Australian Government

Department of the Environment

National Inventory Report 2012
Volume 2

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

Australian National Greenhouse Accounts

April 2014

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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 15.2 Mt CO_2-e in 2012.

Table 7.1: Land Use, Land Use Change and Forestry net CO_2-e emissions, 2012

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	9,297	4,150	1,714	15,161
A. Forest land	-34,596	3,286	897	-30,414
A.1 Forest land remaining forest land	-23,067	3,284	896	-18,888
A.2 Land converted to forest land	-11,528	2	1	-11,526
B. Cropland	14,665	381	223	15,269
B.1 Cropland remaining cropland	2,539	-	-	2,539
B.2 Land converted to cropland	12,126	381	223	12,730
C. Grassland	31,978	484	132	32,594
C.1 Grassland remaining grassland	1,405	IE	IE	1,405
C.2 Land converted to grassland	30,573	484	132	31,190
D. Wetlands	NE	NE	NE	0
E. Settlements	NE	NE	NE	0
F. Other land	NO,NA	NO,NA	NO,NA	0
G. Other[(b)]	-2,750	0	462	-2,288

(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 (*controlled 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 30.4 Mt CO_2-e in 2012.

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 15.3 Mt CO_2-e in 2012.

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 32.3 Mt CO_2-e in 2012.

Forest land converted to cropland and *Forest land converted to grassland* were a net source of 43.9 Mt CO_2-e in 2012.

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 4.2 Mt CO_2-e 'sink' in *harvested wood products*.

Agricultural lime application is estimated to have contributed emissions of 1.4 Mt CO_2-e in 2012.

Trends

By 2012, the net *land use, land use change and forestry* emissions had decreased from 130.5 Mt CO_2-e in 1990 to 15.2 Mt CO_2-e in 2012 (Figure 7.1).

The underlying trend of declining 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 and climate.

Figure 7.1: Net CO_2-e emissions from Land Use, Land Use Change and Forestry, 1990–2012

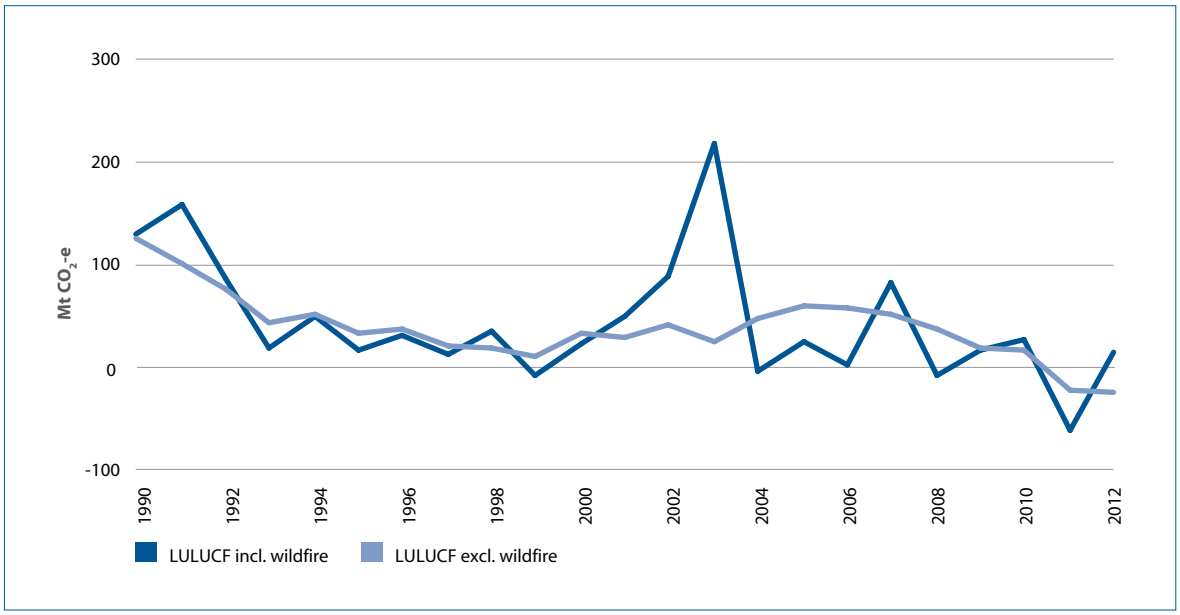
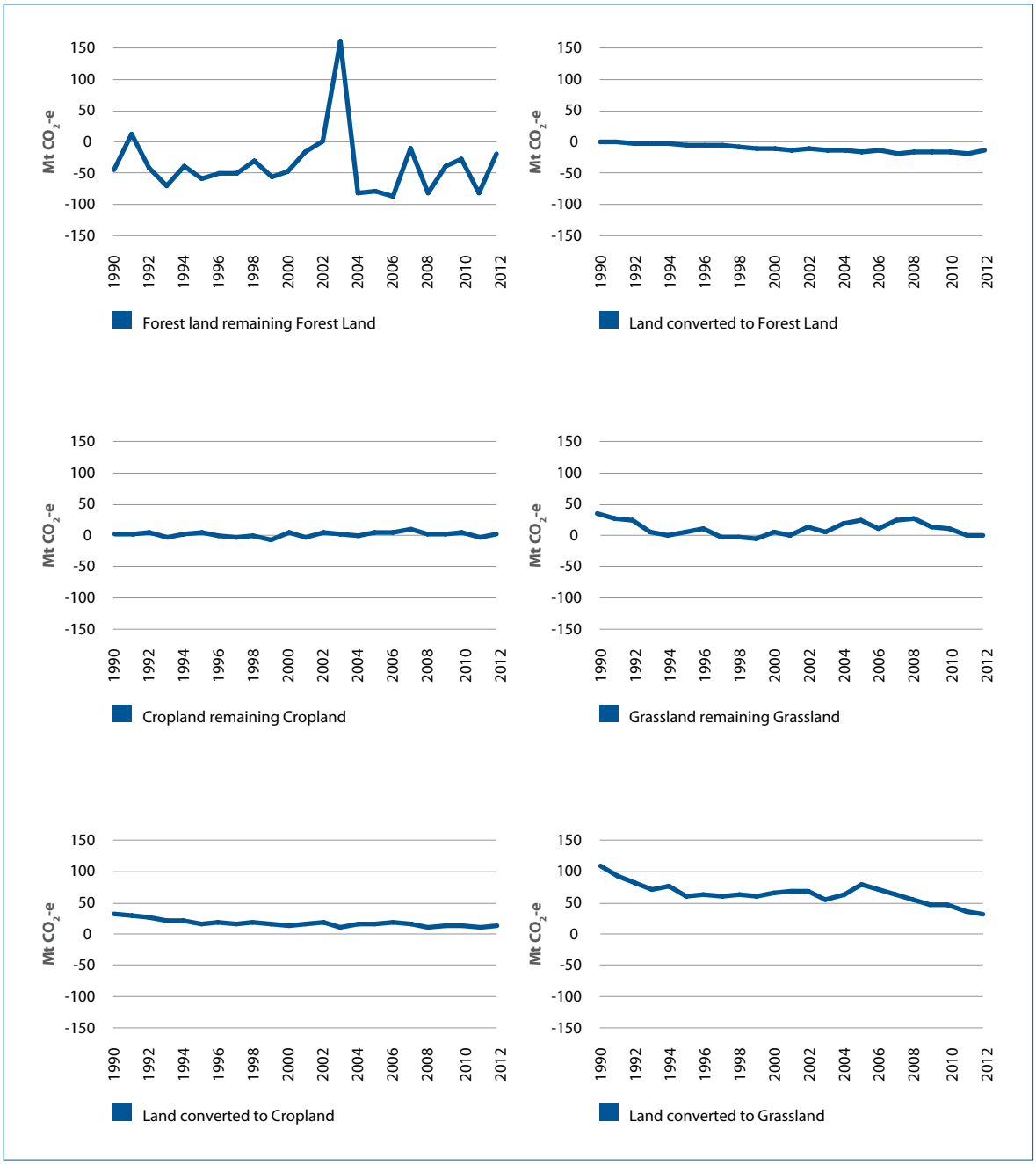


Figure 7.2: Net CO_2-e emissions from Land Use, Land Use Change and Forestry, by sub-sector, 1990–2012

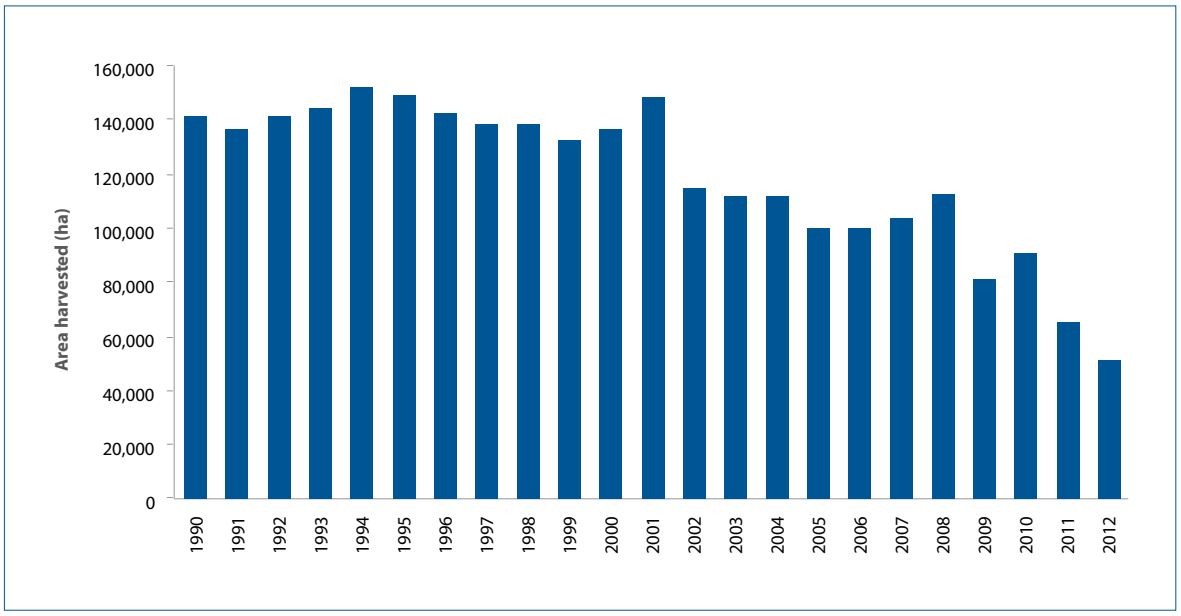


Forest land

Forest land (5A) was a net sink of 43.8Mt CO_2-e in 1990 compared to a net sink of 30.4 Mt CO_2-e in 2012, a difference of 13.4 Mt CO_2-e. Within *forest land, forest land remaining forest land* was a net sink of 43.7 Mt CO_2-e in 1990 compared to a net sink of 18.9 Mt CO_2-e in 2012, while the removals from *land converted to forest land* increased from 0.9 in 1990 to 11.5 Mt CO_2-e in 2012.

On average since 1990, forest land has been accumulating carbon stocks of approximately 13 Mt of carbon each year (equivalent to a sink of approximately 48.3 Mt CO_2 per year, see Figure 7.2). This accumulation reflects the recovery of stands from historical fibre producing activity. A further contributing factor to the accumulation of carbon in forest land over recent years has been the decline of the area harvested in Australia's native forests (Figure 7.3).

Figure 7.3: Area harvested in native forests since 1990

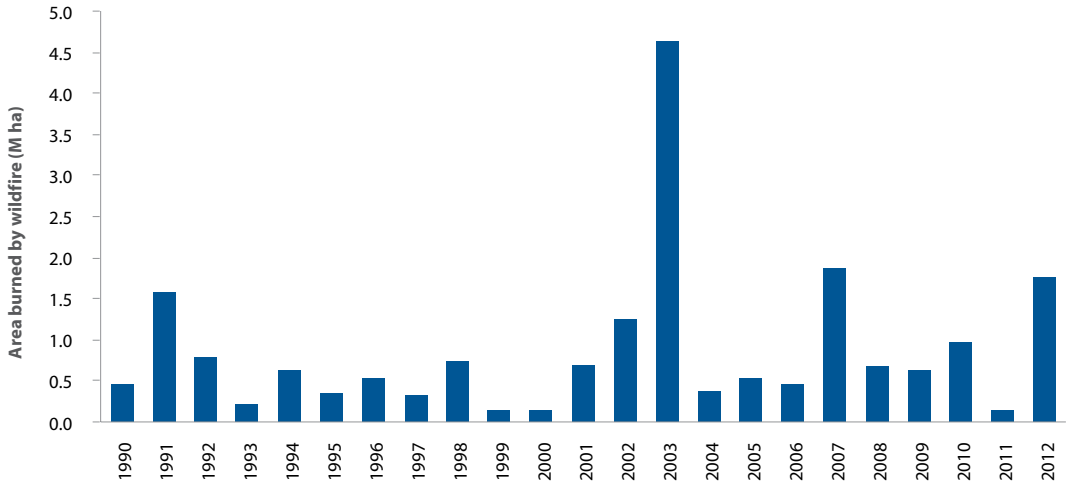


Harvesting in Australia's native forests, including Multiple Use Forests and private native forests, is the key driver of human induced emissions and removals in these forests. Over recent years, harvesting in the native forest sector has reached historically low levels (Figure 7.3). This decline has been associated with changes in supply factors, such as increasing supply from plantations (particularly those established after 1990) and demand factors include the international price of harvested wood products and the value of the Australian dollar as well as shifts in demand patterns, especially between Japan and China.

The key drivers of variation in Forest land are annual harvest areas, the age classes of the forests, prescribed burning, climate 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 108 million hectares of forests with the area burnt varying considerably from year to year (Figure 7.4).

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 burnt during the year with the next largest area burnt, 2007. The large area burnt during 2003 resulted in anomalously high emissions from *forest land remaining forest land* in 2003 (Figure 7.2). In 2012 the area affected by wildfire was estimated to be 1.75 Mha, which is the largest area affected by wildfire since 2007 (Figure 7.4).

Figure 7.4: Annual area of forests burned by wildfire, 1990 – 2012



Cropland remaining Cropland

Cropland remaining cropland (5B1) is estimated to be a net source of 2.5 Mt CO_2-e in 2012. Since 1990, there has been no discernible trend in emissions (Figure 7.5), with variations driven by fluctuations in climatic conditions. In relation to soil carbon stocks, the overall trend has been a steady loss of carbon from these lands (Table 7.2).

Figure 7.5: Net CO_2-e emissions from Cropland remaining Cropland, 1990 - 2012

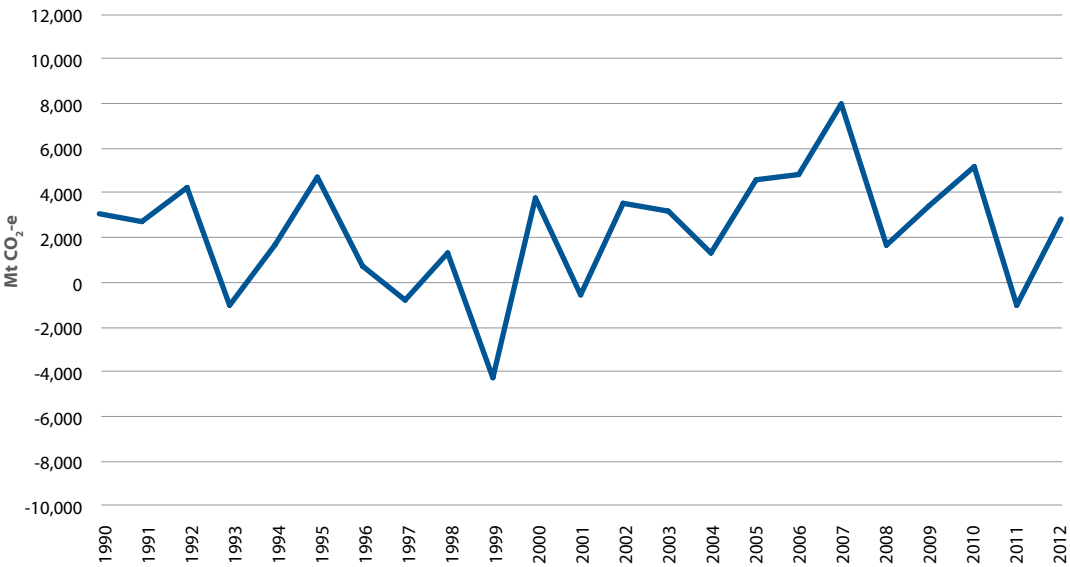


Table 7.2: Net emissions and removals from cropland remaining cropland by sub-division, 1990 - 2012 (Gg)

Year	Soil carbon	Perennial woody biomass (horticulture)	Total
1990	3,062	-198	2,864
2000	3,893	-54	3,839
2005	4,965	-79	4,886
2006	5,493	-244	5,249
2007	9,438	121	9,559
2008	1,110	-163	946
2009	3,604	-311	3,293
2010	6,262	-509	5,754
2011	-2,138	-615	-2,753
2012	2,667	-128	2,539

Grassland remaining Grassland

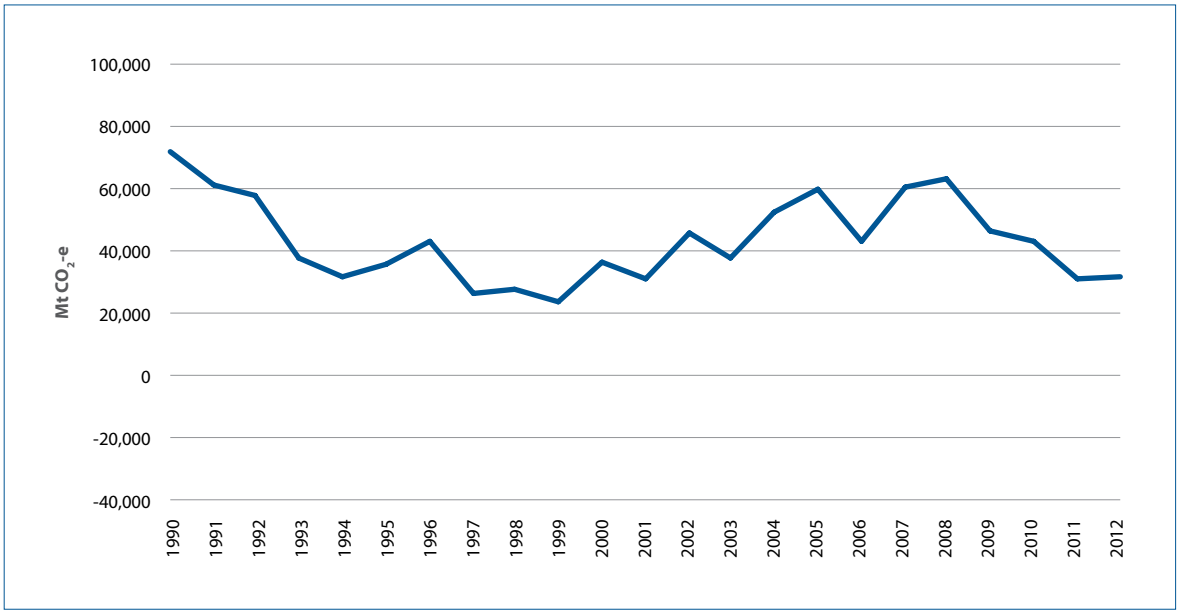
As with *cropland remaining cropland*, there has been no significant longer term trend in emissions discernible for *grassland remaining grassland* (5C1).

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 components to reflect the three elements of the emission estimation:

- herbaceous grassland (soil carbon);
- changes in shrubland extent; and
- fire.

In the reported estimates for herbaceous grasslands, there is a steady net emission rate from soil carbon (Table 7.3), reflecting an on-going loss of the soil carbon stock especially in coastal regions associated with forest land conversion 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.

Figure 7.6: Net CO_2-e emissions from grassland remaining grassland, 1990-2012



Woody shrubs are a key component of grassland ecosystems in semi-arid and arid regions of central Australia. Emission and removals on these shrublands are driven by fire, land management and transitions between shrubs and grasses. These processes are driven by climate as well as anthropogenic activities. The trend in emissions on these lands is primarily the result of natural variability.

Table 7.3: Net emissions and removals from grassland remaining grassland, by sub-division 1990-2012 (Gg)

Year	Herbaceous grasslands	Perennial woody biomass		All
	Soil Carbon	*Transitions*	*Fire*	
1990	35,878	-446	348	35,779
2000	3,963	-348	1,699	5,314
2005	19,831	-217	6,032	25,646
2006	19,526	400	-8,419	11,507
2007	20,608	315	5,250	26,174
2008	26,746	-173	1,713	28,287
2009	15,003	-346	-666	13,991
2010	12,253	-1,191	275	11,337
2011	9,109	-2,003	-6,487	619
2012	1,694	-1,883	1,594	1,405

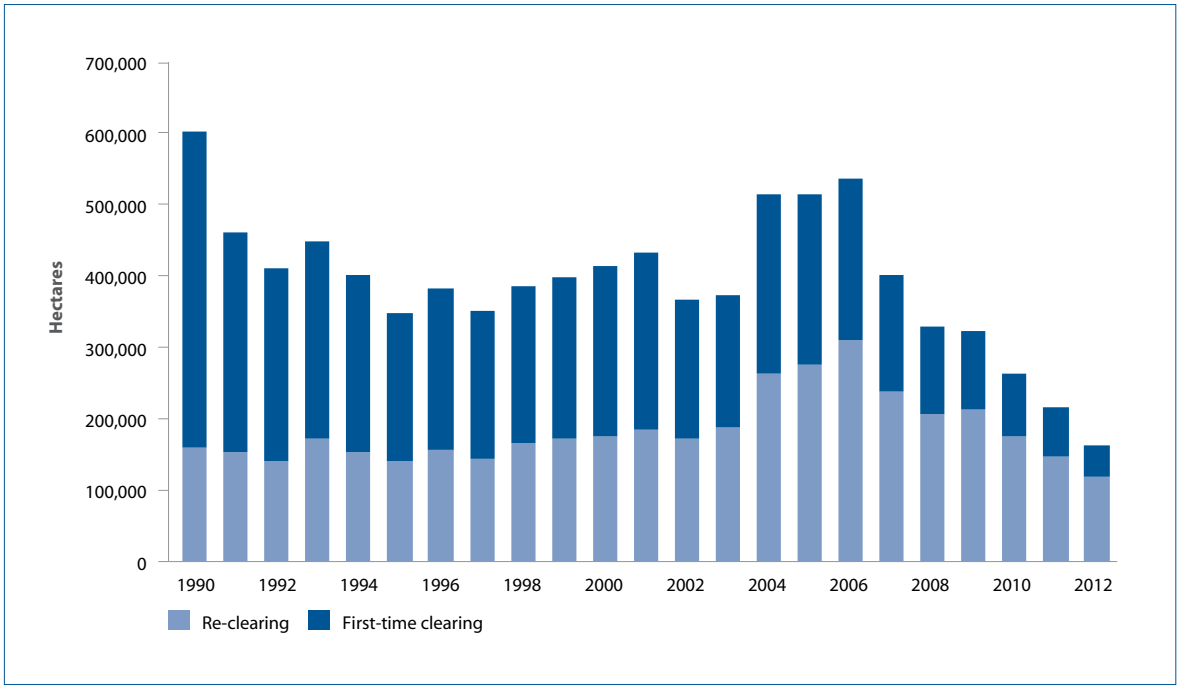
Forest land converted to cropland and grassland

In 2012, total emissions from *forest land converted to cropland* and *forest land converted to grassland* were 69% (96.2Mt) lower than in 1990. This transition from forest to non-forest land use results in an immediate loss of carbon as trees are cleared and burnt, as well as ongoing loss of soil carbon as it decays to a new equilibrium stock level.

Today, most land cleared in Australia is used for cattle grazing or for crop production. For farmers and other landowners but also for the purpose of settlements and mining, 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.

Government policies are another important factor affecting the rate of land clearing. State governments have responsibility for the management of vegetation and have legislation in place to support government objectives. First-time clearing of undisturbed forest is now restricted in many areas. Figure 7.7 illustrates the trend in land clearing in Australia between 1990 and 2012 and shows contribution of first-time clearing of undisturbed forest and re-clearing of forest cover that has re-grown on previously cleared land. The decline in first-time clearing reflects a stabilisation of the area of intensive agricultural management, while the relative stability of reclearing (Figure 7.7) indicates the ongoing need of land managers to re-clear areas on the fringe of agricultural regions where seed from adjacent forests supports forest regeneration.

Figure 7.7: First-time forest clearing and re-clearing in Australia, 1990-2012, as used for Australia's greenhouse accounts.



Although economic conditions are also a factor, the effects of the more restrictive policy changes implemented in 2007 may be seen in the drop in first-time clearing, from 2007 onwards (Figure 7.7). In addition, the current decline may also reflect land managers bringing forward decisions to clear land in the period 2004 and 2006 – the period between announcement of new policies and before they came into force.

This recent shift in the balance between first time and re-clearing (Figure 7.7) 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.

7.2 Overview Of Source Category Description and Methodology – Land Use, Land Use Change and Forestry

7.2.1 National Circumstances

Australia has a land area of 769 million hectares containing unique land, water, vegetation and biodiversity resources. Australia is a dry continent where rainfall is highly variable and floods and droughts are 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 7.8 and 7.9).

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. 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.

The areas of the continent under different land uses are shown in Figure 7.10. Significant agricultural activities include wool, beef, wheat, cotton and sugar production. Australia is also an 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).

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.

The majority of grassland areas occur in inland Australia and are 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 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.

Figure 7.8: Average annual rainfall 1970 – 2012

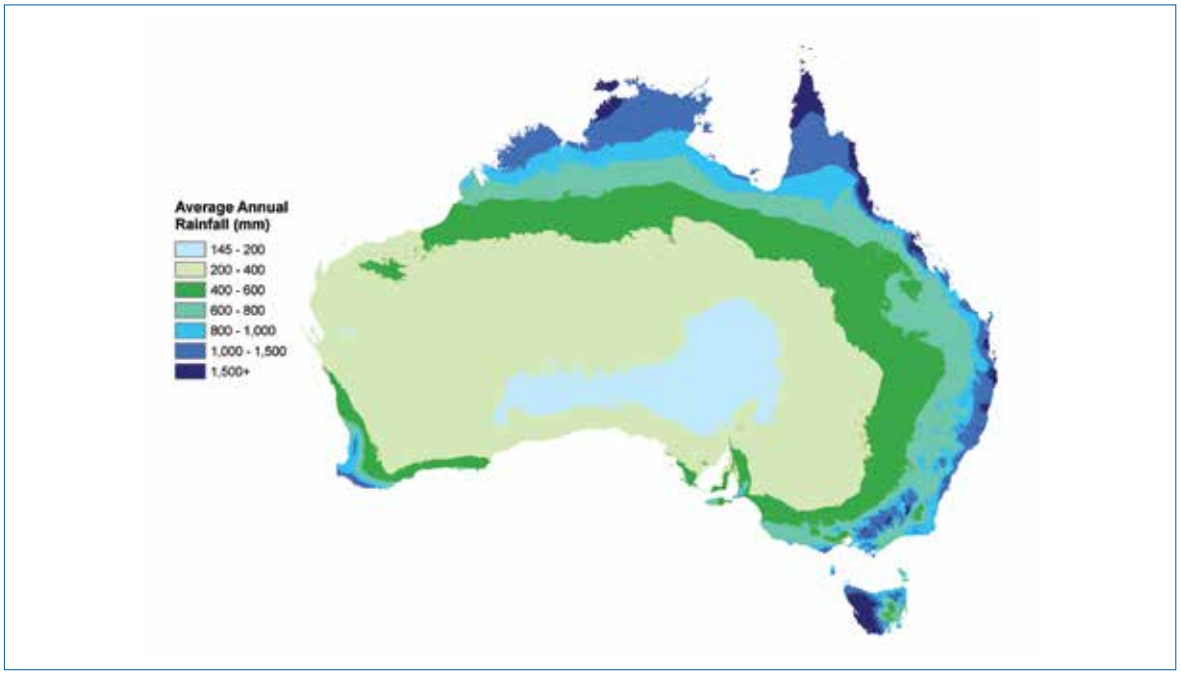


Figure 7.9: Average annual temperature 1970 – 2012

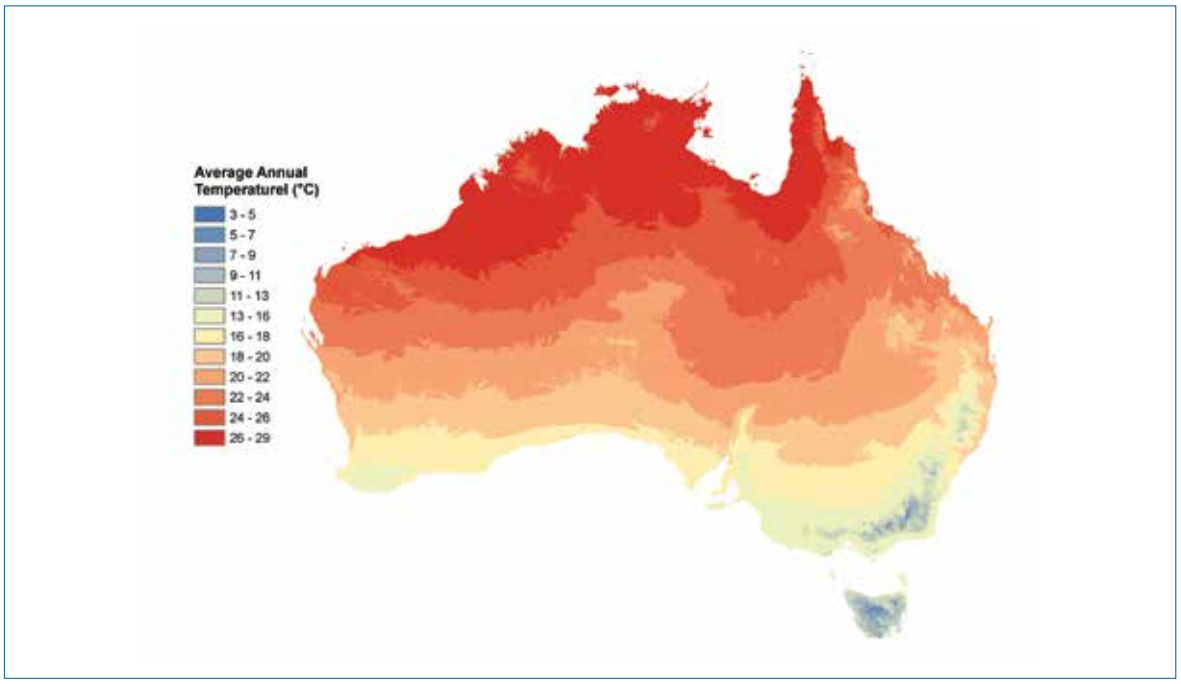
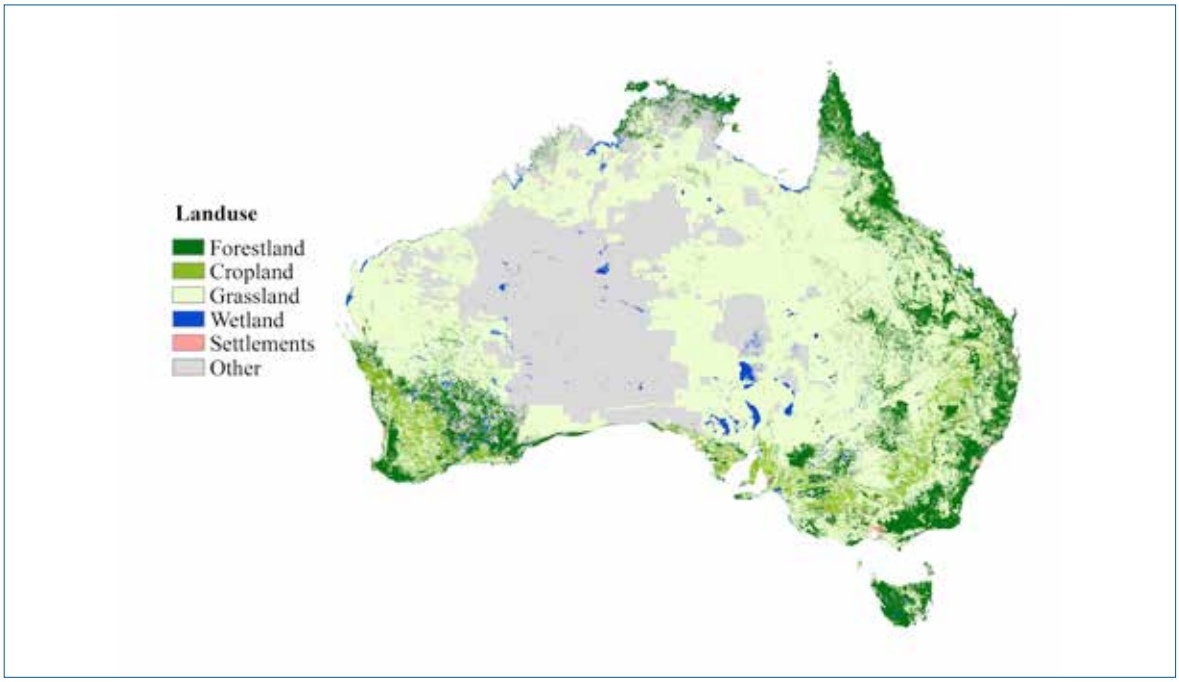


Figure 7.10: Land use in Australia 2012



7.2.2 Estimating emissions from LULUCF

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 7.4). The methods used in the reporting of the LULUCF categories of the inventory are described in detail in Appendices 7.A to 7.K.

Table 7.4: 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	T2	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,

7.2.3 Land Sector reporting in Australia's National Inventory System

In 1998, Australia embarked on a programme to develop a comprehensive system to estimate emissions and removals from Australia's land based sector (AGO, 2005). The system integrates spatially referenced data with an empirically constrained, mass balance, carbon cycling ecosystem model (*FullCAM*) to estimate carbon stock changes and greenhouse gas emissions (including all carbon pools, gases, lands and land use activities). Currently, the system supports Tier 3, Approach 3 spatial enumeration of emissions and removals calculations for the following sub-categories:

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

Spatial enumeration is achieved through the use of a time-series (since 1972) of Landsat satellite data which is used to determine change in forest extent. The forest cover change information is coupled together with time-series climate data and spatially referenced databases of land management practices. This allows Australia to comprehensively account for the principal causes of emissions (see Appendices 7.A and 7.B).

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

As well as supporting Tier 3, approach 3 spatial quantification of carbon stock change *FullCAM* can also be configured to operate in a Tier 3, Approach 2 model where spatially explicit data are unavailable. In this configuration, known as the 'Estate' module, *FullCAM* uses age-based growth data to estimate living above and belowground biomass. Dead organic matter from both turnover and harvest residue are modelled. The 'Estate' module of FullCAM is used to scale regional models of carbon stock change by the areas of each forest type. A fuller explanation of the operation of the 'Estate' module of *FullCAM* can be found in Richards and Evans (2000a).

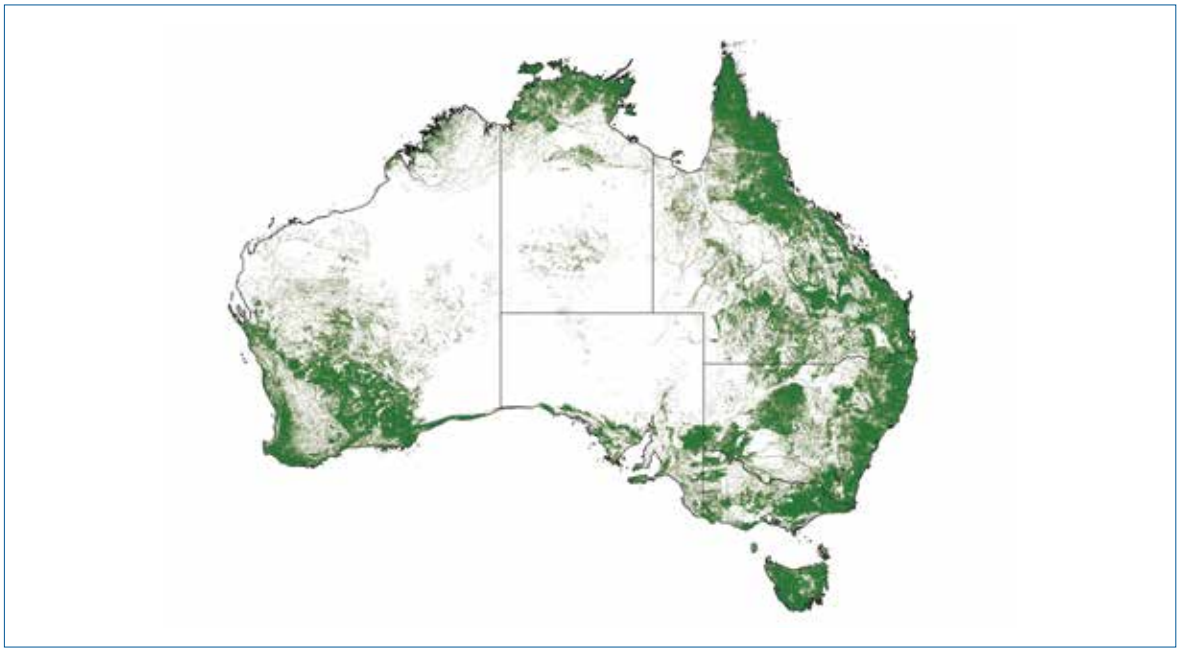
7.3 Land Category Definitions

7.3.1 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 7.11). These thresholds are consistent with the definition used in Australia's National Forest Inventory that has been used for reporting to the Food and Agriculture Organisation and Montreal Process.

Australia has adopted a minimum forest area of 0.2 ha. As the National Forest Inventory DEs 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 7.11: Forest extent in Australia 2012

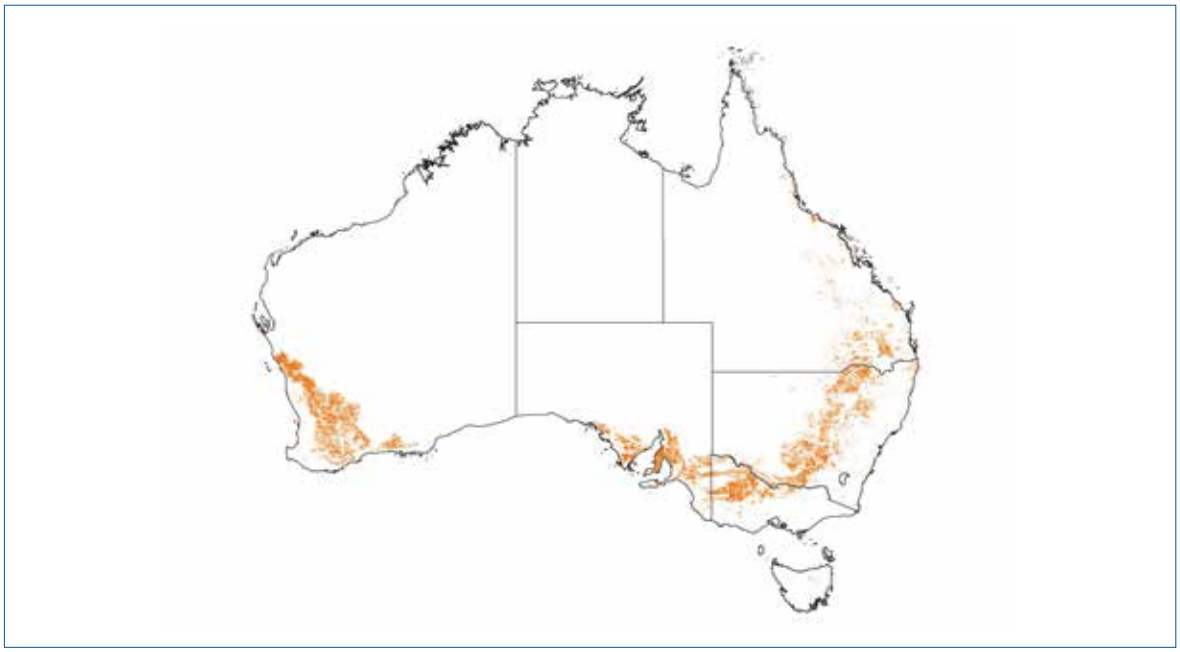


7.3.2 Cropland

Cropland includes all land that is used for continuous cropping, and those lands managed as crop-pasture (grassland) rotations (Figure 7.12). 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 carbon stocks and therefore greenhouse gas emissions. For this reason, if land is cropped under its management system, it is considered *cropland* and reported under a *cropland* category. However, 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 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.

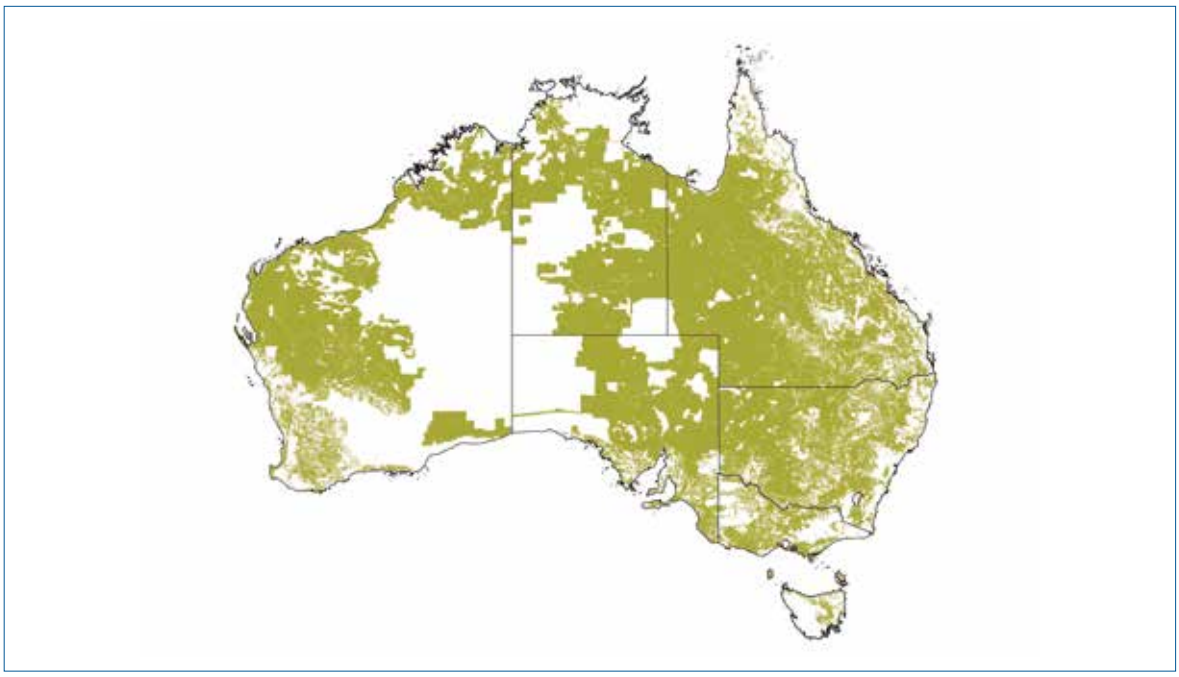
Figure 7.12: Cropland distribution in Australia 2012



7.3.3 Grassland

In Australia, the *grassland* category represents a diverse range of climate, management and vegetation cover (Figure 7.13). 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 7.13: Grassland distribution in Australia 2012



7.3.4 Settlement

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

7.3.5 Wetland

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

7.3.6 Other land

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

7.3.7 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.

Australia has included all forests in its area of managed land. This is 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). 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

Australia uses a combination of geographically explicit land use data to represent land areas, which is consistent with approach two and three as described in the IPCC *Good Practice Guidance for Land Use, Land Use Change and Forestry* (IPCC, 2003). The principal method of representing land is through a time-series national remote sensing program. The primary purpose of the remote sensing program is to identify forest lands and changes in forest cover rather than full land-use mapping. Supplementary information on land use is used to supplement the approach three forest cover change data. Areas of forest cover change are supported by spatially referenced databases of land management information. This is used to identify land use categories of *forest land converted to cropland and grassland*, and *grassland converted to forest land*. Data on areas of forest management is drawn from Australia's National Forest Inventory for *forest land remaining forest land*. Supplementary spatial information from the Land Use Mapping programme of Australia's Bureau of Agricultural Resource Economics and Sciences is used to identify land areas in the *cropland remaining cropland, grassland remaining grassland, wetlands,* and *settlements* categories. 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. Table 7.5 shows the representation of land according to the IPCC land use categories (IPCC, 2003). Annual land area matrices are shown in Table 7.6.

7.4.1 Forest conversion monitoring

Australia monitors forest cover using national coverages of Landsat satellite data (MSS, TM, and ETM+) across 21 time epochs from 1972 to 2012, which have been assembled and analysed for change. These national maps of forest cover are annual from 2004 until present. These maps are used to detect fine scale changes in forest cover at a 25 m by 25 m resolution.

Where forest cover change is identified in an epoch (period between dates for which remote sensing data are available), the actual date of forest cover change in each 25 m by 25 m pixel is randomly allocated within the sequence of satellite pass dates.

Where change in forest area is detected, these changes are inspected by expert operators, to determine if these changes are due to human activity (e.g. harvesting, forest clearing, forest establishment) or due to natural events (e.g. fire, forest die back, natural regrowth). The expert operators are trained in the use of standard criteria to distinguish human-induced from natural events and use databases of supporting information relating to land tenure and fire during this process. Full details of the remote sensing and attribution analysis are provided in Appendix 7.A.

Table 7.5: Land representation matrix (start of 1990 to end of 2012)

Land Use	1990[b] (Mha)	2012 (Mha)	Net Change (Mha)
Forest land total	111.9	109.7	-2.2
Forest land remaining Forest land	111.9	108.5	-3.3
Harvested Native Forest	14.9	14.9	0.0
Plantations	0.8	0.8	0.0
Other Native Forests	96.2	92.8	-3.3
Grassland converted to Forest	0.0	1.1	1.1
Grassland total	444.4	445.0	0.7
Grassland remaining Grassland	437.1	431.7	-5.4
Forest Land converted to Grassland	7.2	13.3	6.1
Cropland total	24.7	26.3	1.5
Cropland remaining Cropland	21.7	21.7	0.0
Forest Land converted to Cropland	3.0	4.6	1.5
Wetlands total	13.5	13.5	0.0
Settlements 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
b) 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 2011 inclusive.

Table 7.6: Annual land area matrices from 1990 – 2012 (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	111.29	0.69					111.99
Grassland	0.46	443.67					444.13
Cropland	0.12		24.73				24.85
Wetlands				13.49			13.49
Settlements					1.60		1.60
Other land						172.94	172.94
Initial Area	111.87	444.37	24.73	13.49	1.60	172.94	769.00
Net change	0.12	-0.23	0.12	0.00	0.00	0.00	0.00

1991

	Forest land	Grassland	Cropland	Wetlands	Settlements	Other land	Final Area
Forestland	111.55	0.55					112.10
Grassland	0.34	443.58					443.93
Cropland	0.09		24.85				24.94
Wetlands				13.49			13.49
Settlements					1.60		1.60
Other land						172.94	172.94
Initial Area	111.99	444.13	24.85	13.49	1.60	172.94	769.00
Net change	0.12	-0.20	0.09	0.00	0.00	0.00	0.00

1992

	Forest land	Grassland	Cropland	Wetlands	Settlements	Other land	Final Area
Forestland	111.72	0.67					112.39
Grassland	0.32	443.26					443.58
Cropland	0.07		24.94				25.01
Wetlands				13.49			13.49
Settlements					1.60		1.60
Other land						172.94	172.94
Initial Area	112.10	443.93	24.94	13.49	1.60	172.94	769.00
Net change	0.28	-0.35	0.07	0.00	0.00	0.00	0.00

1993

	Forest land	Grassland	Cropland	Wetlands	Settlements	Other land	Final Area
Forestland	111.97	0.43					112.40
Grassland	0.34	443.15					443.49
Cropland	0.07		25.01				25.08
Wetlands				13.49			13.49
Settlements					1.60		1.60
Other land						172.94	172.94
Initial Area	112.39	443.58	25.01	13.49	1.60	172.94	769.00
Net change	0.02	-0.08	0.07	0.00	0.00	0.00	0.00

1994

	Forest land	Grassland	Cropland	Wetlands	Settlements	Other land	Final Area
Forestland	112.03	0.38					112.42
Grassland	0.29	443.11					443.40
Cropland	0.08		25.08				25.15
Wetlands				13.49			13.49
Settlements					1.60		1.60
Other land						172.94	172.94
Initial Area	112.40	443.49	25.08	13.49	1.60	172.94	769.00
Net change	0.02	-0.09	0.08	0.00	0.00	0.00	0.00

1995

	Forest land	Grassland	Cropland	Wetlands	Settlements	Other land	Final Area
Forestland	112.11	0.33					112.43
Grassland	0.25	443.08					443.33
Cropland	0.06		25.15				25.21
Wetlands				13.49			13.49
Settlements					1.60		1.60
Other land						172.94	172.94
Initial Area	112.42	443.40	25.15	13.49	1.60	172.94	769.00
Net change	0.02	-0.07	0.06	0.00	0.00	0.00	0.00

1996

	Forest land	Grassland	Cropland	Wetlands	Settlements	Other land	Final Area
Forestland	112.09	0.27					112.36
Grassland	0.27	443.06					443.33
Cropland	0.07		25.21				25.28
Wetlands				13.49			13.49
Settlements					1.60		1.60
Other land						172.94	172.94
Initial Area	112.43	443.33	25.21	13.49	1.60	172.94	769.00
Net change	-0.07	0.00	0.07	0.00	0.00	0.00	0.00

1997

	Forest land	Grassland	Cropland	Wetlands	Settlements	Other land	Final Area
Forestland	112.05	0.24					112.29
Grassland	0.25	443.09					443.34
Cropland	0.06		25.28				25.34
Wetlands				13.49			13.49
Settlements					1.60		1.60
Other land						172.94	172.94
Initial Area	112.36	443.33	25.28	13.49	1.60	172.94	769.00
Net change	-0.07	0.01	0.06	0.00	0.00	0.00	0.00

1998

	Forest land	Grassland	Cropland	Wetlands	Settlements	Other land	Final Area
Forestland	111.95	0.26					112.21
Grassland	0.27	443.08					443.35
Cropland	0.06		25.34				25.41
Wetlands				13.49			13.49
Settlements					1.60		1.60
Other land						172.94	172.94
Initial Area	112.29	443.34	25.34	13.49	1.60	172.94	769.00
Net change	-0.07	0.01	0.06	0.00	0.00	0.00	0.00

1999

	Forest land	Grassland	Cropland	Wetlands	Settlements	Other land	Final Area
Forestland	111.87	0.49					112.36
Grassland	0.28	442.86					443.14
Cropland	0.06		25.41				25.47
Wetlands				13.49			13.49
Settlements					1.60		1.60
Other land						172.94	172.94
Initial Area	112.21	443.35	25.41	13.49	1.60	172.94	769.00
Net change	0.15	-0.21	0.06	0.00	0.00	0.00	0.00

2000

	Forest land	Grassland	Cropland	Wetlands	Settlements	Other land	Final Area
Forestland	112.00	0.51					112.50
Grassland	0.30	442.63					442.93
Cropland	0.06		25.47				25.53
Wetlands				13.49			13.49
Settlements					1.60		1.60
Other land						172.94	172.94
Initial Area	112.36	443.14	25.47	13.49	1.60	172.94	769.00
Net change	0.15	-0.21	0.06	0.00	0.00	0.00	0.00

2001

	Forest land	Grassland	Cropland	Wetlands	Settlements	Other land	Final Area
Forestland	111.72	0.08					111.80
Grassland	0.72	442.86					443.58
Cropland	0.06		25.53				25.59
Wetlands				13.49			13.49
Settlements					1.60		1.60
Other land						172.94	172.94
Initial Area	112.50	442.93	25.53	13.49	1.60	172.94	769.00
Net change	-0.71	0.65	0.06	0.00	0.00	0.00	0.00

2002

	Forest land	Grassland	Cropland	Wetlands	Settlements	Other land	Final Area
Forestland	111.02	0.07					111.09
Grassland	0.72	443.51					444.23
Cropland	0.06		25.59				25.65
Wetlands				13.49			13.49
Settlements					1.60		1.60
Other land						172.94	172.94
Initial Area	111.80	443.58	25.59	13.49	1.60	172.94	769.00
Net change	-0.71	0.65	0.06	0.00	0.00	0.00	0.00

2003

	Forest land	Grassland	Cropland	Wetlands	Settlements	Other land	Final Area
Forestland	110.14	0.08					110.22
Grassland	0.90	444.15					445.05
Cropland	0.06		25.65				25.71
Wetlands				13.49			13.49
Settlements					1.60		1.60
Other land						172.94	172.94
Initial Area	111.09	444.23	25.65	13.49	1.60	172.94	769.00
Net change	-0.88	0.82	0.06	0.00	0.00	0.00	0.00

2004

	Forest land	Grassland	Cropland	Wetlands	Settlements	Other land	Final Area
Forestland	109.26	0.07					109.34
Grassland	0.88	444.98					445.85
Cropland	0.07		25.71				25.78
Wetlands				13.49			13.49
Settlements					1.60		1.60
Other land						172.94	172.94
Initial Area	110.22	445.05	25.71	13.49	1.60	172.94	769.00
Net change	-0.88	0.81	0.07	0.00	0.00	0.00	0.00

2005

	Forest land	Grassland	Cropland	Wetlands	Settlements	Other land	Final Area
Forestland	108.07	0.05					108.13
Grassland	1.19	445.80					446.99
Cropland	0.08		25.78				25.86
Wetlands				13.49			13.49
Settlements					1.60		1.60
Other land						172.94	172.94
Initial Area	109.34	445.85	25.78	13.49	1.60	172.94	769.00
Net change	-1.21	1.13	0.08	0.00	0.00	0.00	0.00

2006

	Forest land	Grassland	Cropland	Wetlands	Settlements	Other land	Final Area
Forestland	107.30	0.05					107.35
Grassland	0.74	446.94					447.68
Cropland	0.08		25.86				25.94
Wetlands				13.49			13.49
Settlements					1.60		1.60
Other land						172.94	172.94
Initial Area	108.13	446.99	25.86	13.49	1.60	172.94	769.00
Net change	-0.78	0.69	0.08	0.00	0.00	0.00	0.00

2007

	Forest land	Grassland	Cropland	Wetlands	Settlements	Other land	Final Area
Forestland	106.64	0.06					106.70
Grassland	0.64	447.62					448.26
Cropland	0.07		25.94				26.01
Wetlands				13.49			13.49
Settlements					1.60		1.60
Other land						172.94	172.94
Initial Area	107.35	447.68	25.94	13.49	1.60	172.94	769.00
Net change	-0.65	0.58	0.07	0.00	0.00	0.00	0.00

2008

	Forest land	Grassland	Cropland	Wetlands	Settlements	Other land	Final Area
Forestland	106.46	0.22					106.68
Grassland	0.18	448.04					448.22
Cropland	0.06		26.01				26.07
Wetlands				13.49			13.49
Settlements					1.60		1.60
Other land						172.94	172.94
Initial Area	106.70	448.26	26.01	13.49	1.60	172.94	769.00
Net change	-0.02	-0.04	0.06	0.00	0.00	0.00	0.00

2009

	Forest land	Grassland	Cropland	Wetlands	Settlements	Other land	Final Area
Forestland	106.46	0.95					107.41
Grassland	0.16	447.27					447.43
Cropland	0.06		26.07				26.13
Wetlands				13.49			13.49
Settlements					1.60		1.60
Other land						172.94	172.94
Initial Area	106.68	448.22	26.07	13.49	1.60	172.94	769.00
Net change	0.73	-0.79	0.06	0.00	0.00	0.00	0.00

2010

	Forest land	Grassland	Cropland	Wetlands	Settlements	Other land	Final Area
Forestland	107.23	0.95					108.18
Grassland	0.12	446.48					446.60
Cropland	0.05		26.13				26.19
Wetlands				13.49			13.49
Settlements					1.60		1.60
Other land						172.94	172.94
Initial Area	107.41	447.43	26.13	13.49	1.60	172.94	769.00
Net change	0.77	-0.82	0.05	0.00	0.00	0.00	0.00

2011

	Forest land	Grassland	Cropland	Wetlands	Settlements	Other land	Final Area
Forestland	108.04	0.47					108.51
Grassland	0.10	446.13					446.23
Cropland	0.04		26.19				26.23
Wetlands				13.49			13.49
Settlements					1.60		1.60
Other land						172.94	172.94
Initial Area	108.18	446.60	26.19	13.49	1.60	172.94	769.00
Net change	0.33	-0.37	0.04	0.00	0.00	0.00	0.00

2012

	Forest land	Grassland	Cropland	Wetlands	Settlements	Other land	Final Area
Forestland	108.41	1.27					109.68
Grassland	0.07	444.96					445.03
Cropland	0.03		26.23				26.25
Wetlands				13.49			13.49
Settlements					1.60		1.60
Other land						172.94	172.94
Initial Area	108.51	446.23	26.23	13.49	1.60	172.94	769.00
Net change	1.17	-1.20	0.03	0.00	0.00	0.00	0.00

7.4.2 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.

7.4.2.1 Classification of lands to IPCC reporting categories

Where a human induced loss of forest cover has been identified, these lands are classified and reported as *forest converted to grassland* or f*orest land converted to cropland*. The allocation of forest conversion areas to cropland or grassland is designated by the relative frequency of the management practices within the particular Interim Biogeographic Regionalisation of Australia region (IBRA region) and soil type in which it occurred. Where there has been human induced conversion to forest cover since 1990, these lands are classified and reported as *land converted to forest*. Pre 1990 plantations are reported as *forest land remaining forest land*. This is because linked spatial and establishment date data needed to accurately allocate lands into the lands converted to forest or land remaining forest land sub-categories is not currently available. This capacity is currently being developed.

Lands classified as *forest land remaining forest land* are disaggregated into the different forest sub-divisions (see Table 7.7) using information on harvested native forests and pre 1990 plantations drawn from data developed for Australia's National Forest Inventory. In accordance with the *Good Practice Guidance* (IPCC, 2003), in cases where there is a temporary change in forest cover, due to a forest harvest or fire, the land remains in *forest land remaining forest land* category.

The remaining land areas are classified into *cropland remaining cropland, grassland remaining grassland, wetlands, settlements* and *other land* using the ABARES land use mapping data.

7.4.2.2 Non-anthropogenic change in forest cover

Forest cover may also change due to processes of forest regrowth and dieback which are largely driven by climate variability and are not directly human induced. The land associated with these naturally caused transitions between forest and grassland are not reported in the land conversion sub-categories. Rather they are re-classified into the relevant land remaining category in the land area matrices. For example, where there is a natural increase in forest cover on grassland the lands are re-classified from *grassland remaining grassland* to *forest land remaining forest land (other native forest)*.

In the case that there is natural regrowth on *forest land converted grassland*, this unit of land will continue to be reported as *forest land converted to grassland*. Emissions and removals associated with the natural regrowth forest on the unit of land will be modelled in the Tier 3 system, including if it is subsequently recleared. It should be noted that even though the unit of land may be identified as *forest land converted to grassland*, natural regeneration of forest cover is identified and modelled through time.

Methods are being investigated to separate the reporting of lands that transfer between forest and non-forest due to natural variability. The purpose of this is to provide greater transparency in the areas of land transferred between land categories without changing land use.

7.4.2.3 Transition to the land remaining sub-division

The IPCC (2003) recommends that for Tier 1 and Tier 2 methods, land should be reported in a "conversion sub-division" for 20 years, and then moved to a "remaining sub-division", unless a further change occurs. However, the IPCC (2003) also states 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. This supports 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.

7.5 Source Category 5A.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 7.7).

Table 7.7: 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	Woody thickening	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.	These forest areas fluctuate above and below the forest cover thresholds, largely as a result of climate influences.	Gain in carbon stock on lands identified as forest, where no forest transitions (gain/loss of forest cover) have been observed.	CO_2 emissions due to wildfire and prescribed burning and subsequent removals from post-fire recovery across all forest categories.

7.5.1 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-division 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, continues to be reported in this category, even if the lands have moved to a reserve status. As a result the land areas do not change with time. The areas of each forest type are shown in Table 7.8.

7.5.1.1 Methodology

The emissions and removals from *harvested native forests* are estimated using the non-spatially explicit Estate modelling capability of *FullCAM*. 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.

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.

Estimating Changes in Biomass

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).

Growth Modelling

The growth rates of *harvested native forests* (t C ha^{-1} yr^{-1}) are modelled based on the broad forest types and age classes reported by Lucas *et al.* (1997) (Table 7.9). The initial carbon stock in 1990 is estimated using *FullCAM* which is configured using the area of each forest type and age class in Table 7.9. *FullCAM* is then configured to model biomass increments based on the growth rates reported in Table 7.10. 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 7.9).

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).

Table 7.8: 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	**96,977**	**305,644**	**645,926**	**3,106,489**	**1,176,000**	**5,206,104**	**616,000**	**3,732,600**	**14,885,740**

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

Table 7.9: 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	2.8	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

Partitioning of biomass to tree components

The ratios used to partition biomass to the different tree components (Table 7.10) are drawn from a synthesis of available data compiled by Snowdon *et al.* (2000) and the results of Ximenes and Gardner (2005) and Ximenes *et al.* (2005).

Table 7.10: 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	0.6	0.08	0.09	0.03	0.17	0.03
Tall Dense Eucalypt Forest	0.55	0.12	0.1	0.03	0.17	0.03
Medium Dense Eucalypt Forest	0.5	0.15	0.12	0.03	0.17	0.03
Medium Sparse Eucalypt Forest	0.47	0.15	0.12	0.03	0.2	0.03
Cypress pine Forest	0.47	0.15	0.12	0.03	0.2	0.03
Other forest	0.47	0.15	0.12	0.03	0.2	0.03

Carbon Fraction of Biomass

The carbon fractions of the tree components (Table 7.11) are based on studies of Australian vegetation (Gifford, 2000a and 2000b).

Table 7.11: 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

Forest Harvest

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 section 7.13.1) (based on production statistics).

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 7.13). 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 7.12: Estimated total area of native forest harvested

Year	Area harvested (ha)
1990	141,441
1995	149,306
2000	136,206
2005	99,363
2006	100,018
2007	103,722
2008	112,433
2009	81,387
2010	90,522
2011	65,164
2012	51,504

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).

Silvicultural systems

Ten broad silvicultural systems are represented in the model (Table 7.13). 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 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.

Table 7.13: 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

Estimating Changes in Debris

The annual change in DOM in harvested native forests is the net result of additions from turnover and movement of living biomass to DOM. This is due to harvesting and losses caused by decomposition of both natural accumulation and harvest residue, and burning of residues as part of some silvicultural systems.

Losses from the DOM pool are accounted as 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 lagged emissions due to the ongoing decay and management of residue from harvesting in previous years.

Initial Debris Levels

The initial amount of forest debris for each forest type and age class combination is based upon model simulations, 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).

Turnover and Decomposition Rates

The turnover rates applied for each plant component in the model are shown in Table 7.14

There is limited information on decomposition rates in the *harvested native forests* of Australia. The decomposition rates for the different debris pools were drawn from the best 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 7.15.

Table 7.14: Turnover for tree components

Tree component	Turnover year^{-1}
Branches	0.05
Bark	0.07
Leaves	0.5
Coarse Roots	0.1
Fine Roots	0.85

Table 7.15: Decomposition rates for debris pools used in the harvested native forests model.

	Breakdown yr^{-1}	
Debris component	Decomposable	Resistant
Deadwood	0.05	0.05
Bark litter	0.5	0.5
Leaf litter	0.8	0.8
Coarse dead roots	0.4	0.1
Fine dead roots	1	1

Harvest residues

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).

7.5.2 Plantations (established prior to 1990)

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. 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.

7.5.2.1 Methodology

The emissions and removals from *plantations* are estimated using *FullCAM* operating in Estate mode. In this mode, *FullCAM* uses 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-division.

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 Appendix 7.A. In future inventories, this separation will be made in the *plantations* sub-division 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. These 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.

Estimating Changes in Biomass

Growth Modelling and Management

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.

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). The purpose of this was 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, and in some instances, no 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. This is because lower densities occur when mass is least, that is, during early growth stages. Table 7.18 shows the wood density values used for the major plantation species in the plantation types.

Stem to Whole Tree Mass Conversions

FullCAM is parameterised to allocate biomass between plant parts, depending upon species and age of the forest. Biomass allocation parameters are based on empirical data presented in Keith *et al.* (2000), Eamus *et al.* (2000), and Snowdon *et al.* (2000).

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 7.18.

Estimating Changes in Debris

Turnover and Decomposition Rates

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 Table 7.18.

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. They 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 7.16: 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 7.17 shows the decomposition rates applied.

Table 7.17: Debris decomposition rates

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

Table 7.18: 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

Region(s)	Species	Density	CC% Leaf	CC% Branch	CC% Wood	CC% Bark	CC% Fine Roots	CC% Coarse Roots	Regime Description
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
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

Estimating Changes in Soil Carbon

It has been shown that in the medium to long term, soil carbon does not change for most plantations (Polglase *et al.* 2000). However 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 7.14 and 7.15 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 7.14: Change in soil carbon (t C yr^{-1}) following plantation establishment from 1940 to 1959

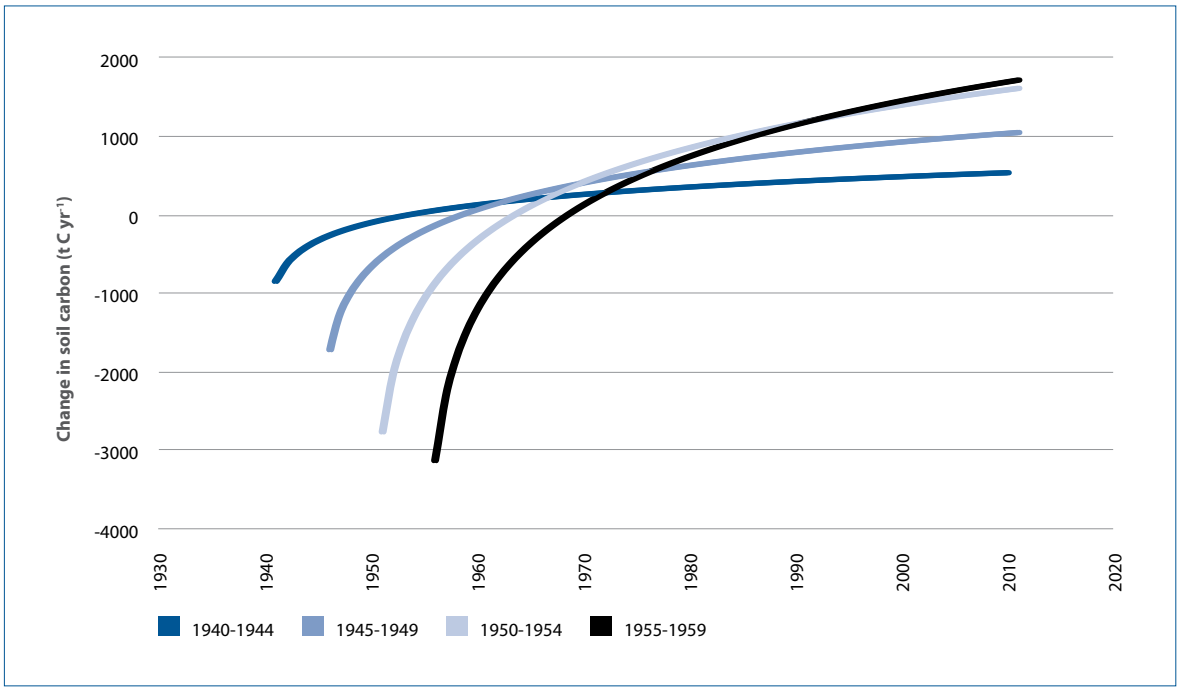
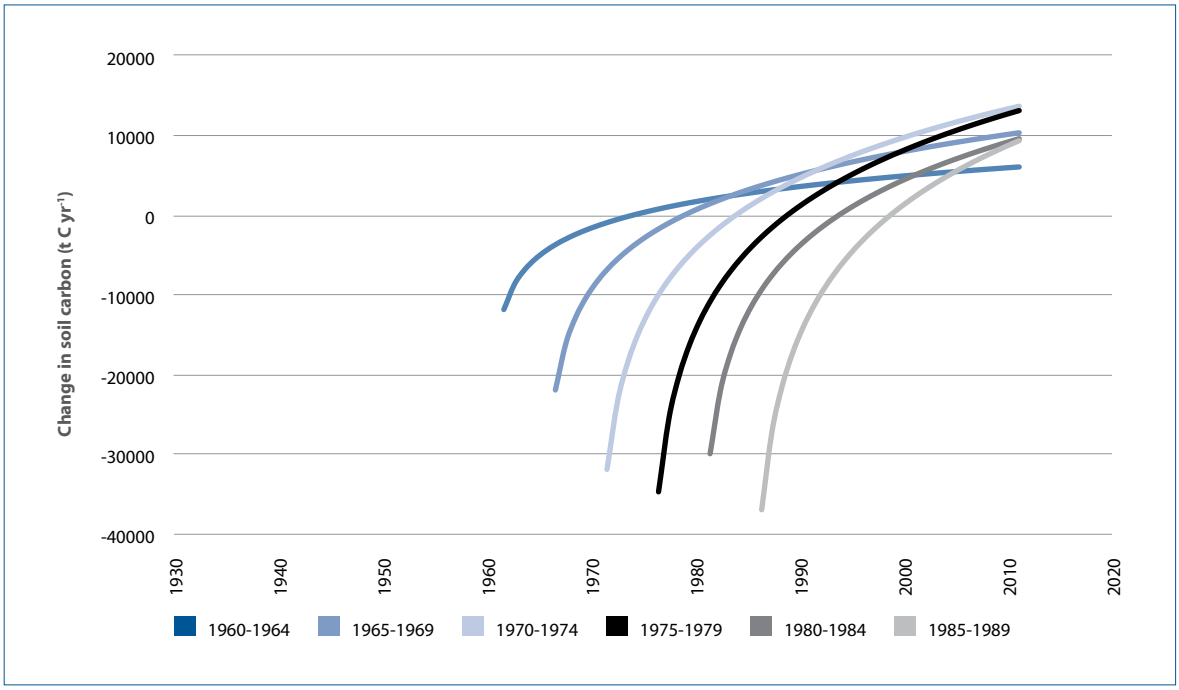


Figure 7.15: Change in soil carbon (t C yr^{-1}) following plantation establishment from 1960 to 1989



Activity data

Activity data for *plantations* is sourced from the National Plantation Inventory (NPI) (Table 7.19). 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 7.14). 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).

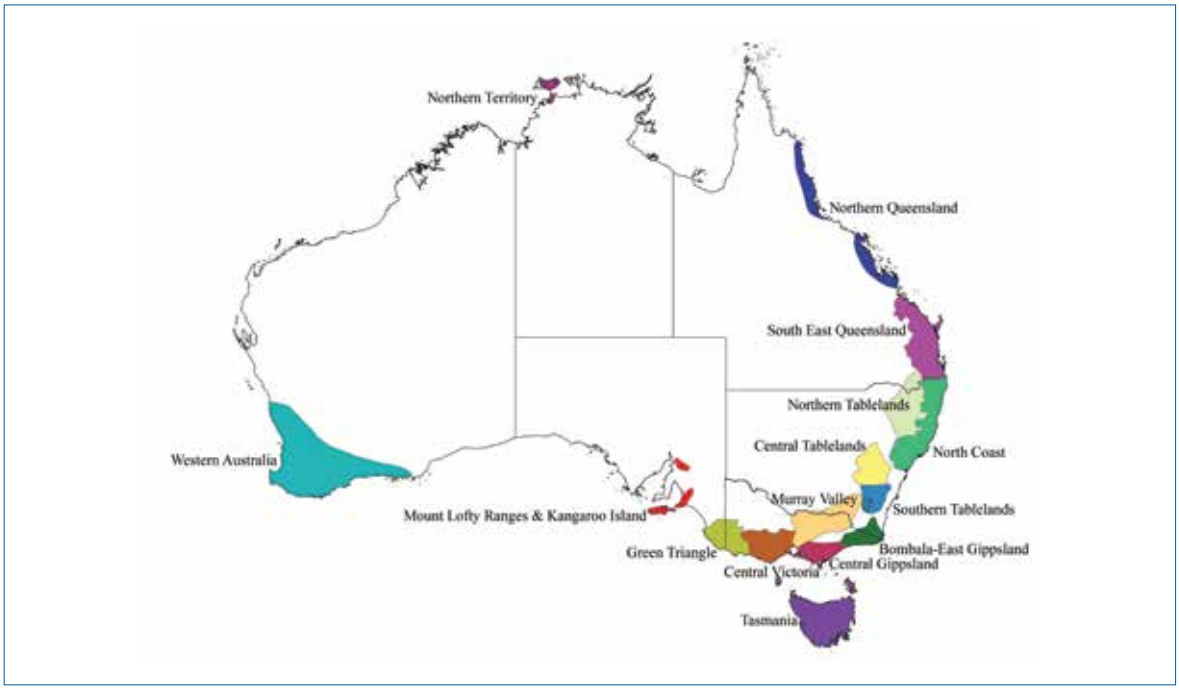
Allocations of the Short Rotation Hardwood (SRH), Long Rotation Hardwood (LRH) and Softwood (SW) classes are made to the region and species specific plantation models as described by Turner and James (2002).

Table 7.19: 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-division is to identify lands converted to (pre-1990) plantation since the commencement of the Landsat archive in 1972. At present, *lands 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 7.16: The National Plantation Inventory regions



7.5.3 Other Native Forests

Other native forests include those forests that are comprised of endemic species, which are not *harvested native forests* or *plantations*. The *other native forests* sub-division includes protected areas (such as Wilderness areas and National Parks) not previously subject to harvesting, areas of extensive forests and woodlands, and lands which have had a non-anthropogenic transition to or from forest. The area of *other native forest* changes through time due to ongoing processes such as fire, dieback and regrowth, and also fluctuates due to climate.

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.

7.5.3.1 Identifying Changes in Other Native Forest Area and Cover

It is possible to extract the lands that exhibit a loss or gain in the area of forest or change in canopy cover from the time-series of remotely sensed data. Figure 7.17 shows the typical fluctuations in forest cover that occur around the prescribed canopy cover definition of a forest (20% in Australia).

Figure 7.17: Patterns of change in forest cover in areas of other native forest

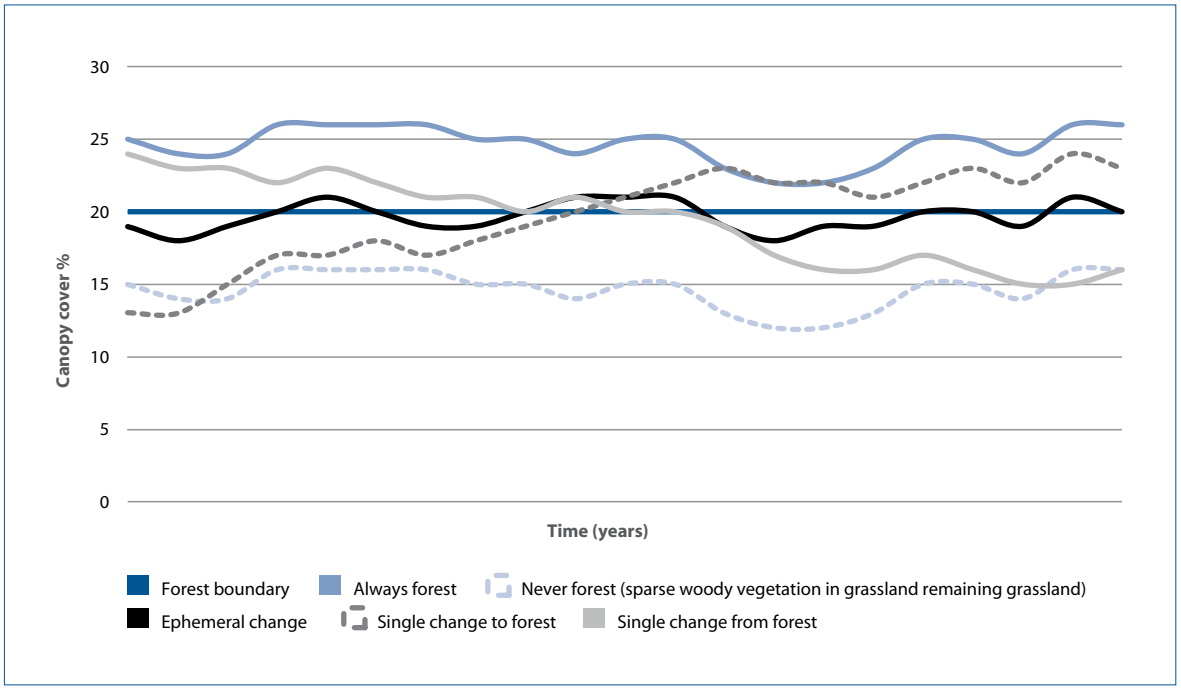
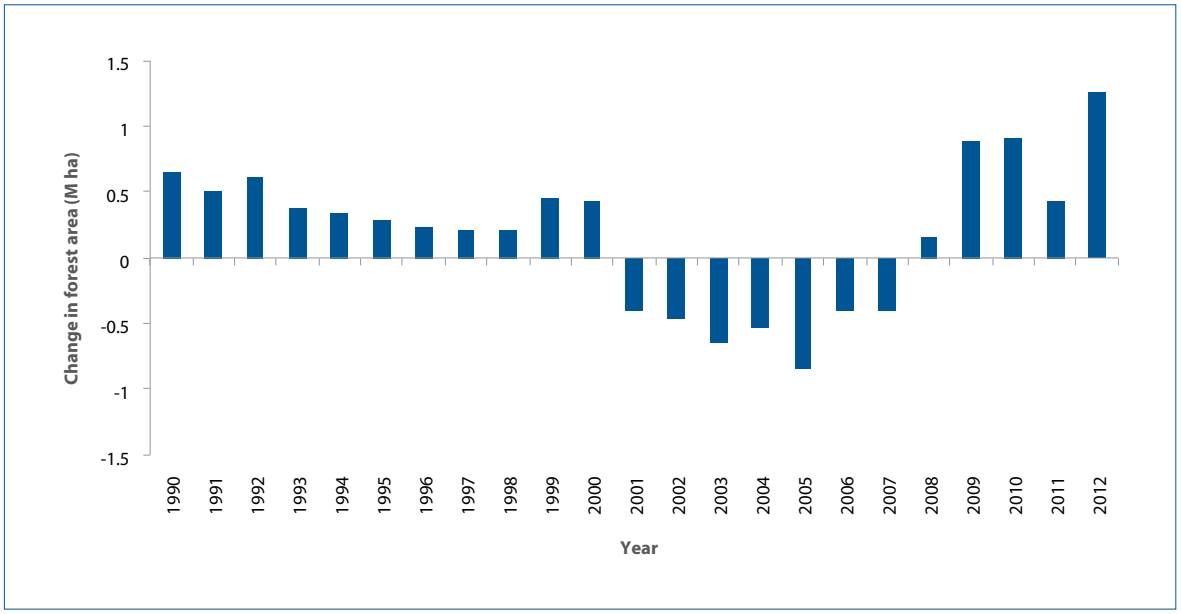


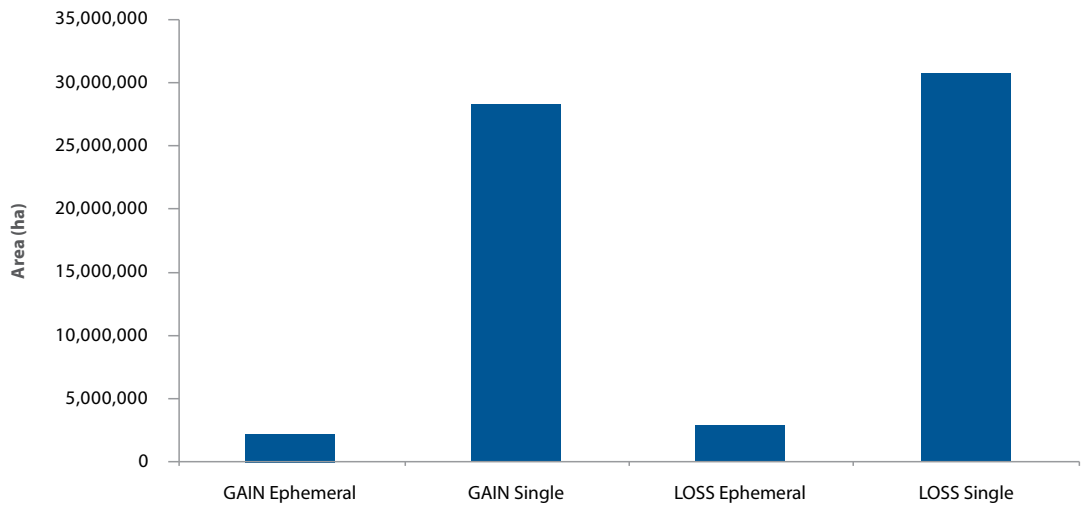
Figure 7.18 below shows the net national gains and losses in forest cover in other native forests since 1972. This represents the areas of forest cover change not assessed as being a land use change.

Figure 7.18: Change in forest area (M ha) not attributable to land use change and included in Other Native Forests, since 1990



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 induced land use change areas from natural cycles in forest cover change is described in Appendix 7.A. Figure 7.19 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 92%.

Figure 7.19: 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 type 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.

7.5.3.1 Methodology

Other native forests are divided into several sub-divisions for modelling purposes. Each sub-division uses country specific emissions factors or models. These sub-divisions include emissions and removals for: permanent changes in forest extent (such as dieback and regrowth); ephemeral changes in forest extent due to climate; woody thickening in continuous forest areas due to climate; and controlled burning and wildfire (including removals post-fire).

Permanent Change in Forest Extent

A permanent change occurs where a single change in forest extent, as either a loss or a gain, has been observed throughout the 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 in the absence of a land use change through dieback and regrowth. This long term land transition is more likely to result from changes in woody biomass than the ephemeral changes that affect only leaf mass.

Emissions and removals associated with these lands are estimated with a Tier 2 model using the parameters shown in Table 7.20. 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 the change in forest cover. 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 7.20: 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

Non-Permanent Changes to Forest Extent and Cover

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. These changes in forest crown do not result in land being moved to the *Forest land converted to Grassland* classification because these lands are considered to include vegetation that falls below, but is expected to exceed, the threshold of the forest land category.

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. 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.

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 7.4), and parameters and input data developed for the estimation of non-CO_2 emissions from forest land (see Section 7.14.1.1). 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:

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

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 7.49 and 7.50),

Z_{jk} = burning efficiency (Table 7.51).

Annual CO_2 emissions are calculated as:

$E_{ijk} = M_{jk} * CC_{jk} * C_i$ ..... (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 7.52),

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

Annual CO_2 removals are calculated as:

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

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

ΣM_{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 7.52),

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

7.5.3.2 Results

For the period 1990 to 2012, the single change in forest cover model indicates a net removal (sink) due to the increase in new forest area from the late 1970s until 2000 (Figure 7.18). 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 7.21: Results of the estimates of annual emissions and removals in other native forests

Year	Emissions (Mt CO_2)				
	Ephemeral change in forest	Single change in forest	Woody Thickening	Fire	Total
1990	-0.01	-4.1	-12.2	3.5	-13
2000	-0.01	-11.0	-12.2	-11.8	-35
2005	0.02	-5.5	-12.2	-42.8	-61
2006	0.01	-4.5	-12.2	-51.4	-68
2007	0.01	-3.6	-12.2	20.2	4
2008	0.00	-3.6	-12.2	-46.7	-62
2009	-0.02	-2.9	-12.2	-3.0	-18
2010	-0.02	-3.4	-12.2	10.1	-6
2011	-0.01	-3.3	-12.2	-34.8	-50
2012	-0.03	-4.4	-12.2	33.2	17

7.5.4 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 Bureau of Resources and Energy (BREE) 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-division.

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-division 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 BREE (2012). The data used to estimate CO_2 emissions are updated annually based on the most recent BREE 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.

7.5.4 Uncertainties and Time Series Consistency

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

7.5.5 Source Specific QA/QC

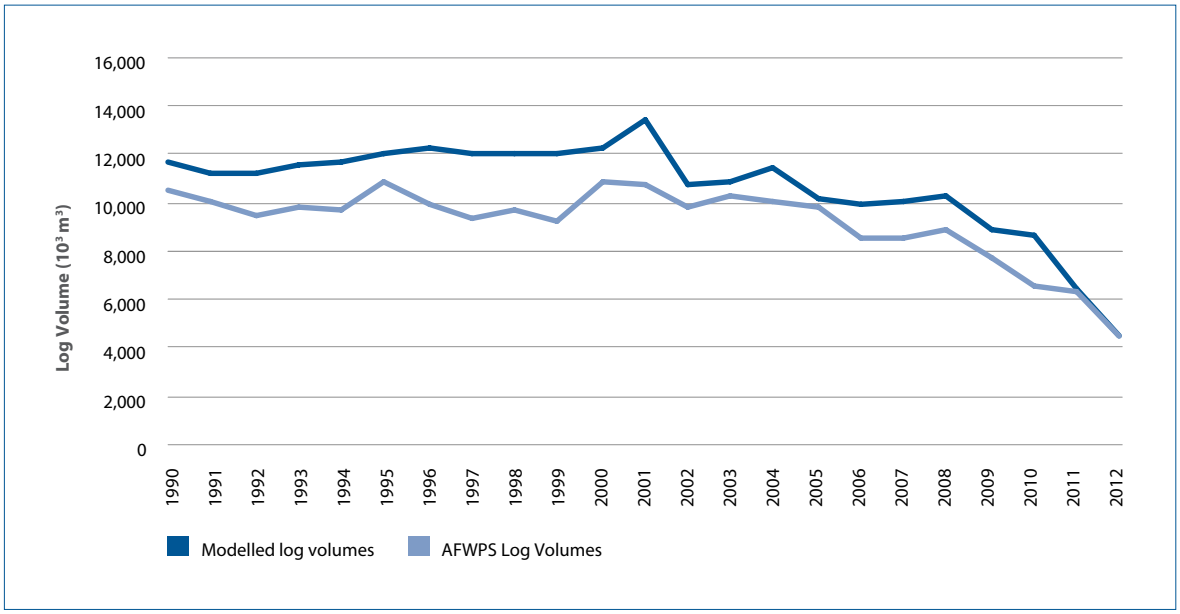
7.5.5.1 Harvested Native Forests

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). 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 were 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 log volume calculated using the harvested native forest model used for emissions estimation with national statistics of round wood production in native forest (ABARES, Forest and Wood Production statistics, March and June quarters 2013) (Figure 7.20). The log volume from the harvested native forest model was estimated by converting the carbon removed from forests as forest products in to stem volume assuming a stemwood carbon percentage of 52% and average wood basic density of 750 kg m^{-3}. The modelled log volumes show similar patterns over time, particularly from 2000 onwards (where the area harvested data is the most certain).

Figure 7.20: Estimated net removals in Harvested Native Forests, new Tier 2 model compared to the former model used in previous inventories



7.5.5.2 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 7.16). 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-division 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 performs QA/QC on these data. 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 were 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.

7.5.5.3 Other native forests

The data required to estimate *other native forests* includes the time-series of the area gained or lost from forest land that is not associated with human activity. Quality control processes for the forest balancing term data were performed by the DE Geospatial Analysis Unit. The leaf area index (LAI) time-series data is provided by the Environmental Resources Information Network (ERIN) (1972-2009) and the Bureau of Meteorology (BOM) (2009+). The prescribed burning and wildfire areas are supplied by CSIRO Marine and Atmospheric Research and sourced from state and remote sensing fire area estimates. These data have had extensive QA/QC applied at their source.

7.5.6 Recalculations Since the 2011 Inventory

Within the *forest land remaining forest land* sub-category, the *Other Native Forests* classification has been updated so that estimates of emissions associated with changes in canopy cover are consistent with observed changes in forest cover. This has resulted in recalculations to the time series.

Table 7.22: Forest land remaining forest land: recalculation of total CO2-e emissions (Gg), 1990-2012

Year	2013 submission	2014 submission	Change	
	(Gg CO_2)	(Gg CO_2)	(Gg CO_2)	(%)
1990	-45,419	-43,732	1,687	4
2000	-39,977	-48,626	-8,649	-22
2005	-74,159	-79,628	-5,469	-7
2006	-84,154	-87,133	-2,979	-4
2007	6,334	-10,214	-16,548	261
2008	-94,895	-80,479	14,415	15
2009	-36,042	-38,726	-2,684	-7
2010	-35,816	-28,087	7,729	22
2011	-84,137	-82,062	2,075	2

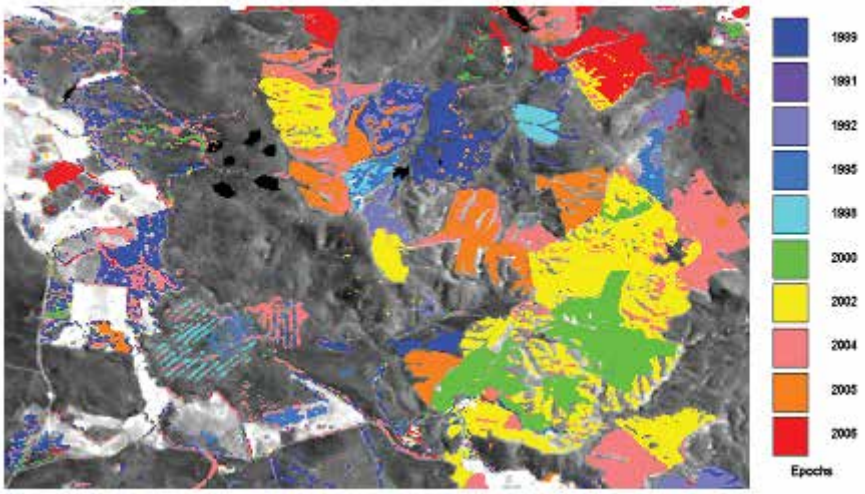
7.5.7 Source Specific Planned Improvements

Harvest Native Forests and pre-1990 Plantations

Australia is continuing to develop capacity to have comprehensive use of Tier 3, Approach 3 modelling in the future for the pre-1990 *plantations* and *harvested native forests* sub-categories. The remote sensing programme is currently developing methods to identify areas of plantation established prior to 1988 using Landsat MSS data.

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-division (see example in Figure 7.21). 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 7.21: An example of harvested area detection using Australia's time-series remote sensing data. Coloured areas represent detected harvest areas in a particular epoch.



Other Native Forests

Currently 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 g*rassland 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, 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.

7.6 Source Category 5A.2 Land Converted to Forest Land

7.6.1 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).

7.6.1.1 Methodology

The emissions and removals from *Grassland converted to forest land* are estimated using the spatially explicit (Approach 3) Tier 3 *FullCAM*, modelling system. Reporting includes carbon in living biomass, dead organic matter and soil pools. A full description of the modelling system is provided in Appendix 7.B and 7.D. The modelling methods and calibration have been published in peer reviewed literature (Waterworth *et al*, 2007; Waterworth and Richards, 2008).

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.

Estimating Changes in Living Biomass

Forest Growth

Plantations commonly produce more biomass than native forest systems in Australia, at least in the short to medium term (15-40 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, and species specific site matching and management.

To estimate plantation growth the native forest regrowth model (Appendix 7.B and 7.D) is supplemented to include functions that represent Type 1 and Type 2 growth responses (Snowdon and Waring, 1984) and the impact of using non-endemic species (Appendix 7.G). Type 1 management practices advance or retard stand development (effectively age) but do not increase underlying site productivity over the life of the rotation (e.g. weed control at establishment). Type 2 treatments increase (or decrease) a site's carrying capacity in the longer term (e.g. phosphorus application).

Stem to Whole Tree Mass Conversions

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. *FullCAM* calculates the partitioning using an empirical approach derived from expansion factors reported in Snowdon *et al.* (2000) and Mokany *et al.* (2006). This method allows allocation to vary between sites and species within set ranges based on age, site productivity and level of stand development.

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 (Table 7.24, Gifford, 2000a and 2000b).

Table 7.23: Percent carbon of tree components – land converted to forest land

Tree Component	Hardwood carbon content %	Softwood carbon content %	Other (environmental plantings) carbon content %
Stems	50	51	50
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

Forest Harvest

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 range of possible management actions is shown in Table 7.25. The management regimes are assigned frequencies relative to the frequency of the range of plantation regimes within each region (Figure 7.23 (a)). This allows time series management regimes to be developed for each plantation pixel through time (Figure 7.23 (b)).

Table 7.24: 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
Wildfire[1]	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 (agriculture)	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 application[2]	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 application[3]	Fertiliser application (forest and agriculture)	Adds N to the mineral N pool	Different levels of N addition (kg ha^{-1})

Source: Waterworth and Richards (2008)

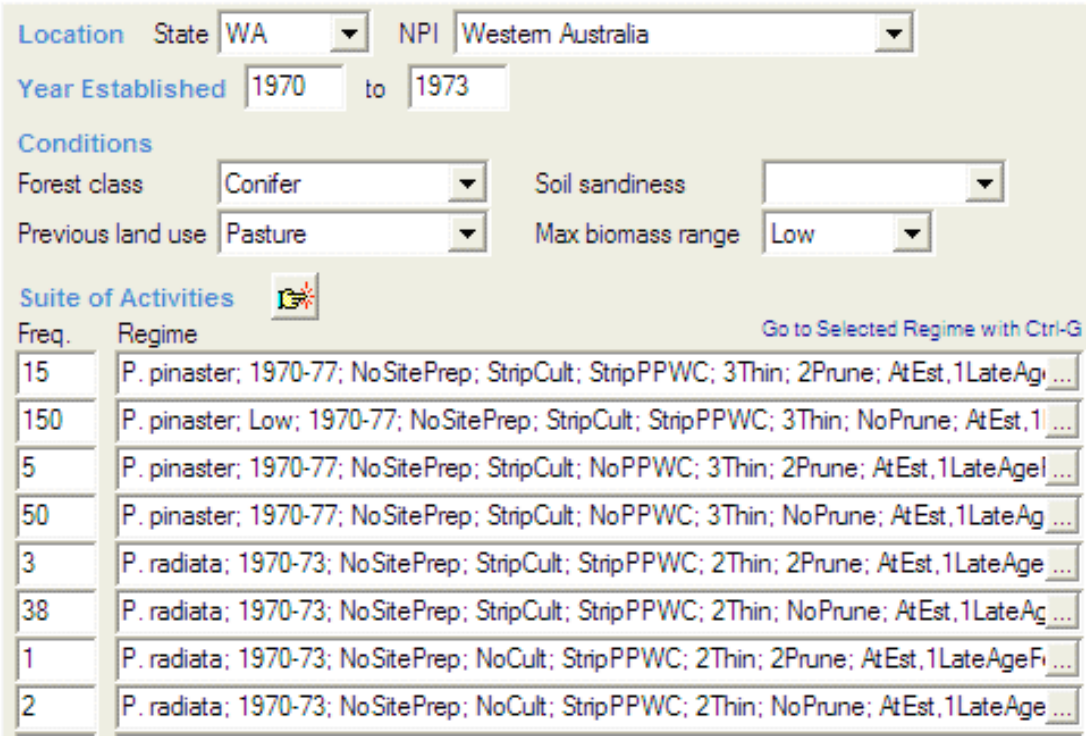
[1] Although not a management practice, wildfire events allow for the future spatial modelling of their effect on carbon stocks. See the discussion for more details.

[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.

Figure 7.22: (a) Each regime is assigned a relative frequency (a) occurring at a given point over time, allowing for(b) time series of management regimes to be developed. Source: Waterworth and Richards, 2008.

(a)



(b)

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

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 7.23(a).

The plantation management database currently consists of around 5,000 regimes each comprising 10-30 events. Many of the management regimes described may only occur rarely.

Estimating Changes in Debris

Turnover and Decomposition Rates

The turnover rate of leaves and fine roots (Table 7.24) 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; they 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).

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.

Table 7.25: 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 7.26 shows the decomposition rates applied.

Table 7.26: Debris decomposition rates

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

Estimating Changes in Soil Carbon

Soil carbon is estimated using the fully spatially explicit approach described in Appendix 7.B, 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 outputted from 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)(Table 7.27). 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-division; 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.

Table 7.27: Annual plantation area from the remote sensing program 1990 to 2012

Year	Area (ha)
1990	46,088
1995	32,986
2000	68,856
2005	53,841
2006	47,672
2007	62,347
2008	65,426
2009	59,104
2010	39,236
2011	31,728
2012	14,457

7.6.2 Uncertainties and Time Series Consistency

Uncertainty in the *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.

7.6.3 Source Specific QA/QC

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

To conduct quality control of the Tier 3, Approach 3 model, a series of Tier 2 models based on 48 plot files drawn from within the *FullCAM* modelling framework were selected. The Tier 2 models are parameterised with site average climate (rainfall, temperature and open pan evaporation) and forest productivity data. The selected plot files are representative of the most common species and management regimes within each state and National Plantation Inventory (NPI) region (Figure 7.16).

The area of each type of forest (hardwood, softwood and native planting) 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:

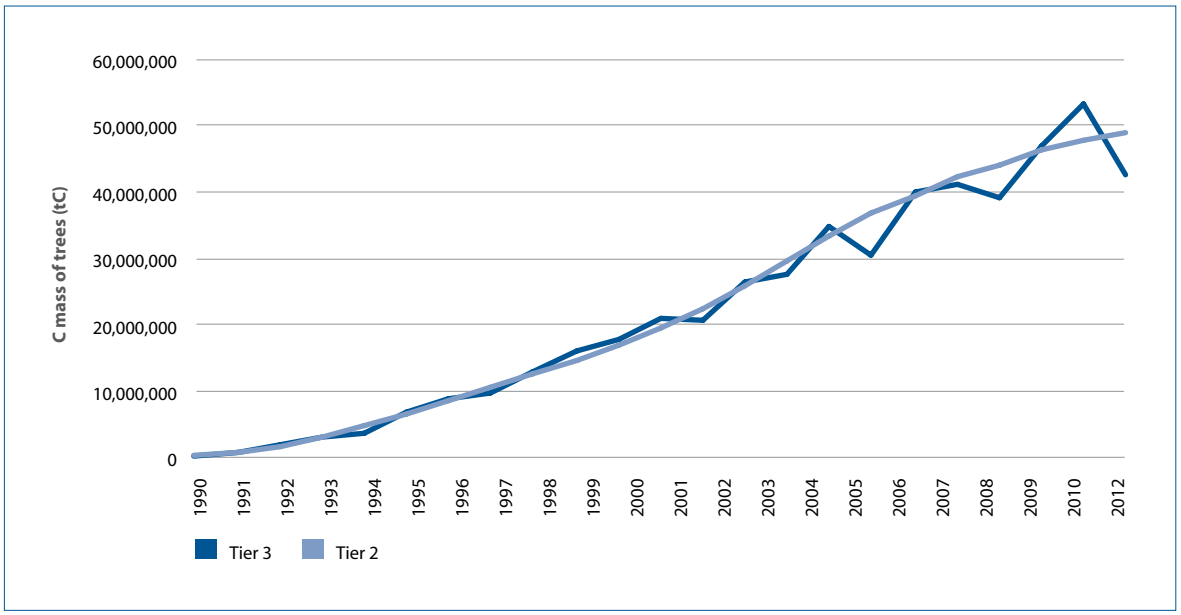
1. Approach 3 component of Australia's inventory method for *grassland converted to forest land*; and
2. The use of annually updated, spatially explicit climate and forest productivity data (Tier 3) as compared to site average data (Tier 2).

The Tier 2 and Tier 3 models are largely in agreement from 1990 through to 2012 (Figure 7.23). The key difference between the two models is the variability in the Tier 3 outputs compared to the invariable results from the Tier 2 models.

A comparison of the yield rate of tree stem mass (Figure 7.23) showed a 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 and temporal variability in climatic variables on plant growth.

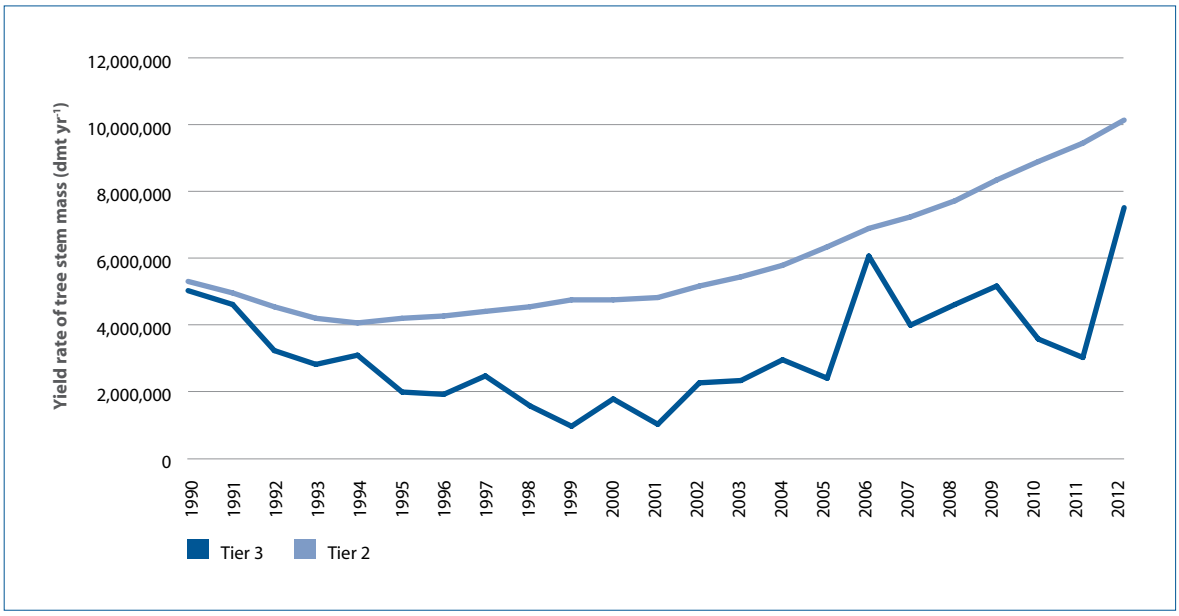
Over the period 2010-2012, the Tier 3 yield rate of stem mass has increased and decreased relative to the Tier 2 models (Figure 7.23). These variations are due to conditions for plant growth being close to optimal in 2011 and then becoming less optimal in 2012. The variability in plant growth in the Tier 3 model is driven by the spatially and temporally explicitly Forest Productivity Index (Appendix 7.C), which is a parameter of the Tree Yield Formula (Appendix 7.B) within the FullCAM model framework. As a result of this deterioration in conditions for plant growth, net emissions in the grassland converted to forest land classification increased by 7.9 Mt CO_2-e between 2011 and 2012 (Figure 7.2).

Figure 7.23: Yield rate of tree stem mass (dm t/yr) output from Tier 2 and Tier 3 methodology, 1990 to 2012



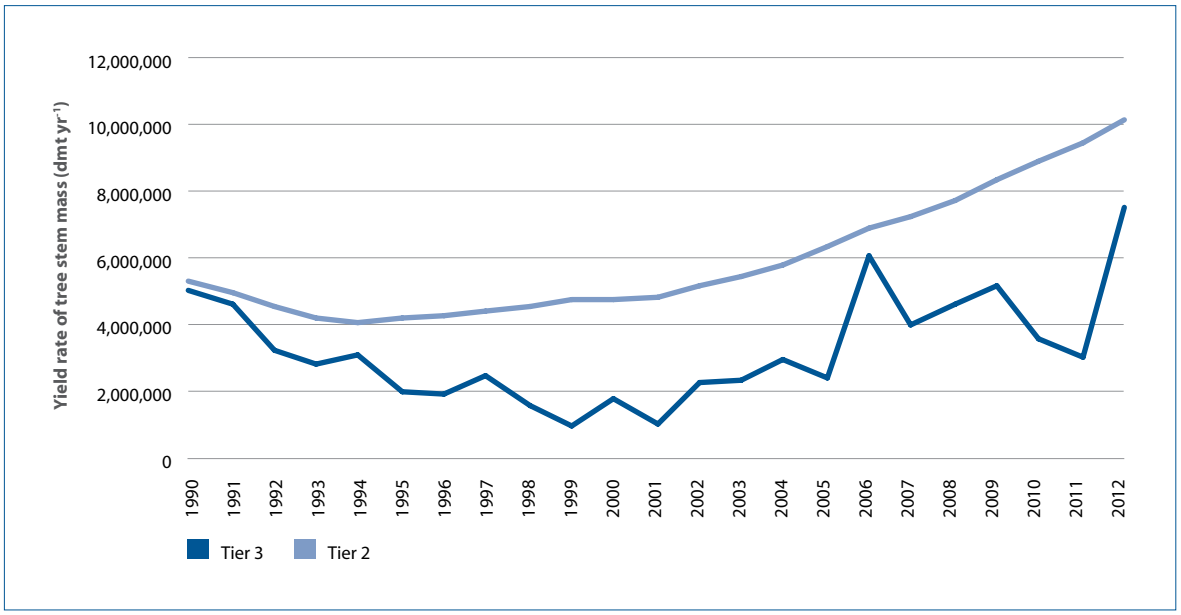
The results of the Tier 3 soil carbon model (Figure 7.26) were also compared to the results of the Tier 2 model based on the same 46 plot files described earlier in this section. The comparison shows that the trend is similar but that emissions estimated from the Tier 3 model are more variable due to 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 7.24: Soil carbon (t C yr^{-1}) output from Tier 2 and Tier 3 methodology, 1990 to 2012



The harvesting rate implemented in the *grassland converted to forestland* FullCAM model was verified by comparing the hardwood log volume, calculated using this model with national statistics of production in hardwood plantation forests (ABARES, Forest and Wood Production statistics, March and June quarters 2013) (Figure 7.25). The use of hardwood species provides for comparability between FullCAM and national statistics, as most hardwood plantations were established post-1990. National statistics for softwood production include a significant proportion of forests that were established prior to 1990. The log volume from the *grassland converted to forest land* model was estimated by converting the carbon removed from forests as forest products in to stem volume assuming a stemwood carbon percentage of 50% and average wood basic density of 600 kg m^{-3}.

Figure 7.25: Comparison of hardwood log production from plantations between the Australia Forest and Wood Production Statistics and the *FullCAM* simulation of grassland converted to forestland, 1990 to 2012



The modelled log volumes show similar patterns over time, with a divergence between the two variables in the period 2010-2012. Harvest events within the FullCAM simulation are supply driven, based on regional and species specific management practices (see section 7.6.1.1). It is possible that the recent divergence is due to a decline in demand, due to effects such as the high value of the Australian dollar in the period 2010-2011, compared to potential supply of wood products. Australia is monitoring this divergence, and as demand for wood products increases, the variables are expected to converge.

7.6.4 Recalculations Since the 2011 Inventory

There have been improvements and updates made to estimates of emissions and removals in the *land converted to forest land* sub-category. These changes included:

- Implementing updated growth calibrations of mixed species environmental plantings and the inclusion of mallee eucalypt species based on CSIRO research;
- Updating the initialisation of the soil carbon pool to be consistent with the method used in the other land use categories; and
- Updates to remote sensing data.

The inclusion of updated growth calibrations of mixed species environmental plantings and the inclusion of mallee eucalypt species within the *Grassland converted to Forest land* has had the largest effect on re-calculations within this classification. DE 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 involved the collection and screening of data from a range of sources and to collect high precision measurements of biomass through destructive sampling. In addition to this work CSIRO analysed the collected data and specified a new set of statistically valid *FullCAM* growth parameters for mixed species environmental plantings and mallee eucalypt plantings.

CSIRO's final report is available at the following website:

http://www.climatechange.gov.au/sites/climatechange/files/files/climate-change/greenhouse-gas-measurement-and-reporting/tracking-australias-greenhouse-gas-emissions/land-sector-reporting/https___corporateservices_zendesk_com_attachments_token_o44wqzpjqsdhjum__name%3DBiomassEnvMalleeplantings.pdf

The net effect of all recalculations was to decrease the 1990 sink estimate by 58 Gg CO_2-e and to increase the 2011 sink estimate by 1,387 Gg CO_2-e.

Table 7.28: Land converted to forest land: recalculation of total CO2-e emissions (Gg), 1990-2011

Year	2013 submission	2014 submission	Change	
	(Gg CO_2)	(Gg CO_2)	(Gg CO_2)	(%)
1990	-149.09	-91.42	58	-38.7%
2000	-10,903	-11,012	-108	1.0%
2005	-14,465	-15,426	-960	6.6%
2006	-12,246	-13,471	-1,225	10.0%
2007	-15,953	-17,202	-1,249	7.8%
2008	-15,320	-16,792	-1,472	9.6%
2009	-13,955	-15,251	-1,296	9.3%
2010	-16,308	-16,649	-342	2.1%
2011	-18,006	-19,393	-1,387	7.7%

7.6.5 Source Specific Planned Improvements

A review of forest harvesting regimes is planned for the *Grassland converted to Forest land* classification. This review will investigate the modelled forest harvesting regimes and compare this to surveys of harvest activity.

7.7 Source Category 5B2 and 5C2 – Forest Conversion

7.7.1 Forest Land Converted to Cropland and Grassland

When the land use subsequent to a forest conversion contains a cropping activity, associated emissions are reported under *forest land converted to cropland*. 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*. Lands which are managed under a crop-pasture rotation are reported under *forest land converted to cropland*.

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.

7.7.1.1 Methodology

The areas of forest conversion are identified and allocated to the cropland and grassland sub-categories as described in section 7.4. Emissions and removals from *forest land converted to cropland* and *grassland* are estimated using the Approach 3, Tier 3 *FullCAM*, as described in Appendix 7.B. The reporting includes all carbon pools (living biomass, dead organic matter and soil). 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 7.31.

N_2O emissions from disturbance associated with land-use conversion to cropland and *grassland* are estimated using the methods described in section 7.13.4. As it is not possible to include the disturbance emissions associated with conversion to grassland 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 7.14.1.3. Other non-CO_2 emissions from these lands are reported in the *agriculture* sector.

Table 7.29: FullCAM configuration used for the Forest to Cropland and Grassland sub-categories

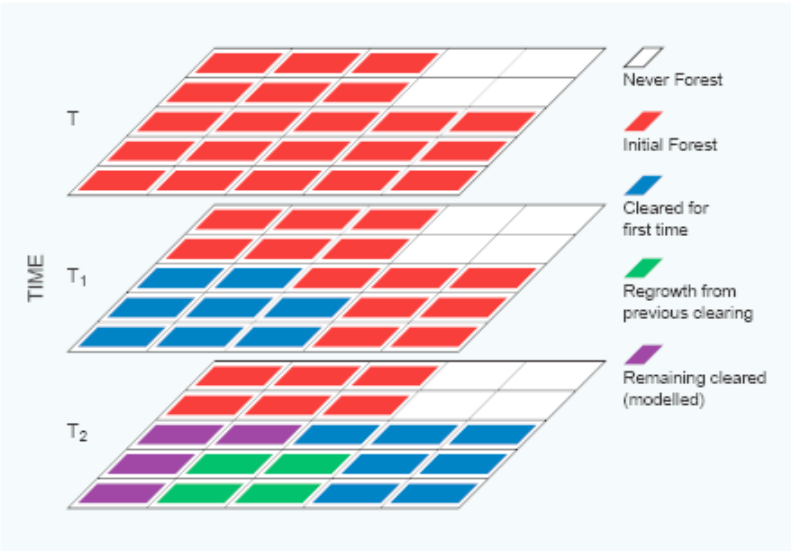
Component	Forest	Agriculture
Living biomass	*CAMFor* – Forest Productivity Index and Tree Yield Formula	*CAMAg* – Crop yield tables
Dead organic matter	*CAMFor*	*CAMAg*
Soil carbon	*Roth-C*	*Roth-C*
Offsite products	NA	NA

Entry of lands into forest land converted to cropland and grassland sub-categories

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 7.27. 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 7.27.

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 7.26: Diagrammatic representation of the spatially explicit approach used to estimate the forest land conversion sub-categories



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 (see Appendices 7.B to 7.E) data for that pixel from a series of spatial grids and databases);
- 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 Appendix 7.D).

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.

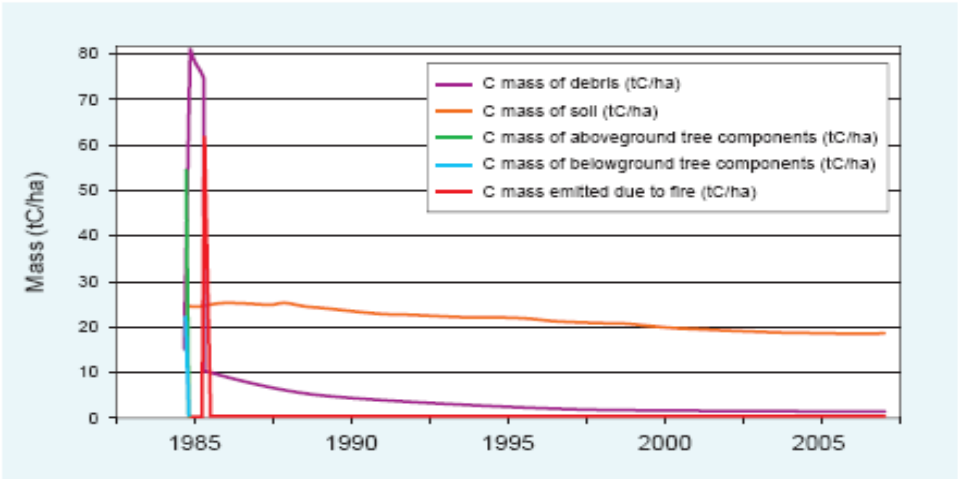
As land remains in the accounts from the time of the initial clearing event, any lagged emissions are reported in the account in the years subsequent to the clearing event. Therefore, for any given year, all sinks and sources including any lagged emissions, from all lands that have entered the account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

The lagged emissions profile in Figure 7.28 shows that the greatest impact of lagged emissions on overall emissions estimates occurs within the first two years following a land clearing event.

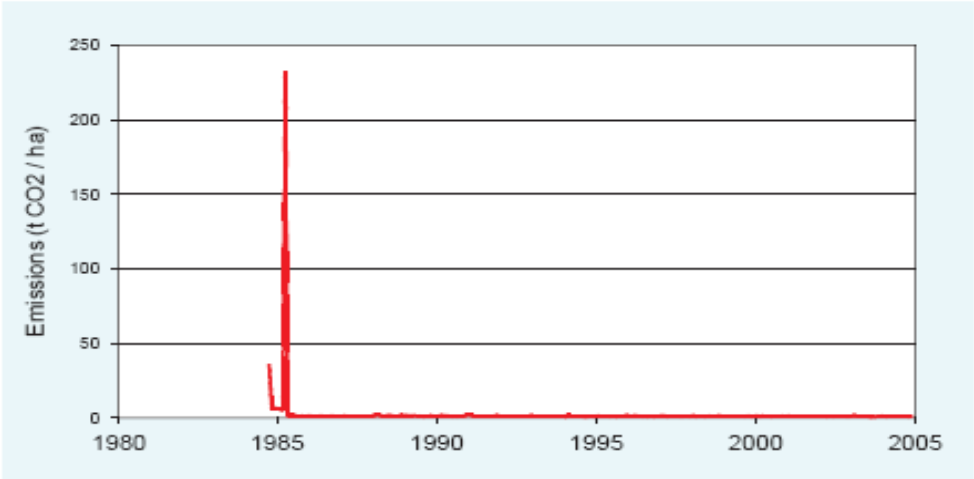
After 50 years, these forest conversion lands and their associated emissions/removals will be reallocated to the land remaining sub-categories.

Figure 7.27: *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; and b) emissions (t CO_2-e ha^{-1}) from all carbon pools

(a)



(b)



Estimating Changes in Biomass

The initial forest biomass and subsequent forest regrowth is estimated using the approaches outlined in Appendices 7.B to 7.D and the parameters described below. The parameters needed to model the subsequent crop and pasture are detailed in Appendix 7.B4.

Wood Basic Density

There is a key benefit 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. It 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 (Table 7.31) is an approximate average of the values for species typically represented in each class.

Table 7.30: 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

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). 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 (Table 7.32) are drawn from the best available data, largely taken from the synthesis of data compiled by Snowdon et al. (2000).

Table 7.31: 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	0.1	0.02	0.08	0.04
Eucalyptus Open Forest	0.45	0.12	0.1	0.02	0.25	0.06
Eucalyptus Low Open Forest	0.45	0.12	0.1	0.02	0.25	0.06
Eucalyptus Woodland	0.44	0.15	0.1	0.02	0.23	0.06
Acacia Forest and Woodland	0.42	0.15	0.1	0.02	0.25	0.06
Callitris Forest and Woodland	0.42	0.15	0.1	0.02	0.16	0.15
Casuarina Forest and Woodland	0.42	0.15	0.1	0.02	0.25	0.06
Melaleuca Forest and Woodland	0.42	0.15	0.1	0.02	0.25	0.06
Other Forests and Woodland	0.42	0.15	0.1	0.02	0.25	0.06
Eucalyptus Open Woodland	0.41	0.18	0.1	0.02	0.23	0.06
Tropical Eucalyptus woodland/ grassland	0.41	0.18	0.1	0.02	0.23	0.06
Acacia Open Woodland	0.22	0.165	0.1	0.025	0.42	0.07
Mallee Woodland and Shrubland	0.22	0.165	0.1	0.025	0.42	0.07
Low Closed Forest and Closed Shrubland	0.22	0.165	0.1	0.025	0.42	0.07
Acacia Shrubland	0.22	0.165	0.1	0.025	0.25	0.24
Other Shrubland	0.22	0.165	0.1	0.025	0.25	0.24
Heath	0	0.3	0.18	0.03	0.25	0.24
Chenopod Shrub, Samphire Shrub and Forbland	0	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 various tree components (Table 7.33) is drawn from an analysis of a range of species across a range of environments by Gifford (2000a, 2000b).

Table 7.32: Carbon content of tree components – forest conversion categories

Tree Component	Carbon Content (fraction of dry matter)
Stems	0.5
Branches	0.47
Bark	0.49
Leaves and Twigs	0.52
Coarse Roots	0.5
Fine Roots	0.48

Estimating Changes in Debris

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 7.37. These draw heavily on the rates determined by Paul et al. (2002b) in a model calibration study.

Table 7.33: Tree component turnover rates

Tree Component	Turnover rate yr^{-1}
Leaf	0.5
Branch	0.05
Bark	0..07
Coarse Roots	0.1
Fine Roots	0.85

Table 7.34: Initial forest litter values (t dry matter ha-1)

Major Vegetation Group (MVG) Class	Decomp-osable Fine Decay	Resistant Fine Decay	Decomp-osable Coarse ecay	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

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 7.35. 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.

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 deadwood, 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 7.36. 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. This was so that a reasonable balance between turnover (input to litter pools) and decomposition of litter pools was achieved.

Table 7.35: Litter decomposition rates for tree components

Plant Component	Decomposition Rate (yr^{-1})
Decomposable Leaf	1
Resistant Leaf	1
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

Estimate Changes in Soil Carbon

A full description of the soil carbon model (*Roth-C*) and the parameterisation of the model are provided in Appendix 7.B.

7.7.2 Uncertainties and Time Series Consistency

Uncertainties for *forest land converted to cropland* and *forest land converted to grassland* at the national scale were estimated to be ±10% for CO_2. 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.

7.7.3 Source Specific QA/QC

The calibration and validation of the *FullCAM* model, along with the associated quality assurance and quality control program are fully described in Appendices 7.B, 7.C, 7.D and 7.G.

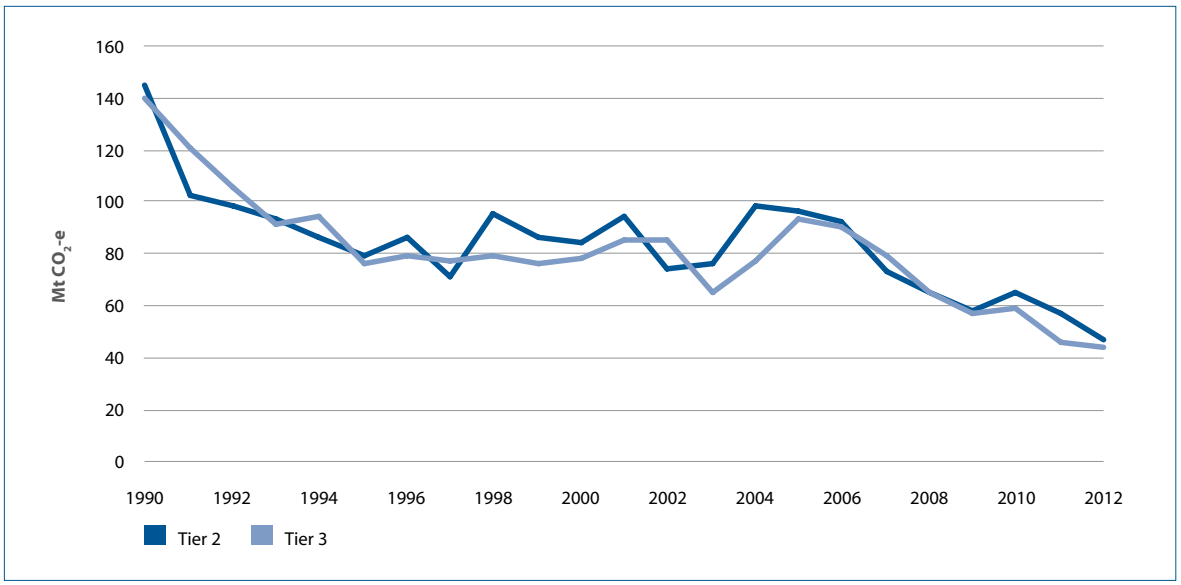
Verification using Tier 2 model

Verification of the Tier 3 based emission estimates from this sub-category was performed through comparison with a Tier 2, Approach 2 method (described in Appendix 7.I). The Tier 2 method is an excel spreadsheet model 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 model includes all carbon pools (living biomass, dead organic matter and soil) and emissions from fire.

The results from the two models are largely consistent and follow the same trend since 1990. By and large, the emissions output does not vary substantially between the Tier 2 and Tier 3 models.

The Tier 2 method uses country-specific coefficients for three regions differentiated by vegetation class 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 finely disaggregated spatial variability relating to soil types (and their characteristics) and climate variability (particularly rainfall) which would have an effect on emission levels. 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 estimates based on the site characteristics of the land subject to clearing.

Figure 7.28: Emissions from *forestland converted to cropland* and *grassland* output from Tier 2 and Tier 3 methodology from 1990 to 2012.



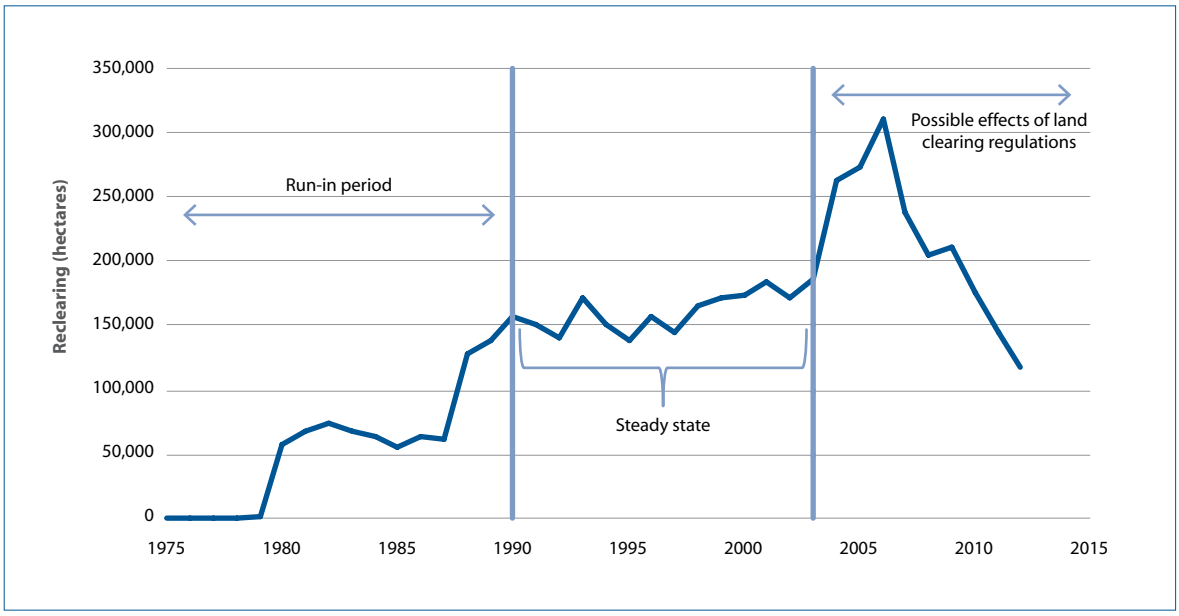
Testing sensitivity of emissions in 1990 to re-clearing prior to 1990

The Tier 2 forest conversion model described in Appendix 7.I has been further used to test the sensitivity of the 1990 estimate of emissions from Forest land converted to other land uses to the amount of re-clearing prior to 1990.

Re-clearing is the observation of forest clearing on land which has been observed to be cleared previously. Observations of re-clearing are constrained by the availability of Landsat data from 1972 (see Appendix 7.A). Despite this constraint, by 1990, observed re-clearing reaches a level that is consistent with the amount of re-clearing observed subsequently – a steady-state of re-clearing is observed (Figure 7.29). From 2004 re-clearing rates increase from the steady-state and then decline in the period 2007 to 2012. Aside from the effects of economic drivers, the recent declines may be due to the more restrictive land clearing policy changes implemented in 2007. The current decline may also reflect land managers bringing forward decisions to clear land in the period 2004 and 2006 – the period between the passage of the new laws and before they came into force.

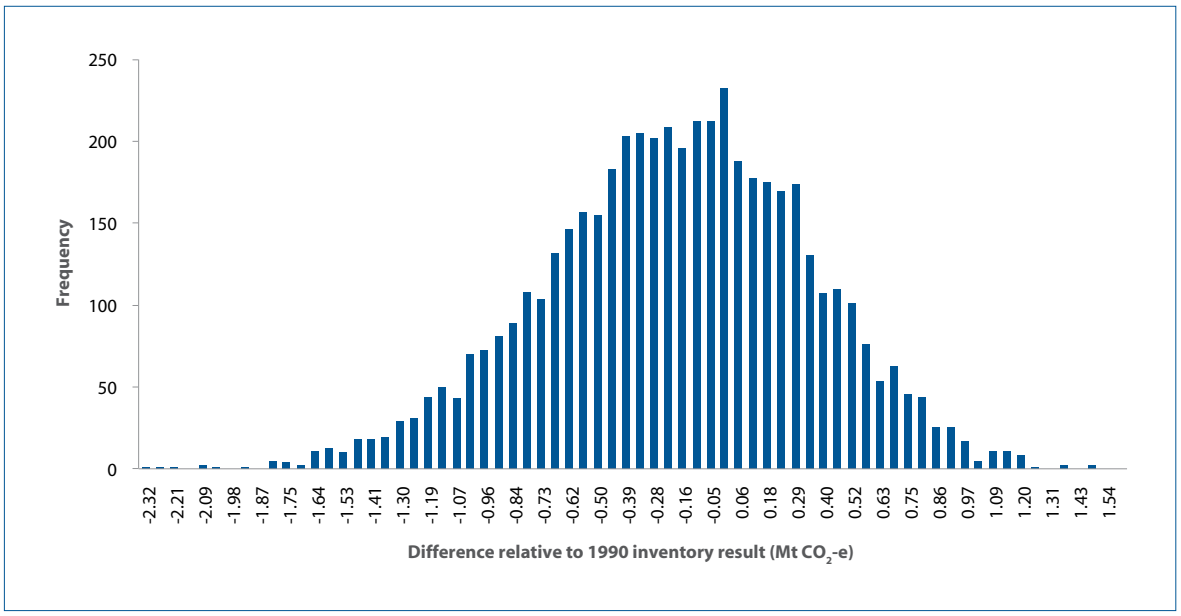
By 1990 re-clearing had reached a steady state, while the observed re-clearing during the run-in period 1972-1989 (Figure 7.29) is less certain. To test the potential interpretation of the impact of varying levels of re-clearing prior to 1990 on estimated emissions in 1990, a simulation with 5,000 iterations was undertaken using the tier 2 forest conversion model (see Appendix 7.I for a description of this model).

Figure 7.29: Observed re-clearing 1975-2012



The simulations were set to randomly select an amount of re-clearing within the range of approximately 0-500,000 hectares per year in the period 1972-1989. The results of this analysis are presented in Figure 7.30.

Figure 7.30: Sensitivity of 1990 emissions estimate (Forest land converted to other land uses) to simulations of re-clearing scenarios prior to 1990.



The results of this sensitivity analysis show that the estimate of emissions in 1990 is relatively insensitive to re-clearing prior to 1990 (Figure 7.30). The results fell within the range of approximately -2.5 Mt CO_2-e to 1.5 Mt CO_2-e relative to the inventory estimate. To simulate re-clearing rates higher than those observed (Figure 7.29), it was necessary to simulate a corresponding first time clearing event further in the past[1]. This results in emissions estimates that are estimated to be lower in 1990 under these scenarios because of the additional time available for the decay of soil carbon and forest debris prior to 1990.

7.7.4 Recalculations Since the 2011 Inventory

The initialisation of soil carbon stocks for land observed to be clear of forest in 1972 has been updated to be consistent with the method used in categories 5.B.1 and 5.C.1.

[1] Where regrowth (prior to re-clearing) was simulated to occur between 5-10 years after first time clearing, which in-turn was simulated to occur between 10-15 years prior to regrowth. As a result the simulation included scenarios where first-time clearing was modelled to occurs as far in the past as 1947 (1972 minus (10+15).

Table 7.36: Forest Conversions: recalculation of total CO2-e emissions, 1990-2011

	Forest land Converted to Cropland					Forest land Converted to Grassland			
	2013 submission	2014 submission	Change			2013 submission	2014 submission	Change	
Year	(Gg CO_2-e)	(Gg CO_2-e)	(Gg CO_2-e)	(%)	Year	(Gg CO_2-e)	(Gg CO_2-e)	(Gg CO_2-e)	(%)
1990	31,248	31,135	-112	-0.4%	1990	109,282	108,956	-326	-0.3%
2000	14,742	14,019	-723	-4.9%	2000	67,481	63,918	-3,563	-5.3%
2005	16,808	15,292	-1,516	-9.0%	2005	81,821	78,372	-3,449	-4.2%
2006	20,264	19,247	-1,017	-5.0%	2006	73,625	70,890	-2,734	-3.7%
2007	17,424	16,094	-1,330	-7.6%	2007	67,733	63,116	-4,618	-6.8%
2008	12,121	11,233	-887	-7.3%	2008	55,019	53,994	-1,025	-1.9%
2009	12,700	11,398	-1,302	-10.3%	2009	46,172	45,183	-990	-2.1%
2010	12,538	12,968	430	3.4%	2010	44,216	45,958	1,742	3.9%
2011	12,998	9,776	-3,222	-24.8%	2011	34,882	36,107	1,225	3.5%

7.7.5 Source Specific Planned Improvements

DE has 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 planned improvements associated with the modelling of crops and grasslands are detailed in *cropland remaining cropland* and *grassland remaining grassland* sections below.

7.8 Source Category 5B1 Cropland Remaining Cropland

The *cropland remaining cropland* sub-category includes continuous cropping lands and 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*.

There are two components of the *cropland remaining cropland* emission estimates – the cropland soils component and the perennial woody crop component.

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).

7.8.1 Methodology

Carbon dioxide emissions and removals from the *cropland remaining cropland* soils component are estimated using *FullCAM* (Appendix 7.B). The CO_2 emissions and removals associated with changes in the area of perennial woody crops are estimated using the tier 2 approach outlined below.

Non-CO_2 emissions from *cropland remaining cropland* are reported in the Agriculture sector.

Soil

The CO_2 emissions and removals from *cropland remaining cropland* soils are estimated using Tier 3, Approach 3 *FullCAM* supplemented by project level data from government abatement programs, as appropriate. When configured for cropland remaining cropland, *FullCAM* uses the same climate, site and management datasets as those used in the *forest land converted to cropland* estimates as described in Appendix 7.B and 7.E.

FullCAM estimates emissions from all on-site carbon pools (living biomass, dead organic matter and soil). However, for *cropland remaining cropland*, only the changes in the soil carbon pool are reported. Carbon stock changes from living biomass and dead organic matter of annual crops are reported to be zero, consistent with the *IPCC Good Practice Guidance for LULUCF* (IPCC 2003 – page 3.71). The rationale for this decision is that yearly carbon stock changes for living biomass of annual crops are assumed to equal to zero because, at the end of each crop cycle, any increase in biomass will tend to equal the losses from harvest and mortality in that same year.

Model Equilibration

FullCAM requires initial soil carbon values before commencing simulations in 1990. The initial soil carbon spatial layer used in *FullCAM* derives from an estimate of carbon stocks, which assumes that the entire landscape was previously covered in native forest or open woodland vegetation. Prior to land-clearing, the native vegetation on the croplands ranged from woodland to sparse woody vegetation. As historical land use records show the introduction of cropping practices and transitional land clearing from 1800 (Heathcote 1987), the *cropland remaining cropland* soil carbon pool is modelled from this date. The purpose of the equilibration period is to allow the soil carbon stocks to reach a stable baseline and remove legacy carbon associated with forest debris prior to the establishment of historical management practices and crop/pasture rotations from 1970.

Crop management practices

Management practices are not varied for the current *cropland remaining cropland* estimates. This is because comprehensive management data that is spatially and temporally explicit is not yet available on a national scale. Additionally, further work is required for *FullCAM* to implement management change over time. Hence, variation in carbon stocks is largely driven by crop production, which varies due to climate and improved breeding. Therefore emissions and removals from this sub-category follow climatic effects on crop production.

Perennial Woody Crops

The CO_2 emissions and removals from changes in the area of perennial woody crops are estimated using a CS Tier 2 approach. The Tier 2 method retains the basic Tier 1 approach from the *IPCC Good Practice Guidance for LULUCF* (IPCC 2003), but with the following differences: of a shorter period over which biomass accumulates (harvest/maturity cycle), more accurate crop-specific coefficients are used and accounting for total crop biomass rather than only above-ground biomass.

Harvest/maturity cycle

Carbon is assumed to accumulate at a steady rate until maturity. Once mature, additional tree growth is assumed to be offset by management practices such as pruning, consequently, CO_2 is no longer removed. Maturity is considered to occur at half the crop's harvest cycle. This approach is consistent with the practice of other countries, such as Greece.

Crop specific data

Crop-specific coefficients were sourced from the literature to calculate CO_2 emissions and removals. The coefficients required are: total biomass carbon stock at harvest (tonnes C ha^{-1}), harvest cycle (yr), biomass accumulation rate (tonnes C ha-1 yr^{-1}) and plot density (trees ha^{-1}). The mathematical relationships between these coefficients are displayed in Table 7.37. Additionally, root to shoot ratios were sourced from the literature and biomass accumulations associated with fruit production were excluded from all calculations.

Table 7.37: Calculations used to develop tier 2 coefficients for perennial woody crops

	total biomass carbon stock at harvest (t C ha^{-1})	harvest cycle (yr)	biomass accumulation rate (t C ha^{-1} yr^{-1})
calculations	(x/2)*y	X	y
e.g. (oranges)	7.5	30	0.5

Note that x and y are sourced from literature and crop maturity is half of harvest cycle.

In total, 27 perennial woody crop types are modelled. However, due to paucity of data, these crops are grouped by major crop-type. The coefficients applied to each group were based on the dominant crop-type (Table 7.38). The four main crop-types and dominant crops are: 1) citrus, with crop coefficients represented by orange data, 2) nuts, with crop coefficients represented by macadamia data, 3) pomes, with crop coefficients represented by apple data and 4) stone fruit, with crop coefficients represented by peach data. Other smaller crops modelled included: olives, grapes kiwifruit, avocados and mangoes. Grape crop coefficients were used to model kiwifruit, and avocado coefficients were used to model mangoes. Regarding nuts, while macadamias were used as the representative crop, almonds were estimated separately as almond-specific coefficients were available.

Estimates of changes in area of perennial woody crops are taken from the ABS agricultural commodity statistics. Most crop data are provided as tree number values and subsequently were converted to area statistics using crop-specific plot density coefficients (Table 7.38).

Table 7.38: Perennial woody crop tier 2 coefficients

Crop type	total biomass carbon stock at harvest (t C ha^{-1})	harvest cycle (yr)	biomass accumulation rate (t C ha-1 yr^{-1})	plot density (trees ha^{-1})	root : shoot
Citrus					
Oranges	7.5	30 ***a***	0.5 ***a***	556 ***b***	0.17 ***c***
Nuts					
Macadamias	45	30 ***d***	3 ***e***	355 ***e***	0.25 ***e***
Almonds	15	25 ***a***	1.2 ***a***	222 ***f***	
Pomes					
Apples	10.2 ***g***	28 ***g***	0.7	500 ***g***	0.17 ***c***
Stone fruit					
Peaches	9.8	15 ***a***	1.3 ***a***	740 ***h***	0.17 ***c***
Grapes	3.8	25 ***a***	0.3 ***a***	N/A	0.5 ***c***
Kiwifruits	3.8	25 ***a***	0.3 ***a***	N/A	0.5 ***c***
Olives	6.67	20 ***i***	0.67 ***j***	250 ***k***	0.145 ***c***
Avocados	7.2 ***l***	25 ***a***	0.6	100 ***l***	0.125 ***l***
Mangoes	16 ***l***	25 ***a***	1.3	222 ***m***	0.125 ***l***
IPCC default	63	30	2.1		

Source and location of study is: ***a*** = Kroodsma & Field (2006) USA California, ***b*** = Morgan *et al*. (2006) USA Florida, ***c*** = German and/or Spanish National Inventory Reports (2013), ***d*** = Australian Macadamia Society website, ***e*** = Murphy *et al*. (2013) Australia, ***f*** = Fernandez-Puriatch *et al*. (2013) Spain, ***g*** = Haynes and Goh (1980) New Zealand, ***h*** = Marini & Sowers (2000) USA, ***i*** = Sanfelipe Olives website (2013) USA California, ***j*** = Villalobos *et al*. (2006) Spain, ***k*** = Olives Australia website (2013), ***l*** = Lovatt (1996) USA California and ***m*** = Western Australian Government Agricultural website (2013). Note that plot density is represented by N/A for Grapes and Kiwifruit as reported in hectares by ABS. All figures not referenced were determined using the calculations presented in Table 7.37.

7.8.2 Uncertainties and Time Series Consistency

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.

There are a number of gaps in the time series of ABS commodity statistics for perennial woody crops. All data-gaps were filled using extrapolation and interpolation techniques consistent with the *IPCC Good Practice Guidance for LULUCF* (IPCC 2003).

7.8.3 Source Specific QA/QC

The calibration, validation and verification of the *FullCAM* model, along with the associated quality assurance and quality control program, are fully described in Appendix 7.B. Additional category specific QA/QC activities are undertaken on the crop yield database and *cropland remaining cropland* emissions and removal estimates.

In relation to crop yields, CSIRO Land and Water has tested the performance of the crop growth model against a database of crop yields (see Appendix 7.E).

The DE Agriculture Inventory Team also undertakes quality control processes on the outputs of the spatial FullCAM simulations. The outputs are reviewed and evaluated against the outputs from the previous inventories.

7.8.4 Recalculations Since the 2011 Inventory

Since the 2011 inventory, the entire time series for cropland remaining cropland has been revised (see Table 7.39) due to the implementation of a:

1. dynamic crop/pasture growth model into *FullCAM* (Appendix 7.E.5). Previously plant yields were selected from a database.
2. new CS Tier 2 method for estimating emissions and removals from perennial woody crops.

Table 7.39: Cropland remaining cropland: Recalculation of CO2-e emissions 1990-2011

Year	2013 submission	2014 submission	Change	
	(Gg CO_2-e)	(Gg CO_2-e)	(Gg CO_2-e)	(%)
1990	1,754	2,864	1,110	63.3%
2000	-2,475	3,839	6,314	-255.2%
2005	-1,294	4,886	6,180	-477.5%
2006	-3,526	5,249	8,775	-248.9%
2007	1,400	9,559	8,159	582.9%
2008	-217	946	1,164	-535.2%
2009	1,693	3,293	1,600	94.5%
2010	7,434	5,754	-1,680	-22.6%
2011	3,122	-2,753	-5,874	-188.2%

7.8.5 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.

Spatial and temporal distribution of agricultural management practices

Significant changes to the types of crops and pastures produced in Australian agricultural systems, the various management practices imposed during their production, and where they are located, have occurred since 1980. To improve the accuracy of soil carbon estimates, alteration to the regimes currently being used in *FullCAM* is required. It is proposed that the data available from the Australian Bureau of Statistics (ABS) for 1980 onwards and additional datasets available pertaining to pasture composition, be used to redefine the relative areas of crops and pastures within each Statistical Area (SA). The selection of which crops and pastures to include will be based on their importance within the Australian state, with all crops and pastures included to cover 99% of the lands allocated to agriculture, provided that there is more than 500 ha of agricultural land within the SA. CSIRO will work with DE staff to develop the most appropriate allocation of crop types to pixels within SAs that respect the boundaries associated with the *cropland remaining cropland*, *grassland remaining grassland* and forest conversion components of the national inventory. Additionally, a series of rules will be created to ensure that crop/pasture rotations typical of the SA are maintained. ABS data pertaining to the use of management practices such as tillage and stubble handling will be used to allocate management events.

Shift from pre-clearing soil carbon layer

The current process implemented for establishing initial soil carbon stock represents the best approach that could be applied when *FullCAM* was developed. However, the enhanced availability of soil carbon stock and composition from the Soil Carbon Research Program (SCaRP) and other sources over the last 10 years allows for the development of a new spatial approach.

SCaRP has collected field measurement data to quantify soil carbon stocks and fraction composition at a national scale. CSIRO has been using this data to construct new national spatial layers of soil carbon stocks and composition with corresponding estimates of certainty. DE and CSIRO are investigating the development of spatial maps of soil carbon stocks and composition for 1970 and 1990 from the 2010 soil organic carbon stock map created by CSIRO from SCaRP and other available soil carbon data. The 1970 surface could then be applied as a new spatial layer for use by *FullCAM*. This would alleviate the need to perform soil run-in calculations from 1800 or earlier for the *cropland remaining cropland* and g*rassland remaining grassland* estimates.

Minimising the impact of climate variability

The *2013 Revised Supplementary Methods and Good Practice Guidance Arising from the Kyoto Protocol* (IPCC 2013) (KP Supplement) acknowledges that tier 3 process models, such as *FullCAM*, can report very high inter-annual variability in emissions and removals as a result of climate variability. This variability can be large enough to mask the signal of human activities which is undesirable. Parties are advised to implement methods to minimise the impact of inter-annual variability on reported estimates. The KP Supplement provides some examples of methods to reduce inter-annual variability in the estimates. These approaches will be investigated with a view to reducing the impact of climate variability on future *cropland remaining cropland* and *grassland remaining grassland* estimates.

7.9 Source Category 5C1 Grassland Remaining Grassland

The *grassland remaining grassland* category includes all areas of *grassland* that are not reported under f*orest 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*.

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.

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). 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.

7.9.1 Methodology

Carbon dioxide emissions from the *grassland remaining grassland* category are estimated using a mix of methods. The grass only component is estimated using *FullCAM* (Appendix 7.B), while the shrubland transition component and CO_2 emissions and removals associated with savanna fires are estimated using the Tier 2 methods outlined below.

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

7.9.1.1 Grass component

Emissions and removals for the grass component are estimated using Tier 3, Approach 3 *FullCAM* supplemented by project level data from government abatement programs, as appropriate. *FullCAM* estimates carbon changes from all on-site pools (living biomass, dead organic matter and soil). However, for the grass component only the changes in the soil pool are reported. Carbon stock changes from living biomass and dead organic matter are not reported, consistent with the *IPCC Good Practice Guidance for LULUCF* (IPCC 2003).

Stratification of grasslands

There are three main agro-ecological categories in grasslands:

- native arid and semi-arid grasslands which comprise sparse woody vegetation and woodlands, and remain as primarily native pastures with some introduced species; and
- high rainfall improved pastures.

The key management practices relevant to estimating changes in carbon stocks in the high rainfall pastures include: grazing intensity; pasture composition; fertiliser and organic amendments; and irrigation. For the native arid and semi arid grasslands, the key drivers include grazing intensity, fire management and the presence of woody vegetation.

Management practice

Management practices are not varied for the current *grassland remaining grassland* estimates. This is because comprehensive management data, which is spatially and temporally explicit, is not yet available on a national scale. For the high rainfall pastoral regions and semi-arid regions where cropping also occurs, the impacts of past clearing events (pre-1970's forest conversion) are modelled. In the other semi-arid and arid regions, it is assumed that these lands have remained native pastures and as such no stock changes are identified on these lands.

Model Equilibration

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). Consistent with the *cropland remaining cropland* equilibrium period, the modelling of the high rainfall pastoral regions, and semi-arid regions where cropping also occurs, commences from 1800 to reflect the gradual clearing of native forest soils for grazing purposes.

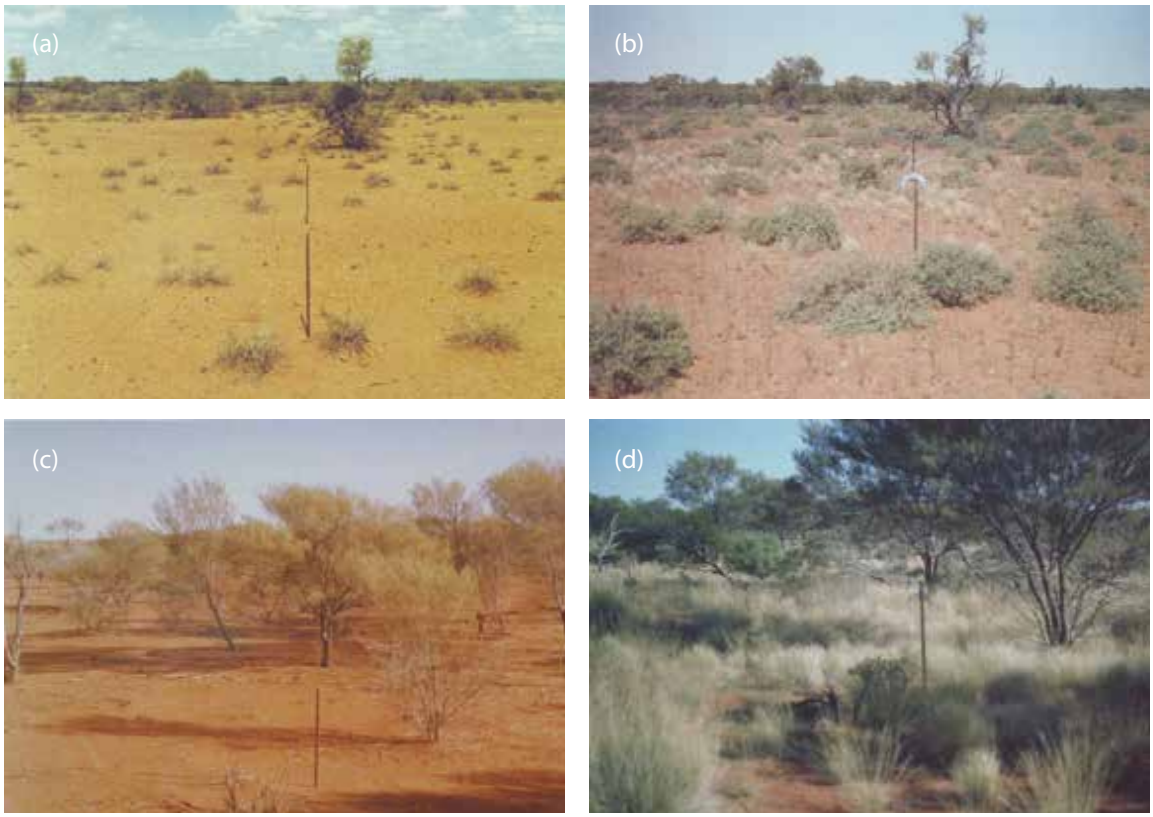
Emissions and Removals

With only pre-1970's forest conversion impacts being modelled, the emissions and removals from this sub-category primarily follow climate effects on pasture production. The impacts of inter-annual variability in climate conditions may result in incorrect conclusions about long-term trends. As a result, a five year averaging period is currently applied to the reported estimates. Alternative approaches for minimising the impact of climate variability on the estimates are under investigation (see section 7.8.5).

Grass and Shrub Transitions

There are many processes that lead to transitions between shrubs and grasses in Australian ecosystems. Direct anthropogenic transitions between shrub and grass systems, such as land clearing and establishment of shrub plantations (e.g., saltbush for grazing and tea-tree for oils), are readily identifiable as the 'cause' for the transition. Equally, losses due to natural and managed fires are also straight forward to interpret. Transitions that are not in response to a direct human intervention are difficult to assign a cause to, as they may occur in response to the combination of past or current land management and climate. While the climate driven process is well understood, quantifying its effects is not straight forward. Figure 7.31 highlights how the presence of shrubs can be affected by climate variability with 'flushing' in standing plants following a rainfall event.

Figure 7.31: The impact of climate variability on woody shrubs. Photos (a) and (c) are drought affected shrublands, while photos (b) and (d) are the same shrublands following a rainfall event.



(Source: Watson *et al*. 2004).

A combination of climate and past management practices may contribute to the 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.

Mapping of Extent and Change in Shrubs

To supplement the forest extent 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:

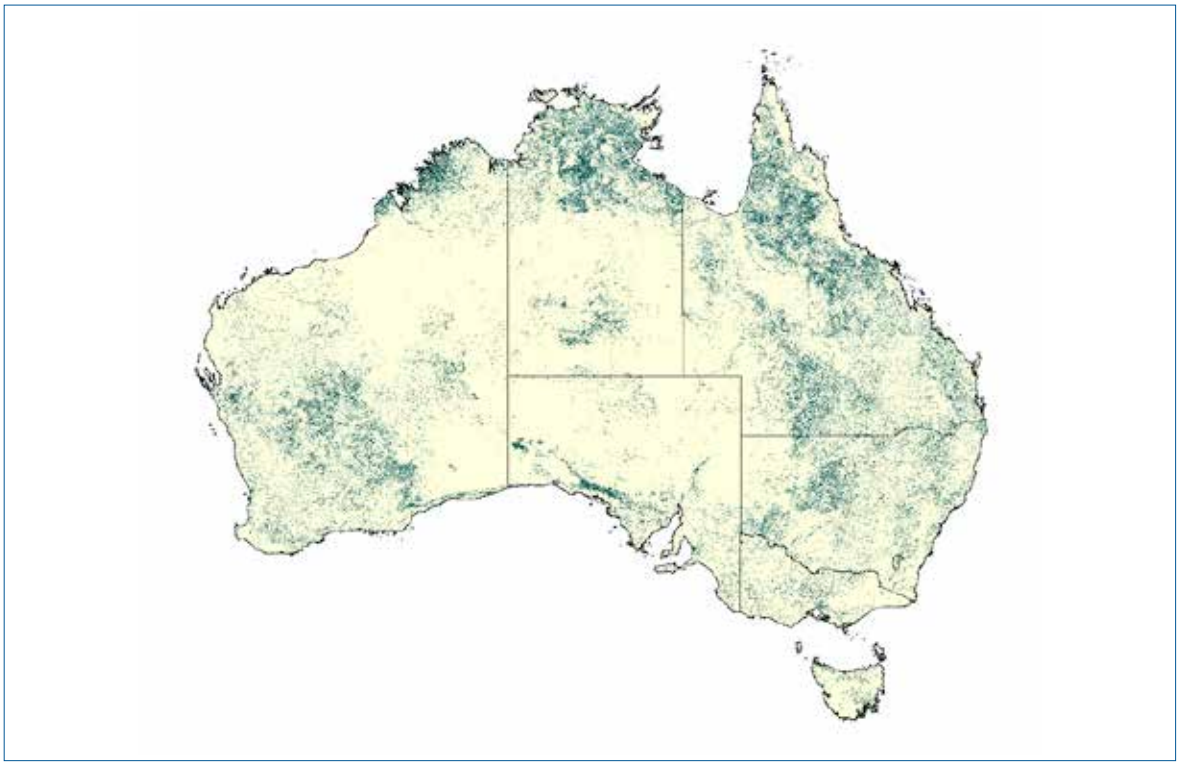
1. reliable extent and change mapping is possible (Caccetta and Furby, 2004) by supplementing the techniques applied to forest mapping to deal with the impact of low signal (proportion of woody vegetation of interest) to noise (other vegetation) ratio;
2. the low signal to noise ratio leads to a variable 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
3. 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.

To date, a national coverage of shrubland extent (Figure 7.32) and change data is available for the years from 1989 to 2006. For a subset of areas change, analysis has been applied and verified for the period 1991 to 2004.

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 twenty years. Where the area of sparse vegetation increases, it is assumed that these will regrow to 10 t DM ha^{-1} over twenty years (i.e., a growth rate of 0.5 t DM ha^{-1} yr^{-1}).

Figure 7.29: Extent of sparse vegetation



Fires

Fires are the major natural disturbance in grasslands, and area burnt 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 the areas of savanna woodland burnt and country-specific parameters used for the *prescribed burning of savannas* (4.E).

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
- 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). Fuel load consumed by fire is in accordance with 4.E savanna burning. The accumulation of fuel load is estimated using a linear growth model which is based on the years since last burnt (YSLB). For example, where YSLB is five years the fuel load accumulates evenly over five years, and where YSLB is one year, all fuel accumulates within a single year.

7.9.2 Uncertainties and Time Series Consistency

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.

7.9.3 Source Specific QA/QC

The calibration and validation of *FullCAM* along with the associated quality assurance and quality control programs are described in Appendices 7.B and 7.E. Additional category specific QA/QC activities are undertaken on the yield database and *grassland remaining grassland* emissions and removal estimates.

The quality assurance and control process associated with the yield data is the same as that performed for *cropland remaining cropland* (see section 7.8.3). The DE Agriculture Inventory Team also undertakes quality control processes on the outputs of the spatial *FullCAM* simulations by reviewing and evaluating them against the outputs from the previous inventory.

The fire data for the shrubland component is collated and quality assured by CSIRO Sustainable Ecosystems (Darwin) before being received by the DE. Once the fire data is received by DE, it undergoes a quality control process by comparing the most recent data to the previous year's data. The shrubland and grass transitions use the updated LAI data as per *other native forests*, which has already undergone QA/QC processes.

7.9.4 Recalculations Since the 2011 Inventory

Soils

The time-series for soils has been recalculated following the implementation of a dynamic crop/pasture growth module in *FullCAM*. Previously, plants yields were selected from a yield database.

Fire

The effect of the fire recalculations on the *grassland remaining grassland* sub-category is presented in Table 7.40.

Shrubland Transitions

The methodology to estimate emissions associated with transitions in sparse woody vegetation has been amended from the 2013 inventory submission. The methodology is a variant of the previous methodology with the following modifications:

- Annual change in sparse woody (shrub) vegetation is based on time series Landsat data from 1989 to 2006, as opposed to the previous method that relied upon extrapolated data using a relationship derived from the observed shrubland changes in the NSW and the national trends in leaf area index. Annual change in sparse woody vegetation for the period from 2007 to 2013 is estimated based on five year moving average method.

Table 7.40: Grassland remaining grassland: Recalculation of CO2-e emissions 1990-2011

Year	2013 submission	2014 submission	Change	
	(Gg CO_2-e)	(Gg CO_2-e)	(Gg CO_2-e)	(%)
1990	13,954	35,779	21,826	156.4%
2000	38,385	5,314	-33,071	-86.2%
2005	18,438	25,646	7,209	39.1%
2006	1,828	11,507	9,679	529.6%
2007	34,852	26,174	-8,678	-24.9%
2008	17,713	28,287	10,575	59.7%
2009	32,777	13,991	-18,786	-57.3%
2010	29,853	11,337	-18,516	-62.0%
2011	13,733	619	-13,114	-95.5%

7.9.5 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.

Grass Component

As outlined in section 7.8.5, planned improvements include: improving the spatial and temporal distribution of agricultural management practices and pasture types used by *FullCAM*; investigating the development of a new 1970 soil organic carbon stock map based on SCaRP data to alleviate the need to perform soil run-in calculations from 1800 or earlier; and investigation methods for minimising the impact of climate variability on the estimates.

Shrubland transitions

In addition to the new modelling capabilities, Australia is completing a full national time series of change in sparse woody (shrub) vegetation cover from 2007 to 2013 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.

7.10 Source Category 5D Wetland

7.10.1 Methodology

7.10.1.1 Wetland Remaining Wetland

Emissions and removals from this voluntary reporting category were not estimated.

7.10.1.2 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'.

7.11 Source Category 5E Settlements

7.11.1 Methodology

7.11.1.1 Settlements Remaining Settlements

Emissions and removals from this voluntary reporting category were not estimated.

7.11.1.2 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.

Australia intends to develop methods 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.

7.12 Source Category 5F Other Lands

7.12.1 Methodology

7.12.1.1 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.

7.12.1.2 Land Converted to Other Land

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

7.13 Source Category 5G Other

7.13.1 Harvest 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. Emissions from landfill are reported under the *waste* sector of the inventory.

7.13.1.1 Methodology

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. Initial model development was undertaken by Jaakko Pöyry Consulting (1999, 2000). Updates and model refinement were subsequently undertaken by MBAC Consulting and DE staff. The refined model and its sensitivity analysis are reported in Richards *et al.* (2007).

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 and Sciences (ABARES 2013c). Log removals data are also published by the relevant State Forest Services, and these provide a valuable crosscheck on ABARES 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 ABARES information by applying a conversion factor to sawn-wood consumption and applying a conversion factor to convert back to 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 ABARES (2013c) by end use categories.

Details of the flows are shown in Appendix 7.J.

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. 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 7.41: Basic densities, moisture and carbon contents

Carbon Fractions	
Description	**Value**
Fraction of softwood sawmilling dry matter that is carbon, by weight	0.5
Fraction of particleboard dry matter that is carbon, by weight	0.4
Fraction of MDF dry matter that is carbon, by weight	0.4
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	1.1
Ratio of weight of water to weight of wood substance in hardwood chips	0.9

(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. All slabs and edgings are chipped for paper pulp or panel board feedstock and the sawdust and shavings are 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 ABARES (2012c).

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. This is 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. It is 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 ABARES (2012c).

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 ABARES quarterly reports (ABARES 2012d).

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 ABARES. Jaakko Pöyry Consulting (2000) estimated annual production is less than 10,000 m^3. Data sources used in the model for plywood was from ABARES (2012c) 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 ABARES (2013c).

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. 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

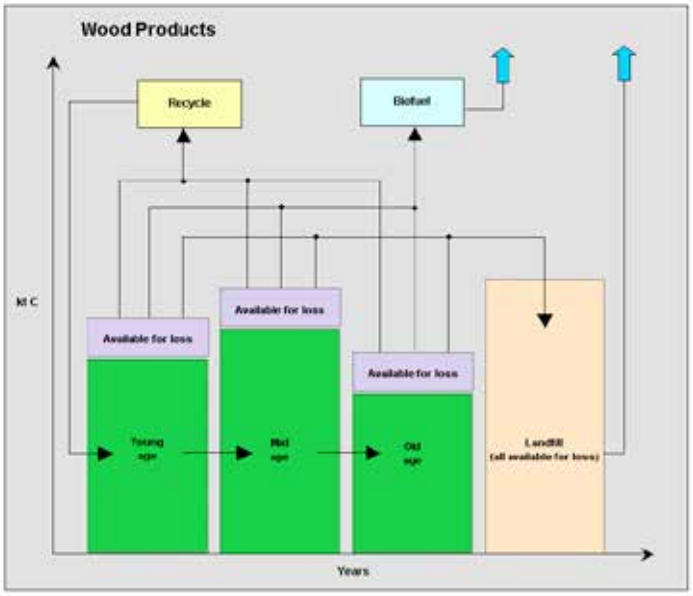
Export woodchips constitute a significant proportion of the annual harvest from Australian forests. The ABARES quarterly forest products statistics report both bone dry tonnes (BDt) of softwood chips and BDt of hardwood chips exported. The model uses the ABARES reported export figures directly in bone dry tonnes.

Total exports of coniferous logs reported by ABARES (2012c) 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 7.33).

Figure 7.30: 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. 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 7.40 and 8.5 (in Chapter 8).

Table 7.42: 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	0.6	0.5	0.65	0.333	0.9
2	0.333	0.3	0.167	0.5	0.1	0.9
3	0.1	0.15	0.05	0.65	0.033	0.45
4	0.05	0.25	0.033	0.65	0.02	0.8
5	0.033	0.2	0.02	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.

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 7.43, 7.44, 7.45 and 7.46. Distributions of possible outcomes were stabilised over 100,000 model iterations. The Tornado Graph (Figure 7.34) 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 7.43: 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 7.44: Decomposition rate uncertainty ranges used in the Monte Carlo Analysis

Age	Pool	Lower Bound	Expected Value	Upper Bound
Young	1	2	1	0.667
	2	1	0.333	0.333
	3	0.2	0.1	0.067
	4	0.067	0.05	0.04
	5	0.05	0.033	0.025
Medium	1	1	0.5	0.333
	2	0.333	0.167	0.111
	3	0.067	0.05	0.04
	4	0.05	0.033	0.02
	5	0.025	0.02	0.017
Old	1	0.5	0.333	0.25
	2	0.2	0.1	0.067
	3	0.05	0.033	0.025
	4	0.025	0.02	0.017
	5	0.013	0.011	0.01

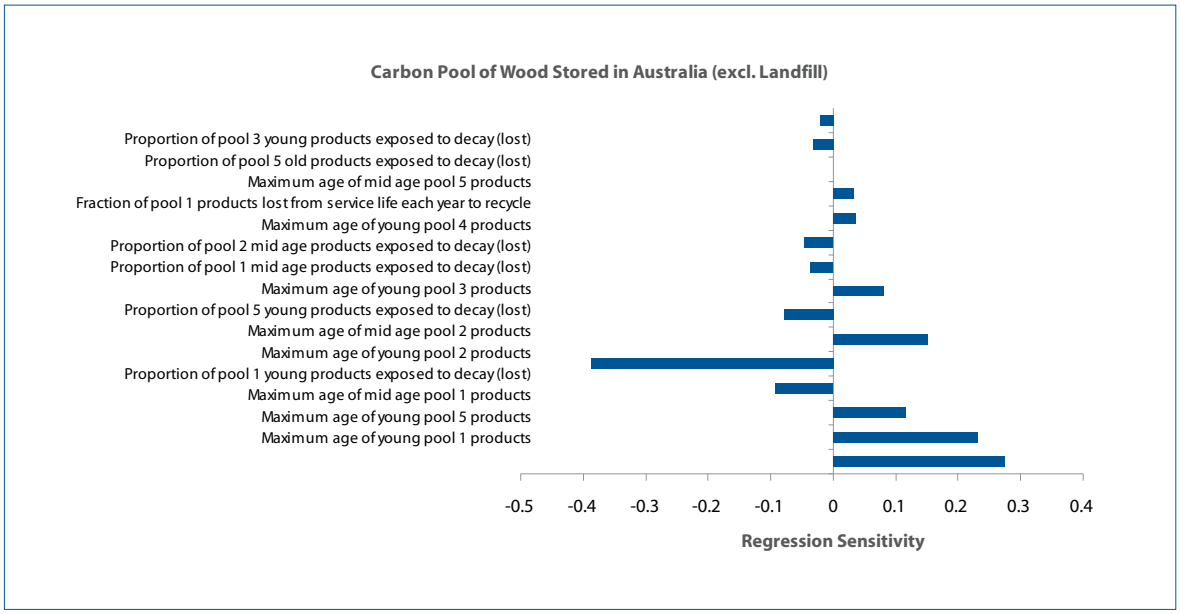
Table 7.45: Pool fractions exposed to decomposition uncertainty ranges used in the Monte Carlo Analysis

Age	Pool	Lower Bound	Expected Value	Upper Bound
Young	1	0.5	0.6	0.7
	2	0.25	0.3	0.35
	3	0.12	0.15	0.18
	4	0.225	0.25	0.275
	5	0.175	0.2	0.225
Medium	1	0.55	0.65	0.75
	2	0.4	0.5	0.6
	3	0.55	0.65	0.75
	4	0.55	0.65	0.75
	5	0.45	0.55	0.65
Old	1	0.8	0.9	1.1
	2	0.8	0.9	1.1
	3	0.4	0.45	0.5
	4	0.7	0.8	0.9
	5	0.8	0.95	1.15

Table 7.46: 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	0.38	0.44	0.5	0.45	0.49	0.53	0.63	0.04	0.05
	2	0.6	0.75	0.9	0.18	0.2	0.22	0.04	0.05	0.06
	3	0.8	0.95	1.1	0.4	0.05	0.06	-	0	-
	4	0.7	0.85	1	0.13	0.15	0.17	-	0	-
	5	0.7	0.85	1	0.09	0.1	0.11	0.04	0.05	0.06

Figure 7.31: Results of the @Risk sensitivity analyses



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 ABARES (2012c) by end use categories.

Table 7.47 shows the annual additions and losses and carbon pool sizes.

Table 7.47: 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	2,190	730	80	3,957	76,756
2000	2,765	920	313	4,439	89,782
2005	3,009	1,005	479	4,696	96,915
2006	2,960	960	493	4,550	98,369
2007	2,931	985	500	4,515	99,802
2008	3,065	1,056	468	4,785	101,369
2009	2,900	922	483	4,398	102,613
2010	2,900	989	515	4,436	103,913
2011	2,797	1,088	556	4,357	105,195
2012	2,713	1,040	568	4,170	106,332

(a) Exports of wood products excluded exports of woodchips

7.13.1.2 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.

7.13.1.3 Source Specific QA/QC

Wood product data are available through the Australian Forests Products Statistics published quarterly by the Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES, 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.

7.13.2 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.

7.13.3 N_2O Emissions from Drainage of Soils 5(II)

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

7.13.4 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. This leads to zero emissions for forest to *cropland* and *grassland* conversions where appropriate at the regional level (State, by vegetation class by age class).

7.13.5 CO_2 Emissions from Agricultural Lime Application 5 (IV)

7.13.5.1 Methodology

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:

$$E_{ijk} = ((M_{jk} \times FracLime_{jk} \times P_{k=1} \times EF_{k=1}) + (M_{jk} \times (1 - FracLime_{jk}) \times P_{k=2} \times EF_{k=2})) \times C_I / 1000 \quad \text{(5IV_1)}$$

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

7.13.5.2 Uncertainties and Time Series Consistency

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.

7.13.6 Recalculations Since the 2011 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 7.48: Other: recalculation of total CO2-e emissions, 1990-2012

Year	2013 submission	2014 submission	Change	
	(Gg CO_2-e)	(Gg CO_2-e)	Change (Gg CO_2-e)	Change (%)
1990	-4,365	-4,389	-24	-0.5%
2000	-4,175	-4,240	-65	-1.6%
2005	-4,138	-4,198	-60	-1.4%
2006	-3,974	-4,034	-60	-1.5%
2007	-3,769	-3,854	-84	-2.2%
2008	-4,177	-4,234	-57	-1.4%
2009	-3,067	-3,107	-40	-1.3%
2010	-2,864	-2,690	173	6.0%
2011	-2,938	-2,943	-5	-0.2%

7.13.7 Source Specific Planned Improvements

All data and methodologies are kept under review and development.

7.14 Source Category 5(V) Biomass Burning

7.14.1 Methodology

7.14.1.1 Forest Land (5A.1)

Prescribed Burning and Wildfires

Only methane and 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 7.49 and Table 7.50),

Z_{jk} = burning efficiency (Table 7.51).

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 7.52),

EF_{ij} = emission factor for gas *i* from vegetation (Table 7.53),

C_i = factor to convert from elemental mass of gas species i to molecular mass (Table 7.54),

and total annual emissions for NO_x and N_2O are:

$$E_{ijk} = M_{jk} \times CC_{jk} \times NC_{jk} \times E_{ijk} \times C_i \quad \text{(5V_3)}$$

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 7.52)

NC_{jk} = nitrogen to carbon ratio in biomass (Table 7.52)

EF_{ijk} = emission factor for gas *i* from vegetation (Table 7.53)

C_i = factor to convert from elemental mass of gas species *i* to molecular mass (Table 7.54)

The CO_2 emissions and removals associated with the burning and subsequent regrowth of forest lands are reported under 5.A.1 *other native forest*, 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 section 7.5.3. The method uses the same data used to estimate non-CO_2 emissions.

Table 7.49: 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	17.9	12

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

Table 7.50: 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	35.8	33.4

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

Table 7.51: Burning efficiencies for Prescribed Burning and Wildfires in Australia

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

Tolhurst (1994)

Table 7.52: 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 7.53: 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 7.54: Elemental to molecular mass conversion factor (Ci)

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:

$$E_{ijk} = FC_{jk} * EF_{ijk} * C_i \quad (5V_6)$$

and for total annual emissions for NO_x and N_2O are:

$E_{ijk} = FC_{jk} * NC_{jk} * EF_{ijk} * C_i$ ..... (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 7.53),

NC_{jk} = nitrogen to carbon ratio in biomass (Table 7.252)

C_i = factor to convert from elemental mass of gas species i to molecular mass (Table 7.54).

7.14.1.2 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*. Thus, they 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 section 7.9.1.

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

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

Carbon dioxide emissions from on-site burning associated with land conversion are estimated using *FullCAM* 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:

$E_{ijk} = FC_{jk} * EF_{ijk} * C_i$ ..... (5V_8)

and for total annual emissions for NO_x and N_2O are:

$E_{ijk} = FC_{jk} * NC_{jk} * EF_{ijk} * C_i$ ..... (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).

7.14.2 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.

7.14.3 Source Specific QA/QC

Specific QA/QC and verification activities undertaken for emission estimation using *FullCAM* are described in Sections 7.5-7.9.

7.14.3.1 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, 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).

7.14.4 Recalculations Since the 2011 Inventory

Small recalculations to the *forest land remaining forest land, forest land converted to cropland* and f*orest land converted to grassland* biomass burning emissions have resulted in a decrease in emissions estimates across the time series from 1990 to 2011 (Table 7.53).

Table 7.55: Biomass Burning: recalculation of total CO2-e emissions, 1990-2011

	2013 submission	2014 submission	Change	
Year	(Gg CO_2-e)	(Gg CO_2-e)	(Gg CO_2-e)	(%)
1990	6,077	6,105	27	0.4%
2000	3,456	3,549	92	2.7%
2005	5,074	5,154	79	1.6%
2006	4,472	4,568	96	2.1%
2007	7,747	7,819	72	0.9%
2008	3,709	3,798	90	2.4%
2009	3,799	3,880	81	2.1%
2010	4,476	4,582	106	2.4%
2011	2,039	2,147	108	5.3%

7.14.5 Source Specific Planned Improvements

All data and methodologies are under review and development.

Appendix 7.A: Land Cover Change

7.A.1 Introduction

Human induced land cover change is a key driver of the pattern of greenhouse gas emissions and removals in Australia's land sector. 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. 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.
- Secondly, the emissions and removals by current activities will be affected by the site history. For example, a current conversion event will likely generate fewer emissions if the forest cleared is secondary forest (regrowth after a previous deforestation) rather than a primary (mature) forest.

With Australia's land area of 769 million hectares, establishing this record of activity presented many challenges. To address this challenge, Australia has assembled a series of national coverages of Landsat satellite data (MSS, TM, ETM+ and OLI) across 22 time epochs from 1972 to 2013 which are analysed to identify both where and when change occurs. This analysis provides the key source of activity data in the LULUCF sector.

7.A.2. Monitoring Change with Remote Sensing Imagery

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.

7.A.2.1 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 *FullCAM*, 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, ETM+ and OLI 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 and 25 m data sets. Differences in the extents of forest between these two outputs are due to "sensor change". An overlap technique 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

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

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. 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).

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.A.2.2 Data processing

In producing the assessment of an Australia-wide land cover change over the time series the sequence of processing stages carried out is:

- image acquisition and selection;
- image registration[3] and calibration[4];
- mosaicing[5] of registered and calibrated images to the single map tiles for each time sequence (Figure 7.A1);
- sun-angle (terrain illumination) correction (Wu *et al.* 2004);
- thresholding[6] through all time sequences; and,
- attribution[7] of change to direct human-induced change.

[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] Mosaicing aggregates images into the map tiles shown in Figure 7.A2, removing overlaps in the original 185 km* 185 km images.

[6] 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.

[7] 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.

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

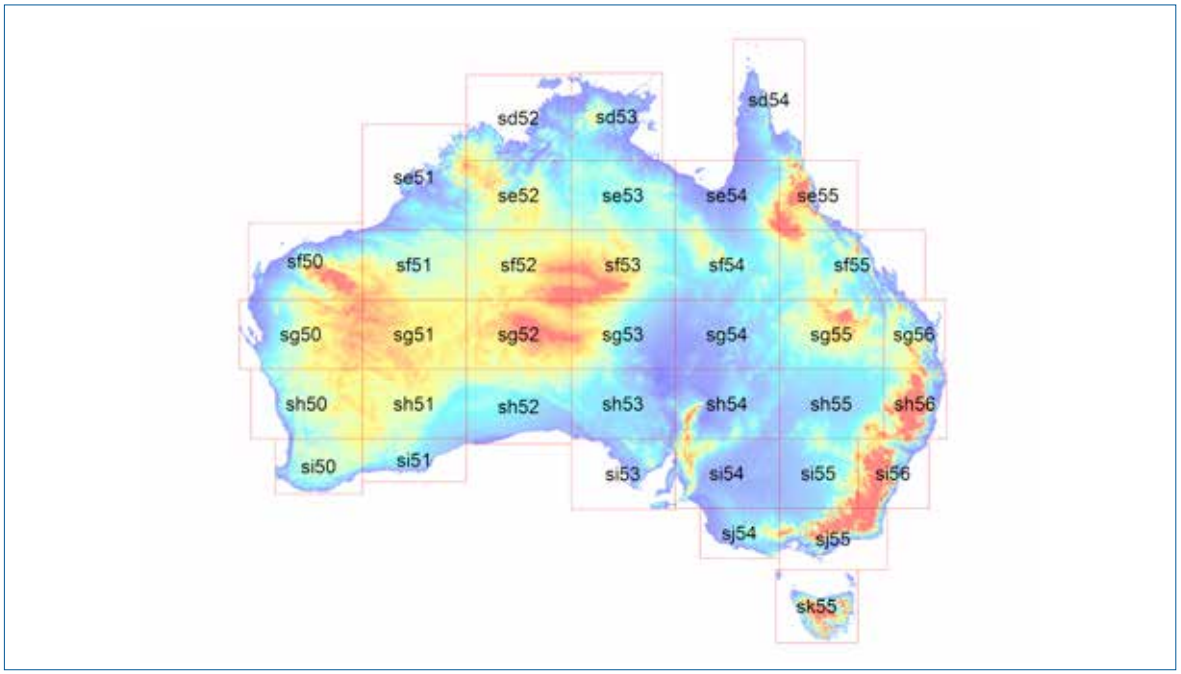


Image Acquisition and Selection

The sequence of images shown in Table 7.A.1 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).

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 7.7.1.1), 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
2012	25	1
2013	25	1

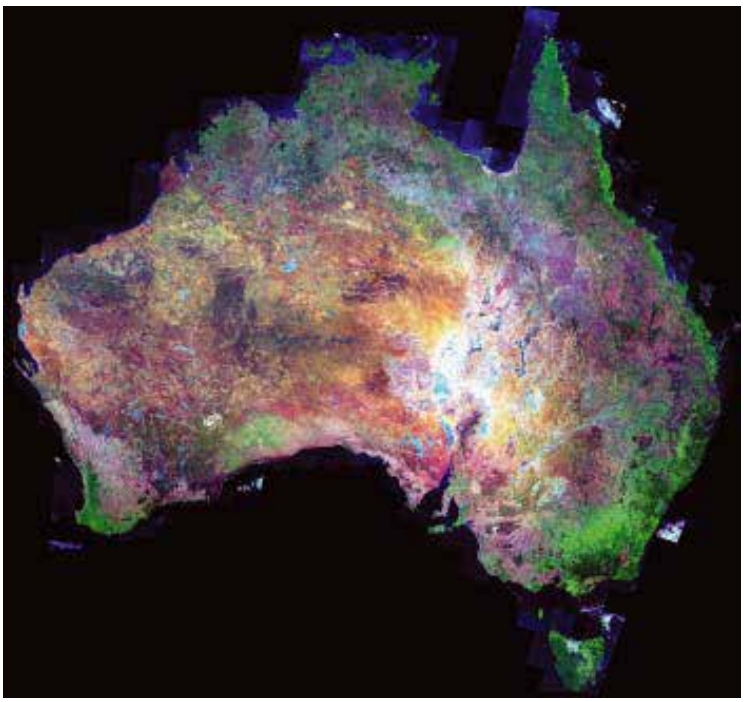
Image registration and Calibration

A Year 2000 Australia mosaic (Figure 7.A.2) 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. There were three steps in the process of creating the base image:

1. Rectification (registration) base
   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.
2. Calibration to create a radiometrically (spectrally) consistent base
   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.

3. Mosaicing into 1:1,000,000 map sheet tiles to form a seamless base (see Figure 7.A.2)
   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.

Figure 7.A.2: The year 2000 mosaic registration and calibration base



Thresholding

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.

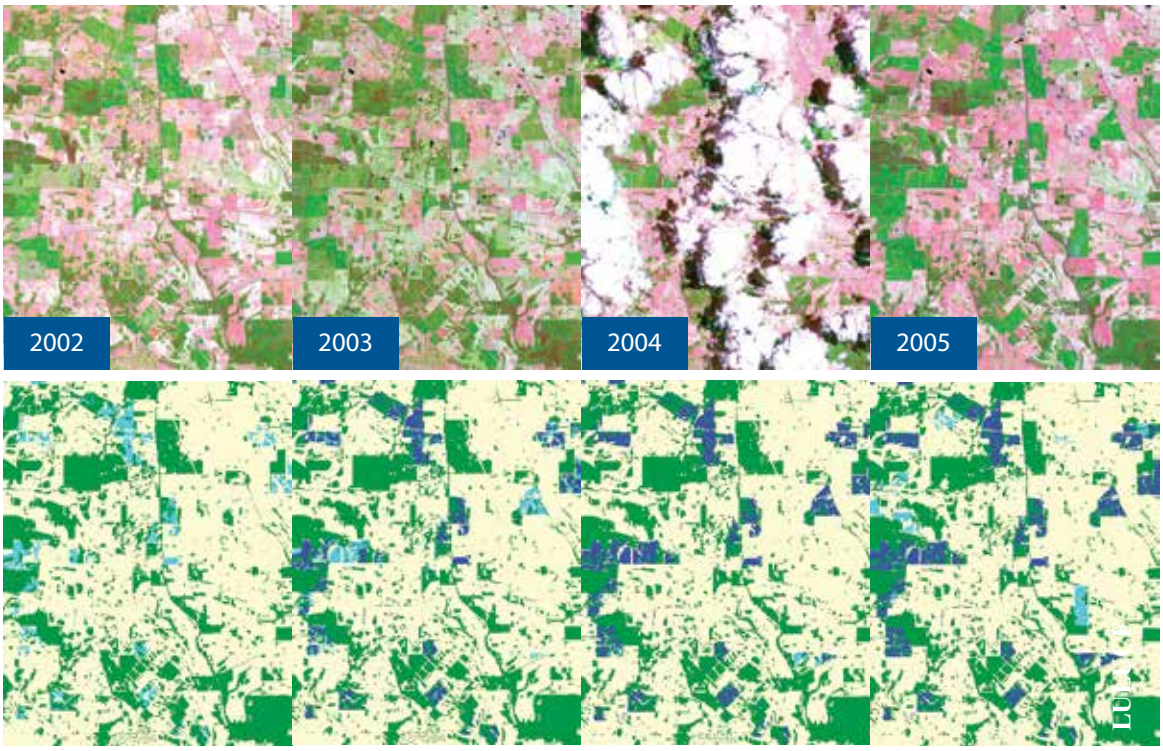
Conditional Probability Network

The land cover change program uses a Conditional Probability Network (CPN) to strengthen 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.A.3).

Figure 7.A.3: Images of forest extent and change based on CPN analysis 2002-2004: area – 16 x 20 km



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

Appendix

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.

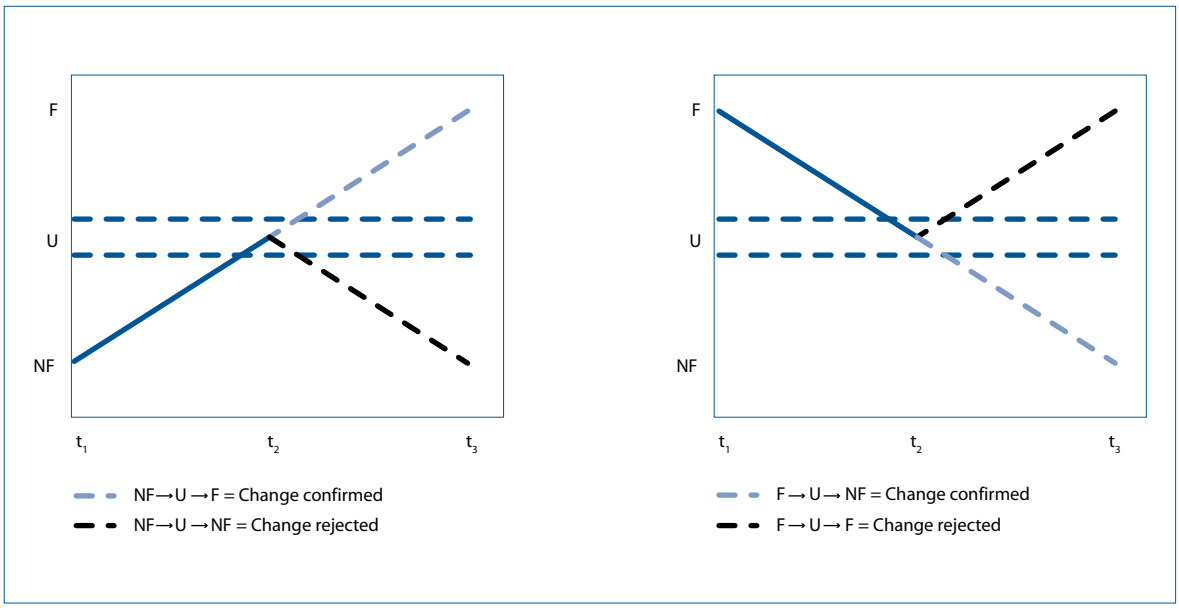
Forest extent and change analysis

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.A.4). 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.A.4). 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.4: Three class determination of forest cover and confirmation/rejection of change over time using the CPN. F- Forest, U – uncertain, NF – Not Forest.



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 as either human induced or due to natural effects/methodological artefacts. Examples of forest cover loss events that do not meet the definition of human induced 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 a fire mask developed during the image processing, and a tenure mask 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. Department staff use visual image backdrops (such as Google Earth or SPOTMaps data) for this discrimination.

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 are designed to exclude change due to:

- forest harvesting 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.3 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+ OLI data is used for plantation classification.

7.A.4 Quality Assurance and Quality Control

7.A.4.1 Program implementation

During the initial implementation of the remote sensing program, 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 quality assurance and quality control (QA/QC). The results of the pilot studies are published in Furby and Woodgate (2002).

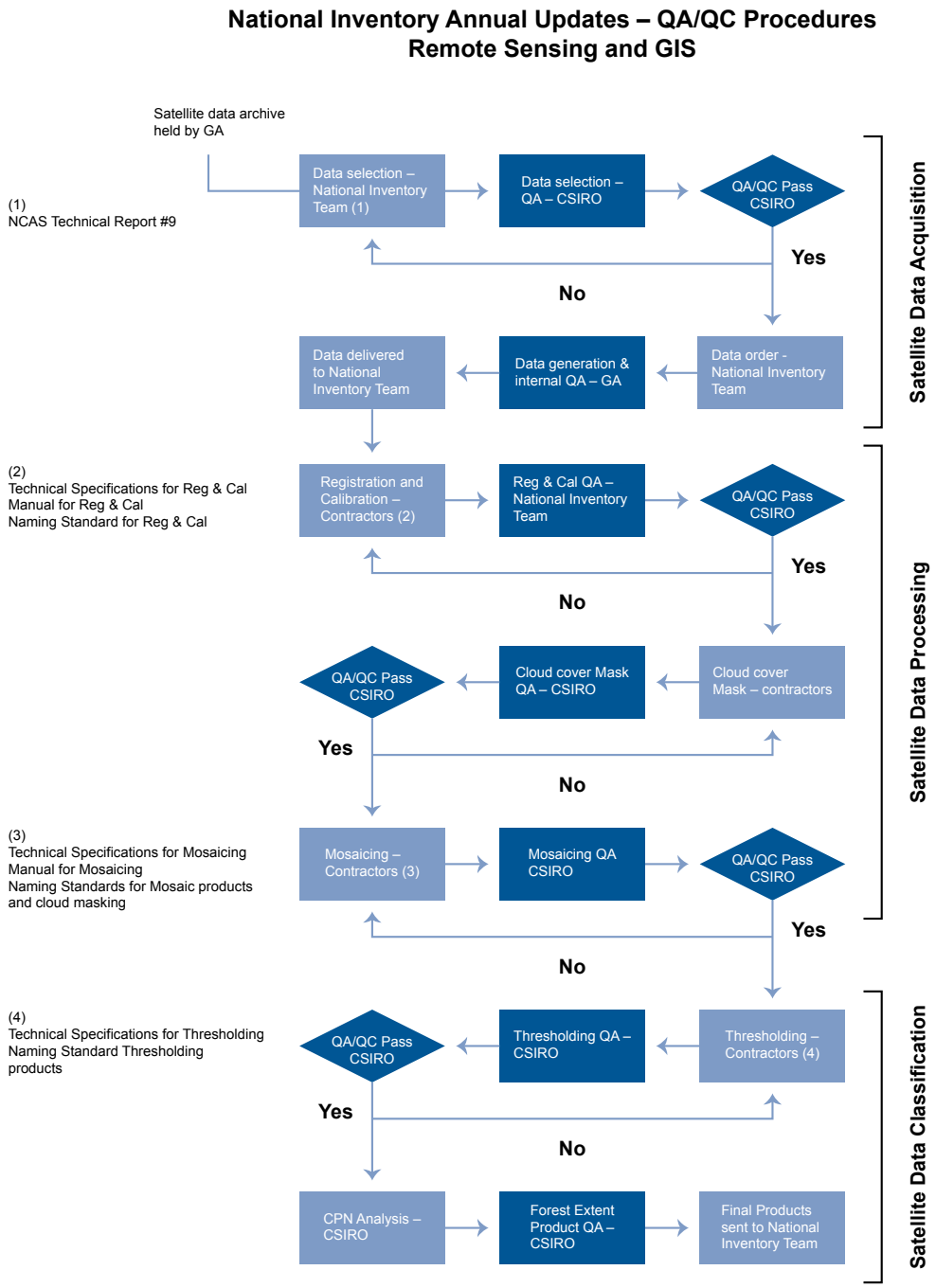
The approach to program administration provides for centralised progress monitoring and QA/QC at each stage in the processing of the Landsat data. Figure 7.A.5 outlines each of the processing and QA/QC stages. Each processing stage is a regionally defined package of work based on 37 1:1,000,000 (1:1 M) map tiles of Australia (Figure 7.A.1).

The three primary QA/QC stages 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 are described in full in Furby (2002).

Figure 7.A.5: Overview of QA/QC procedures associated with Land Cover Change calculations



7.A.4.2 Acquisition & selection of satellite imagery

Data (scene) selections and raw data quality are thoroughly checked and reviewed by the CSIRO and DE to ensure that:

- the images purchased overlap to prevent gaps in the coverage;
- optimal, spatially and temporally consistent image dates are purchased;
- cloud in overlap areas is covered by cloud-free data in adjacent images whenever possible;
- 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,
- image problems are correctly entered into a scene selection database.

7.A.4.3 Registration & Calibration

Registered and calibrated images are returned to DE after both processes are complete. The assessment of each registered and calibrated image is performed in three stages:

- the information and data provided to the DE is checked for completeness and the registration assessed, based on the summary information provided to the DE;
- 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,
- a Registration/Calibration Quality Assurance form is completed, the processing status of the image updated in the DE Image Catalogue, and the image returned to the contractor for reprocessing if required.

7.A.4.4 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:

- the information and data provided by the contractor is checked for completeness and the consistency of the mosaiced image assessed; and,
- 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.A.4.5 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:

- 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.
- 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.
- 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).
- The plausibility of the change images produced by the contractor is checked by CSIRO.
- If the accuracy appears doubtful, images are further investigated so that the exact nature of any problem can be reported to the contractor.
- 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).
- The final products supplied by the contractor are checked for completeness and the remainder of the processing by the contractor is assessed.
- 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.A.4.6 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 otho-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.A.4.7 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. DE staff use visual image backdrops (such as Google Earth or SpotMap data) for this discrimination. Results of this discrimination are then quality assured. This process provides for an additional independent process of checking the land cover change results.

7.A.4.8 Plantation 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. 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.

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.A.4.9 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.

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.

A second verification program was completed in April 2012 to assess the accuracy of forest/non-forest classification for the period from 2002-2010 using the same methodology that was used previously. This involves establishing four hundred points selected in accordance with a temporally stratified random sample across each mapsheet, followed by human interpretation of the likelihood of forest for each point using very high resolution imagery and cross tabulating the interpretation against the CPN classification.

The study concluded that 92% of points were definitely or probably correct. A relatively small 3% of points were definitely wrong (incorrectly classified) and 7% were probably or definitely wrong. About 81% of interpretations are consistent with the change for points that underwent land cover change at some point between 2002 and 2010 (Lowell *et al.* 2012).

7.A.5 Planned Improvements

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

i) areas of plantation established prior to 1988 using Landsat MSS data;

ii) areas subject to harvest in the *Harvested Native Forests*, and

iii) areas of sparse vegetation and change in sparse vegetation since 2006 to complete the national coverage.

Appendix 7.B: *FullCAM* framework

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), and covers both forest and non-forest land uses.

The terrestrial ecosystem model implemented within Australia's National Inventory System is the Full Carbon Accounting Model (*FullCAM*) (Richards, 2001; Richards and Evans, 2004). *FullCAM* is an ecosystem model that calculates greenhouse gas emissions and removals in both forest and agricultural lands using a mass balance approach to carbon cycling. 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.

7.B.1 Overview of the *FullCAM* Model Framework

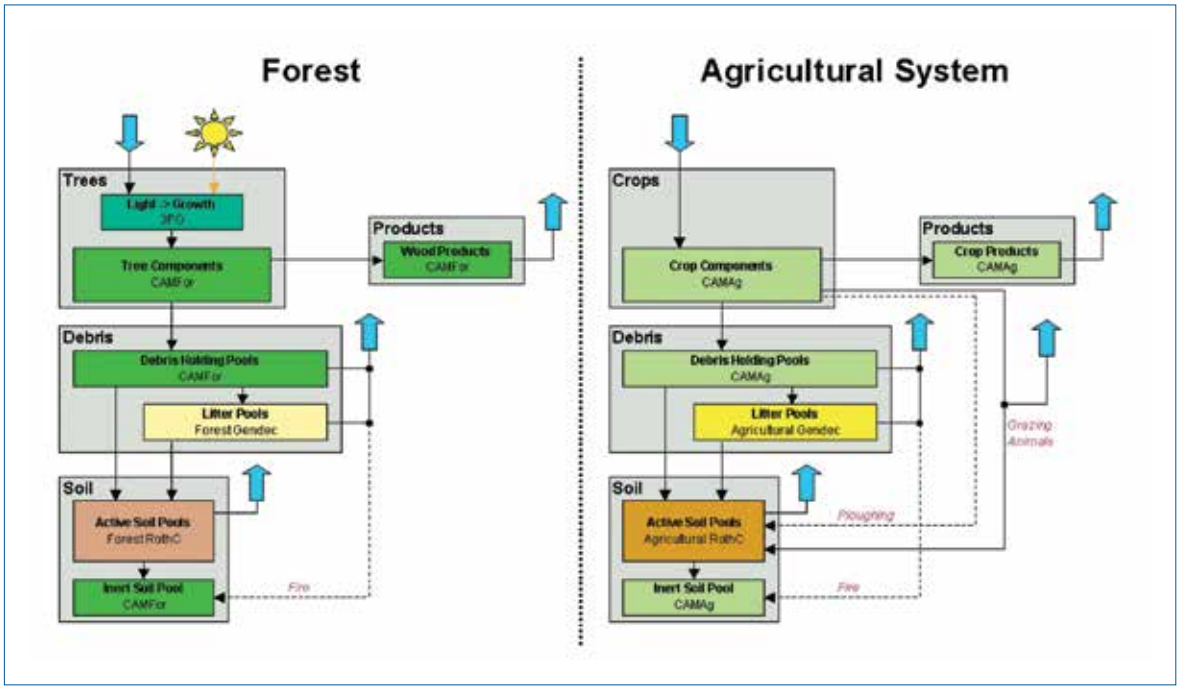
The *FullCAM* framework and its development are described in Richards (2001) and Richards and Evans (2004). In addition to providing spatial modelling, *FullCAM* also provides for mixes and transitions between forest and agricultural systems. *FullCAM* also has the capability to support the modelling 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.B.1).

7.B.1.1 *FullCAM* Sub-Models

The three sub-models integrated to form *FullCAM* as used in the National Inventory are:

1. *CAMFor* (Richards and Evans, 2000a), the carbon accounting model for forests (Figure 7.B1).
   CAMFor is used to model carbon mass and transfers between the living tree and debris pools of forest lands. *CAMFor* has its origins in the 1990 CO_2 Fix model of Mohren and Goldewijk (1990);
2. *CAMAg* (Richards and Evans, 2000b), the carbon accounting model for cropping and grazing systems (Figure 7.B1).
   The *CAMAg* model reflects the impacts of management on carbon accumulation and allocates masses to various plant, debris and soil pools. Yields need to be prescribed in the model;
3. Rothamsted Soil Carbon Model, *Roth-C* (Jenkinson, *et al.* 1987, 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. It is used in conjunction with both *CAMFor* and *CAMAg*.

Figure 7.B.1: The *FullCAM* model pool structure



7.B.1.2 Sub-model integration

The sub-models described above are integrated into *FullCAM* which was developed in the programming language C++ with a graphical user interface (Richards, 2001; Richards and Evans, 2004). 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 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.

7.B.1.3 Quality Assurance and Quality Control

Sub-model integration

The integration of the sub-models into a single compendium model was initially undertaken in Excel as a test version. The prototype forest model derived (Richards and Evans, 2000c) was subsequently tested by CSIRO (Paul *et al.* 2002a). Several independent studies to test and calibrate the model were completed on various parts, integrations and applications of the models. When there was confidence that the Excel developmental models were giving the same results as the original source code versions, the Excel models were fully documented and returned for verification to the original authors or host organisations. Modifications were only considered subsequent to this initial review. These modifications were made for a variety of reasons including efficiency in code (computational speed and resources) and in recognition of Australia's different biophysical conditions.

Model coherence and validation

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[8]. 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.

Representative individual pixels in *FullCAM* simulations have been validated against field data. These validations have been undertaken by independent agencies. The results of these studies have shown that the model is robust. Examples of the independent initial biomass, debris and soil carbon validation results are shown in Appendix 7D, section 7.B.3, and section 7.B.5, respectively.

Individual pixel models are internally checked to ensure that all emissions, removals and transfers of carbon between pools are accounted for. At each monthly time-step *FullCAM* reconciles removals due to growth, transfers between carbon stocks in pools, and emissions from pools for every pixel modelled. Taking a mass balance, full carbon-cycle approach for each pixel, and running this over an extended period, is a very rigorous way of testing the model's ability to appropriately reflect transfers between carbon pools, and hence the balance of emissions and removals. When multiple pixels are simulated, pixel results are consolidated and then reported at an aggregate level. These aggregate outputs are cross checked by both internal and external processes to ensure that the consolidation process accurately reports all spatial simulation results. The correct summing of model outputs is also critical to model performance and therefore internal and external quality control checks are made on this aspect of the model. The results from the Tier 3 model have also been compared with the results using Tier 2 methods (see section 7.5.5, 7.6.3, 7.7.3) and were found to be broadly consistent.

Transparency and Peer Review

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.

Australia has published six series of strategic and technical reports which document the development of *FullCAM*, the specifications, protocols and methods used, and the results of verification, validation and calibration of *FullCAM*. All reports are accessible by the public via the DE website (http://pandora.nla.gov.au/pan/102841/20090728-0000/www.climatechange.gov.au/publications/index.html). The methods and data used as part of the land sector accounts have also been extensively published in peer-reviewed papers in scientific journals.

[8] 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. Analysis of IEFs in the LULUCF sector is further complicated by reporting of accumulating land areas.

7.B.2 Estimating Changes in Forest Biomass

7.B.2.1 Forest Growth

Forest growth in *FullCAM* is controlled through two separate biomass increment components of the model:

1. The tree yield formula (Richards and Brack (2004a), Brack *et al.* (2006) and Waterworth *et al.* (2007); and
2. Direct entry of biomass increment data.

Tree yield formula

The tree yield formula is embedded into the *FullCAM* code and when applied within the National Inventory System provides an empirically constrained process model for the calculation of biomass increment in the living components of *forest land*. 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. It is the empirical data that constrains the model to reflect extensive field data (both existing and specifically collected).

The tree yield formula is applied to estimate the forest biomass increment in the following sub-categories:

- Forest land converted to Cropland;
- Forest land converted to Grassland; and
- Grassland converted to Forest land.

The tree yield formula is provided in Equation 7B_1:

$$\text{Aboveground Tree Mass at age a} = M \times e^{(-k/a)} \quad \text{(7B_1)}$$

Where: a = age of the tree stand

M = biomass predicted by the assumed initial biomass model (Appendix 4D), and

k =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 0.5k. In *FullCAM* this value is known as BI_a, the age of maximum aboveground biomass increment.

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*) (see Appendix 7.C):

$$I_a = (6.011 \times \sqrt{P} - 5.291)^2 \times (e^{(-k/a)} - e^{(-k/a+1)}) \quad \text{(7B_2)}$$

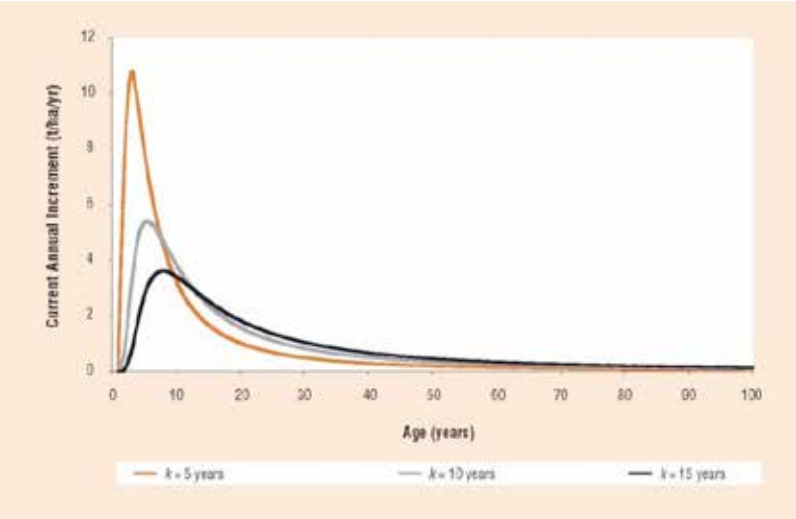
However, as productivity in any given year may vary around the average due to non-average weather or other factors, the average annual increment may be adjusted by the productivity in a given year (P_a) as a ratio with the long-term average productivity (*P*):

$$I_a = I_a \times P_a/P \quad \text{(7B_23)}$$

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.

Maximum aboveground biomass increment One of the key parameters in the tree yield formula is the age of maximum aboveground biomass increment (BI_a). Figure 7.B.2 presents the results of 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.

Figure 7.B.2: Effects of varying age of maximum current annual increment



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. 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 10 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.

Direct entry of biomass increment data

When the direct entry of biomass increment data component of *FullCAM* is in use, the model uses these data in calculations and so there is no calculation of biomass increment within *FullCAM*. The direct entry of biomass increment data component of *FullCAM* is applied in the source category *forest land remaining forest land*.

7.B.3 Estimating Changes in Forest Debris

FullCAM 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 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.

7.B.3.1 Calibration and Validation of Debris Calculations

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 was used to calibrate algorithms and the other half was used to validate the decomposition predictions (Paul *et al.* 2004).

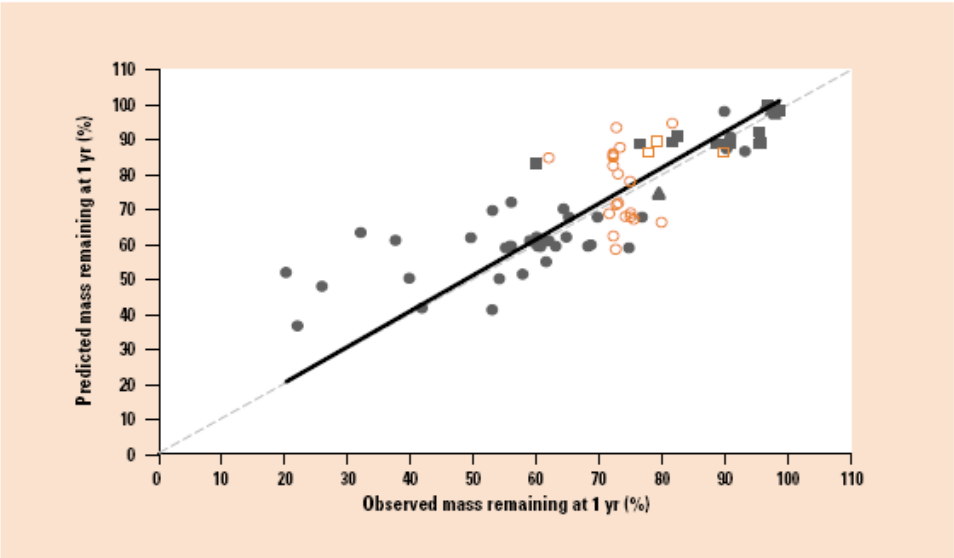
To calculate the decay rate of plant material before it enters the soil pool two groups of parameters used are calibrated: i) decomposable fraction of plant residues, and ii) rate constants for decomposition of decomposable and resistant debris pools of plant residues. The model was set-up to run using 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 (MEF) is calculated as the difference between the field-measured and model-simulated mass of litter remaining. Values of MEF 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 MEF 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.B.3).

Figure 7.B.3: Relationship between observed mass remaining after one year of decomposition of eucalypt leaf (●), eucalypt bark (▲), eucalypt dead wood (■), pine needles (○) and pine dead wood (□) from the calibration dataset, and that predicted using *CAMFor*.

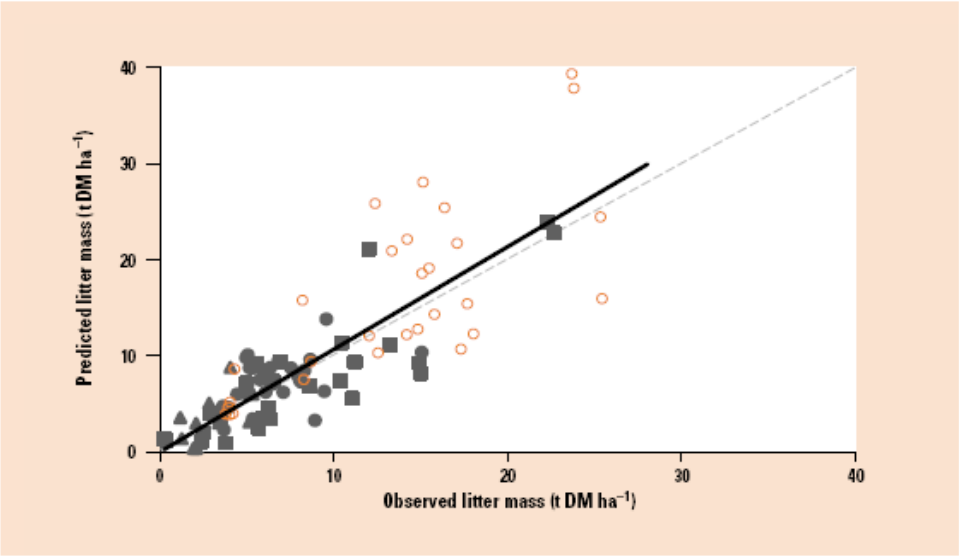
Dashed line represents the 1:1 line. Solid line represents the linear function of best fit when forced through the origin (Slope=1.03, R^2=0.57, n=80). MEF and MSE were 0.65 and 177 g^2 100 g^{-2}, respectively.



Using the validation data, the model predicted mass remaining with an MEF 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.B.4).

Figure 7.B.4: Relationship between observed mass remaining after one year of decomposition of eucalypt leaf (●), eucalypt bark (▲), eucalypt dead wood (■), pine needles (○) and pine dead wood (□) from the validation dataset, and that predicted using *CAMFor*.

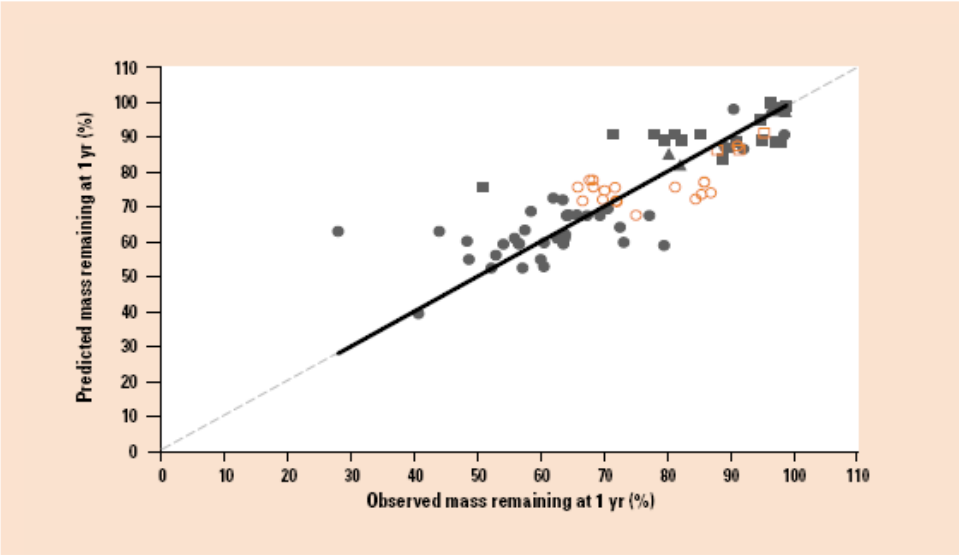
Dashed line represents the 1:1 line. Solid line represents the linear function of best fit when forced through the origin (Slope=1.00, R^2=0.60, n=83). MEF and MSE were 0.70 and 80 g^2 100 g^{-2}, respectively.



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 4 and 100+ years with an MEF of 0.65 and a MSE of 15 t2 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.B.5).

Figure 7.B.5: Relationship between observed mass of eucalypt leaf (●), eucalypt bark (▲), eucalypt dead wood (■) and pine needles (○) 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=1.06, R^2=0.67, n=95). MEF and MSE were 0.65 and 15 t^2 ha^{-2}, respectively.



7.B.4 Estimating Changes in Crop and Pasture Biomass and Debris

CAMAg, 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 the debris pool (Richards, 2001).

7.B.4.1 Biomass

The model uses crop and pasture yield data and the proportional allocation of dry matter to different plant components to estimate annual dry matter accumulation in agricultural ecosystems. The available data have been reviewed to develop appropriate harvest indices for each plant type to enable conversion from mass of saleable product to total plant mass (Unkovich *et al.* 2010). The proportional allocation of dry matter to plant components were determined from estimates by expert field agronomists and include allocation to roots, GBF (grains, buds and fruit), stalks and leaves. The crop types and plant partitioning used in the model are shown in Table 7.B.1.

The crop and pasture yield data for each cropping system, IBRA region and soil type are estimated in *FullCAM* (see Appendix 7.E5)

Table 7.B.1: Plant partitioning by crop and pasture 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)
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
Crop	0.27	0.00	0.43	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
Horticulture	0.00	0.00	0.30	0.60	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
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
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
Sunflower	0.32	0.39	0.20	0.00	0.10
Wheat	0.26	0.00	0.44	0.00	0.30
Winter grain (wheat)	0.28	0.00	0.42	0.00	0.30

Carbon Contents of Crop and Grass Species

Plant dry matter is converted to carbon using a crop carbon content value that is specific to the species in use, in the model. These average values for crop species were determined from an analysis of plant materials obtained from around the country, using a dry combustion method and published in the Technical Report series.

7.B.4.2 Debris

The amount of plant residue generated by a crop or grass species is dependent on both the plant growth and management practice. As well as containing the crop/pasture growth and species data, the relational database describes the agricultural management practices, (e.g., stubble management) applied to each crop/pasture (see section 7.E.4). 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.

Initial Crop Litter Mass and Decomposition Rates

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.B.2.

Table 7.B.2: 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 the sigmoidal growth response of agricultural plant species, including pastures (Table 7.B.3), 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.

Table 7.B.3: Turnover rates applied to crop and pasture systems

Plant Component	Turnover Rates yr^{-1}	
	Pasture species	Annual crop species
Grains, Buds, Fruit	0.4	0.10
Stalks	0.4	0.10
Leaves	0.4	0.10
Coarse Roots	0.4	0.10
Fine Roots	0.4	0.10

7.B.5 Estimating Changes in Soil Carbon

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.

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.

7.B.5.1 Model Calibration, Validation and Verification

Calibration of *Roth-C* was undertaken using available long-term field trial data, 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).

Calibration and Validation

Two agricultural and seven forestry long term trail sites were selected for estimating changes in soil carbon. 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.

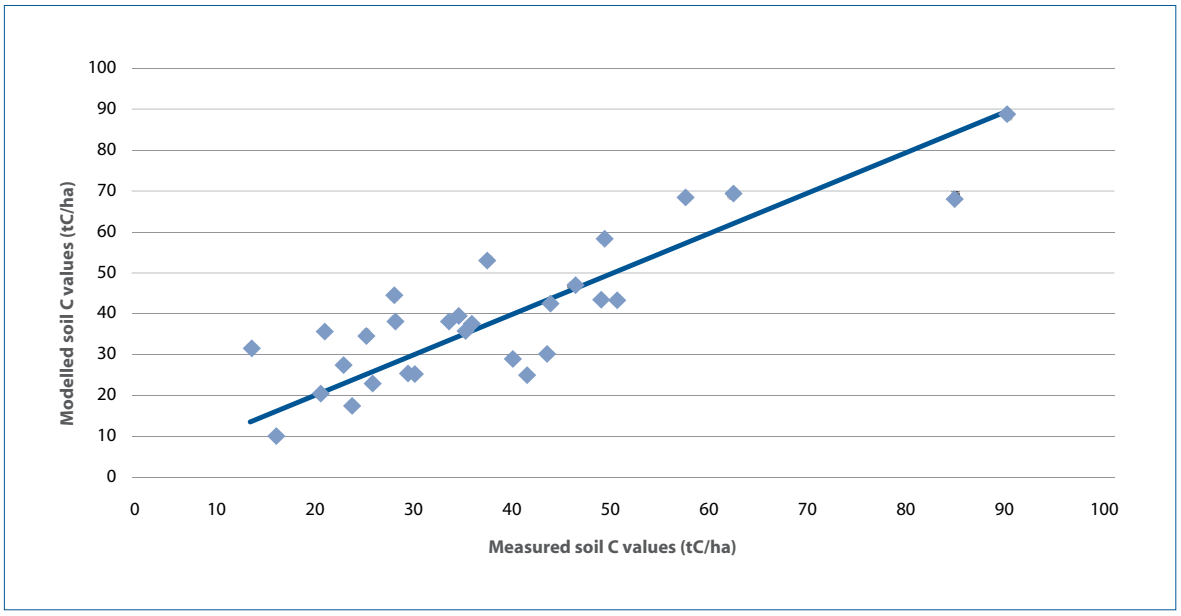
Testing of the seven forestry sites and two agricultural sites confirmed the model calibrations for soil carbon pool allocations for both forestry and agricultural sites. Details of the calibration and testing of the model are provided in Paul *et al.* (2002b and 2003b).

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*, 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).

A regression (Figure 7.B.6) found a significant correlation (r^2 = 0.701) between the measured soil carbon values of the 29 samples 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.* 2000a and b).

Figure 7.B.6: Measured versus modelled soil carbon data collated from 29 sites across a range of soil types in northern and southern Australia.



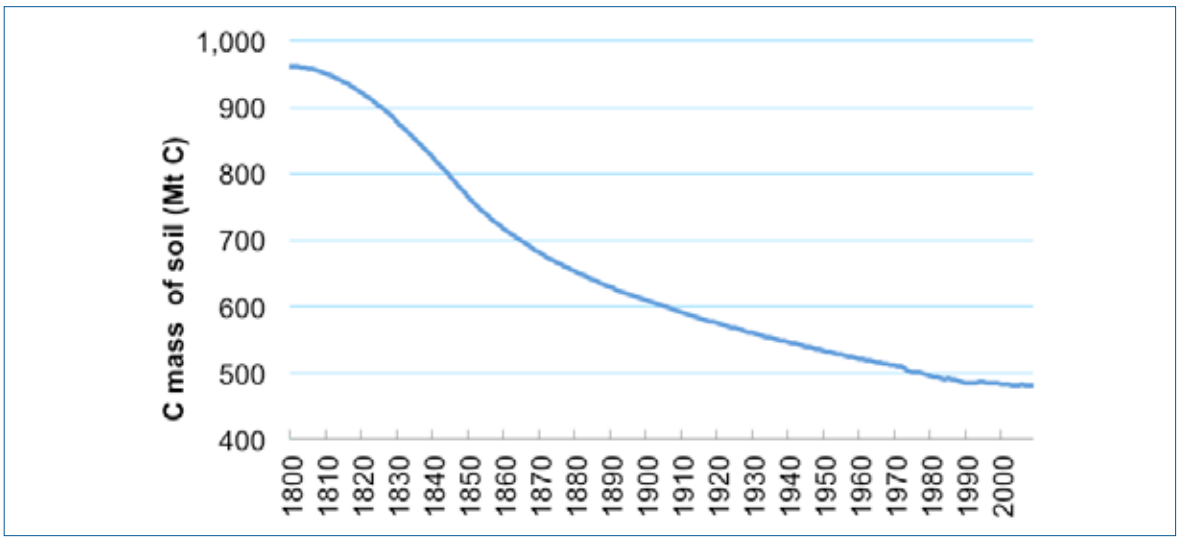
In general terms the coefficient of variation for modelled outputs of soil carbon is around 5% (Janik *et al.* 2002), whereas the coefficient of variation for measured soil carbon is 15-40% (McKenzie *et al.* 2000a and b; Janik *et al.* 2002). Further details are provided in Murphy *et al.* (2002), Harms and Dalal, (2003) and Griffin *et al.* (2002).

Verification:

The change in soil carbon stocks derived from *FullCAM* for *cropland remaining cropland* show a decline in total carbon stocks of 479 Mt C over 22Mha from 1800 to 2000 (Figure 7.B.7). This is equivalent to 109 kg C/ha/yr due to the change in land use from forest land to agricultural croplands. Recent publications of the loss in soil C stocks due to the impacts of agriculture after land clearing have shown similar rates of C loss. For example Grace *et al.* (1998) using the Century carbon model showed that soil C losses amounted to 120 kg/ha/yr since land

clearing. Another paper by CSIRO (2009) using Roth C modelling estimated the rates of soil carbon loss to be about 90 kg/ha/yr. These independent studies support the modelling outputs of *FullCAM* and verify the trends in soil carbon loss from croplands as observed in the national inventory.

Figure 7.B.7: Decline in soil C stocks due to land use change from 1800 to 2000 as modelled by *FullCAM*.



7.B.6 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 Tier 3, Approach 3 spatially explicit modelling approach to *land 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, validated, verified, quality assured and peer reviewed.

Spatial 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, validation and verification of the soil carbon model to estimate emissions and removals from soils in the *forest land remaining forest land* category.

Management Change

The methods for the cropland and grassland categories are being reviewed for consistency with 2006 IPCC Guidelines requirements. A key planned improvement is to improve the way that *FullCAM* estimates the impact of management changes on emissions and removals.

One area the Department has been investigating is the options for utilising the GENDEC module in *FullCAM* to better model the impacts of management strategies on the entry of crop residues into the soil as well as additions of various organic amendments derived from offsite.

CSIRO has proposed a schema consisting of "Standing debris" that is not in contact with the soil, and a "Mulch" layer that is in contact with the soil. The "Standing debris" will include standing stubble that will transition to either the Mulch pools on events such as rolling and trampling by grazing, or into the soil pools on incorporation through events such as cultivation and sowing operations. In addition to residues on the soil surface after harvest or events that knock standing stubble onto the ground, the "Mulch" layer will receive offsite additions of organic amendments. A "Root debris" pool receives dead root material that is greater than 2 mm in size, whilst fine roots less than 2 mm enter the soil organic matter pools as previously. The proposed "Standing debris" and "Mulch" layers do not represent a significant departure from the use of 'Agricultural debris' currently in *FullCAM* and the optional mulch layer represented by Gendec. Further work is required to assemble the data required to build, test and run the proposed system.

FullCAM software flexibility

DE has recently commissioned a detailed designed for a *FullCAM* Outputs Analysis System (*FullCAM* OASys) which will support quality control and enable complex year-by-year reporting tables and is updating the system hardware to manage the task. The task is computationally demanding and an upgrade will be necessary to achieve the processing required.

Soil Carbon

In 2011, the Soil Carbon Research Program (SCaRP) collected more than 4,000 soil samples across sites in the major cropping regions of Queensland, New South Wales, South Australia, Northern Territory and Western Australia. Sites were established in collaboration with State Agencies, and 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. The report has been finalised and published (www.daff.gov.au). DOE will review this data to determine if it could be used to provide a range of verification targets for model testing and validation and/or data to recalibrate the model.

Appendix 7.C: The Forest Productivity Index

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.

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 7C_1) as half the amount of short-wave (global) incoming radiation (SWRadn) absorbed by plant canopies.

$$APAR = SWRadn \times 0.5 \times (1-e^{(-0.5 \times LAI)}) \times \text{days in month} \quad (7C_1)$$

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 1 (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).

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.

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 (7C_2) used is:

$$VPDmod = e^{(-0.05 \times VPD)} \quad (7C_2)$$

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 7C_6) in the root zone of plants. Plant water use (Equation 7C_4) is calculated from the equation for equilibrium evaporation (Equation 7C_3, see Landsberg and Gower 1997; p. 79), modified by feed-back from current soil water content, and a conventional water balance equation (Equation 7C_5):

$$EqEvapn = ((0.67 \times NetRadn *(1-0.05)) / 2.47) \times days\ in\ month \quad (7C_3)$$

$$Transpiration = EqEvapn_j \times SWmod_{j-1} \quad (7C_4)$$

$$WaterBal = (Rain \times (1-interception)) - Transpiration \quad (7C_5)$$

$$SoilWaterContent_j = SoilWaterContent_{j-1} + WaterBal_j \quad (7C_6)$$

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 3 years, after which Soil Water Content had essentially equilibrated to stable monthly values. Soil Water Content values in year 3 were therefore used in the analysis. The soil water modifier (*Swmod*, Equation 7C_8) was calculated from the moisture ratio (*MoistRatio*, Equation 7C_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).

$$MoistRatio = SoilWaterContent/SWcapacity \quad (7C_7)$$

$$SWmod = 1 / (1 + ((1-MoistRatio)/0.6)^{0.7}) \quad (7C_8)$$

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 (7C_9) describing the effect of temperature is:

$$T_{mod} = ((T_{av} - T_{low}) / (T_{opt} - T_{low})) \times ((T_{high} - T_{av}) / (T_{high} - T_{opt})) \quad (7C_9)$$

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 (7C_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 0oC, 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 0oC). T_{max} is set to 5oC 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.

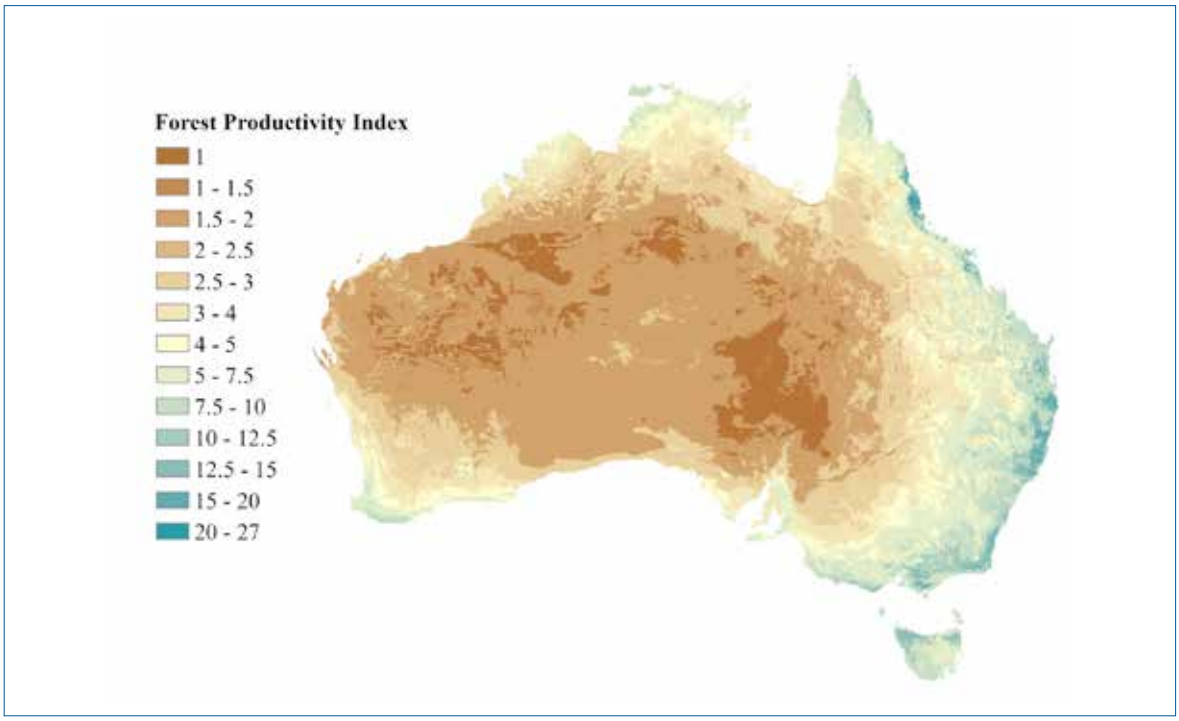
A frost modifier is included, using the simple assumption that frost temporarily inactivates the photosynthetic mechanism in foliage, so there is no growth on a frost day. The modifier is, therefore, simply the ratio of number of frost days/month to the number of days in the month.

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 Appendix E. A further 250 m long-term average FPI is also calculated, using a slope and aspect corrected APAR calculation (Figure 7.C.1).

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

Figure 7.C.1: 250 m slope and aspect corrected productivity index map



Appendix 7.D: Initial Forest Biomass

The initial forest biomass layer is used to estimate the initial biomass of forests on lands that is incremented in the following sub categories:

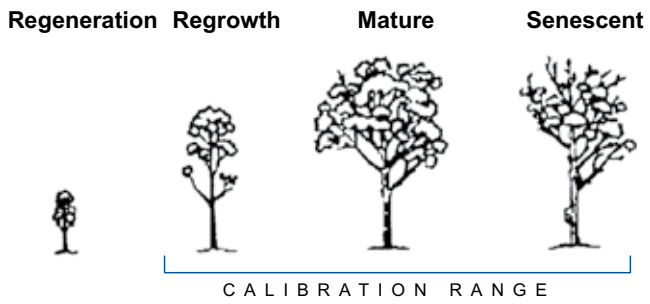
- Forest land converted to Cropland; and
- Forest land converted to Grassland.

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. The assumed initial biomass for a pixel 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).

Calibration data

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.D.1) and therefore the potential variation in field biomass conditions.

Figure 7.D.1: 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.

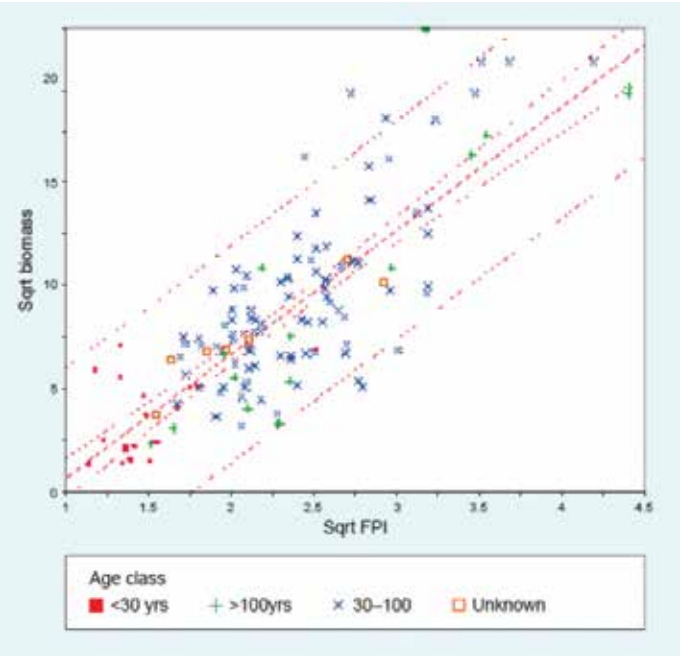
Assumed initial biomass relationship

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.D.2 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 7D_1). A square root transformation was required to meet assumptions of normality and homogeneity (Figure 7.D.2).

$$M = (6.011 \times \sqrt{P} - 5.291)^2 \quad (7D_1)$$

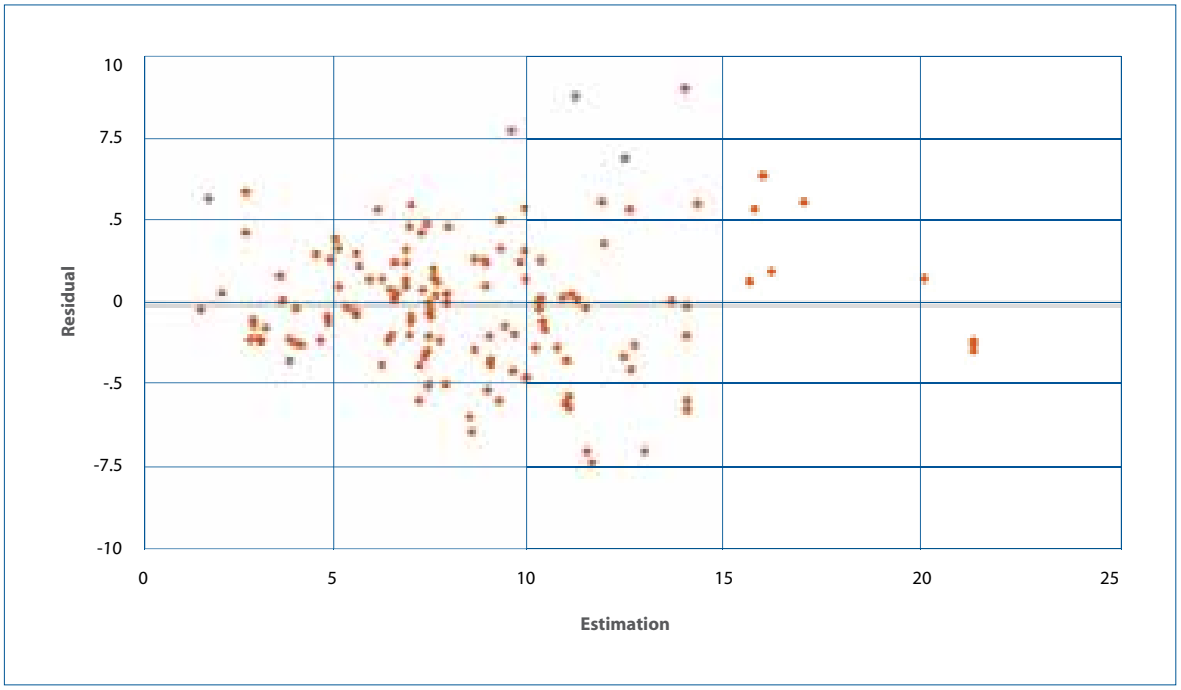
Figure 7.D.2: The assumed initial biomass relationship



The goodness of fit of Equation (7D_1) to the measured data ($r^2 = 0.68$, $p < 0.01$) 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 (7C_1) to the FPI mapping (Appendix 7.C). While the goodness of fit and lack of bias in error estimates (Figure 7.D.3) provides confidence in the application of Equation (7C_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.

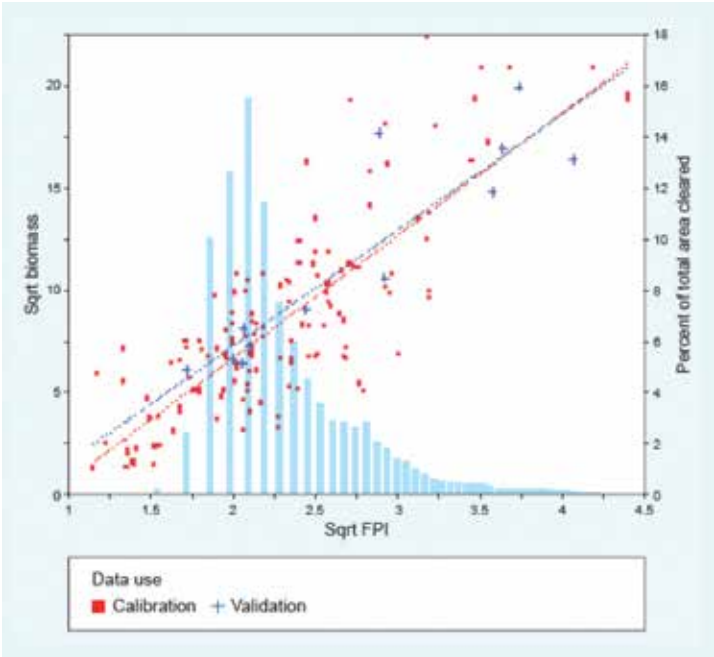
Figure 7.D.3: Error distribution for equation 7D_1.



Validation and verification of assumed initial biomass

Calibration of the initial assumed above ground biomass regression model has been validated by using independent research and field studies of biomass estimates, excluding forest areas with young regrowth. The DE 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 relationship 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.D.4). 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.D.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.

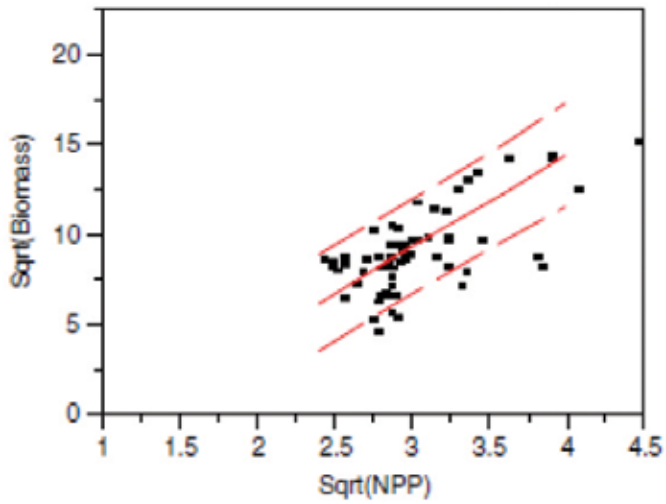
The DE also utilises data collected by other agencies for verifying the biomass relationship. This data is typically of a lower quality (i.e., no direct biomass measurements) that precludes its use in calibration or validation. A key example of this verification approach is outlined in Brack *et al.* (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.D.5). 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 DE is actively working with state agencies and research agencies to collect and collate additional data.

Figure 7.D.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.D.1 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.

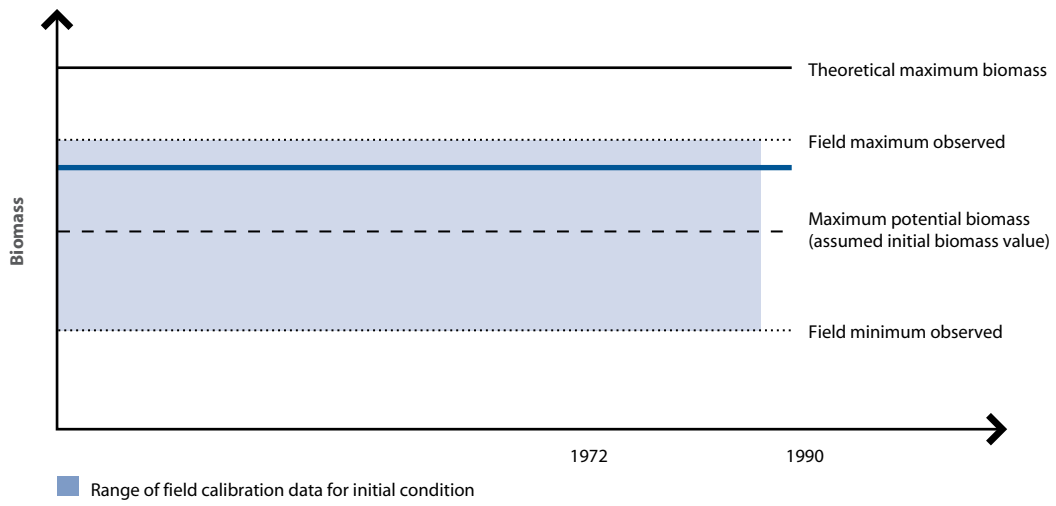
Site productivity – an estimate of the ability of a site to produce biomass (Kesteven et al. 2004).

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.D6 (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.D.6(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.

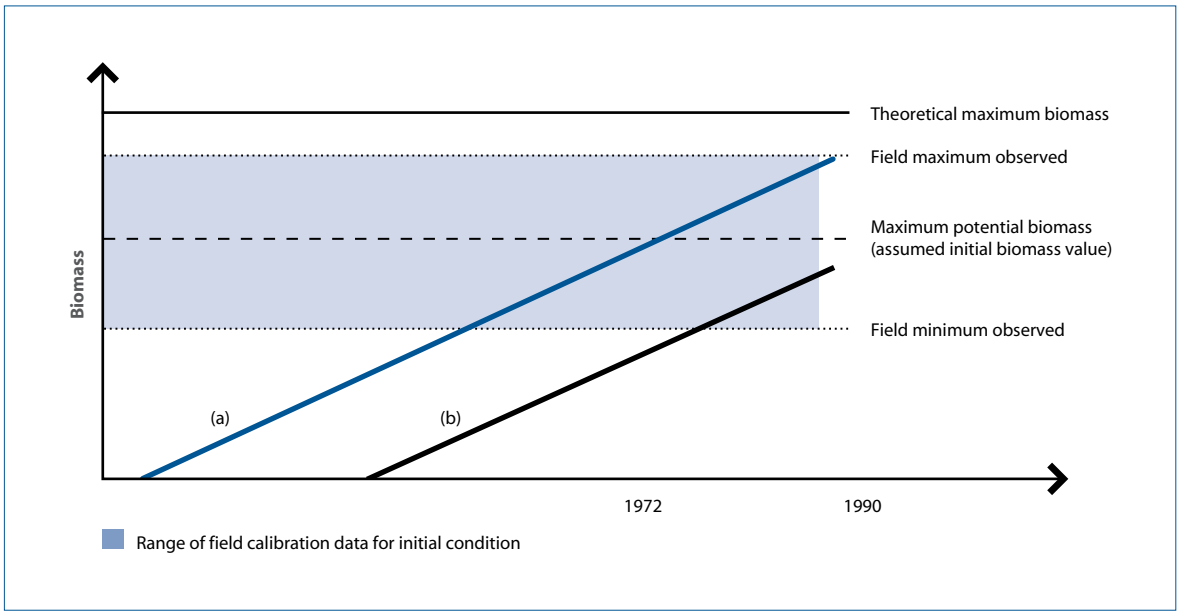
Figure 7.D.6 (a): Biomass of forest undisturbed prior to 1972



Appendix

In Case 2 (Figure 7.D.6(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.

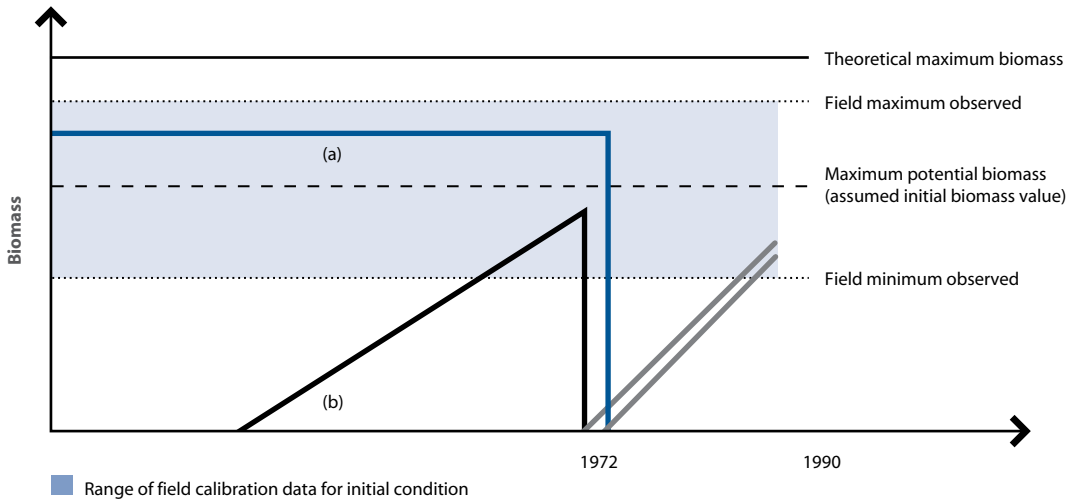
Figure 7.D.6(b): Biomass of forest cleared prior to 1972



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 of the length of time that the forest has had to regrow means that 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 8 to 11 years, with 80% of re-clearing happening within 18 years of the last regrowth event (Figure 7.D.7). 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).

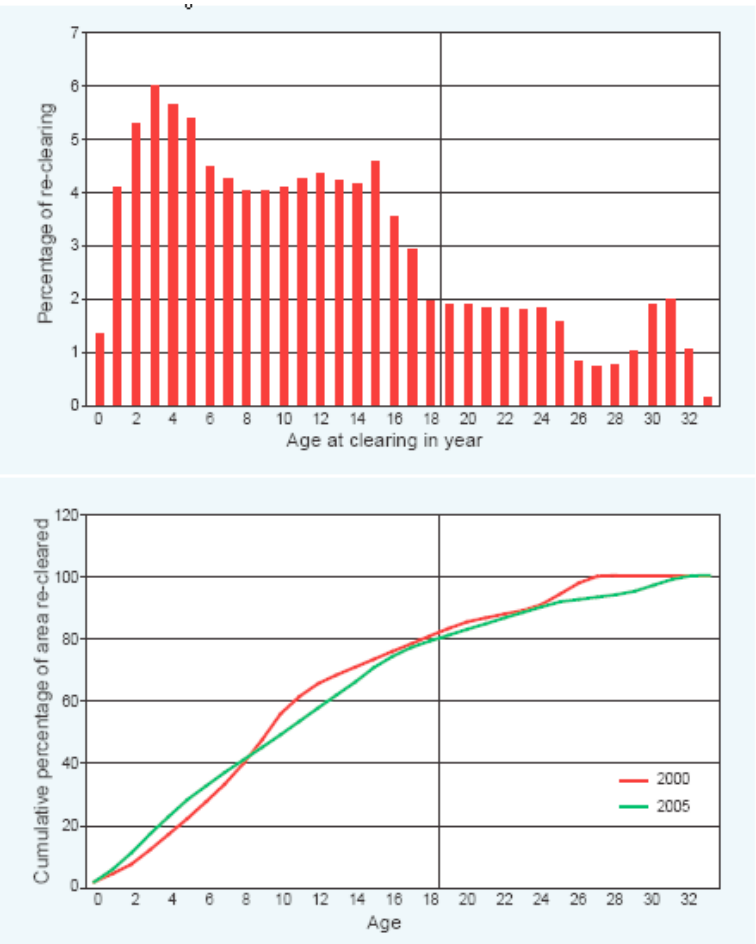
Figure 7.D.6(c): Biomass of forest cleared post-1972



In Case 3 (Figure 7.D.6(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. The key points of Case 3 are:

- The age of the forest is known and the biomass is modelled directly using the age of the forest and site productivity using the Tree Yield Formula (see Appendix 7.B);
- 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.D.7: Percentage of re-clearing by age



Appendix 7.E: Other *FullCAM* input data

7.E.1 Soil carbon input data

To estimate soil carbon stock changes *FullCAM* requires spatial soil data including soil type, clay content and pre-disturbance carbon content; The soil type data is used to derive water holding capacity which along with soil clay content determines the rate of decomposition of plant residues and the allocation of carbon to the different soil pools (Richards, 2001; Webb, 2002).

The process of developing the spatial dataset is described in Webb (2002), which was supported by the development of soil sampling protocols and standardised laboratory methods (McKenzie *et al.* 2000a and b). and a standardisation of existing archival data to this new national analytic protocol (Skjemstad *et al.* 2000).

Spatial soil coverage for all Australian states and territories were 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 mapping of soil units was completed at a level of precision which could be supported by available data.

Soil type descriptions varied according to jurisdiction, but within the modelling framework these differences could be accommodated. The soil types 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.

Considerable additional analytic work was required to achieve consistency in data on pre-disturbance soil carbon contents. 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). This approach led to variable resolutions in the mapping, generally determined by the regional data availability and heterogeneity of soil landscapes. Figure 7.E.1 shows the derived pre-disturbance soil carbon map. 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.

To provide a common and consistent national dataset, 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 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.

In conjunction with the development of the pre-disturbance soil carbon map, a map of clay content was also developed (Figure 7.E.2). Clay content was a consistent measure and was relatively easily drawn from the available resource inventories into a national synthesis.

Figure 7.E.1: Pre-disturbance soil carbon map.

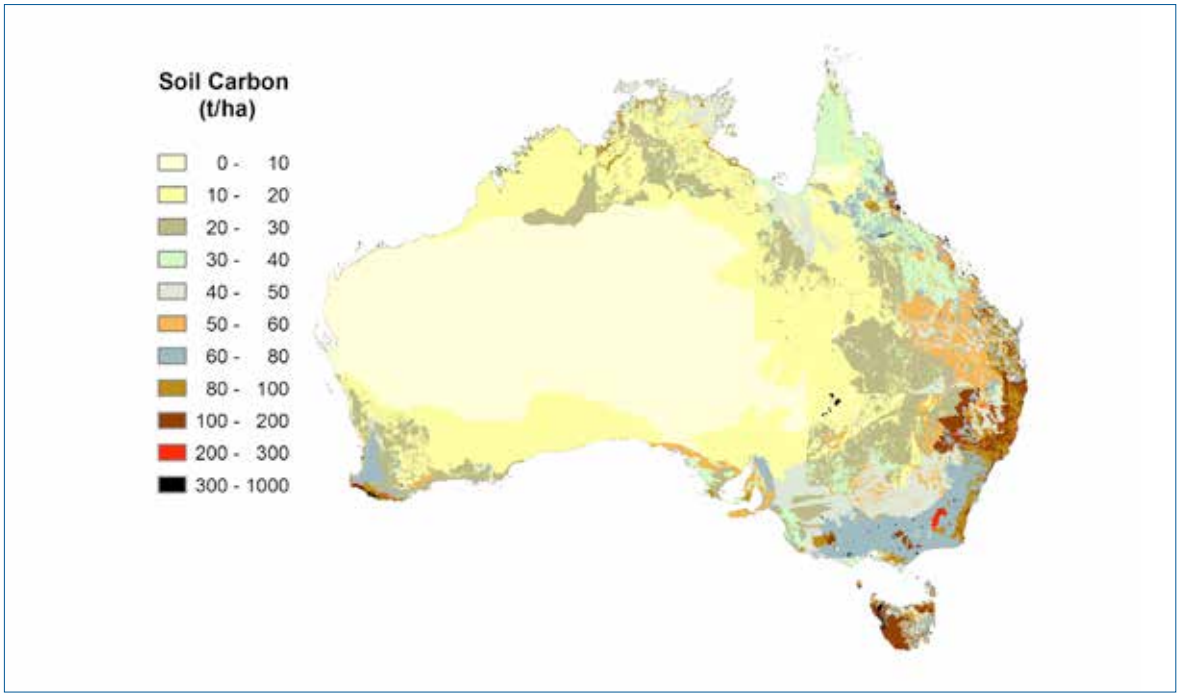
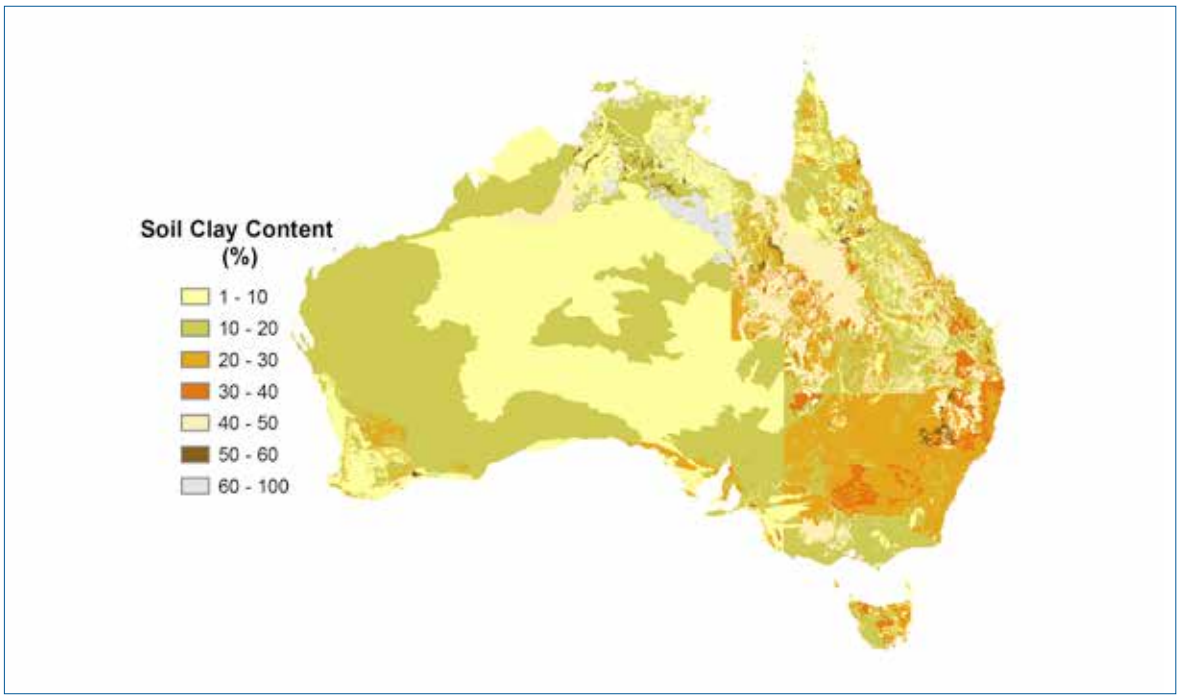


Figure 7.E.2: Clay content map



7.E.2 Native forests input data

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.

7.E.3 Climate data

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.E.2. Figures 7.E3 to 7.E4 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.

Table 7.E.2: 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 1968-2012
Temperature	1 km resolution min., max., and average continentally, monthly 1968-2012
Evaporation	1 km resolution continentally, monthly 1968-2012
Frost Days	1 km resolution continentally, monthly 1968-2012
Solar Radiation	1 km continentally, monthly direct and diffuse 1968-2012, 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.E.3: Long-term average annual evaporation

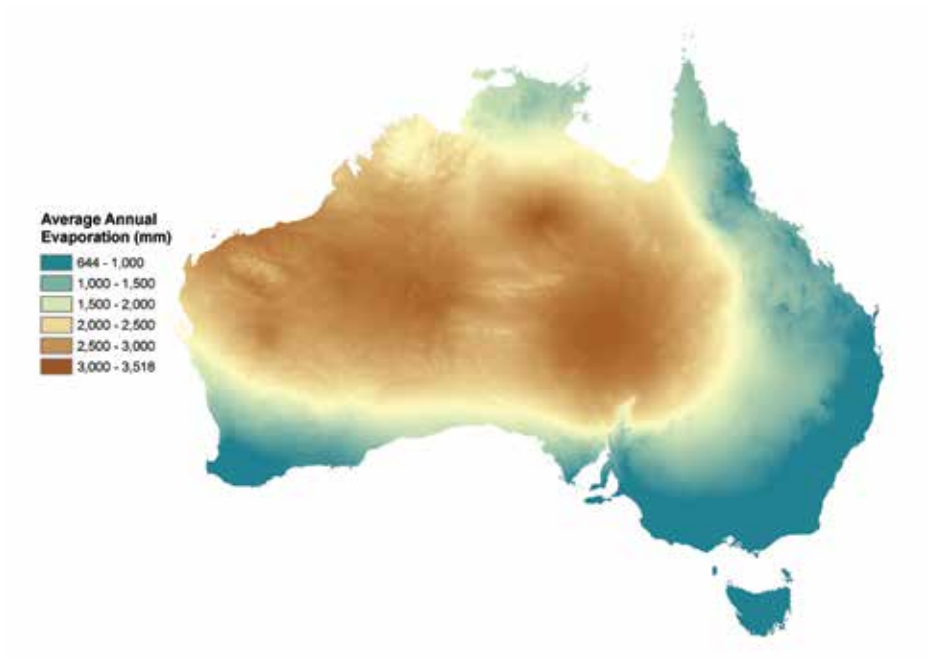
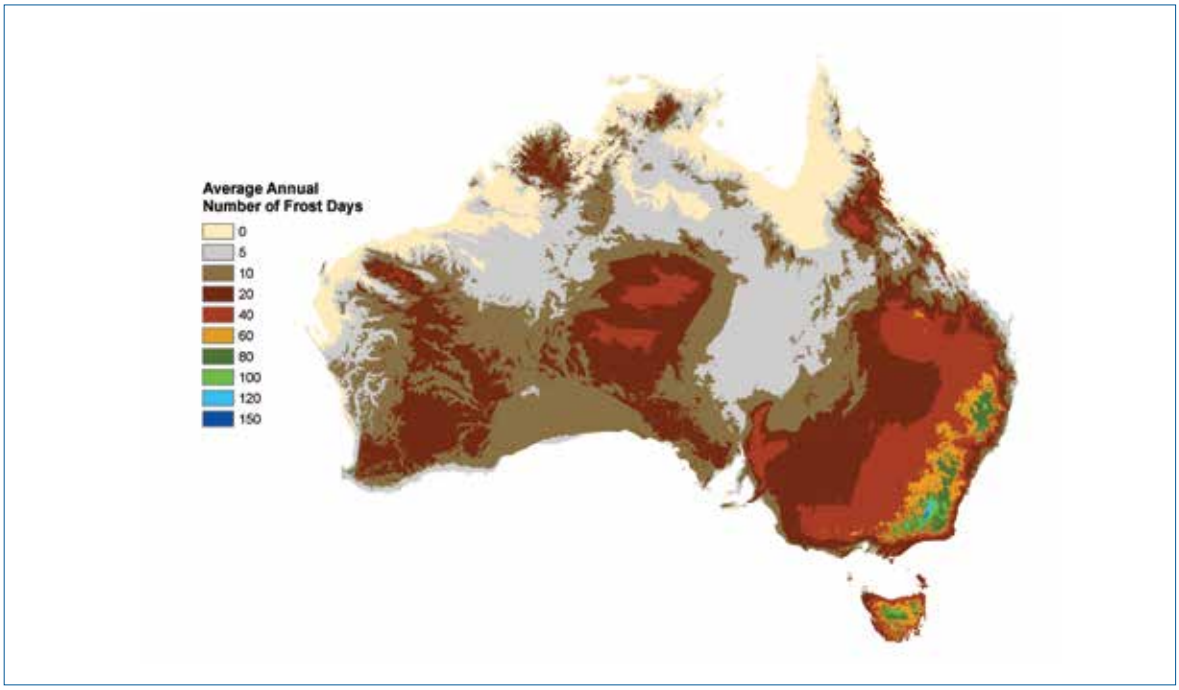


Figure 7.E.4: Long-term average number of frost days per year



7.E.4 Land tenure, land use and land management

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.

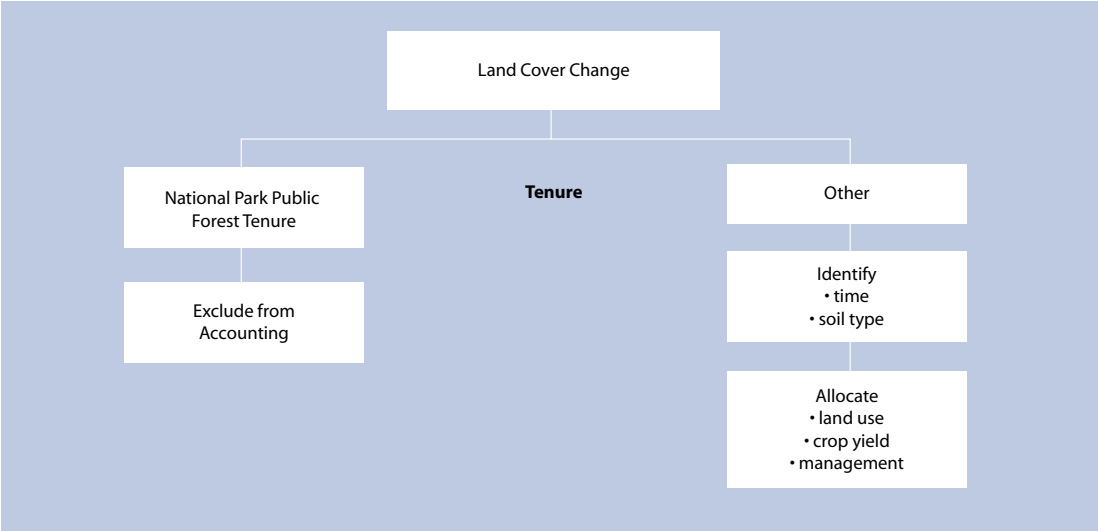
Land Use and Management Data

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.E.5).

Figure 7.E.5: Overview of the land use and management program



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.E.3). 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.E.6) 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.

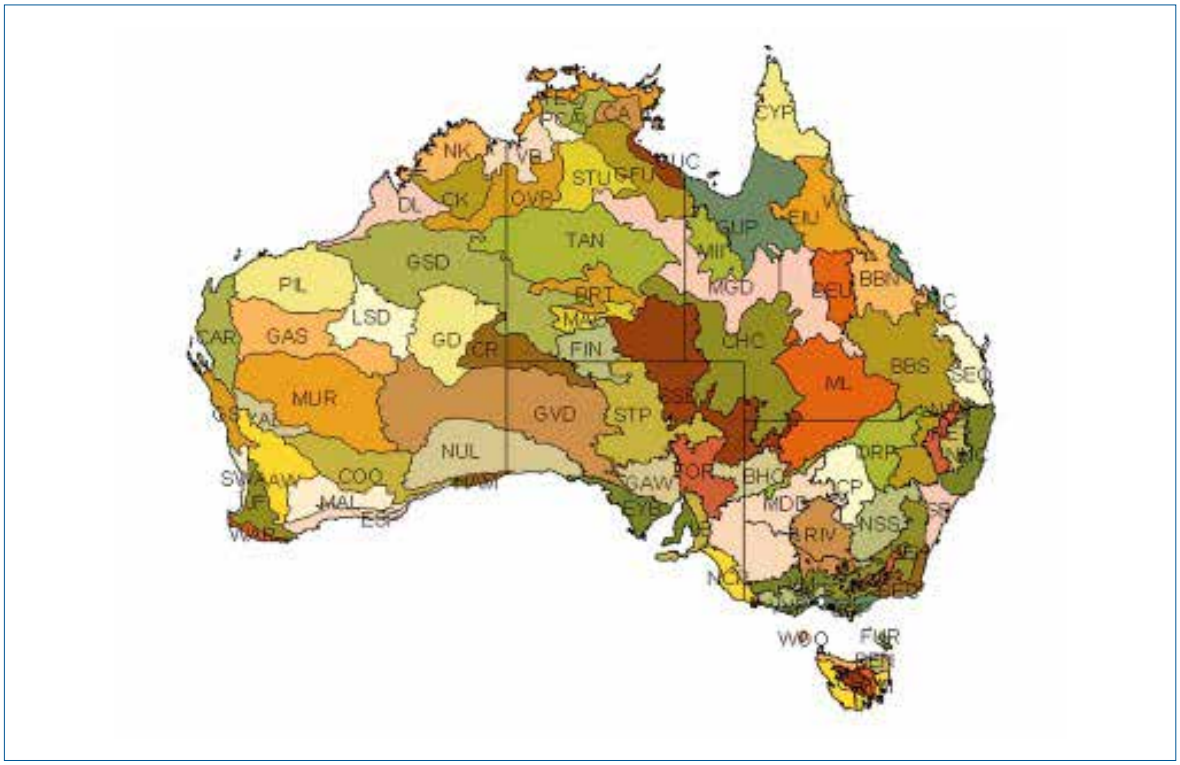
Table 7.E.3: Example land use table

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.E.6: 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

Code	Name	Code	Name
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
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

7.E.5 Crop Yield

Crop/pasture growth model

FullCAM uses the crop and pasture yield data in the estimation of biomass accumulation in agricultural systems. Yield data is estimated in *FullCAM* using a simple crop/pasture growth model to estimate yields based on rainfall availability during the growth period (Unkovich *et al.* 2009). The model uses the *FullCAM* water balance routine to estimate daily evapotranspiration, using fixed crop x region specific splits for bare soil evaporation or crop water use (transpiration) to estimate crop and pasture productivity. Two plant production modules are used, one to accommodate annual crops and pastures (Figure 7.E.7), and the other for perennial pasture systems across the continent (Figure 7.E.8). The two modules cover summer and winter grain and forage crops, sugarcane, sown and native pastures, and grass growth in rangeland ecosystems.

Figure 7.E.7: Conceptual model of annual crop growth module

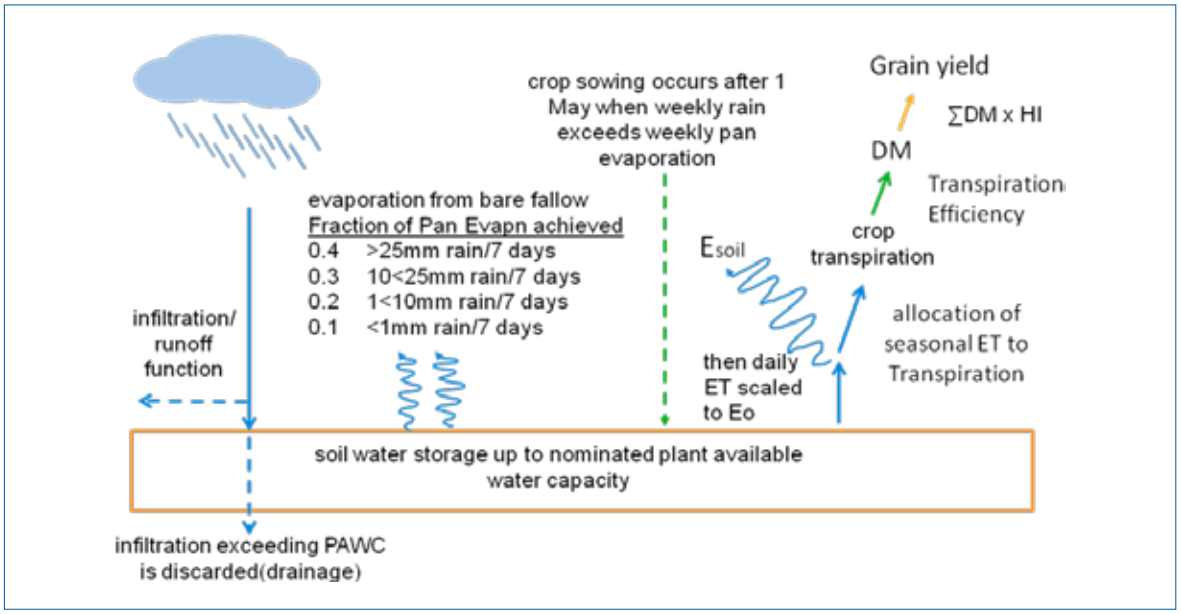
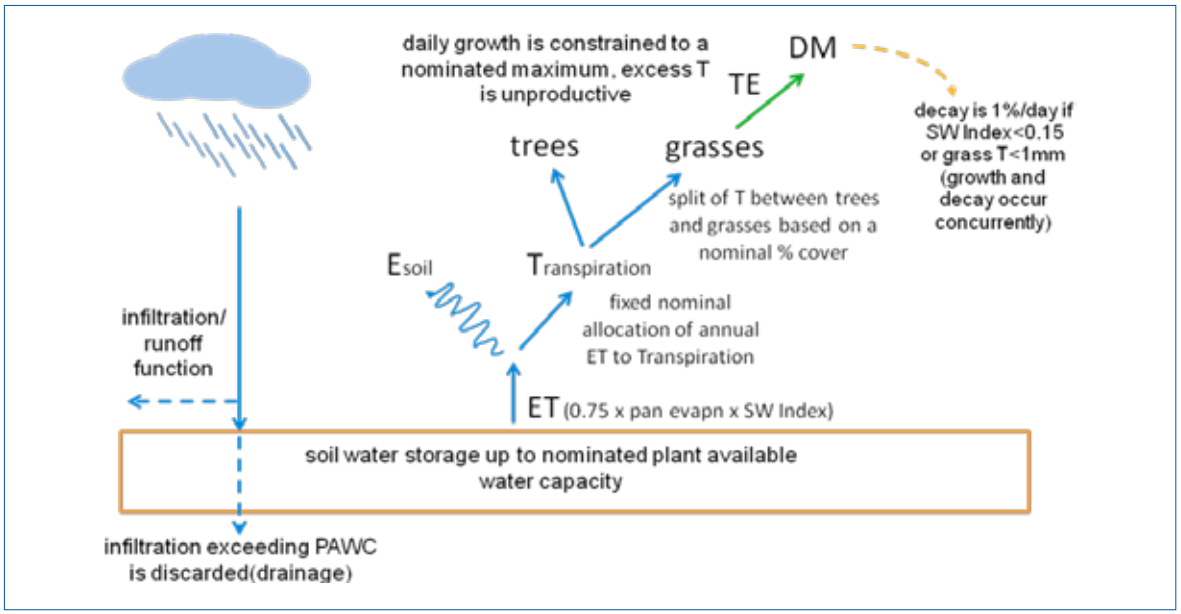


Figure 7.E.8: Conceptual model of perennial grass/pasture module



Productivity improvement trends

As the model of crop growth is based on recent agricultural management practices it is necessary to scale the modelled dry matter production backwards in time according to long term trends in farm crop productivity. Taking 2000 as the base year, modelled yields have been scaled, both backwards and forwards, from this time at the indicative rate (1.36% pa) for the 1970-2010 time period. While this rate of change also includes yield increases due to improvements in crop harvest index (Unkovich *et al.* 2010) these have not removed from the dry matter productivity increases because HI is currently held constant in *FullCAM*.

Testing the model

CSIRO has test the model construct output against a database of crop yield data (Unkovich *et al*. 2014). In general (regional) testing, the modules accounted for about 50% of the variance in annual crop grain yield or of shoot dry matter of perennial pastures on any given day. In site specific tests the annual grain crop model was able to explain up to 80% of the variance in crop yield.

Appendix 7.F: Harvested Native Forests and 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 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.F.1). 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.F.1: 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)	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.F.2). 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.F.2: 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	6.1	-22.4	-33.1
2000	-8.9	10.9	-25.6	-23.6
2011	-20.1	3.4	-25.7	-42.4
2012	-24.8	2.1	-25.9	-48.6

Appendix 7.G: Post-1990 Plantations – Forest Growth Model

Forest growth model

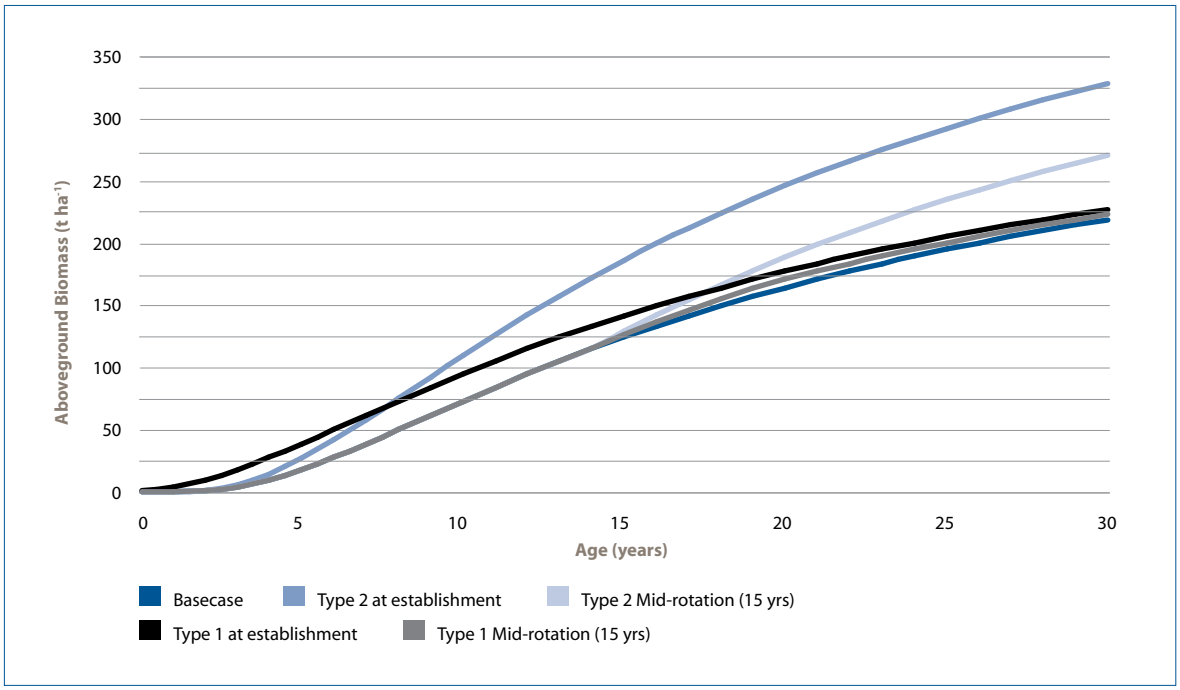
Plantations commonly produce more biomass than native forest systems in Australia, at least in the short to medium term (15-40 years). For example, Baker and Attiwill (1985) showed that *Pinus radiata* achieved 70-100% of the biomass of an 80 year old native forest, grown under similar conditions, in 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 (Appendix 7.D) 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.

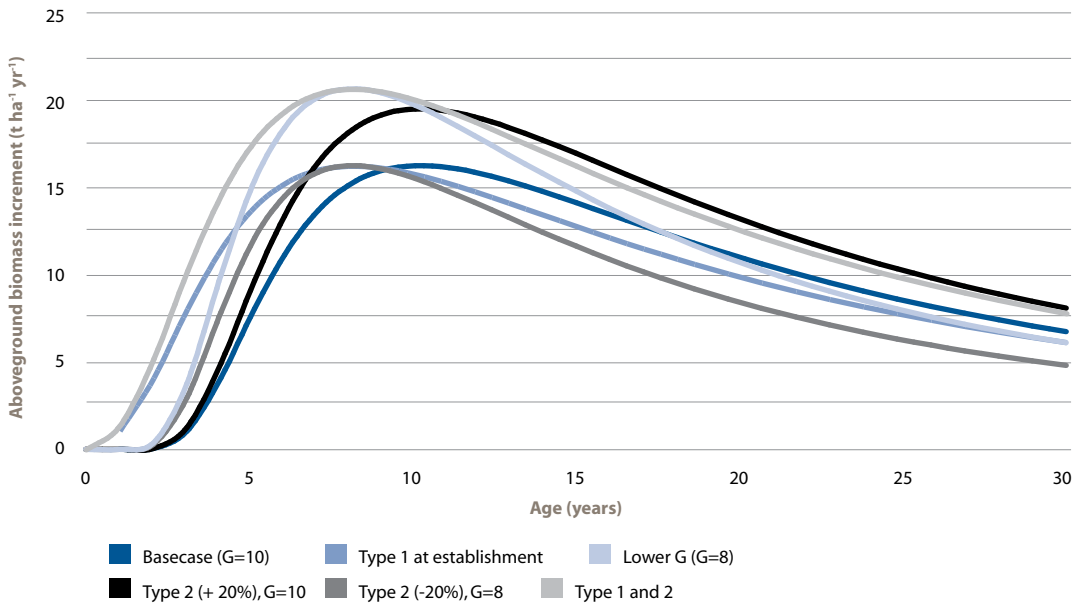
To account for the effects of management practices on growth the native forest regrowth model (the Tree Yield Formula, Appendix 7.B) is supplemented to include functions that represent Type 1 and Type 2 growth responses (Snowdon and Waring, 1984) (Figure 7.G.1). Type 1 management practices advance or 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.G.1: Effect of Type 1 and Type 2 management practices on (a) cumulative and (b) annual growth

(a)



(b)



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 7G_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 7G_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.C) for each point, the type of plantation established and is stratified by State and National Plantation Inventory (NPI) region (Figure 7.16). 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.

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 m^3 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 m^3 ha^{-1} yr^{-1} in long rotation systems and 35 m^3 ha^{-1} yr^{-1} in short rotation systems.

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.G.1.

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 7G_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.D), 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.G.1: Range of FPI (P) values on which plantation types occur, the minimum, average and maximum growth rates (Mean Annual Volume Increment, m3 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 ..... (7G_ 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.G.2) (Equation 7G_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.

$$\ln(r) = b_0 + b_1 * \ln(P_{av}) \quad (7G_2)$$

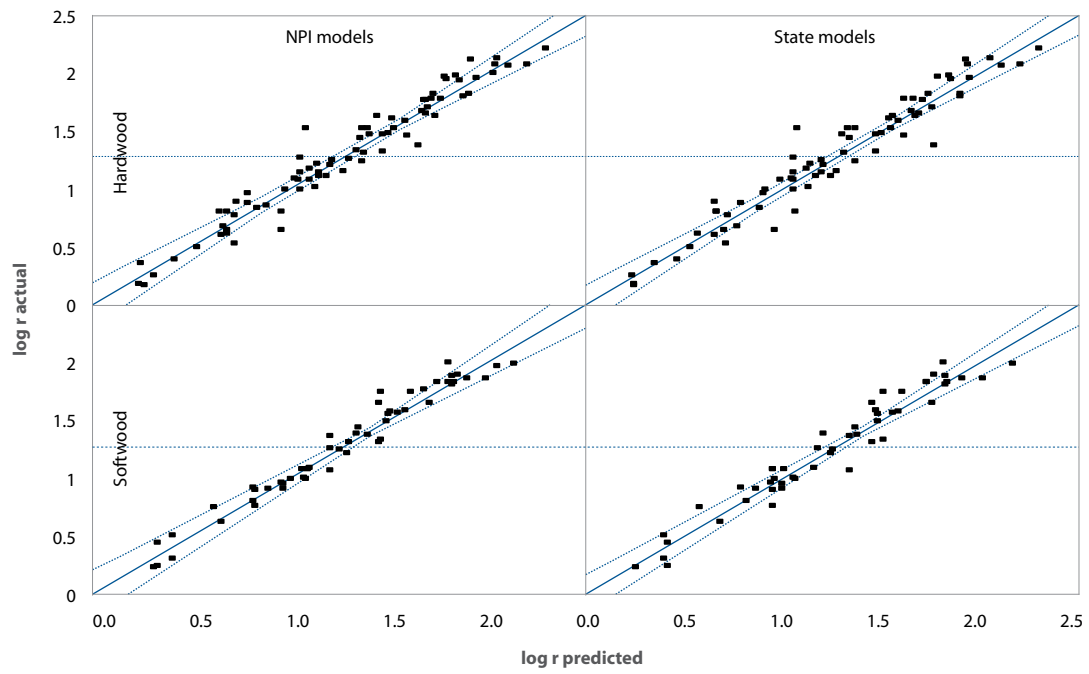
Where: r = non-endemic species multiplier

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.G.2: Actual vs predicted r values for hardwood and softwood plantations by State and NPI



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.B; Equation 7G_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 7G_3):

$$G = G_{man} + T1_{pre\text{-}g} \quad \text{(7G_3)}$$

Where: 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 (7G_4) was calibrated based on 'unaffected stands' by adding 2 years of Type 1 effect to the current age of canopy closure (Equation 7G_3), resulting in a range of nine to 14 years for G. Regionally specific data for G and Gman was not available so this range was applied for all long rotation systems. However Gman DEs 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 7G_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 2 to 3 years earlier than for long rotation systems

Final model form used for post-1990 plantations

$$G = s * M + c \quad \text{(7G_4)}$$

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:

$$I_a = r * M * ((y_2 * e^{-k/d}) - (y_1 * e^{-k/d-1})) * (P/P_{av}) \quad \text{(7G_5)}$$

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}

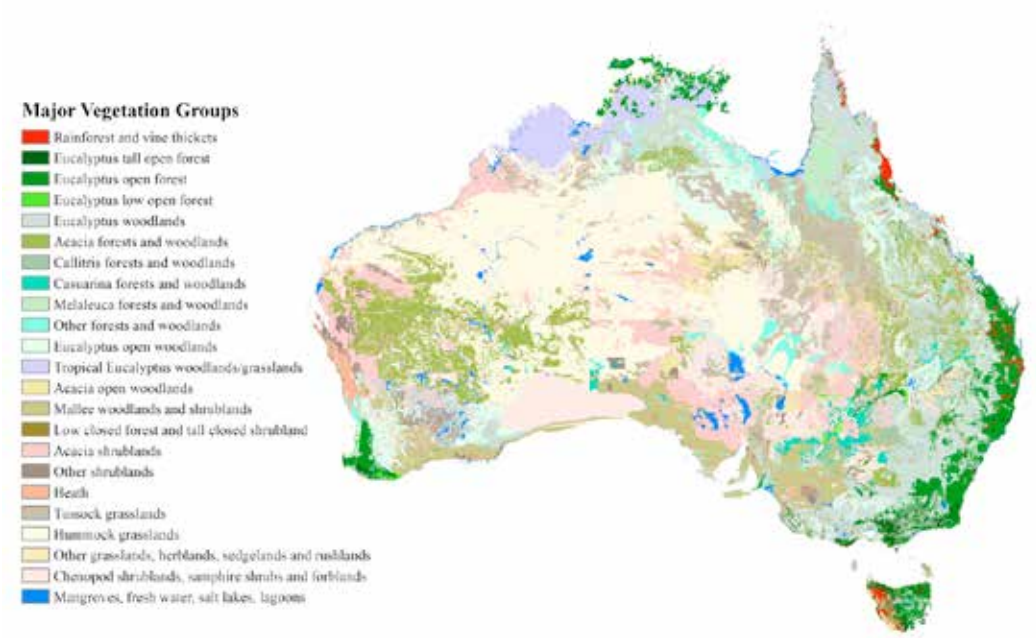
P_{av} =Long term average FPI value

Appendix 7.H: Major Vegetation Groupings Classified by the National Vegetation Information System

The Major Vegetation Groups (MVG) (Figure 7.H.1) are used to specify the biomass allocations of *forest land converted to cropland* or *grassland*. In additional the MVG are used to spatially disaggregated the land included in the *forest land converted to cropland* or *grassland* classifications in the CRF tables.

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. For the purposes of carbon accounting the Level III MVG categories were applied. These vegetation types are described in below.

Figure 7.H.1: Major vegetation groups (MVG)



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.

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 harpohylla*) 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 component 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.I Tier 2 Forest Conversion Model

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 is used to estimate changes in biomass from the conversion of 'mature' forest, the regrowth of forest on previously cleared land, the growth of crops and grasses on cleared land, and the subsequent re-clearing of a proportion of this regrowth.

The model also calculates changes in the dead organic matter and soil pools and emissions (CO_2 and non-CO_2) associated with burning;

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.

In the Tier 2 model land clearing is stratified into three broad forest classes:

1. closed (tropical forest);
2. open (predominantly eucalypt forest); and
3. 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.H).

Figure 7.I.1: Initial assumed biomass of land cleared post-1989 which has entered Australia's deforestation accounts.

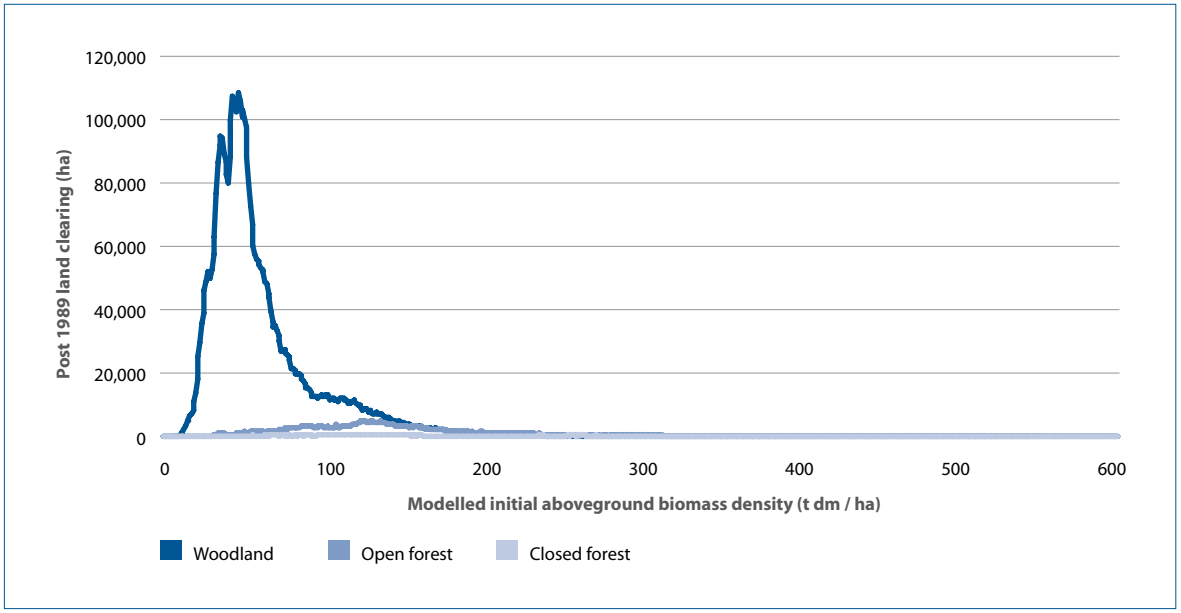


Figure 7.I.1 shows that the majority of land clearing since 1989 has occurred in woodland forests. This information was used in the Tier 2 model to allocate the area cleared in each year to clearing of woodland, open forest and closed forest (Table 7.I.1).

Carbon pools

Biomass – aboveground and below ground trees

To determine the biomass of each forest class that is used in the Tier 2 model, analysis was undertaken of the initial assumed above ground 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 above ground biomass surface. Table 7.I.1 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.I.1: Tier 2 forest coefficients used to estimate emissions and removals from first time forest clearing

	Closed Forest	Open Forest	Woodland Forest
Proportion of annual clearing (%)	2	10	88
Initial biomass of forests(a)(b) (t dm ha^{-1})	198.7	152.8	67.6
Root: shoot ratio	0.25	0.25	0.40
Debris onsite mass(b) (t dm ha^{-1})	100	75	50
Initial soil carbon (t C ha^{-1})	70	73	60
Proportion of area subject to forest regrowth (%)	25	25	25

(a) Aboveground biomass.
(b) Used for all States and Territories.

Areas of previously cleared land that re-grew to forest are assumed to achieve their original biomass in 25 years. The biomass of forest subject to reclearing is 32% of the mature biomass.

Biomass – above ground and below ground herbaceous species

Sequestration associated with the growth of crop and grass species is included in the model, on land which is not subject to forest regrowth. Table 7.I.2 provides the biomass increment parameters applied to estimate this variable. These parameters are multiplied by the total area of clearing recorded each year to estimate the biomass accumulated by crop and grass species on cleared land.

	Crops	Grasses
Proportion of cleared land (%)	15	60
Above ground mass, including debris (tdm ha^{-1})	4.0	4.2
Root: shoot ratio	0.5	0.5

Dead organic matter

The forest debris onsite prior to forest clearing is presented in Table 7.I.1 and debris associated with crops and grasses is included with living biomass (Table 7.I.2). Forest debris, including initial debris and debris remaining after forest conversion, was assumed to decay over a period of 10 years (IPCC, 2003).

Soil carbon

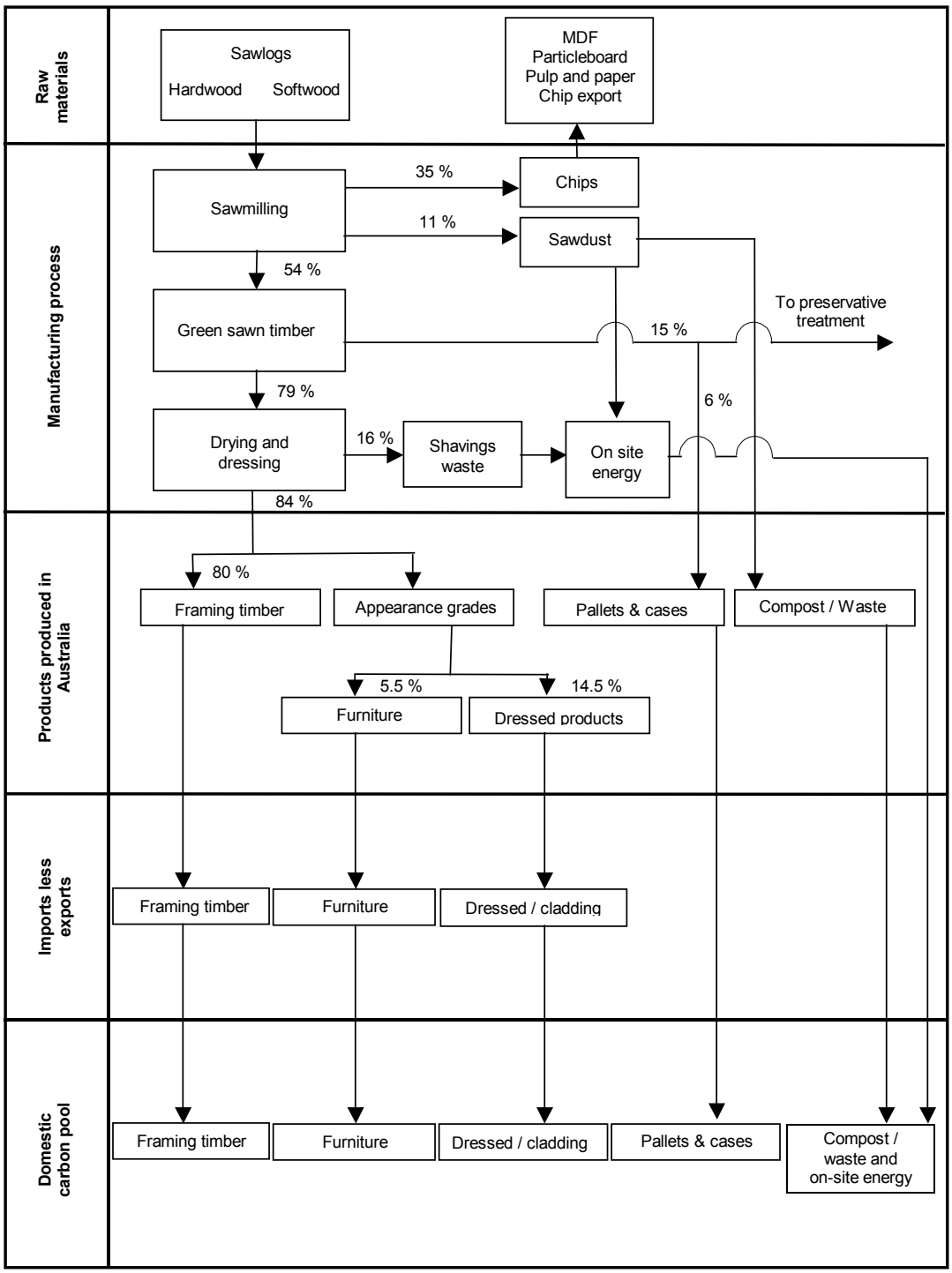
Emissions of soil carbon following conversion are estimated by applying the Roth C model for all first time cleared land (See Appendix 7.B). The Roth C model was parameterised with climate data (rainfall, temperature, open pan evaporation) from a representative site in central Queensland.

Non CO_2 emissions

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.

Appendix 7.J: Wood Flows By Sector

Figure 7.J.1: 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.J.2: National Carbon Accounting Model for Wood Products – Wood flows in preservative treated products

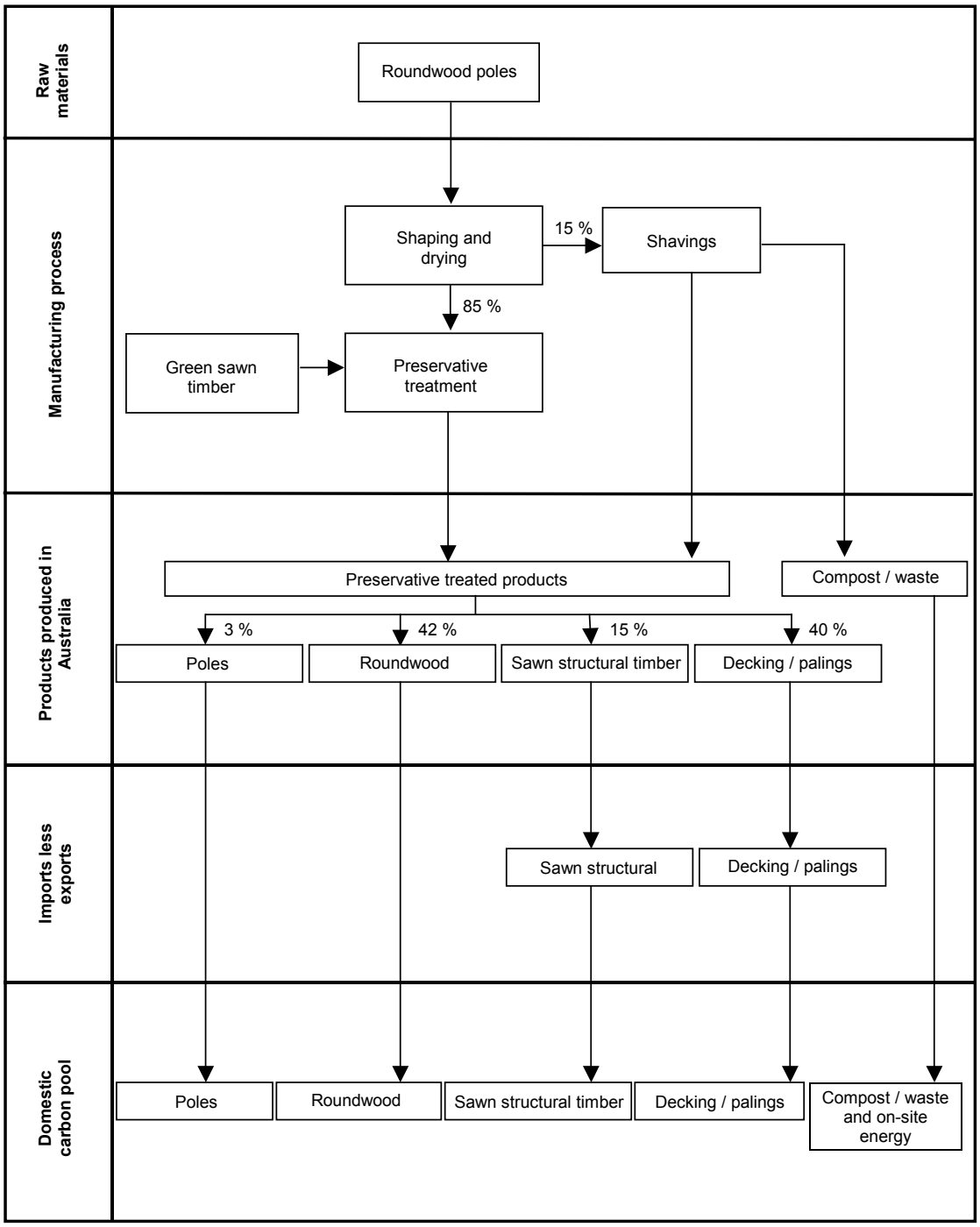
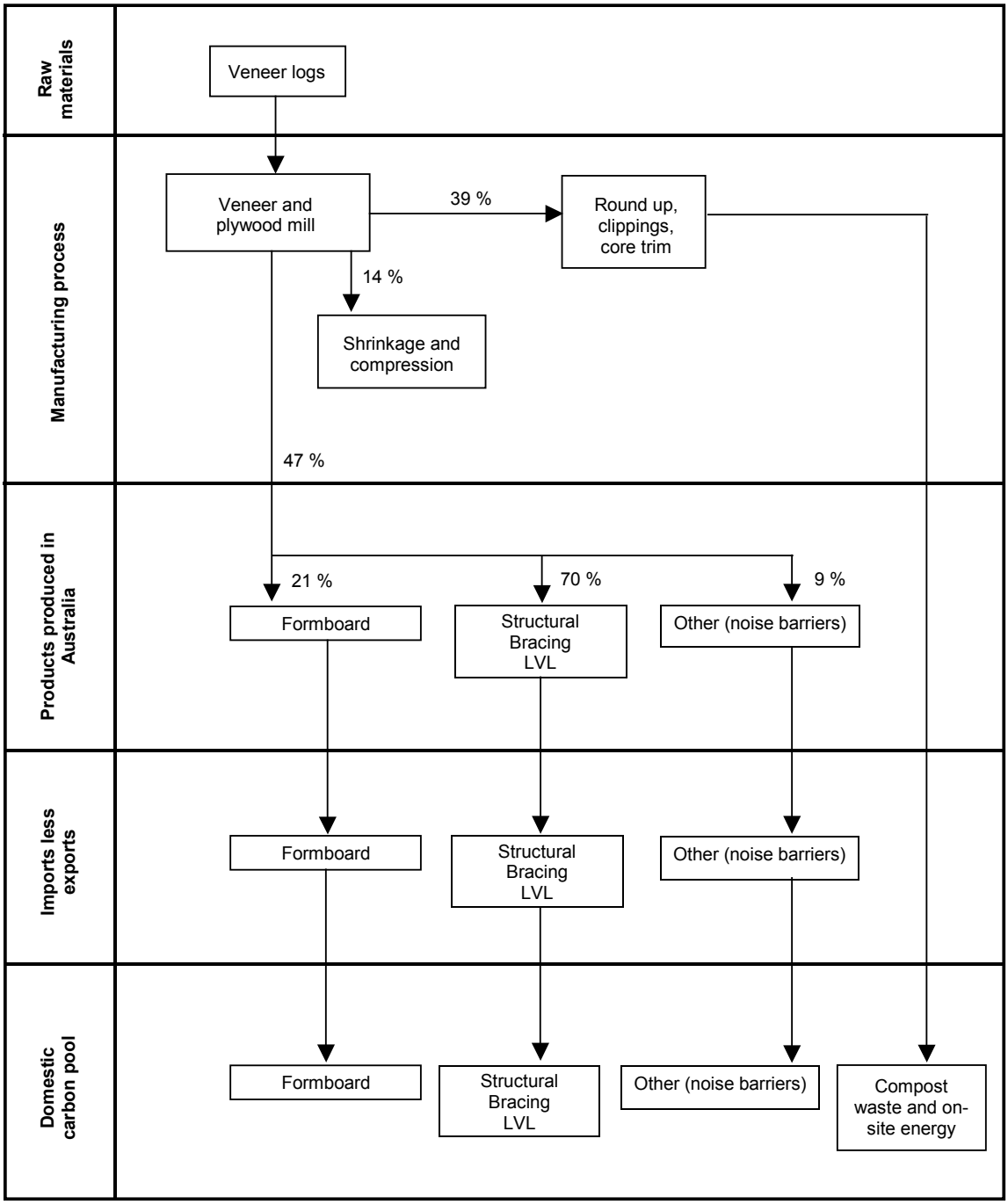
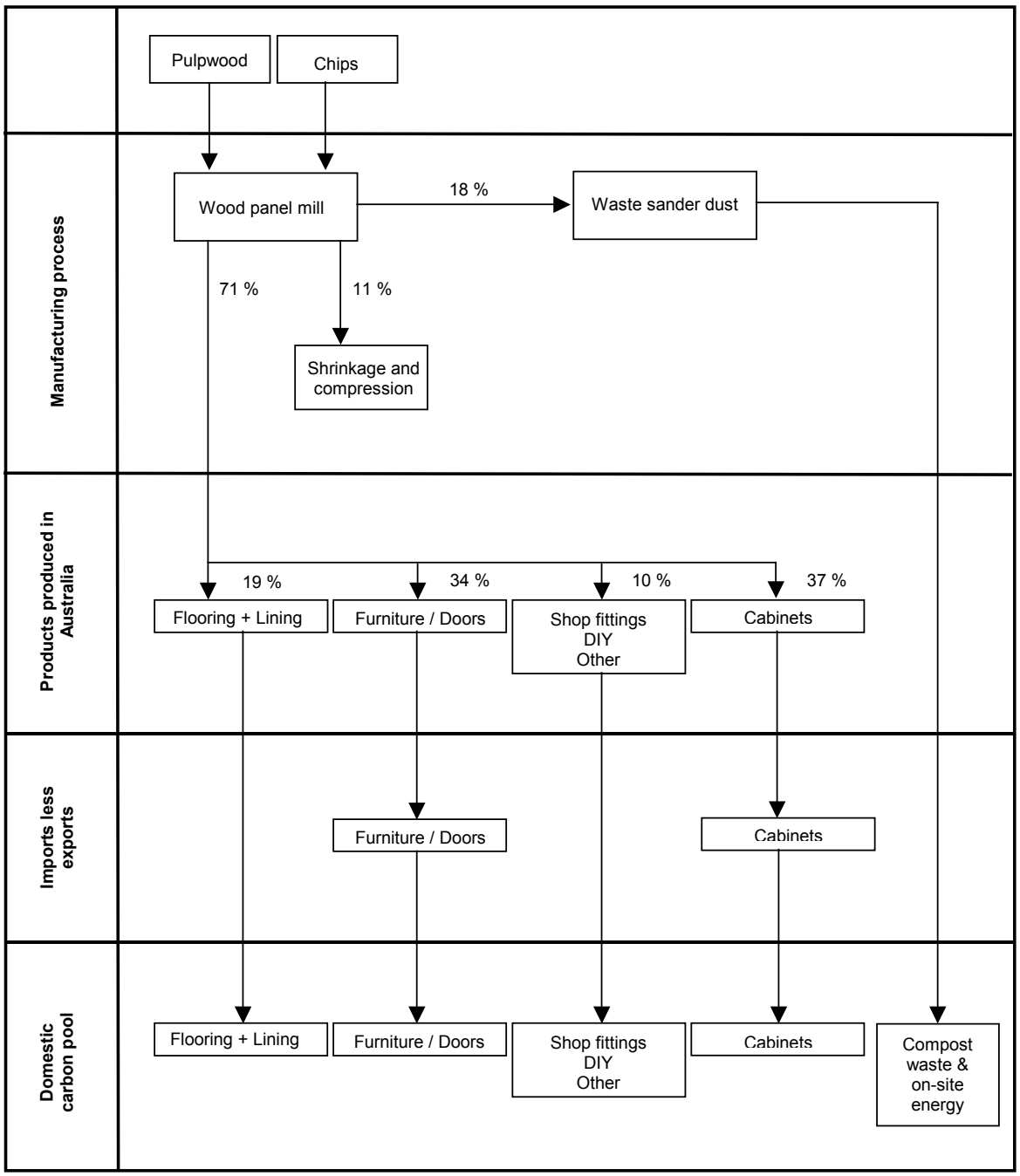


Figure 7.J.3: National Carbon Accounting Model for Wood Products – Wood flows in plywood production



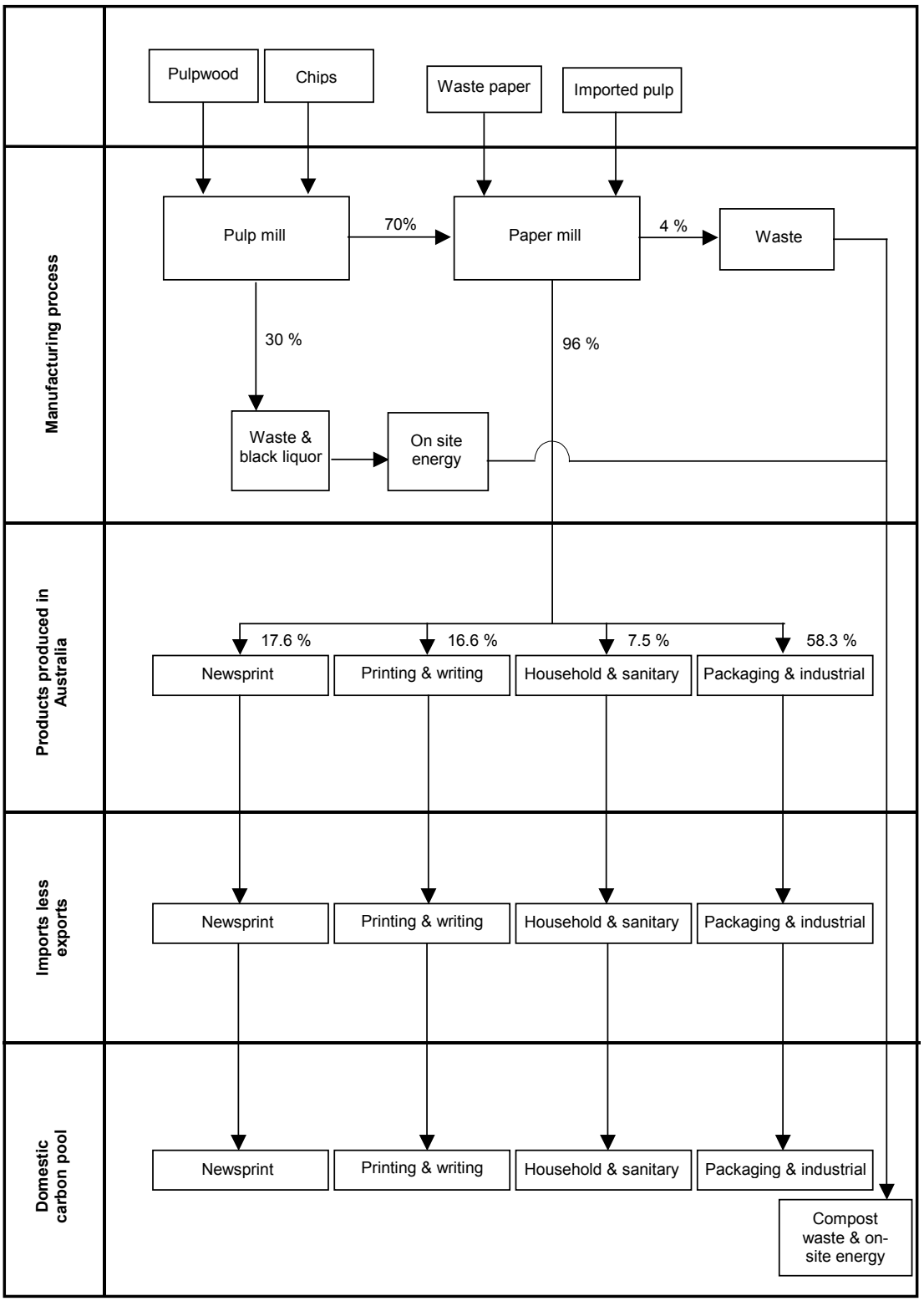
Appendix

Figure 7.J.4: National Carbon Accounting Model for Wood Products – Wood flows in MDF and particleboard manufacture*



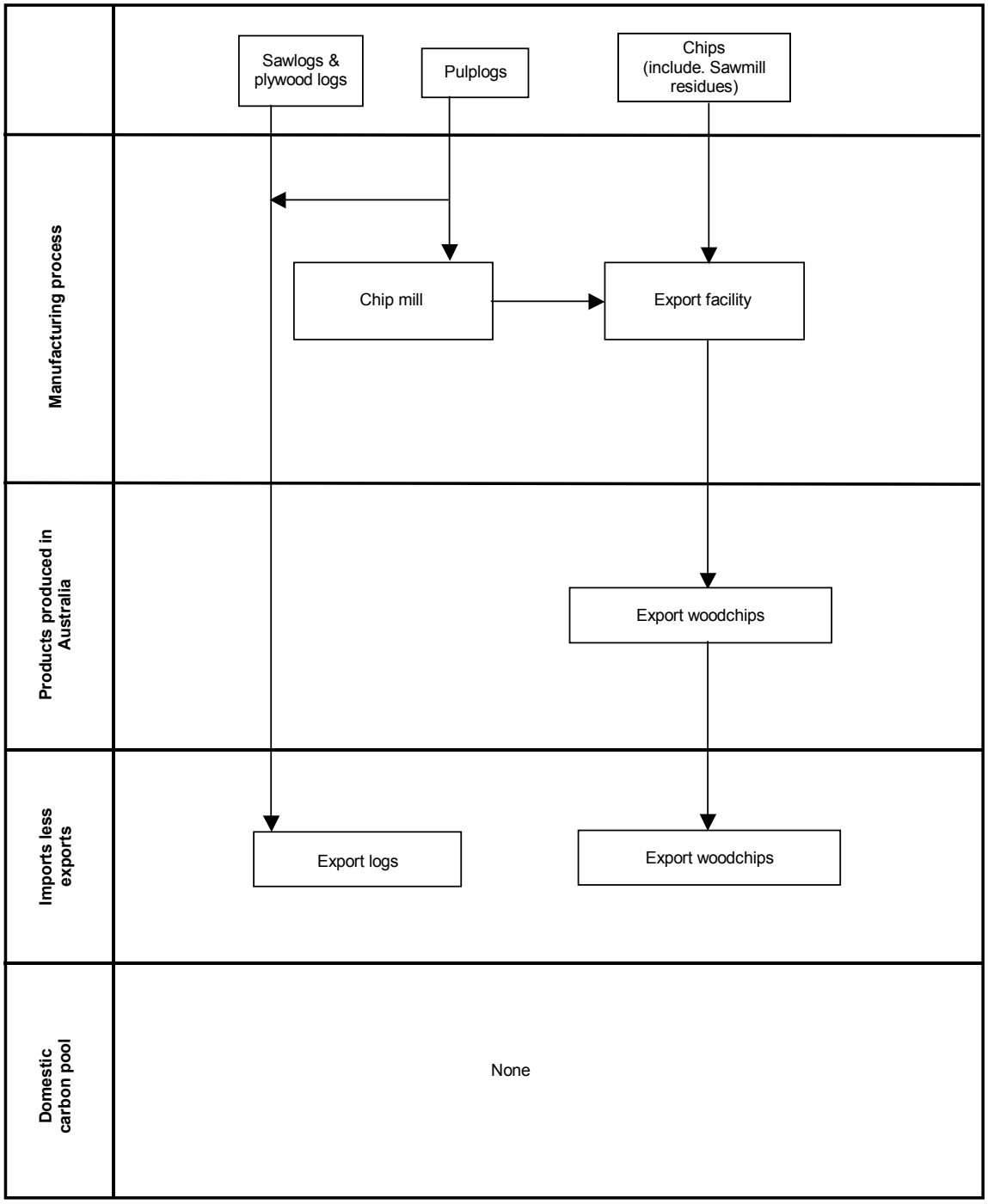
*percentages shown for particleboard manufacture – see model for details on MDF

Figure 7.J.5: National Carbon Accounting Model for Wood Products – Wood flows in pulp and paper manufacture



Appendix

Figure 7.J.6: National Carbon Accounting Model for Wood Products – Wood flows in export woodchips and logs



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