 and Tier 2 accounting as described in the IPCC *Good Practice Guidelines*.

The *FullCAM* soil carbon sub-model has been optimised for Australian conditions by adjusting the decomposition rate variables for the five pools used by the model; a decomposable plant material pool (DPM); a resistant plant material pool (RPM); a microbial biomass pool (BIO), a humified organic matter pool (HUM), and an inert organic matter pool (IOM), consisting mostly of charcoal. Sensitivity analysis of the model inputs demonstrated that there was a comparative insensitivity to the BIO and DPM pool quantities and rate constants (see Table 7.J5). These pools have a rapid turnover rate and consequently have reduced impact on soil carbon content in the longer term. In contrast to the slower decomposition rates of the HUM and RPM pools leads to these pools being more important in the longer term.

Table 7.J 5 Predicted carbon change (tC ha^{-1}) for a + 10% change in C pool variables over a 20-year period.

Variable	Carbon 1975	Change 1980	(tC ha^{-1})1990
BIO rate constant	-0.03	-0.03	-0.03
DPM rate constant	-0.01	-0.01	-0.01
RPM rate constant	-0.24	0.36	-0.54
HUM rate constant	-0.07	-0.13	-0.23
RPM pool	-0.40	-0.57	0.73
IOM pool	0.04	0.07	0.13

Source: Janik et al., (2002)

The standard error of the prediction of the soil carbon due to uncertainties in each variable is the product of the sensitivity and the standard deviation of the estimate of that variable. The actual sensitivity for each variable is determined by fitting a polynomial to the predicted data, and then differentiating at the required values of the variable. When sensitivity data are combined with estimates of their uncertainty, the variables that will potentially cause the greatest uncertainty in the modelling process may be indicated. For example, the uncertainty analysis for plant input data (i.e., grain yield, root, and aboveground dry matter (AGDM)), demonstrated that all of the soil carbon pools showed moderate uncertainty, but small changes in the RPM pool had a significant impact upon model uncertainty (Table 7.J6).

Table 7.J 6 Summary of model response to changes in rate constants and plant input data.

Variable	Response	Expected Variability	Uncertainty	Contribution to uncertainty	20 year change (tC ha^{-1})
Decomposition rate of BIO pool	Very low	High	Moderate	Very small	< 0.1
Decomposition rate of DPM pool	Very low	High	Moderate	Very small	< 0.1
Decomposition rate of RPM pool	Moderate	High	Moderate	Significant	1.1
Decomposition rate of HUM pool	Moderate	High	Moderate-High	Moderate	0.4
Ratio AGDM:Grain yield	Moderate	High	Moderate	Significant	1.4
Root:AGDM	Low	High	High	Significant	0.8
TOC:TDM	High	Low	Low	Small	1.2

Source: Janik et al., (2002)

In regard to time scale of the simulation, those variables with rapid rate constants are likely to have less impact on the carbon simulations than those with longer time scales, but the impact will be greatest at or near clearing. The high sensitivity of soil total organic carbon (TOC) to variables associated with the RPM pool and RPM rate constant carries on throughout the 30-year simulation period (Table 7.J7). The response to the IOM pool is only moderately sensitive at the start of the simulation but becomes increasingly more sensitive at longer simulation periods.

Table 7.J 7 Summary of model responses to changes in soil variables.

Variable	Response	Variability	Uncertainty	Contribution to uncertainty	Range (tC ha^{-1})
% clay	Small	Large	Moderate	Small	< 0.1
RPM pool (tC ha^{-1})	Moderate-High	High	Moderate	Significant	1.5
IOM pool (tC ha^{-1})	Moderate	High	Low- Moderate	Moderate	0.3

Source: Janik et al. (2002)

The response of the model to changes in the soil variables is summarised in Table 7.J8, including the values of the soil carbon within the individual pools. The prediction of soil carbon is fairly insensitive to the amount of clay in the soil (Janik *et al.,* 2002). The final estimate is affected by less than 0.1 tC ha^{-1} when the clay content was varied between five and 70%, but is increasingly sensitive with very low clay content.

7.J.3 SOURCE CATEGORY

Australia reports on *forest land remaining forest land*, *forest land converted to grassland*, *forest land converted to cropland*, *grassland converted to forest land*, *grassland remaining grassland* and *cropland remaining cropland*. This section describes the QA/QC activities associated with the emissions estimates for each of the reporting sub-categories.

7.J.3.1 Forest land remaining forest land

7.J.3.1.1 Harvested native forests

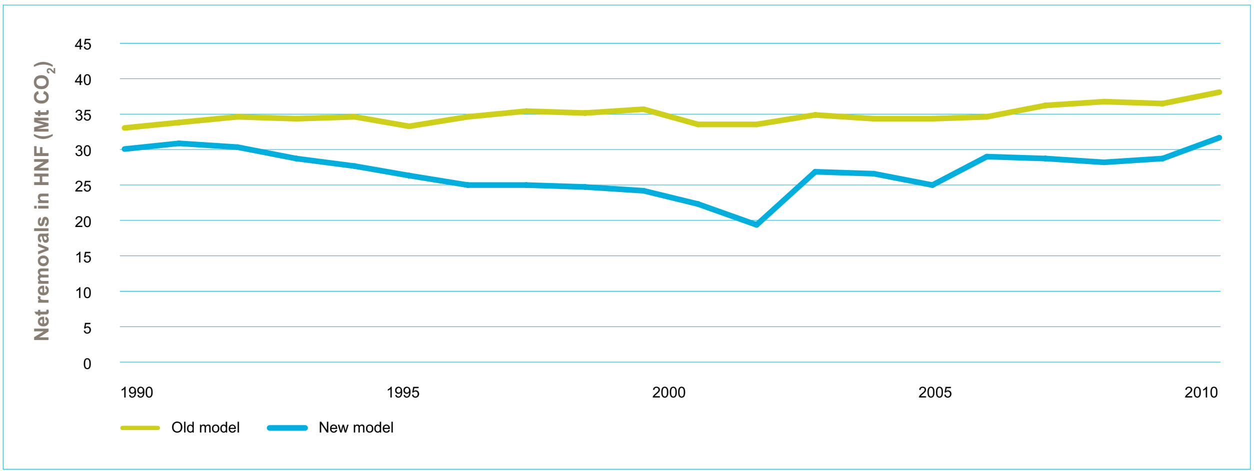
Data on forest extent (area), age class and growth that are used in the *harvested native forests* model were derived from Australia's National Forest Inventory (NFI). These data have also been published as part of Australia's Inventory Report and as such is publicly available, and subject to domestic and international review.

The estimates of growth rates by forest type are sourced from the NFI and can be verified against independent data published by the Resource Assessment Commission Forest and Timber Inquiry findings (Resource Assessment Commission, 1991; Resource Assessment Commission, 1992a,b). Additionally, growth rates reported for important harvested forest types in Australia were based on the data available from the Research Working Group of the Standing Committee on Fisheries and Forestry of the Australian Government (West and Mattay, 1993). Comparisons show that the growth rates used in *FullCAM* are within the range of those described by the Resource Assessment Commissions (lower estimate) and West and Mattay (higher estimate).

Data on harvest areas was obtained from a combination of annual reports of Australian State agencies, financial statements, and spatial harvest area data. This data has been subject to state review processes and financial auditing. Data on stem to whole tree conversions, carbon contents and wood densities are within the ranges published in Gifford, 2000a; Gifford, 2000b; Ilic *et al.,* 2000; and Snowdon *et al.,* 2000. The estimated slash produced by forest harvesting is in line with independent studies of slash production from forest harvesting for major Australian harvested forests (Snowdon *et al.* 2000; Ximenes *et al.* 2008a).

The *harvested native forests* model was verified by comparing the emissions estimated for the current inventory (using *FullCAM*) with those estimated using a Tier 2 model (Figure 7.J12). The current estimates produce lower net removals than previously estimated, and display greater variability by including the effects of age-based forest growth, debris accumulation and the effects of management. The impact of using the area harvested to estimate emissions and removals is clearly observed with peak harvest areas during the mid 1990s with a sharp increase in 2001, before a significant decrease in the annual area harvested through the 2000s. The reduction in the harvested area has been driven by a reduction in the maximum allowable harvest volume in many of the *harvested native forests* in Australia (Montreal Process Implementation Group for Australia 2008). This has been driven by improved resource information particularly forest yield, as well as reductions in the areas of forests where harvesting is permitted (Montreal Process Implementation Group for Australia 2008).

Figure 7.J 12 Estimated net removals in Harvested Native Forests, new Tier 2 model compared to the former model used in previous inventories



The outputs of the *harvested native forests* model were verified against independent data on annual roundwood removals drawn from national statistics on forest products production and consumption (ABARE, 2009c) (Figure 7.J14). The total carbon removed from the forest as forest products was converted back to stem volume assuming a stemwood carbon percentage of 52% (see Table 7.B6 in Appendix 7.B) and average wood basic density of 750 kg m^{-3}. From 2000 onwards (where the area harvested data is the most certain), the model output and roundwood data are similar. During the 1990s the *harvested native forests* model estimates slightly higher product removal. However, the estimates show similar trends and provide confidence in the model.

7.J.3.1.2 Pre-1990 plantations

Modelling of pre-1990 *plantations* is not currently implemented spatially but uses area extent data from the National Forest Inventory (NFI) based on the 14 National Plantation Inventory regions (see Figure 7.C3). Biomass (including the effects of ongoing management) and soil carbon are also estimated in the model.

The data used in the model to estimate emissions and removals in the pre-1990 *plantations* sub-category are based from several different sources. Growth is calculated using stem volume and yield data obtained from Australia's National Plantation Inventory which was then annualised by Turner and James (2002). The NFI perform QA/QC on these data and further checks were conducted by Turner and James (2002) as part of their work to annualise the National Forest Inventory (NFI) data. The basic density and expansion factors applied were sourced from the technical reports and are well within the ranges of newer data collections such as Polglase *et al*. (2004). The methods and data applied have also been subject to peer review and have been published in Richards and Brack (2004b).

The soil carbon estimates are based on the model developed by Polglase et al. (2000) and was used to estimate soil carbon change following the establishment of plantations between 1940 and 1989. Forest extent data used for estimating soil carbon was obtained from the NFI.

An independent review of the models used to estimate emissions and removals in the *Plantations* category was undertaken by CSIRO in 2001.

7.J.3.1.3 Other native forests

Carbon stock change and emissions from *other native forests* were estimated using four sub-models to represent the important processes occurring in *other native forests* at the national scale. These include:

1. Permanent changes in forest extent due to climate;
2. Ephemeral changes in forest extent due to climate;
3. Foliage mass loss in permanent forest due to climate; and,
4. Controlled burning and wildfire.

In addition, the data required for each of these models include the time-series of the forest balancing term from the land area matrix, the national leaf area index provided by the DCCEE Geospatial Analysis Unit, and wildfire areas which are supplied by CSIRO Sustainable Ecosystems (based in Darwin). Quality control processes for the forest balancing term data and its use within sub-model (i) and (ii) were performed by the DCCEE Geospatial Analysis Unit. The leaf area index (LAI) time-series data was, up until 2009, obtained from the environmental resources information network (ERIN). The LAI for 2009 was obtained from the bureau of meteorology (BOM) and appended to the time series of ERIN data. This approach will be replaced by the sparse data method this is currently being developed. The controlled burning and wildfire data is calculated based on fires that are supplied by CSIRO Sustainable Ecosystems and sourced from state and remote sensing fire area estimates. These data have had extensive QA/QC applied at their source.

7.J.3.2 Forest land converted to cropland and grassland

Forest land converted to cropland and *grassland* emissions estimates are based on the Tier 3 Approach 3 model and national time-series of Landsat satellite data. Verification of the use of the Tier 3 model to estimate emissions from this sub-category was performed through comparison with a Tier 2, Approach 2 method. The Tier 2 model was developed as an excel spreadsheet model. This model formed the basis for reporting emissions prior to the implementation of the Tier 3, Approach 3 methods and has been subsequently enhanced. The Tier 2 model accounts for emissions from both conversion of 'mature' forest, the regrowth of forest on previously cleared land and the subsequent re-clearing of a proportion of this regrowth.

The emissions include:

1. Emissions from residue burning (CO_2 and non-CO_2);
2. Emissions from decay of dead organic matter;
3. Emissions from release of carbon from the soil; and
4. Emissions from burning of dead organic matter.

The annual area converted or re-cleared (activity data) were the same as those used as input to the Tier 3 model for *Forest land converted to cropland* and *grassland* (see Appendix 7.A).

In the Tier 2 model land clearing is stratified into three broad forest classes:

- closed (tropical forest);
- open (predominantly eucalypt forest); and
- woodland forest

This stratification was undertaken by overlaying the areas cleared from the remote sensing analysis on the major vegetation groups of the National Vegetation Information System (NVIS; see Appendix 7.A).

Figure 7.J 13 Initial assumed biomass of land cleared post-1989 which has entered Australia's deforestation accounts

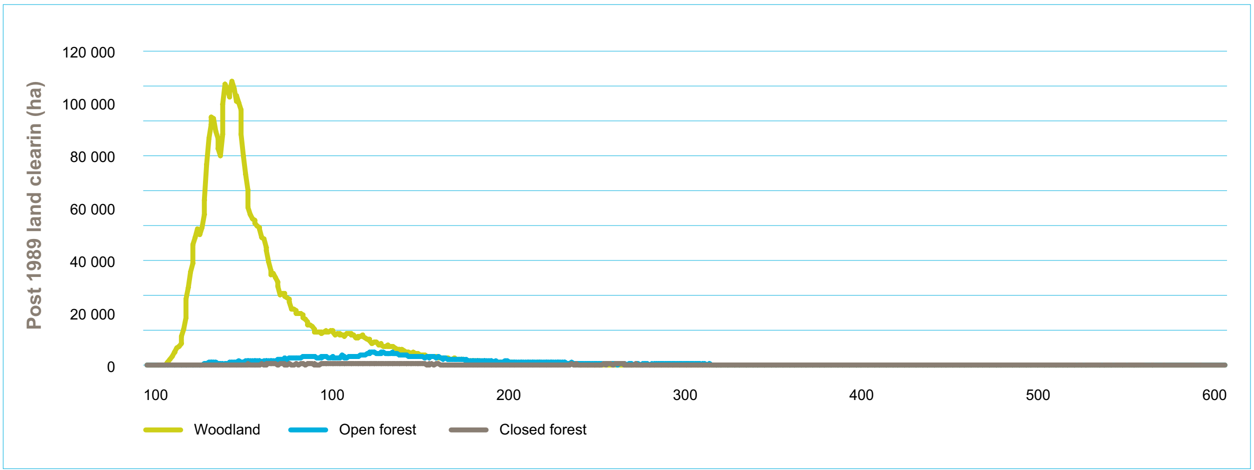


Figure 7.J14 shows that the majority of land clearing since 1989 has occurred in woodland forests. This information was used in the Tier 2 model to allocate the area cleared in each year to clearing of woodland, open forest and closed forest (Table 7.J8).

To determine the biomass of each forest class that is used in the Tier 2 model, analysis was undertaken of the initial assumed aboveground biomass of the lands that are within Australia's deforestation account. To undertake this analysis the simulated cells layer for lands within the deforestation account were intersected with the initial assumed aboveground biomass surface. Table 7.J8 shows the results of this analysis. The estimates are expressed as averages within three forest types – closed forest, open forest and woodland. Deforested areas were allocated to the three forest types by matching their locations to the locations of Australia's major vegetation groups.

Table 7.J 9 Tier 2 coefficients used to estimate emissions and removals from forest clearing

Core parameters	Closed Forest	Open Forest	Woodland Forest
Proportion of annual clearing (%)	2	10	88
Initial biomass of forests[#*] (t dm ha^{-1})	198	158	67.6
Root : shoot ratio	0.25	0.25	0.40
Debris onsite mass* (t dm ha^{-1})	100	75	50
Initial soil carbon[¥] (t C ha^{-1})	70	73	42

[#] Aboveground biomass.
* Used for all States and Territories.
¥ Used to calculate ultimate loss of soil carbon.

Areas of previously cleared land that re-grew to forest are assumed to achieve their original biomass in 20 years. The biomass of forest subject to reclearing is 30% of the mature biomass. A proportion of the cleared biomass is burnt in the year of clearing, with the remaining debris decaying linearly for ten years. Following clearing areas of land are allocated to either grassland or cropland based on the National Inventory method.

Emissions of soil carbon following conversion are estimated by allocating the land to cropland or grassland and linearly increasing or decreasing the initial soil carbon stock (Table 7.J8) by a percent per year (Table 7.J9) for 20 years. Soil carbon is not included in regrowing forests.

Net emissions from forest clearing were calculated as the difference between emissions and removals. Both CO_2 and non-CO_2 emissions from land clearing were incorporated.

Non-CO_2 (CH_4 and N_2O) emissions were estimated by multiplying the CO_2 emissions from onsite burning and onsite burning of debris with a 'non-CO_2 to CO_2' coefficient. The non-CO_2 to CO_2 coefficient incorporates the ratio of mass of non-CO_2 gas to the mass of carbon it contains, the ratio of non-CO_2 gas emitted to carbon emitted, the ratio of the amount of CO_2 with equivalent greenhouse gas effect to an amount of non-CO_2 gas and the fraction of CO_2 that is carbon by weight.

Both aboveground and belowground (based on root:shoot ratios) biomass was incorporated for the estimation of CO_2 emissions from burning and forest decay (Table 7.J8). Forest debris was assumed to decay over a period of ten years (IPCC, 2003). The removal of CO_2 includes regrowth of forest biomass and regrowth of agricultural (crop and grass) biomass, both above and belowground. Forests were assumed to reach maturity at 25 years. The CO_2 emission from the soil carbon pool was calculated as the difference between the ultimate loss of carbon from the soil (that is, the amount of carbon a soil could lose) and the amount of carbon remaining in the soil after a fraction has been lost during that year (Table 7.J8).

Table 7.J 10 Tier 2 coefficients used to estimate emissions and removals from soil carbon pool following conversion from forest and forest types

Core parameters	Pasture	Grass	Crops
% loss of soil carbon following conversion from forest¥	-5	10	30
Ultimate loss of soil carbon from closed forest (tC ha^{-1})	-3.50	7.00	21.00
Ultimate loss of soil carbon from open forest (tC ha^{-1})	-3.65	7.30	21.90
Ultimate loss of soil carbon from woodland forest (tC ha^{-1})	-2.10	4.20	12.60

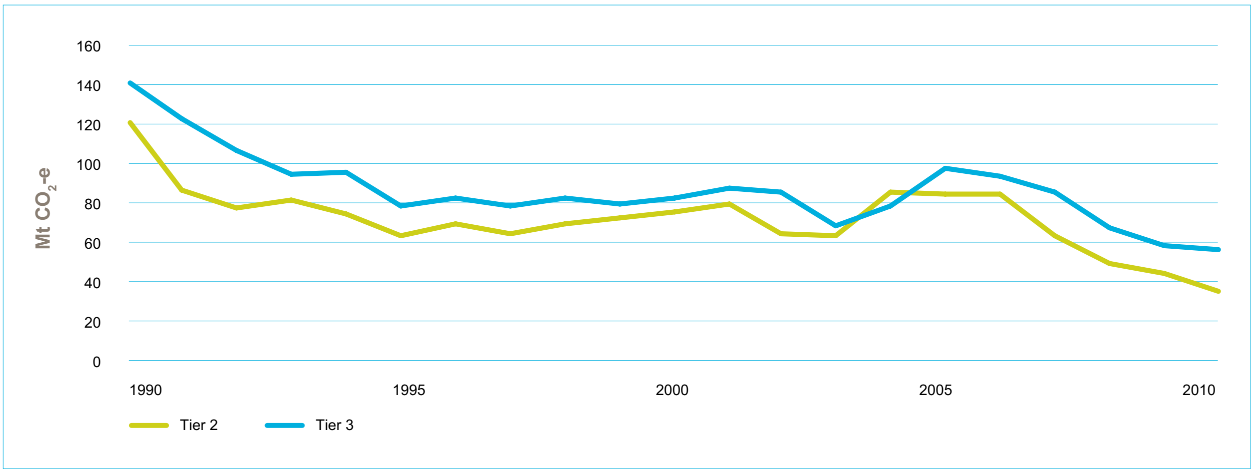
¥ Used to calculate ultimate loss of soil carbon.

The Tier 3, Approach 3 model for land use change was carried out with *FullCAM* . A full description of the Tier 3, Approach 3 is provided in Appendices 7.A and 7.F.

The difference in emissions output between the Tier 2 method and the Tier 3 method ranged from 6% in 2000 up to 38% in 2010 (Figure 7.J15). By and large, the emissions output does not vary substantially between the Tier 2 and Tier 3 models; however, the discrepancies between the two model approaches can be explained further.

The Tier 2 method uses country-specific 'default' coefficients to estimate emissions and removals from deforestation (land use change). It standardises the biophysical (soil, climate, etc.) environment, and hence forest productivity, across Australia. That is, the Tier 2 model does not encompass the spatial variability relating to soil types (and their characteristics) and climate variability (particularly rainfall) which would have an effect on emission levels and as such, CO_2 emissions and removals could therefore be overestimated or underestimated. The Tier 3, Approach 3 method is spatially explicit, operates at a fine scale (25 m) and incorporates the variability of the biophysical environment (climate and soil) across Australia. This therefore includes the effects of climate, better represents regrowth and reclearing cycles and varies emissions based on the site characteristics of the land subject to clearing.

Figure 7.J 14 Emissions from *forestland converted to cropland* and *grassland* output from Tier 2 and Tier 3 methodology from 1990 – 2010



Soils under cropland

In most Australian cropping systems there has been and continues to be a general decline in soil carbon stocks (Hennan et al. 1995; Grace *et al*. 1998) which does not reach an equilibrium until 100 years or more following land conversion from native forests (see Figure 7.J17). The verification data collected during model development provided guidance on the general results expected under different cropping systems. Figure 7.J18 shows the decline in soil carbon stock for two long-term cropping sites.

Figure 7.J 15 Changes in soil carbon stocks for cropping systems in Australia since 1800

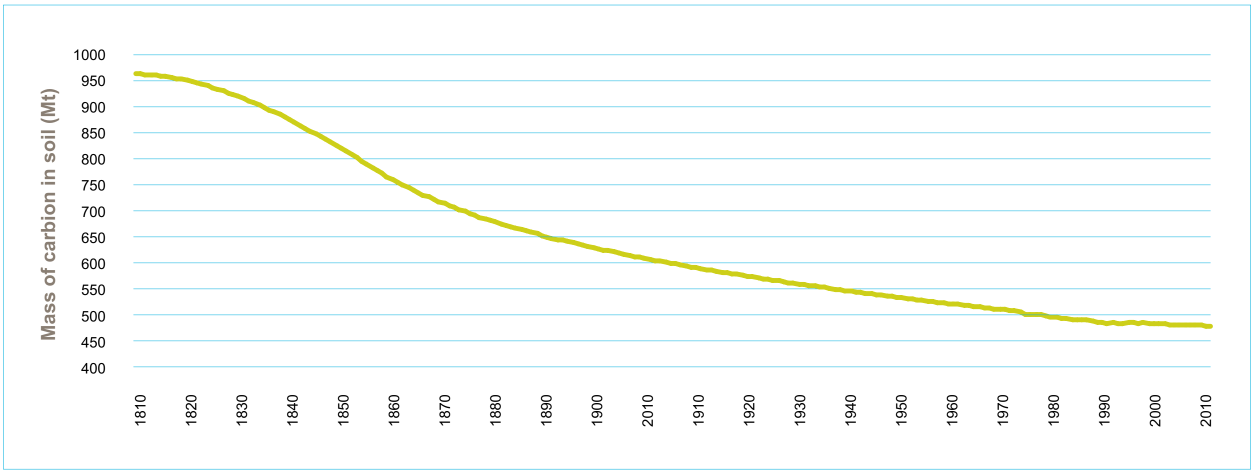
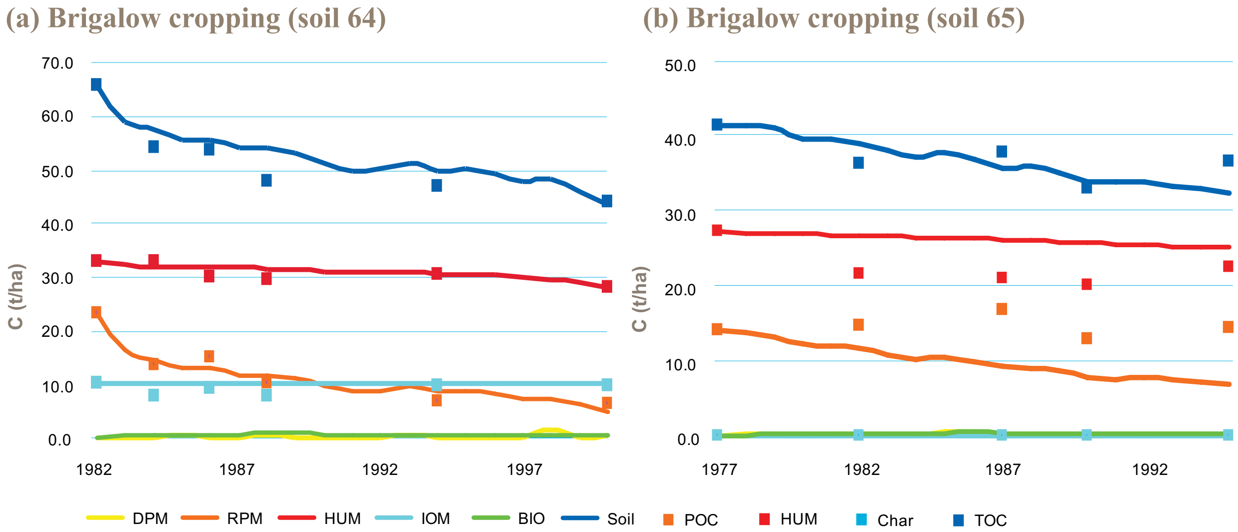


Figure 7.J 16 Changes in soil carbon for two long-term sites under continuous cropping.



(▪ measured and - modelled)

(Key: DPM – decomposable plant material; RPM – resistant plant material; HUM – humic matter; IOM inert organic matter; BIO – biological matter; Soil – total soil carbon; POC – plant organic carbon; HUM – humic matter; Char – char; TOC – total organic carbon)

Soils under grassland

A similar trend exists for grasslands with soil carbon stocks declining in Australia post 1800 after equilibration of soil carbon pools from 1500 to 1800 (Figure 7.J19). Further interrogation of the *FullCAM* model outputs and associated QA/QC processes identified that the modelled transition from forest lands to pasture production systems using *FullCAM* contains a carryover of legacy carbon from decaying forest debris. Removal of this forest debris transitional effect is likely to allow the pasture soil carbon stock to equilibrate sooner than demonstrated in Figure 7.J19. It was not possible to investigate this effect for the 2012 inventory submission, but this will be a component of the on-going inventory development plan for 2013. Specific long-term pasture sites where soil carbon stocks had already reached a low equilibrium due to a long history of cropping practices were able to demonstrate an increase in soil carbon stocks (Figure 7.J20). In the high rainfall regions of Australia a number of permanent pasture systems established after a history of long-term cropping frequently show increases in soil carbon, however this increase is also associated with an increase in soil fertility (Chan and McCoy 2010) through fertiliser additions.

Both Guo and Gifford (2002), Skemstad and Spouncer (2003), Sanderman et al. (2007), and Chan and McCoy (2010), have shown that continuous cropping, crop and pasture rotations and continuous pasture will each drive specific patterns of soil carbon change after a land use change. The direction of this change will be very much related to the starting soil carbon stock prior to land use change.

Figure 7.J 17 Modelled changes in soil carbon stocks for grassland systems in Australia since 1500

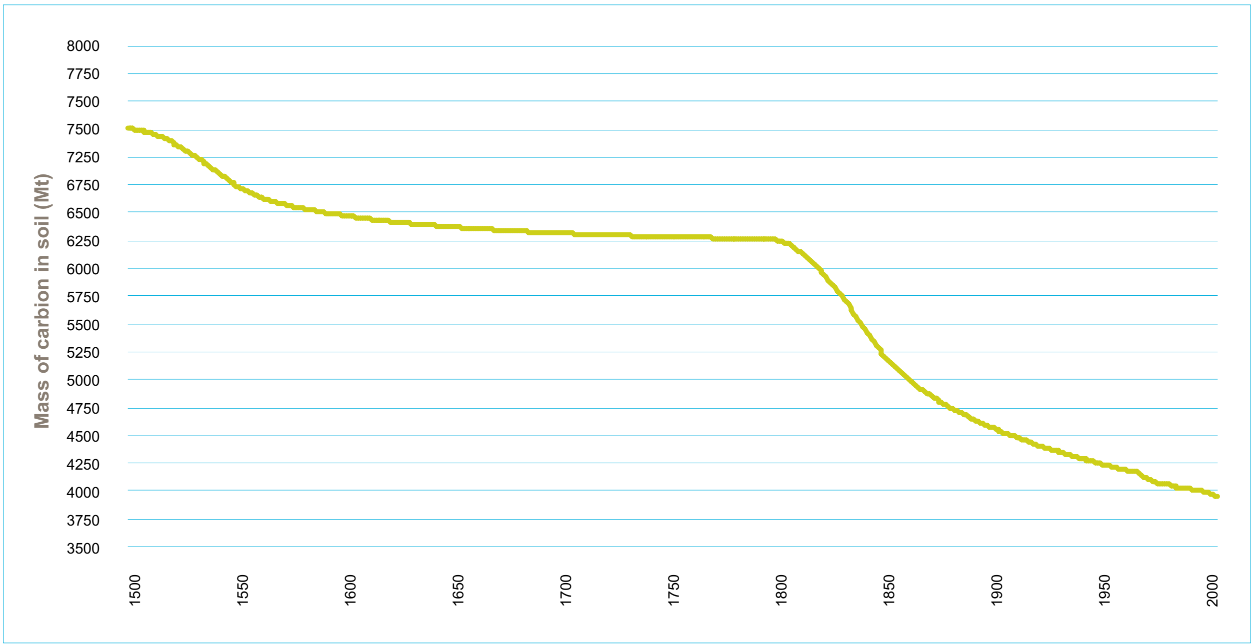
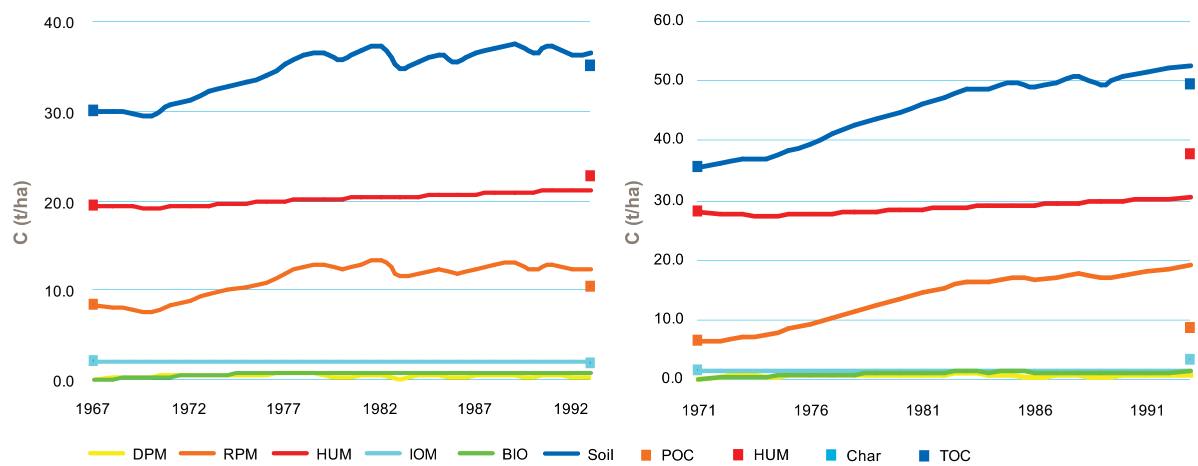


Figure 7.J 18 Changes in soil carbon for two long-term sites under crop - pasture rotations after a history of long-term cropping practices.

(a) Freeling barley / pasture **(b) Padthaway wheat / pasture**



(• measured and - modelled)

(Key: DPM – decomposable plant material; RPM - resistant plant material; HUM – humic matter; IOM inert organic matter; BIO- biological matter; Soil – total soil carbon; POC – plant organic carbon; HUM – humic matter; Char – char; TOC – total organic matter)

7.J.3.3 Grassland converted to forest land

To conduct quality control of the Tier 3, Approach 3 model a new series of Tier 2 models based on 46 plot files drawn from within the Tier 3 modelling framework were selected. The selected plot files are representative of the most common species and management regimes within each state and National Plantation Inventory (NPI) region.

The area of each type of forest in each region was determined from the land sector remote sensing program. As *FullCAM* is used for both the Tier 2 and Tier 3 models, the model inter- comparison primarily represents a test of the Approach 3 component of Australia's inventory method for *grassland converted to forest land*.

The Tier 2 and Tier 3 models are largely in agreement from 1990 through to 2010. There are very slight differences in stocks, with higher stocks in the Tier 3 model in early to mid years.

A comparison of the increment in carbon mass of trees (Figure 7.J20) and yield rate of tree stem mass (Figure 7.J21) showed very close agreement between the two models. This is not surprising given that the Tier 2 model uses plots representing the most common plantation type, soil and climate in each region resulting in estimates similar to those used to calibrate the Tier 3 model. The Tier 3 model results are more variable, reflecting the ability of the Tier 3 model to represent the effects of spatial variability in soil and climate, on plant growth.

Figure 7.J 19 Carbon mass of trees (t C) output from Tier 2 and Tier 3 methodology from 1990 – 2010

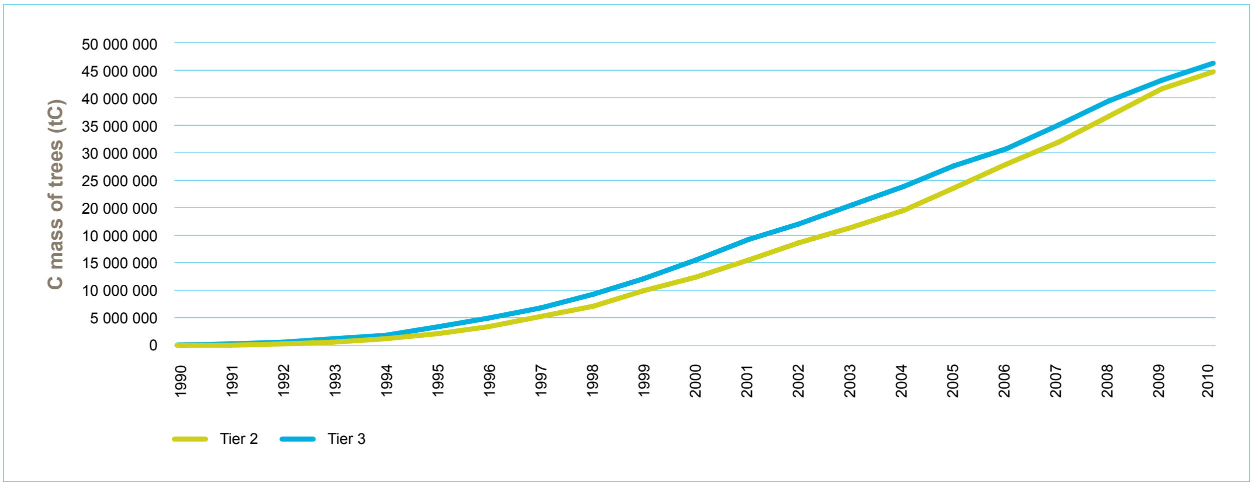
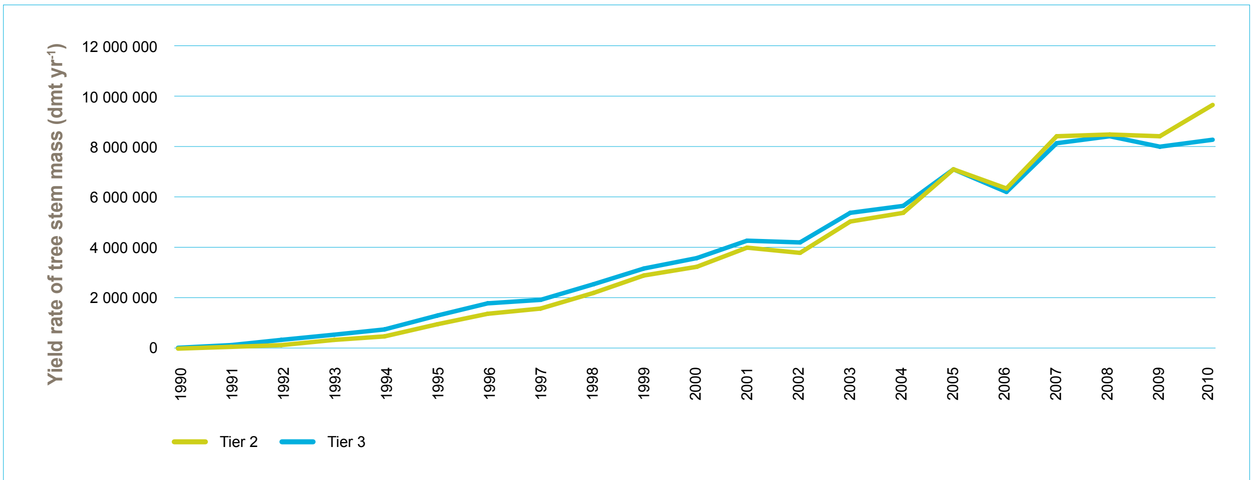
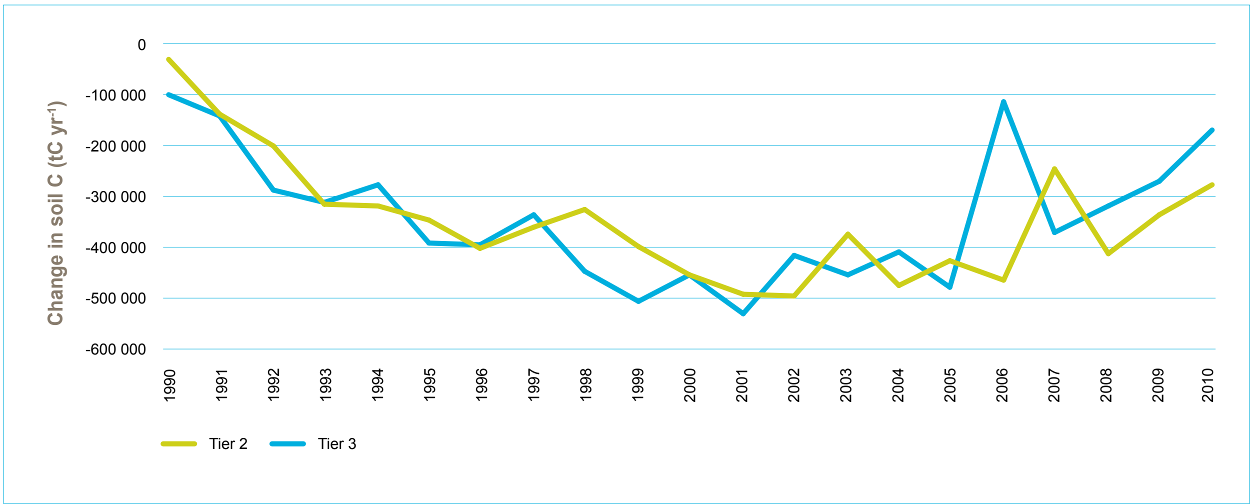


Figure 7.J 20 Yield rate of tree stem mass (dm t yr^{-1}) output from Tier 2 and Tier 3 methodology from 1990 – 2010



The results of the Tier 3 soil carbon model (Figure 7.J22) were also compared to the results Tier 2 Model based on the same 46 plot files described earlier in this section. The comparison shows that the trend is similar but that emissions estimated from the Tier 3 model are more variable due to the effects of spatial variability in soil and climatic conditions and better representation of the effects of previous land use on initial soil carbon stocks.

Figure 7.J 21 Soil carbon (t C yr^{-1}) output from Tier 2 and Tier 3 methodology from 1990 – 2010



7.J.3.4 Cropland remaining cropland

The crop yield database for *cropland remaining cropland* was a subset of the crop yield database that was compiled for the *forest land converted to cropland* and *grassland* sub-categories with the exclusion of grasses that were not part of a crop-pasture rotation regime. There are some grass species in the *cropland remaining cropland* crop yield database to account for crop-pasture rotations under a cropping system.

Crop yield data is collated and quality assured by CSIRO Land and Water before it is received by the Department of Climate Change and Energy Efficiency (DCCEE). DCCEE performs another quality assurance and quality control process on the crop yield data before it is entered into *FullCAM*. Crop yield data was primarily based on ABARES and BRS data for crop yields; however, there were gaps in the crop yield data across locations in Australia. As such, CSIRO Land and Water incorporated a methodology to fill the gaps in the crop yield data across those locations. Therefore, from 2004 onward, gaps in the crop yield data from ABARES and BRS were gap-filled using climate derived modelling of plant yield/growth for the gaps in data at a State-IBRA-Soil location. The gap-filled data is then cross-referenced with previous yields from that State-IBRA-Soil location to ensure that the updated data remains within 10% of the variance of the historical yield (back from 1970). The climate data is received by CSIRO Land and Water from the Australian National University and is the same climate dataset that is received by the DCCEE as part of its spatial inputs.

Carbon stock change and emissions estimates for *cropland remaining cropland* were determined spatially using *FullCAM*. Outputs of the spatial simulation were reviewed and evaluated against the outputs from the previous inventory. All quality control processes of outputs are conducted internally by the Agriculture Inventory Team in DCCEE.

7.J.3.5 Grassland remaining grassland

The *grassland remaining grassland* sub-category incorporates grasslands as well as sub-forest woody vegetation (sparse or shrubby vegetation) that is not classified as forest under Australia's UNFCCC definition of forest. The grassland component of the sub-category is modelled using *FullCAM* (Tier 3). The sub-forest woody vegetation component ('sparse') is modelled using Tier 2 Excel spreadsheet models.

The crop yield database is used for the grassland component of the *grassland remaining grassland* sub-category. The database was a subset of the crop yield database that was compiled for the *forest land converted to cropland* and *grassland* accounts with the exclusion of crops that were not part of a perennial pasture system. The quality assurance and control process of acquiring and inputting crop yield data that is used in *grassland remaining grassland* is the same as that performed for *cropland remaining cropland*. Outputs of the spatial simulation were reviewed and evaluated against the outputs from the previous inventory. All quality control processes of the outputs are conducted internally by the Agriculture Inventory Team in DCCEE.

Carbon stock change and emissions estimates for the sparse component of *grassland remaining grassland* is calculated in excel spreadsheet models. The sparse component also incorporates sparse fires and sparse transitions (between grassland and sparse). The fire data for the sparse component is collated and quality assured by CSIRO Sustainable Ecosystems (Darwin) before being received by the National Inventory Team. Once the fire data is received by DCCEE, it undergoes a quality control process by comparing the most recent data to the previous year's data. The sparse transitions use the updated LAI data as per *other native forests* which had already undergone QA/QC processes.

7.J.3.6 Harvested wood products

A national database of domestic wood production, including import and export quantities, has been maintained in Australia since the 1930's. This consistent and detailed collection of time-series data provides a sound basis for the development of a national wood products model. Wood product data are available through the Australian Forests Products Statistics published quarterly by the Australian Bureau of Agricultural and Resource Economics and Sciences (ABARE, 2008c). Data are also available through the Levies Management Unit of the Department of Agriculture, Fisheries and Forests, on behalf of the Forest and Wood Products Research and Development Corporation (FWPRDC), and are also published by the relevant State Forest Services and these provide a valuable crosscheck on ABARES data.

An independent review of the models used to estimate emissions in the wood products category was undertaken by Jaakko Pöyry Consulting.

Once data on production inputs, processing flows and initial stocks were determined other model calibration requirements included:

1. the age at which material moves from young to medium and from medium to old pools;
2. the amount of each age class for each product pool exposed to loss;
3. the rate of loss from each age class in each product pool; and,
4. the fraction of loss from each age class, in each product pool, to each of landfill, recycling, bioenergy and the atmosphere.

The model estimates used are presented in Tables 7.J10 and 8.5 (in Chapter 8).

Table 7.J 11 Decomposition rates and maximum possible loss

Pool	YOUNG		MEDIUM		OLD	
	Loss Yr^{-1}	Max. Possible Loss (%)	Loss Yr^{-1}	Max. Possible Loss (%)	Loss Yr^{-1}	Max. Possible Loss (%)
1	1.0	0.60	0.500	0.65	0.333	0.90
2	0.333	0.30	0.167	0.50	0.100	0.90
3	0.10	0.15	0.050	0.65	0.033	0.45
4	0.05	0.25	0.033	0.65	0.020	0.80
5	0.033	0.20	0.020	0.55	0.011	0.95

With the consistent and comprehensive monitoring of wood production in Australia since 1944, and the confidence in this data gained through cross-verification with other datasets, little uncertainty will likely be derived from the production data. The most likely sources of uncertainty will be derived from the allocation to decomposition and recycling pools, and the rates of decomposition in those pools. To test the relative importance of the pool ages and decomposition rates, *Monte Carlo* analyses were implemented using the @Risk add-in software (Palisade 1997) to the Tier 2 wood products carbon model. The principal model parameters of interest are the decomposition rates within pools (e.g., losses from service life and landfill) and transfers (e.g., to recycling, bioenergy and landfill). *Monte Carlo* analysis samples values from within specified ranges (probability distributions) for nominated parameters within repeated applications of the model. Probability distributions for values within ranges for each variable can be nominated, as can positive and negative correlations between variables so that sampling can reflect these correlations. In this application the nominated probability distributions were 'triangular', that is, values within the ranges sampled formed a triangular distribution around a central expected value. No correlations between variables were specified, so that value selection was random within the triangular probability distributions.

The life cycle pools affected and the distributions of their possible values for the *Monte Carlo* analyses are shown in Tables 7.J11, 7.J12, 7.J13 and 7.J14. Distributions of possible outcomes were stabilised over 100,000 model iterations. The Tornado Graph (Figure 7.J24) shows the relative importance of each input variable to the overall uncertainty in the model outcome. The effects of uncertainty in the carbon stock estimates in 1990 and 2004 national harvested wood product emissions estimates can be derived by looking at the annual stock change for the 0.10, 0.50 and 0.90 levels of confidence in potential stock outcome.

Table 7.J 12 Pool age uncertainty ranges used in the *Monte Carlo* Analysis

Life Cycle Pool	Lower Bound (yrs)			Expected Value			Upper Bound (yrs)		
	Young	Medium	Old	Young	Medium	Old	Young	Medium	Old
Very Short Term	0.5	1	2	1	2	3	1.5	3	4
Short Term	1	3	5	2	6	10	3	9	15
Medium Term	5	15	20	10	20	30	15	25	40
Long Term	15	20	40	20	30	50	25	40	60
Very Long Term	20	40	75	30	50	90	40	60	105

Table 7.J 13 Decomposition rate uncertainty ranges used in the *Monte Carlo* Analysis

Age	Pool	Lower Bound	Expected Value	Upper Bound
Young	1	2.000	1.000	0.667
	2	1.000	0.333	0.333
	3	0.200	0.100	0.067
	4	0.067	0.050	0.040
	5	0.050	0.033	0.025
Medium	1	1.000	0.500	0.333
	2	0.333	0.167	0.111
	3	0.067	0.050	0.040
	4	0.050	0.033	0.020
	5	0.025	0.020	0.017
Old	1	0.500	0.333	0.250
	2	0.200	0.100	0.067
	3	0.050	0.033	0.025
	4	0.025	0.020	0.017
	5	0.013	0.011	0.010

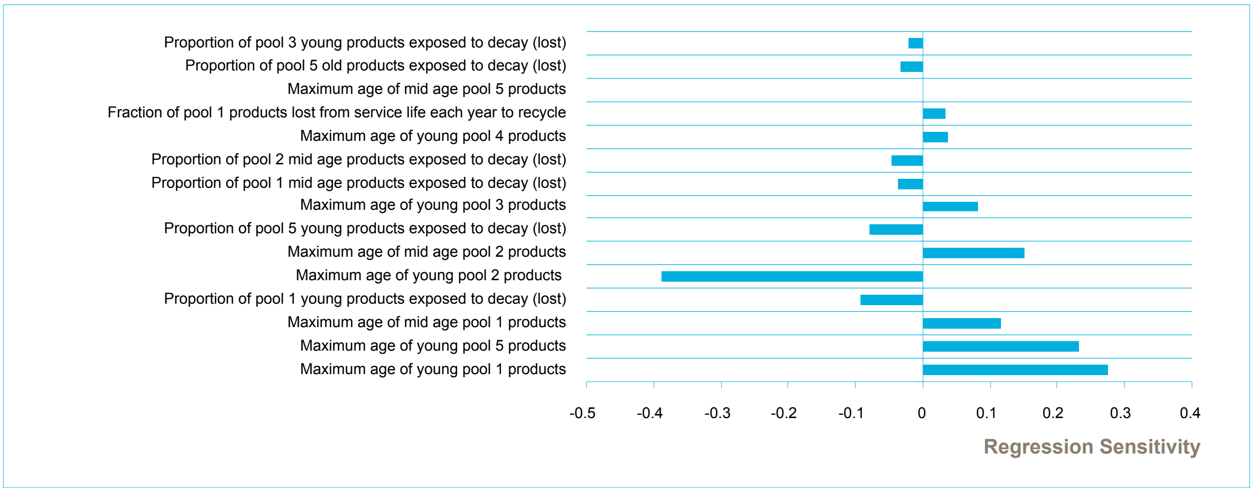
Table 7.J 14 Pool fractions exposed to decomposition uncertainty ranges used in the *Monte Carlo* Analysis

Age	Pool	Lower Bound	Expected Value	Upper Bound
Young	1	0.500	0.600	0.700
	2	0.250	0.300	0.350
	3	0.120	0.150	0.180
	4	0.225	0.250	0.275
	5	0.175	0.200	0.225
Medium	1	0.550	0.650	0.750
	2	0.400	0.500	0.600
	3	0.550	0.650	0.750
	4	0.550	0.650	0.750
	5	0.450	0.550	0.650
Old	1	0.800	0.900	1.100
	2	0.800	0.900	1.100
	3	0.400	0.450	0.500
	4	0.700	0.800	0.900
	5	0.800	0.950	1.150

Table 7.J 15 Destination fraction uncertainty ranges used in the *Monte Carlo* Analysis

Age	Pool	Landfill			Recycle			Biofuel		
		Lower Bound	Expected Value	Upper Bound	Lower Bound	Expected Value	Upper Bound	Lower Bound	Expected Value	Upper Bound
Young	1	0.380	0.440	0.500	0.450	0.490	0.530	0.630	0.040	0.050
	2	0.600	0.750	0.900	0.180	0.200	0.220	0.040	0.050	0.060
	3	0.800	0.950	1.100	0.400	0.050	0.060	-	0	-
	4	0.700	0.850	1.000	0.130	0.150	0.170	-	0	-
	5	0.700	0.850	1.000	0.090	0.100	0.110	0.040	0.050	0.060

Figure 7.J 22 Results of the @Risk sensitivity analyses. Carbon pool of wood stored in Australia (excluding landfill)



7.J.4 MODEL & DATA MANAGEMENT

7.J.4.1 Model versions

The model software development life cycle involves stages of requirements, analysis, design, implementation, verification and maintenance. Testing activities associated with *FullCAM* fall across the design, implementation, verification and maintenance domains of the software development life cycle, because the development of *FullCAM* follows an agile, or iterative, development philosophy. An iterative development philosophy was suitable because requirements and solutions evolved through collaboration between *FullCAM* end users, scientists, *FullCAM* software developers and the Australian Government. Thus, frequent adaptations and subsequent testing were required to guide the complex *FullCAM* model through various iterations of development.

FullCAM version control is managed using Sourcegear Vault, an application development source code version control system. Sourcegear Vault is used by the *FullCAM* development team to manage the source code for the *FullCAM* application. Local code updates by *FullCAM* developers are checked in, with any resulting errors being fixed prior to the next build. User registration is required to access Sourcegear Vault. User registration is managed by the *FullCAM* development team. Unit testing is a software development procedure that tests whether individual units of source code are fit for use. Regression testing is used to ensure that corrections to source code in one unit have been implemented correctly, and do not introduce errors in other units.

Errors or inconsistencies in model versions are managed using Fogbugz, a web-based project management application. Fogbugz is used to record bugs, errors and feature requests identified during *FullCAM* development or by *FullCAM* end-users. Cases are recorded in Fogbugz as either bugs or features, then assessed, prioritised and allocated to application developers for necessary action. Resolved cases are passed to the *FullCAM* systems analyst for testing. Once successfully tested, cases are closed and added to the current build cycle. Release notes are created for each build accordingly. User registration is required to access Fogbugz, and access is maintained by the *FullCAM* system analyst. Fogbugz also records details of *FullCAM* inquiries from the public email address. Such inquiries are actioned by the *FullCAM* system analyst.

7.J.4.2 Data storage

Each year, the *FullCAM* generates large amounts of data during the preparation of the land sector accounts. All data, including input data, models and output data are stored on a Sun-Microsystems server (the *FullCAM* server) with 77 terabytes of storage space. Associated with this server is a high-performance cluster with 26 compute nodes. This storage and computing capacity is required to run *FullCAM* for the million-plus individual pixels of Australia's land-cover change in each reporting category.

7.J.4.3 Backup & data recovery plan

DCCEE has a data back-up strategy and recovery plan to avoid the loss of all input, processing, output and development data used in calculating the land sector accounts. Given the extensive amount of spatial input data used in *FullCAM*, the back-up of these data is outsourced to the data-providers, as these organisations have existing back-up and recovery plans in place, as well as comprehensive data management and storage systems. The back-up of *FullCAM* input data is outsourced in the following way:

1. All data on *FullCAM* server are backed up daily [incremental back-up] and monthly off-site tape back-up service is also in place through DCCEE IT Service Provider.
2. CSIRO Mathematics, Informatics and Statistics – Provides a back-up of all satellite imagery as well as imagery provided at various stages of processing by contractors. Thus, all processing data needed for the creation of the final land cover change data used as input to *FullCAM* are backed up.
3. ANU Fenner School of Environment and Society – This organisation provides all climate data used in *FullCAM* and has a comprehensive back-up and recovery strategy.

4. Reported errors in, and updates to, *FullCAM* model code are backed up nightly to a secure off-site data repository. This repository is also backed up. In addition, *FullCAM* developers each have a copy of the current version of code on their workstations. These measures provide the capacity to retrieve all versions of model code in the event of an IT infrastructure failure.

7.J.5 TRANSPARENCY & REVIEW

As with the methods for uncertainty and sensitivity analysis, the approach to transparency and peer review will differ for a Tier 3 (spatially explicit) approach from those used in a Tier 1 or Tier 2 (area by emissions factor) approach. For Tier 1 and Tier 2 the focus is on the determination of area estimates and the selection of appropriate emissions factors. For the complex Tier 3 methods, which incorporate models and large datasets, different approaches to transparency and peer review are required. Transparency and review of the land sector accounts is founded on:

1. published specifications, protocols and methods;
2. published verification results;
3. public release of models, tools and data ; and,
4. publication in peer reviewed journals or other literature.

7.J.5.1 Published specification, protocols & methods

Six series of strategic and technical reports have been written detailing the development and strategic plans and the framework around which the land sector accounts been developed. This also includes the development of *FullCAM*, and the methods and data for verification, validation and calibration of *FullCAM*. All reports are accessible by the public via the DCCEE website (http://pandora.nla.gov.au/pan/102841/20090728-0000/www.climatechange.gov.au/publications/index.html).

7.J.5.1.1 NCAS Technical Report Series 1

Australian Greenhouse Office. 1999. Setting the Frame: Part 1 - System Framework & Part 2 - Project Specification for 1990 Baseline Estimation, Land Use Change and Forestry Sector. **National Carbon Accounting System Technical Report No. 1**. Australian Greenhouse Office: Canberra, Australia.

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Eamus, D., McGuinness, K. and Burrows, W. 2000. Review of Allometric Relationships for Estimating Woody Biomass for Queensland, the Northern Territory and Western Australia. **National Carbon Accounting System Technical Report No. 5A**. Australian Greenhouse Office: Canberra, Australia.

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Mackensen, J. and Bauhus J. 1999. The Decay of Coarse Woody Debris. **National Carbon Accounting System Technical Report No. 6**. Australian Greenhouse Office: Canberra, Australia.

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7.J.5.1.2 NCAS Technical Report Series 2

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Ilic, J., Boland, D., McDonald, G., Downes, G. and Blakemore, P. 2000. Wood Density Phase 1: State of Knowledge. **National Carbon Accounting System Technical Report No. 18**. Australian Greenhouse Office: Canberra, Australia.

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7.J.5.1.3 NCAS Technical Report Series 3

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7.J.5.1.4 NCAS Technical Report Series 4

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7.J.5.1.5 NCAS Technical Report Series 5

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7.J.5.1.6 NCAS Technical Report Series 6

Jones, S., Lowell, P., Woodgate, L., Buxton, L., Mager, A. and Liebchen, S. 2004. Update on the National Carbon Accounting System Continuous Improvement and Verification Methodology. **National Carbon Accounting System Technical Report No. 46**. Australian Greenhouse Office: Canberra, Australia.

7.J.5.2 Public release of models, tools & data

In 2005, the National Carbon Accounting Toolbox (NCAT) was released to the public. The NCAT was released as a pack with a CD and DVD. The CD included a copy of *FullCAM*l (version 3.10) as well as the six series of NCAS technical reports. The DVD was a Data Viewer providing the user with a visual record of landscape and vegetation change in Australia since 1972, as well as a 30 year record of regional climate statistics, including average temperature and rainfall. Over 10,000 copies of the NCAT have been distributed nationally and internationally since 2005.

During 2011 DCCEE released a package of tools to support the Carbon Farming Initiative (CFI). This package included:

- The Reforestation Modelling Tool (RMT); and
- The CFI Mapping Tool (CMT).

The RMT provides user-friendly access to the capabilities of *FullCAM* and supporting data for reforestation projects. *FullCAM* is still available upon request and is planned to be published on the DCCEE website from April 2012.

The CMT provides access to high resolution satellite imagery for most of Australia and the 1990 forest map layer.

Figure 7.J 23 The publically available Reforestation Modelling Tool, released in 2011.

Further information on the CFI Tools is available at:
http://ncat.climatechange.gov.au

Land sector accounting data are released to state and territory governments, science research agencies (e.g., CSIRO) and national government departments (e.g., ABS) when requested. These data may be required by the governments or agencies to assist with policy development or as part of research and development function. It is most often the case that state and territory governments and science research agencies do not have the processing power to obtain outputs from these data; therefore DCCEE will assist by processing the input data and supplying the required output data.

7.J.5.3 Publications in peer review journals or other literature

Methods and data which are used as part of the National Inventory System for the land sector accounts have been published in technical reports, and peer-reviewed papers in scientific journals. These are listed below. External stakeholders have also published papers in peer-reviewed journals related to land sector reporting in the National Inventory System. This collaboration (between DCCEE and external stakeholders) has resulted in the formulation of methodologies and data that have been used to assist in developing, validating and calibrating *FullCAM*.

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2. Brack, C., Richards, G.P. and Waterworth, R.M. 2006. Integrated and comprehensive estimation of greenhouse gas emissions from land systems. *Sustainability Science* **1**: 91-106.

3. Dalal, R., Wang, W., Robertson, P. and Parton, W.J. 2002. *Nitrous oxide emissions from agricultural lands and mitigation options: a review. Australian Journal of Soil Research* **41**: *165 -195.*

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5. Kaur, R., Kumar, S. and Gurung, H. P. 2002. A pedo-transfer function (PTF) for estimating soil bulk density from basic soil data and its comparison with existing PTFs. *Australian Journal of Soil Research* **40**: 847 – 858.

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10. Paul K.I. and Polglase P.J. 2004. Calibration of the Roth-C model to turnover of soil carbon under eucalypts and pines. *Australian Journal of Soil Research* **42**: 883-95.

11. Paul, K.I. and Polglase, P.J. 2004. Prediction of decomposition of litter under eucalypts and pines using the *FullCAM* model. *Forest Ecology and Management* **191**: 73-92.

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13. Paul, K.I., Polglase, P.J. and Richards G.P. 2003. *Predicting Change in Soil Carbon following Afforestation or Reforestation, and analysis of controlling factors by linking a C accounting model (CAMFor) to models of forest growth (3PG), litter decomposition (GENDEC) and soil C turnover (RothC). Forest Ecology and Management* **177**: 485–501.

14. Paul, K., Polglase, P.J. and Richards, G.P. 2003. *Sensitivity analysis of predicted change in soil carbon following afforestation*. *Ecological Modelling* **164**: 137–152.

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

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

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

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7.J.6 DEFINITION OF KEY TERMS

Calibration

Calibration is a fundamental process which that ensures that models perform accurately and realistically for the ecosystems and conditions for which they were developed. Calibration requires high quality data that represent the range of conditions under which the model is required to perform.

Calibration data needs to be of high quality to ensure that the model parameters derived through calibration are accurate and do not produce biased emissions estimates. Calibration data is collected from new and existing research where strict measurement protocols have been implemented. Data which has been collected in time series is particularly valuable for calibration, especially for the soil carbon components of the models.

Validation

Validation data and processes are used to test that the calibration of the models does not produce biased emissions estimates. Validation data may be either the same or of a slightly lower quality than calibration data, but must still of high quality to ensure that the results of the validation processes reflect reality. Validation data is independent of calibration data and is sourced from ongoing DCCEE funded research and development programs, other government research programs (e.g., soil carbon analyses as part of Australia's Farming Futures program) or derived from other relevant research which has become available since the original calibration of the models. Validation by direct measurement provides the benefit that independent data can be used to assess model and land use attribution performance in detail (e.g., by carbon pool per pixel).

Verification

Verification is conducted by checking, in detail, land cover change areas and modelled emissions estimates. The model can also be tested against lower quality data that does not meet the strict criteria for calibration and validation data. These data are used to verify that models are responding correctly and that the estimates are within known ranges. Non-site specific data, such as regional averages (e.g., by soil type and vegetation type) that cannot be used for calibration or validation within the point specific model can be used to verify overall model performance.

Quality Assurance & Quality Control (QA/QC)

Quality assurance (QA) activities include independent reviews of data inputs and model outputs that are conducted by personnel not directly involved in compiling the inventory of greenhouse gas emissions from the land sector. Such activities assess how different steps in the emissions estimation process comply with detailed specifications, protocols, testing and verification procedures documented in the NCAS technical report series. Periodic external review of the overall land sector emissions reporting program is also conducted to ensure systems and processes align with current best practice in method and application.

Quality control (QC) activities are undertaken routinely to measure and control the quality of the inventory as it is being developed. This ensures the integrity, correctness and completeness of model inputs and outputs, at all stages of the modelling process. Such QC activities include:

- checking for errors in the derived input data;
- checking the integrity of data sets on entry to model databases (prior to their use in models);
- testing to ensure the integrity of the model code between versions (version control);
- testing the sensitivity of model outputs and emissions estimates to changes in input data and model parameters; and,
- checking model results using auditing technique and implementation of policy specific rules.

Sensitivity & Uncertainty Testing

The methods of uncertainty testing described by the 2003 IPCC *Good Practice Guidance* are typically designed for Tier 1 and Tier 2 emissions factor based approaches. The fundamental approach of using *Monte Carlo* analysis for sensitivity and uncertainty testing in Tier 1 and Tier 2 remains relevant in Tier 3. However, methods for dealing with potential error propagation and inter-correlation of parameter uncertainties need to be applied to the models used in a Tier 3 inventory.

Monte Carlo analysis can be used to test the sensitivity and uncertainty of emissions estimates made using *FullCAM*. The *Monte Carlo* analysis determines:

- that the best estimate of emissions (most likely outcome) is not subject to bias;
- parameter sensitivity to aid understanding of the drivers of uncertainty and guide improvement programs and verification priorities; and,
- the probability distribution of possible outcomes.

To enable these tests a *Monte Carlo* analysis capability has been integrated into the *FullCAM* framework and is routinely applied. Uncertainty tests using *Monte Carlo* analysis are also supplemented by the determination of accuracies of spatial data through verification programs. Verification can also be used to identify if there is any potential bias in the spatial inputs to the emissions modelling.

Transparency & Review

Australia ensures that information regarding the assumptions and methodologies used in its inventory are clearly explained, easily accessible and open to review. Transparency and review for a Tier 3 inventory approach are not the same as for Tiers 1 and 2. For Tiers 1 and 2 the focus is on the estimation of activity areas and the selection of appropriate emissions factors. For the models and datasets used in Tier 3 model-based systems, different approaches to transparency and review are required. The basis of transparency and peer review for land sector emissions reporting are founded on:

- periodic review;
- published specifications, protocols and methods;
- published verification results;
- public release of models, tools and data; and,
- publications in peer reviewed journals and other literature.

Time-series consistency

A nationally consistent time-series of satellite data allows a country to monitor land use change, from which the net change of emissions and removals can be accounted. It allows for the spatially explicit detection of land use change, attribution of the type of land use change, and allows a country to develop baselines and reference years from which change can be monitored over time.