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AUSTRALIAN NATIONAL GREENHOUSE ACCOUNTS

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May 2010

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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 68.5 Mt CO_2-e in 2008 (Table 7.1).

Table 7.1 Land use, land use change and forestry net CO_2-e emissions, 2008

Greenhouse gas source and sink categories	CO_2-e emissions (Gg)			
	CO_2 [(a)]	CH_4	N_2O	Total
5 Land use, land use change and forestry	**63,658**	**3,338**	**1,523**	**68,518**
A. Forest land	-106,413	1,720	469	-104,225
A.1. Forest land remaining Forest land	*-89,447*	*1,720*	*469*	*-87,258*
A.2 Land converted to Forest land	*-16,966*			*-16,966*
B. Cropland	-13,003	599	276	-12,128
B.1 Cropland remaining Cropland	*-18,769*	*IE*	*IE*	*-18,769*
B.2 Land converted to Cropland	*5766*	*599*	*276*	*6,641*
C. Grassland	187,110	1,019	279	188,407
C.1 Grassland remaining Grassland	*137,824*	*IE*	*IE*	*137,824*
C.2 Land converted to Grassland	*49,286*	*1,019*	*279*	*50,584*
D. Wetlands	NE	NE	NE	NE
E. Settlements	NE	NE	NE	NE
F. Other land	NO, NA	NO, NA	NO, NA	NO, NA
G. Other[(b)]	-4,036	NA	449	-3,537

(a) A negative sign denotes a sink. (b) Includes Harvested Wood Products, Agricultural lime application and N_2O from disturbance associated with land-use conversion to Grassland. N_2O from disturbance associated with land-use conversion to Cropland is reported under Cropland.
Notes: NE = not estimated (voluntary reporting categories), IE = included elsewhere (reported in the agriculture sector), NA = not applicable, NO = not occurring.

Forest land (5A) comprises emissions and removals from *plantations*, *harvested native forests* and *other native forests*. Emissions from *fuelwood consumption* and biomass burning in forests (*slash burning*, *prescribed burning* and *wildfire*) are also included as are the removals associated with post fire recovery. These categories are estimated to have constituted a net sink of 104.2 Mt CO_2-e in 2008.

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 sink of 12.1 Mt CO_2-e in 2008.

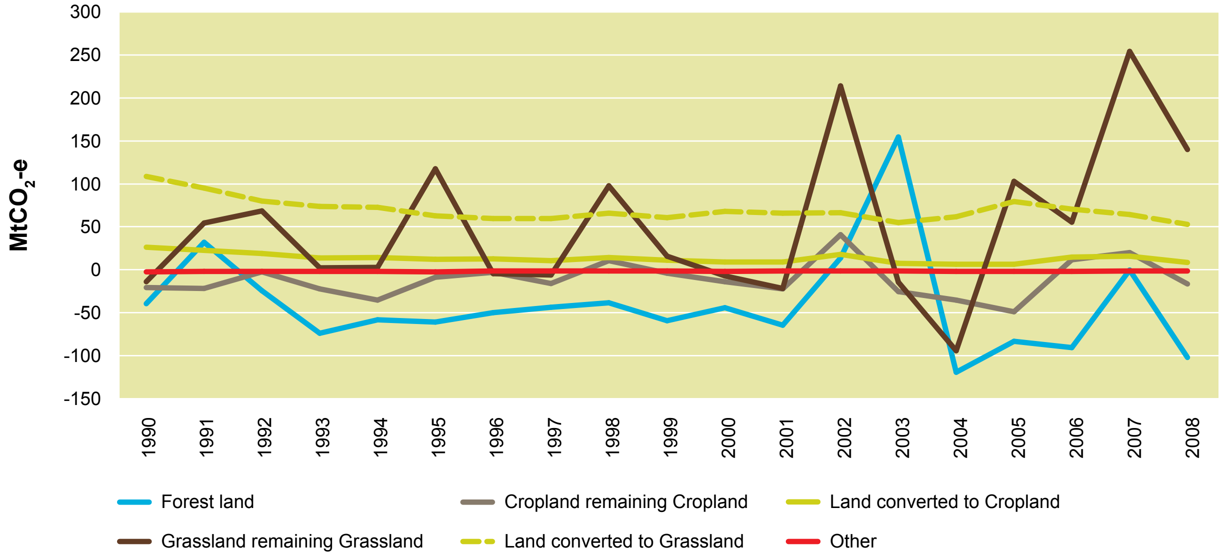
Grassland (5C) comprises emissions and removals from *grassland remaining grassland* and *forest land converted to grassland*. The *grassland* subsector is estimated to have constituted a net source of 188.4 Mt CO_2-e in 2008.

Forest land converted to cropland and *grassland* was a net source of 57.1 Mt CO_2-e in 2008, while the associated emissions of *N_2O from soil disturbance* were 0.6 Mt.

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 5.1 Mt 'sink' in *harvested wood products*.

Agricultural lime application is estimated to have contributed emissions of 1.1 Mt CO_2-e in 2008.

Figure 7.1 Net CO_2-e emissions from Land use, land use change and forestry, by sub-sector, 1990–2008



Trends

From year to year the LULUCF sector may change from a net source to a net sink (Figure 7.1). The trends in the LULUCF sector are primarily driven by inter-annual climate variability and natural disturbance, which tends to mask other, underlying patterns in the sector directly associated with human activities. In 2008, the net *land use*, *land use change and forestry* emissions increased from 46.1 Mt CO_2-e in 1990 to 68.5 Mt CO_2-e.

The trend in net emissions in the early 1990's is primarily driven by the reduction in emissions from forest conversion, however the shift from a net sink to net source in 1995, 1998 and 2002 along with the spike in emissions in 2007 reflect natural disturbances such as fires and extensive drought conditions which caused a loss of carbon from all pools. These effects can be seen most clearly in the *grassland remaining grassland* and *cropland remaining cropland* sub-categories.

The 2008 estimate of total emissions from *forest land converted to cropland* and *forest land converted to grassland* was 56.3% (73.6 Mt) lower than in 1990. Since 1990 the annual rates of forest conversion have decreased substantially (Table 7.2) reflecting both the effects of changing market and climatic conditions and of regulatory impacts with consequent reductions in estimated emissions. Legislation recently introduced by the Queensland and New South Wales State Governments has resulted in further reductions in forest conversions. Emissions from the decay of aboveground biomass and belowground carbon due to extensive past land use change have also been diminishing.

Emissions of *N_2O from soil disturbance* associated with conversion of *forest land to cropland* and *grassland* has declined by 5.9% (0.04 Mt) between 1990 and 2008.

Within *forest land* (5A), *forest land remaining forest land* changed from a net sink of 41.6 Mt in 1990 to a net sink of 87.3 Mt CO_2-e in 2008, while the removals from *lands converted to forest land* increased from 0.2 to 17.0 Mt CO_2-e. The combined effect of these changes is an increase in the *forest land* net sink of 62.5% (149.8 Mt) between 1990 and 2008.

Emissions from *agricultural lime application* have increased from 0.2 Mt in 1990 to 1.1 Mt in 2008.

Table 7.2 Annual area of forest change (ha)

Year	Forest land converted to	
	Cropland	Grassland
1990	116,657	444,011
1991	88,966	338,546
1992	69,517	321,701
1993	65,696	324,450
1994	75,893	295,455
1995	61,232	255,667
1996	66,213	252,835
1997	65,535	249,169
1998	63,358	269,992
1999	62,410	279,033
2000	63,166	298,673
2001	65,189	297,722
2002	64,534	249,115
2003	63,566	233,925
2004	80,991	325,691
2005	79,595	317,541
2006	91,286	294,408
2007	71,792	203,812
2008	68,153	148,389

Trends due to climate variability

Several categories of the LULUCF inventory are estimated using the process based, Tier 3 model *FullCAM*. As a result, trends in the emissions reported for these categories reflect all the factors which lead to emissions and removals, including land use change, ongoing management, and climate. The inclusion of climatic effects means that the implied emissions factors can vary considerably between years even though the activity data remains similar. The domination of natural climate variability upon emissions patterns become much stronger in years of extreme conditions (such as drought) and the effects of these can have flow-on effects for several years. This large variability in year-to-year emissions levels does not represent an error or inconsistency in the reporting, but is due to Australia's complex land systems, highly variable climate and the large land areas being modelled. An example of this effect is described below.

An example of climate effects on emissions from cropland

During 2002/3 emissions from the *forest land converted to cropland* and the *cropland remaining cropland* sub-categories spiked after several years of relatively stable emissions levels (Figure 7.2). This spike led to a sudden increase in the implied emission factors for both categories. The spike is driven by a large reduction in crop yield (Figure 7.3) caused by one of the worst droughts in Australia's history (Figure 7.4).

Figure 7.2 Emissions from Cropland remaining Cropland

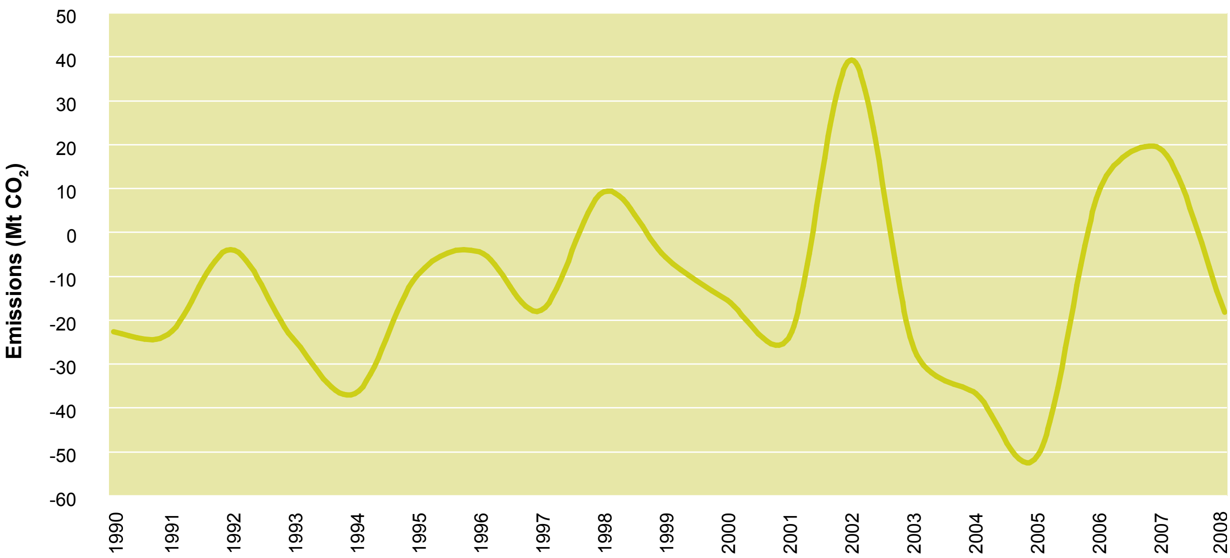


Figure 7.3 Average yield of crops (not area weighted) used in the Tier 3 process model since 1990

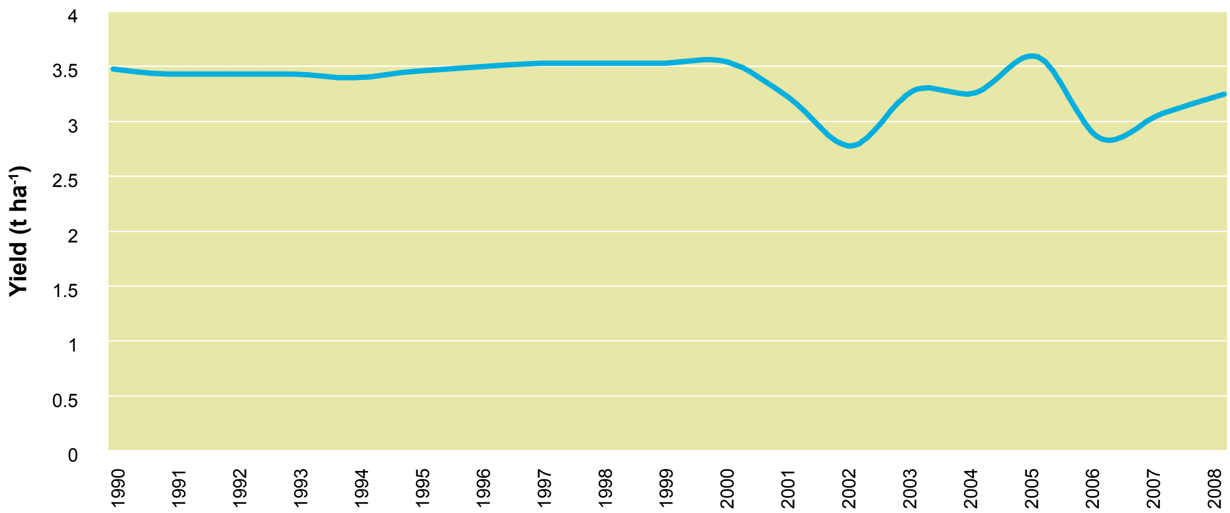
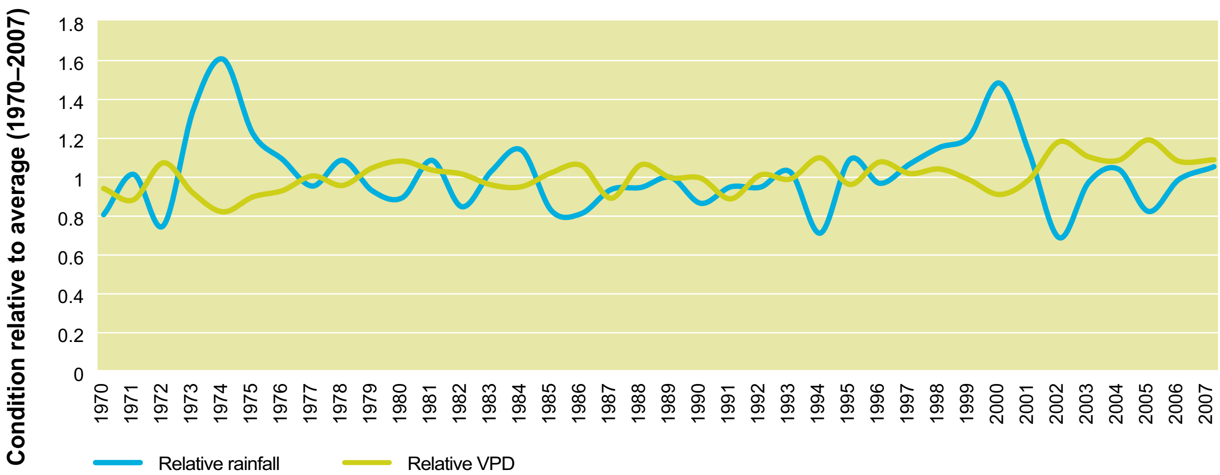


Figure 7.4 Relative rainfall and Vapour Pressure Deficit (VPD) across Australia



The effect of the drought on emissions in the *cropland* categories is clearly visible when represented as the percentage change in carbon stocks by pool (Figure 7.5). In Australia, crops are generally still growing at the end of the calendar year, unlike many northern hemisphere countries where crops are not present at this time. This means that any change in crop yield will directly affect the emissions estimates as the biomass of crops will vary between calendar years. In 2002 the large decrease in crop yields, due to drought, led to a large decrease in plant and debris stocks at the end of the 2002 calendar year, which resulted in a large spike in emissions from these pools. In 2003, the plant and debris stocks recovered to more average levels as conditions improved and the crops survived. While soil carbon stocks varied only by a small percentage, because soils are a large store of carbon (around 55 t ha^{-1} on average), these small changes had a considerable effect on absolute emissions and removals. In 2002, the soil carbon stocks had increased slightly as the dry conditions limited decomposition. During 2003 the soils were deprived of residues from harvest due to the large number of crop failures in 2002, while the wetter conditions allowed for more decomposition, leading to a reduction in the soil carbon stocks.

Figure 7.5 Percentage change in carbon stocks in the Cropland remaining Cropland category

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

Land use and management activities influence a variety of ecosystem processes that affect greenhouse gas fluxes. The focus of this sector is the estimation of emissions and removals of carbon dioxide (CO_2) from these activities. CO_2 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 7.3). The methods used in the reporting of the LULUCF categories of the inventory are described in detail in Appendices 7.A to 7.J:

- Appendix 7.A – Overview of the development and implementation of the National Carbon Accounting System;
- Appendix 7.B – Harvested Native Forests (*forest land remaining forest land*);
- Appendix 7.C – Pre-1990 Forest Plantations (*forest land remaining forest land*);

- Appendix 7.D – Post-1990 Forest Plantations (*grassland converted to forest land*);
- Appendix 7.E – Other Native Forests (*forest land remaining forest land*);
- Appendix 7.F –Forest land converted to Cropland and Grassland;
- Appendix 7.G – Cropland remaining Cropland;
- Appendix 7.H – Grassland remaining Grassland;
- Appendix 7.I – Harvested Wood Products, and
- Appendix 7.J – Calibration, validation, verification and QA/QC for LULUCF.

Table 7.3 Summary of methodologies and emission factors – Land use, land use change and forestry sector

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

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

7.2.1 Australia's National Carbon Accounting System

In 1998 Australia embarked on a development program for a National Carbon Accounting System (NCAS) to provide a complete accounting capability for Australia's land based sectors (AGO, 2005). Australia currently invests approximately AUD $4 million per year in the NCAS. The NCAS is being progressively developed to provide a complete greenhouse gas accounting capability for agriculture, forestry and land use change (including all carbon pools, gases, lands and land use activities). The eventual capacity will be a full spatial enumeration with emissions and removals calculated using a process-based, mass balance, carbon and nitrogen cycling ecosystem model.

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

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

The progressive development of the NCAS is set around priorities according to the scale of emissions from either the land use activity or carbon pool. To date the full Tier 3, Approach 3 (i.e., fully spatially explicit process-based ecosystems modelling) capability of the NCAS has been completed for the *forest land converted to cropland*, *forest land converted to grassland*, *grassland converted to forest land* and *cropland remaining cropland* sub-categories. Over the inventory time series the conversion of forest to cropland and grassland represents the majority of emissions associated with LULUCF activities.

The other principal reporting elements, *forest land remaining forest land* and *grassland remaining grassland* are reported using a combination of interim Tier 2 and 3 methods that, as yet, have not been fully developed within the NCAS framework. This is also the case for *harvested wood products*. Appendix 7.A gives an outline of the current and planned NCAS capabilities for inventory improvement.

7.3 Land Areas and Land Use Category Definitions

7.3.1 National Circumstances

7.3.1.1 Land Use in Australia

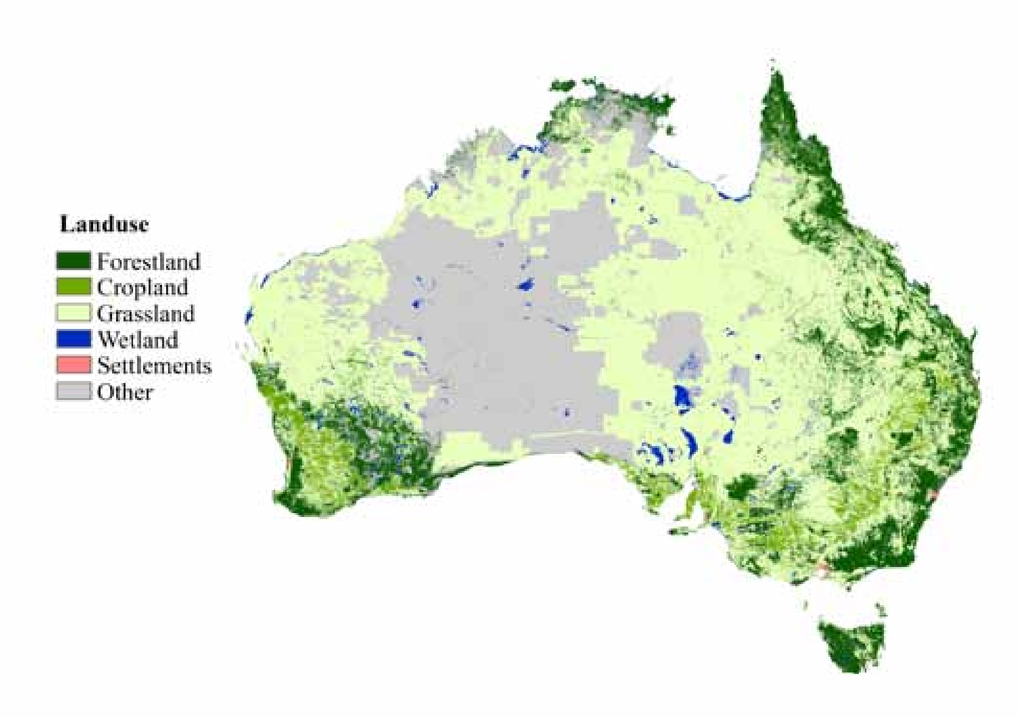
Australia has a land area of 769 million hectares containing unique land, water, vegetation and biodiversity resources. The distribution and land areas of the continent under different land uses are shown in Figure 7.6. The most significant agricultural activities include wool, beef, wheat, cotton and sugar production. Australia is also a significant exporter of dairy produce, fruit, rice and flowers. Australia's forest resources consist of native forests (primarily *Eucalyptus* species) which are used for wood production, recreation and conservation, and plantations of native (primarily *Eucalyptus* species) and exotic species (primarily *Pinus* species).

7.3.1.2 Climate

Australia is a dry continent where rainfall is highly variable and both recurring floods and droughts are a common feature. There are a number of distinct climatic zones with summer dominant rainfall in the tropics and subtropics in the north, Mediterranean climates in the south, the 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 7.7 and Figure 7.8).

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

Figure 7.6 Land use in Australia



LULUCF

Figure 7.7 Average annual rainfall

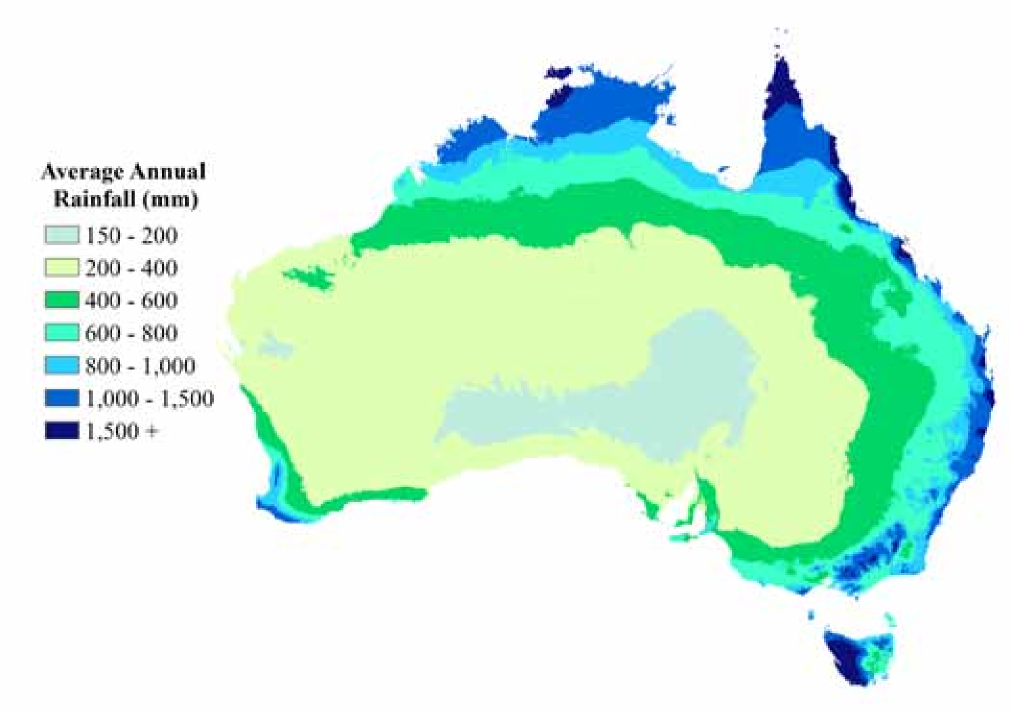
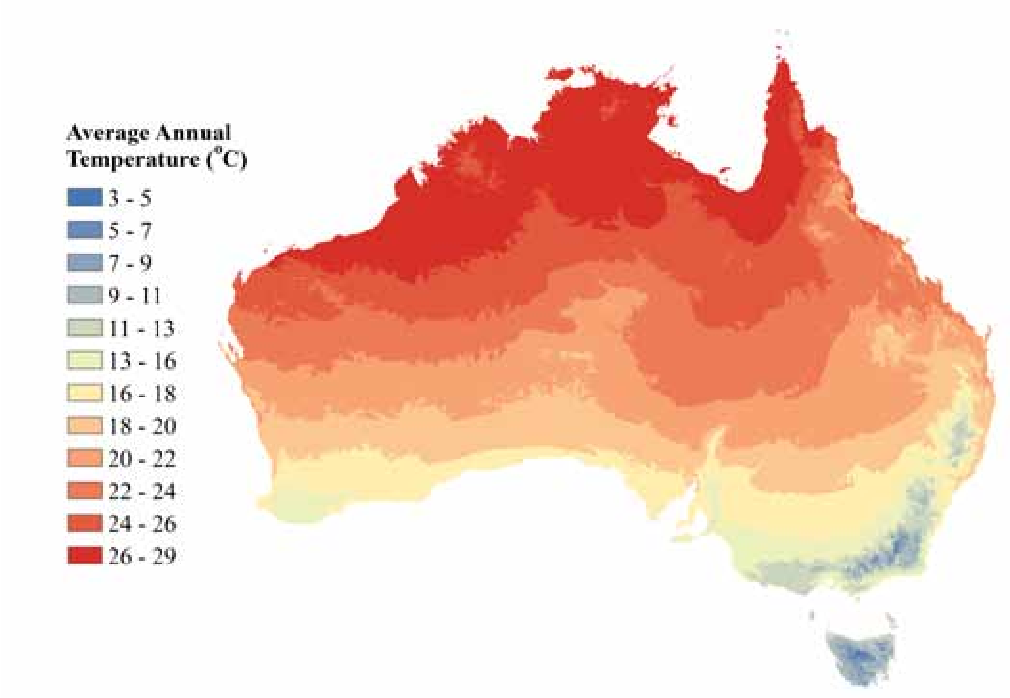


Figure 7.8 Average annual temperature

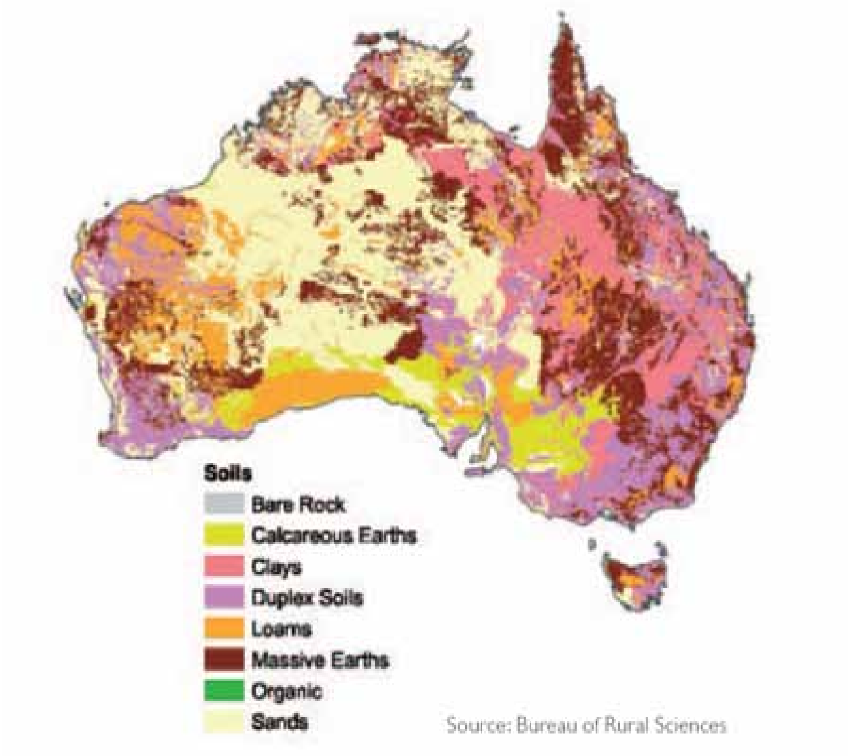


LULUCF

7.3.1.3 Soils

Australia has a diversity of soil types ranging from old, deeply weathered and infertile, to younger, more fertile soils derived from volcanic rocks and alluvium (Figure 7.9). Approximately 50 per cent are sandy, 37 per cent are earths and loams, and 13 per cent are clay textured. Many soils have low levels of phosphorus and other nutrients. Soils under agricultural management are managed by maintaining ground cover, avoiding disturbance on steep slopes and use of fertilizer (mainly phosphorus and nitrogen).

Figure 7.9 Soil types of Australia



7.3.2 Land Category Definitions

7.3.2.1 Forest Land

Forest land includes all lands with a tree height of at least 2 metres and crown canopy cover of 20% or more (Figure 7.10). These thresholds are consistent with the definition used for Australia's National Forest Inventory that has been used for reporting to the FAO and Montreal Process.

In choosing a forest definition Australia took several factors into account, including:

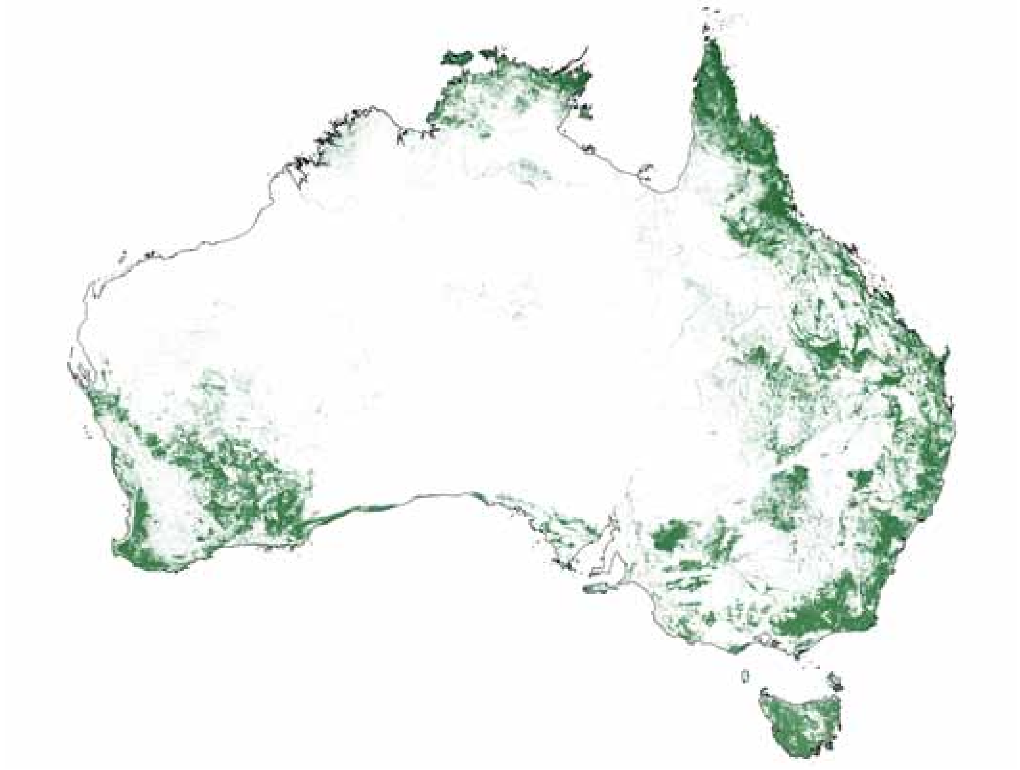
- the range of values provided for in the Marrakesh Accords LULUCF decision;
- the call in the Marrakesh Accords for consistency of Parties LULUCF reporting with existing international reporting;
- available data sources;
- the nature of deforestation and reforestation, and forest management activity, in Australia; and,
- the requirement that the definition would need to remain consistent across all uses in the UNFCCC and Kyoto Protocol inventories and remain in place for time-series consistency.

The Marrakesh Accords provide ranges for forest attributes from within which countries are to derive national definitions. The ranges are a minimum height of 2 to 5 metres, a crown canopy cover of 10 to 30% and a minimum area of 0.05 to 1.0 hectare. Consistent with the definition used since 1992 for Australia's National Forest Inventory, which has been used for reporting to the FAO and Montreal Process, a height of 2 metres and crown canopy cover of 20% were adopted for the forest definition.

This definition differs to that used in older reports, such as the Resource Assessment Commission (RAC) of 1992, which used 5 metres height and a crown canopy cover of 30%. This older definition, while suitable for areas of commercial forests of interest to the RAC, excluded large areas of other forest types in drier regions which are of particular interest in the LULUCF inventory.

Australia has adopted a minimum forest area of 0.2 ha. As the National Forest Inventory does not apply a minimum area requirement in its definition, an extensive process was undertaken to select an appropriate minimum area value. The selection process considered the structure and distribution of forest 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 7.10 Forest extent in Australia



7.3.2.2 Cropland

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

7.3.2.3 Grassland

In Australia, the *grassland* category represents a diverse range of climate, management and vegetation cover. Grasses range from highly productive, improved introduced pastures, with applications of fertiliser and irrigation, through to unimproved native grasses which cover vast areas and extend into the 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, cover and area criteria for *forest land*.

7.3.2.4 Settlements

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

7.3.2.5 Wetlands

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

7.3.2.6 Other land

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

7.3.2.7 Managed and unmanaged lands

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

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

Other lands are the only land category considered to be unmanaged.

7.4 Representation of Land Areas

The principal method of representing land is through a time-series national remote sensing program. This consistent representation of land is a fully spatial and time-series application of Approach 3 as described in the IPCC *Good Practice Guidance for Land Use, Land Use Change and Forestry* (IPCC, 2003). Reconciliations are done on a land unit by land unit basis to ensure that there are no gaps or overlaps which would lead to omission or double counting of areas of land. To support estimation of emissions and removals in the *forest land* category, Australia uses some non-spatial data drawn from Australia's National Forest Inventory. This is used exclusively within a reporting category consistent with Approach 3. Land areas in the *cropland remaining cropland* and *grassland remaining grassland* sub-categories are drawn from the Land Use Mapping programme of Australia's Bureau of Rural Sciences. Areas of *forest land* and *forest land converted to grassland* and *cropland*, (as determined from the NCAS remote sensing programme) are excluded from this mapping to prevent double counting of land areas. Table 7.4 shows the representation of land according to the IPCC Land use categories (IPCC, 2003). Annual land area matrices are shown in Table 7.5.

Table 7.4 Land representation matrix (1990 to 2008)

	1990 (Mha)	2008 (Mha)	Net Change (Mha)
Forest land total	**112.0**	**105.9**	**-6.1**
Forest land remaining Forest land	111.9	104.9	-7.1
Harvested Native Forests	14.9	14.9	0.0
Plantations	0.8	0.8	0.0
Other Native Forest	96.2	89.1	-7.1
Grassland converted to Forest land	0.1	1.1	1.0
Grassland total	**444.2**	**449.0**	**4.8**
Grassland remaining Grassland	436.6	436.4	-0.2
Forest land converted to Grassland	7.6	12.5	5.0
Cropland total	**24.8**	**26.1**	**1.3**
Cropland remaining Cropland	21.7	21.7	0.0
Forest land converted to Cropland	3.2	4.4	1.3
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**

Table 7.5 Annual land area matrices from 1990 to 2008

1990	Forest land	Grassland	Cropland	Wetlands	Settlements	Other land	Final Area
Forest land	111.32	0.68					111.99
Grassland	0.44	443.71					444.16
Cropland	0.12		24.73				24.84
Wetlands				13.49			13.49
Settlements					1.60		1.60
Other land						172.92	172.92
Initial Area	111.88	444.39	24.73	13.49	1.60	172.92	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**
Forest land	111.56	0.54					112.11
Grassland	0.34	443.61					443.95
Cropland	0.09		24.84				24.93
Wetlands				13.49			13.49
Settlements					1.60		1.60
Other land						172.92	172.92
Initial Area	111.99	444.16	24.84	13.49	1.60	172.92	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**
Forest land	111.72	0.68					112.39
Grassland	0.32	443.28					443.60
Cropland	0.07		24.93				25.00
Wetlands				13.49			13.49
Settlements					1.60		1.60
Other land						172.92	172.92
Initial Area	112.11	443.95	24.93	13.49	1.60	172.92	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
Forest land	112.00	0.40					112.41
Grassland	0.32	443.19					443.52
Cropland	0.07		25.00				25.07
Wetlands				13.49			13.49
Settlements					1.60		1.60
Other land						172.92	172.92
Initial Area	112.39	443.60	25.00	13.49	1.60	172.92	769.00
Net change	0.01	-0.08	0.07	0.00	0.00	0.00	0.00

1994	Forest land	Grassland	Cropland	Wetlands	Settlements	Other land	Final Area
Forest land	112.04	0.39					112.42
Grassland	0.30	443.13					443.43
Cropland	0.08		25.07				25.14
Wetlands				13.49			13.49
Settlements					1.60		1.60
Other land						172.92	172.92
Initial Area	112.41	443.52	25.07	13.49	1.60	172.92	769.00
Net change	0.01	-0.09	0.08	0.00	0.00	0.00	0.00

1995	Forest land	Grassland	Cropland	Wetlands	Settlements	Other land	Final Area
Forest land	112.10	0.33					112.44
Grassland	0.26	443.10					443.35
Cropland	0.06		25.14				25.20
Wetlands				13.49			13.49
Settlements					1.60		1.60
Other land						172.92	172.92
Initial Area	112.42	443.43	25.14	13.49	1.60	172.92	769.00
Net change	0.01	-0.08	0.06	0.00	0.00	0.00	0.00

1996	Forest land	Grassland	Cropland	Wetlands	Settlements	Other land	Final Area
Forest land	112.12	0.24					112.36
Grassland	0.25	443.11					443.36
Cropland	0.07		25.20				25.27
Wetlands				13.49			13.49
Settlements					1.60		1.60
Other land						172.92	172.92
Initial Area	112.44	443.35	25.20	13.49	1.60	172.92	769.00
Net change	-0.07	0.01	0.07	0.00	0.00	0.00	0.00

1997	Forest land	Grassland	Cropland	Wetlands	Settlements	Other land	Final Area
Forest land	112.05	0.24					112.29
Grassland	0.25	443.12					443.37
Cropland	0.07		25.27				25.34
Wetlands				13.49			13.49
Settlements					1.60		1.60
Other land						172.92	172.92
Initial Area	112.36	443.36	25.27	13.49	1.60	172.92	769.00
Net change	-0.07	0.01	0.07	0.00	0.00	0.00	0.00

1998	Forest land	Grassland	Cropland	Wetlands	Settlements	Other land	Final Area
Forest land	111.95	0.26					112.21
Grassland	0.27	443.11					443.38
Cropland	0.06		25.34				25.40
Wetlands				13.49			13.49
Settlements					1.60		1.60
Other land						172.92	172.92
Initial Area	112.29	443.37	25.34	13.49	1.60	172.92	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
Forest land	111.87	0.51					112.38
Grassland	0.28	442.87					443.15
Cropland	0.06		25.40				25.46
Wetlands				13.49			13.49
Settlements					1.60		1.60
Other land						172.92	172.92
Initial Area	112.21	443.38	25.40	13.49	1.60	172.92	769.00
Net change	0.17	-0.24	0.06	0.00	0.00	0.00	0.00

2000

	Forest land	Grassland	Cropland	Wetlands	Settlements	Other land	Final Area
Forest land	112.02	0.54					112.56
Grassland	0.30	442.61					442.91
Cropland	0.06		25.46				25.53
Wetlands				13.49			13.49
Settlements					1.60		1.60
Other land						172.92	172.92
Initial Area	112.38	443.15	25.46	13.49	1.60	172.92	769.00
Net change	0.17	-0.24	0.06	0.00	0.00	0.00	0.00

2001

	Forest land	Grassland	Cropland	Wetlands	Settlements	Other land	Final Area
Forest land	111.74	0.08					111.82
Grassland	0.75	442.83					443.58
Cropland	0.07		25.53				25.59
Wetlands				13.49			13.49
Settlements					1.60		1.60
Other land						172.92	172.92
Initial Area	112.56	442.91	25.53	13.49	1.60	172.92	769.00
Net change	-0.74	0.67	0.07	0.00	0.00	0.00	0.00

2002

	Forest land	Grassland	Cropland	Wetlands	Settlements	Other land	Final Area
Forest land	111.01	0.08					111.09
Grassland	0.75	443.50					444.25
Cropland	0.06		25.59				25.65
Wetlands				13.49			13.49
Settlements					1.60		1.60
Other land						172.92	172.92
Initial Area	111.82	443.58	25.59	13.49	1.60	172.92	769.00
Net change	-0.74	0.67	0.06	0.00	0.00	0.00	0.00

2003

	Forest land	Grassland	Cropland	Wetlands	Settlements	Other land	Final Area
Forest land	110.10	0.08					110.18
Grassland	0.92	444.17					445.10
Cropland	0.06		25.65				25.72
Wetlands				13.49			13.49
Settlements					1.60		1.60
Other land						172.92	172.92
Initial Area	111.09	444.25	25.65	13.49	1.60	172.92	769.00
Net change	-0.91	0.85	0.06	0.00	0.00	0.00	0.00

2004

	Forest land	Grassland	Cropland	Wetlands	Settlements	Other land	Final Area
Forest land	109.19	0.08					109.27
Grassland	0.91	445.02					445.92
Cropland	0.08		25.72				25.80
Wetlands				13.49			13.49
Settlements					1.60		1.60
Other land						172.92	172.92
Initial Area	110.18	445.10	25.72	13.49	1.60	172.92	769.00
Net change	-0.91	0.83	0.08	0.00	0.00	0.00	0.00

2005							
	Forest land	Grassland	Cropland	Wetlands	Settlements	Other land	Final Area
Forest land	107.90	0.05					107.95
Grassland	1.29	445.87					447.16
Cropland	0.08		25.80				25.88
Wetlands				13.49			13.49
Settlements					1.60		1.60
Other land						172.92	172.92
Initial Area	109.27	445.92	25.80	13.49	1.60	172.92	769.00
Net change	-1.32	1.24	0.08	0.00	0.00	0.00	0.00
2006							
	Forest land	Grassland	Cropland	Wetlands	Settlements	Other land	Final Area
Forest land	107.08	0.05					107.13
Grassland	0.78	447.12					447.90
Cropland	0.09		25.88				25.97
Wetlands				13.49			13.49
Settlements					1.60		1.60
Other land						172.92	172.92
Initial Area	107.95	447.16	25.88	13.49	1.60	172.92	769.00
Net change	-0.82	0.73	0.09	0.00	0.00	0.00	0.00
2007							
	Forest land	Grassland	Cropland	Wetlands	Settlements	Other land	Final Area
Forest land	106.10	0.06					106.15
Grassland	0.96	447.84					448.80
Cropland	0.07		25.97				26.04
Wetlands				13.49			13.49
Settlements					1.60		1.60
Other land						172.92	172.92
Initial Area	107.13	447.90	25.97	13.49	1.60	172.92	769.00
Net change	-0.98	0.90	0.07	0.00	0.00	0.00	0.00
2008							
	Forest land	Grassland	Cropland	Wetlands	Settlements	Other land	Final Area
Forest land	105.88	0.05					105.93
Grassland	0.21	448.75					448.95
Cropland	0.07		26.04				26.11
Wetlands				13.49			13.49
Settlements					1.60		1.60
Other land						172.92	172.92
Initial Area	106.15	448.80	26.04	13.49	1.60	172.92	769.00
Net change	-0.22	0.16	0.07	0.00	0.00	0.00	0.00

7.4.1 Land Classification

Australia's reporting meets the IPCC *Good Practice Guidance for Land Use, Land Use Change and Forestry* (IPCC, 2003) land representation criteria of being consistent over time and that land is represented in only one category. Movement of land between categories is reported where a land use change occurs, such as a conversion of *forest land to cropland* and *forest land to grassland*, and *grassland to forest land*. Areas of forest may also change to grassland and vice versa due to forest regrowth and dieback. This process is largely driven by climate variability and is not directly human induced. These naturally caused ephemeral transitions are included as transfers between *other native forest* and *grassland remaining grassland*.

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

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

Australia has elected to move lands from the conversion sub-category to the remaining category after 50 years. This longer period of time reflects the long term impacts of conversion on carbon dynamics 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 0 to 20 years and 21 to 50 years. After 50 years, the lands will be moved into the "land remaining" sub-categories.

7.4.2 Monitoring of Forest Conversion

7.4.2.1 Understanding Patterns of Change

To understand the structure and distribution of forest cover change in Australia, a study was commissioned on the drivers, locations and patterns of forest cover change (AGO, 2000a). This work showed significant regional differences in the nature of the drivers of deforestation and reforestation over time. Broadly, in southern Australia, patterns of deforestation since 1990 have strongly featured small 'patch' clearance for rural residential development, infrastructure such as roads, and the removal of remnant tree patches in agricultural lands. Reforestation includes broad-scale plantation establishment as well as many small-scale environmental plantings for revegetation and rehabilitation purposes.

In the north of Australia, where the majority of deforestation occurs, the clearing patterns were for large development fronts involving the removal of remnant forest for expansion of the agricultural estate. Ongoing maintenance of removal of woody regrowth on 8 to 15 year cycles was also very common within the existing agricultural estate.

Another factor that became evident from this work was that many ecosystems subject to change, such as woodlands, were characterised by highly variable patterns of tree cover and open spaces. The combination of a large proportion of forest cover change events being small scale, and the variable patterns of tree cover and open space, led to a need for monitoring at the lowest reliably applied spatial scale. This scale is driven by monitoring requirements, international agreements and data availability.

The nature of the deforestation activity also became evident as being largely in mature forests, except in cases where cyclic clearance and regrowth cycles (8 to 15 years) were being observed. Natural disturbances in the forest types, most commonly subject to deforestation, are rarely stand-replacing (stand-replacing occurs when the original forest is killed and replaced with new regrowth). As such, there are few instances of conversion where the initial carbon stocks pre-clearing are below that of mature stands.

In addition to the work described above on forest cover monitoring, parallel studies on post-deforestation land management and emissions profiles were completed. These studies highlighted that the patterns of emissions over time were characterised by the majority of emissions occurring within 1 to 2 years of the deforestation event.

7.4.2.2 Data Availability

Australia has available an extensive archive of Landsat satellite data collected since the first Landsat sensor delivered data in 1972. Review of the archive in 1998 showed that there was sufficient continental coverage to allow for time-series continental change analysis commencing in 1972.

Once the availability of the Landsat data was established, it was necessary to establish whether the data and processing systems would be able to identify change at the different spatial resolutions at which forest conversion was occurring. Extensive processes were put in place to:

- select an analytic method;
- develop scene acquisition specifications for the geometric registration, radiometric calibration, and analysis and processing of the images to forest monitoring products;
- trial the methods using pilot studies of which the results were used to form detailed operational specifications (Furby and Woodgate, 2002);
- develop methods for continuous improvement and verification of the data; and
- establish the R&D programs that led to enhancement of the processes, such as described by Caccetta *et al.*, (2003) and Wu *et al.*, (2004).

Pilot testing was also used to refine the methods to deal with technical issues including:

- time-series stability given sensor change in the Landsat series;
- consistent application in the diversity of Australian vegetation types; and,
- ability to detect change in the variety of spatial configuration and patterns.

7.4.2.3 Mapping Resolution and Re-sampling

Modelling grid resolution

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

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

Land cover grid resolution

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

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

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

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

7.4.2.4 Time-series Consistency

From the remote sensing pilot testing, the need for time-series consistency in image data pre-processing, analysis, and subsequent formation of time-series forest presence/absence labels became clear. To this end, the operational standards (Furby, 2002) give explicit emphasis through documented rules to each of these processes. 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 the time-series of forest cover presence/absence labels. This process produces far superior forest extent and change results than a process reliant on pair-wise differencing of images. This greatly reduces the errors associated with pair-wise differencing methods which 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 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 presence/absence and change (forest and non-forest conversions). The temporal rules bias against unlikely events such as multiple one year conversions between forest and non-forest – for example conversion from non-forest to forest and then back to non-forest is an unlikely event over a short, for example, three year period. 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 key reasons and advantages for having a relatively dense time-series sampling of Landsat data.

The spatial rules also 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 year to year) and subsequent error in pixel and change labelling.

7.5 Source Category 5A Forest Land

7.5.1 Methodology

7.5.1.1 Forest Land Remaining Forest Land

There are four broad components to *forest land remaining forest land*: *harvested native forests*, *other native forests*, fuelwood consumed and *plantations*. These are treated as independent sub-categories and emissions estimates are modelled independently to ensure that no emissions are double-counted or omitted (Table 7.6). The definition of *forest land* is provided in section 7.3.2.1 and the description of managed and unmanaged land is discussed in section 7.3.2.7.

Table 7.6 Sub-categories used in the Forest land remaining Forest land category

Harvested Native Forests	Fuelwood	Plantations	Other Native Forests			
			Single change in cover	Ephemeral change in cover	Always forest	Fire
This sub-category represents areas of native forest that have been harvested at some time, may still be available for harvest, or have been harvested in the past but are now in a reserve or other land tenure unavailable for harvest	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	These are the commercial plantations that were established prior to 1990	These forest areas have changed their cover status, but there is no identifiable human intervention and they are likely to change again	These forest areas move above and below the forest determining thresholds, largely from climate influences	These forest areas are always under forest cover, but without commercial forest production	The CO_2 emissions due to wildfire and prescribed burning and subsequent removals from post-fire recovery

Harvested native forests

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

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

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

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

Other native forests

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

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

Plantations (established prior to 1990)

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

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

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

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

Fuelwood consumed

Fuelwood is extracted from dead organic matter across all forest categories and as such the CO_2 emissions associated with the consumption of *fuelwood* are reported separately rather than against any specific sub-category of *forest land*. The CO_2 emissions associated with *fuelwood* consumption are based on energy use (Petajoules, PJ) of fuelwood by industry as reported by the Australian Bureau of Agricultural and Resource Economics (ABARE) (2009a). The data used to estimate CO_2 emissions are updated annually based on the most recent ABARE statistics.

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.

7.5.1.2 Land Converted to Forest Land

Grassland converted to forest land

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

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

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

7.5.2 Uncertainties and Time Series Consistency

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

7.5.3 Source Specific QA/QC

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

7.5.4 Recalculations Since the 2007 Inventory

There have been several improvements made to estimates of emissions and removals in the *forest land* category for the 2008 inventory submission. These improvements have resulted in recalculations to the entire time series of several sub-categories.

The *harvested native forests* sub-category is now modelled using the Tier 2, non-spatial capabilities of the *FullCAM* model. This has enabled significant enhancements beyond the previous model including the use of age-based growth data, modelling of dead organic matter accumulation, and incorporating the effects of differing silvicultural treatments on the generation and management of harvest slash. This change led to a 3358.3 Gg reduction to the 1990 sink estimate and an 8867.1 Gg reduction to the 2007 sink estimate.

Emissions and removals for soil carbon under plantations are being reported for the first time using a Tier 2 model. This change led to a 248.5 Gg reduction to the 1990 sink estimate and a 997.2 Gg reduction to the 2007 emission estimate.

For *other native forests*, a small recalculation has occurred in this category due to the improved identification of areas under *grassland converted to forest land* and an increase in the carbon mass fraction of debris used to calculate carbon emissions from fire to be consistent with the value used for the calculation of non-CO_2 fire emissions. This change led to a 409.5 Gg reduction to the 1990 sink estimate and a 2785.4 Gg increase to the 2007 emission estimate.

The estimates of emissions and removals for *grassland converted to forest land* are now made using the full NCAS Tier 3, Approach 3 modelling system. This represents a significant improvement over the previous methods, and for the first time allows for the reporting of changes in soil carbon. In addition, improved mapping of areas of *grassland converted to forest land* have been implemented to ensure these forests meet the definition of direct human induced. These changes led to a 1884.0 Gg reduction to the 1990 sink estimate and a 4054.4 Gg reduction to the 2007 sink estimate.

The net effect of all the changes was to reduce the 1990 sink estimate by 5615.2 Gg and to reduce the 2007 sink estimate by 16387.5 Gg.

Table 7.7 5.A Forest land: recalculation of total CO_2-e emissions (Gg), 1990-2007

	2009 submission	2010 submission	Change	
	(Gg CO_2-e)		(Gg CO_2-e)	(%)
1990	-47342.63	-41727.47	5615.16	-11.9
2000	-62400.11	-46122.00	16278.11	-26.1
2001	-87480.36	-66460.04	21020.31	-24.0
2002	-6526.35	11469.81	17996.16	-275.7
2003	115297.72	152389.03	37091.31	32.2
2004	-131556.86	-121261.27	10295.58	-7.8
2005	-95720.45	-85131.85	10588.60	-11.1
2006	-104686.02	-92483.57	12202.45	-11.7
2007	-18915.66	-2528.18	16387.48	-86.6

7.5.5 Source Specific Planned Improvements

The methods used for estimating emissions and removals in the *forest land* category are yet to completely reflect the fully spatially explicit (Approach 3), Tier 3 process-based modelling methods of Australia's NCAS. The methods described in Appendices 7.B, 7.C and 7.E. provide interim methods using a combination of Tier 2 and Tier 3 methods. Development of a comprehensive estimation capability for future reporting is ongoing and will be released once the national implementation has been fully calibrated, verified, quality assured and peer reviewed. This is consistent with the approach to inclusion of NCAS results in the national inventory only after all appropriate cross-cutting processes have been completed.

It is Australia's intention to have comprehensive use of Tier 3, Approach 3 modelling in its 2011 inventory submission for the *plantations* and *harvested native forests* sub-categories. Australia currently uses National Forest Inventory statistics to estimate the area of pre-1990 *plantations* (see Appendix 7.C). The remote sensing programme is currently developing methods to identify areas of plantation established prior to 1988 using Landsat MSS data. Work to assess the areas of *harvested native forest* (see Appendix 7.B) using remote sensing data is ongoing.

7.6 Source Category 5B Cropland

7.6.1 Methodology

7.6.1.1 Cropland Remaining Cropland

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://nlwra.gov.au/). *Cropland remaining cropland* covers an area of over 20 million hectares (Figure 7.11) and includes both continuous cropping and the rotational crop and pasture systems that swap from grassland to cropland on a regular basis. No lands are converted from *cropland to forest land* or from *cropland to grassland*. In this reporting structure, *cropland remaining cropland* includes only those lands that were used for cropping prior to 1972, and remain as *cropland*. Table 7.8 shows the various crop types that are in this land use category.

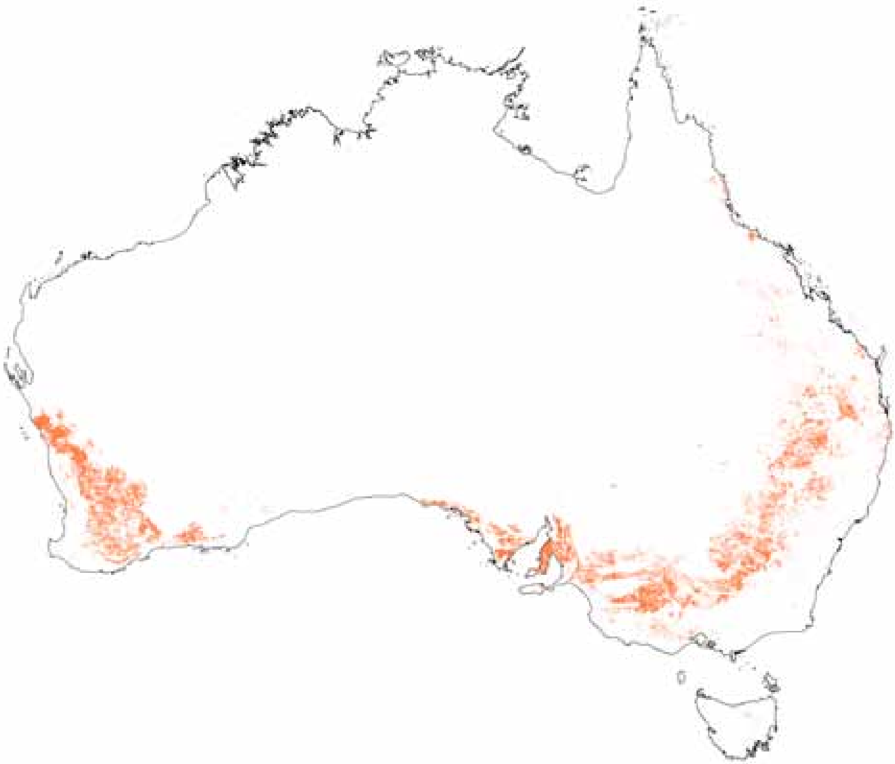
Cropland is generally located along a broad inland fringe across the southern and eastern land areas of Australia, with the highest yields commonly obtained in the south west and the eastern regions. In the southern regions, *cropland* is dominated by wheat production, with barley, oats, lupins and canola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

The majority of crops grown in Australia are winter dominant. These crops are predominantly reliant on winter rainfall and yields are subject to the climatic conditions in any given year. Crop yields vary according to the annual distribution of rainfall and the types of crops grown within a region.

The reporting of *cropland remaining cropland* includes all carbon pools (living biomass, dead organic matter and soil). Emissions and removals are estimated using the Tier 3, Approach 3 NCAS mass balance, process-based ecosystem model *FullCAM*, as described in Appendix 7.A. The data used in the modelling are provided in Appendix 7.G.

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

Figure 7.11 Distribution of Cropland in 2001/02 from National Land Use Summary Statistics



Source: Bureau of Rural Sciences
Note: figure presents areas of both cropland remaining cropland and forest land converted to cropland

LULUCF

Table 7.8 The crop types and approximate areas in Cropland in 2001/02 from National Land Use Summary Statistics

Crop type	Area (M ha)
Cereals	18.57
Legumes	2.27
Oil seeds	1.47
Irrigated cereals	0.61
Irrigated cotton	0.43
Sugar	0.29
Irrigated sugar	0.25
Irrigated vegetables and herbs	0.15
Irrigated vine fruits	0.15
Cropping	0.13
Irrigated tree fruits	0.11
Irrigated cropping	0.04
Cotton	0.04
Perennial horticulture	0.03
Hay and silage	0.03
Tree fruits	0.03
Tree nuts	0.02
Irrigated oil seeds	0.02
Vine fruits	0.02
Irrigated tree nuts	0.02
Irrigated legumes	0.02
Irrigated perennial horticulture	0.01
Vegetables and herbs	0.01
Irrigated hay and silage	0.01

Source: Bureau of Rural Sciences
Note: table presents data for both cropland remaining cropland and forest land converted to cropland

7.6.1.2 Land Converted to Cropland

Forest land converted to cropland

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

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

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

7.6.2 Uncertainties and Time Series Consistency

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

7.6.3 Source Specific QA/QC

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

7.6.4 Recalculations Since the 2007 Inventory

Improved management and spatial data have been applied to the *cropland remaining cropland* sub-category. This has led to a recalculation of the entire time series. There have been no methodological changes. These changes result in a 1587.8 Gg reduction in the 1990 sink estimate and a 1337.2 Gg increase in the 2007 emission estimate.

The estimates of the area of *forest land converted to cropland* from 2005 to 2007 have been revised with the provision of updated data from the NCAS. As the system randomly allocates the date of forest conversion between satellite overpasses in each update of the *FullCAM* model this leads to small recalculations through the entire time-series although there have been no methodological changes. These recalculations result in a minor reduction in the 1990 emission estimate and a 6733.5 Gg increase to the 2007 emission estimate.

Australia has also processed a further two years of remote sensing data (2008 and 2009) to allow reporting of 2008 emissions from the LULUCF sector in this inventory submission. This updating process will continue to ensure timely and accurate reporting of emissions and removals in all LULUCF categories.

Table 7.10 5.B Croplands: recalculation of total CO_2-e emissions, 1990–2007

	2009 submission	2010 submission	Change	
	(Gg CO_2-e)		(Gg CO_2-e)	(%)
1990	-255.63	1316.21	1571.84	-614.9
2000	-12366.29	-9254.54	3111.75	-25.2
2001	-12932.43	-17081.15	-4148.73	32.1
2002	58596.23	54234.63	-4361.60	-7.4
2003	-23250.37	-21766.08	1484.29	-6.4
2004	-27264.09	-32680.75	-5416.66	19.9
2005	-43704.97	-46863.29	-3158.33	7.2
2006	20439.68	22065.25	1625.57	8.0
2007	23565.20	31635.92	8070.72	34.2

7.6.5 Source Specific Planned Improvements

Crop growth estimates are currently obtained from industry estimates. A new crop growth model is being developed for integration with the existing inventory methods. It is envisaged that the new crop yield model will be available for the 2011 inventory submission.

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

7.7 Source Category 5C Grassland

7.7.1 Methodology

7.7.1.1 Grassland Remaining Grassland

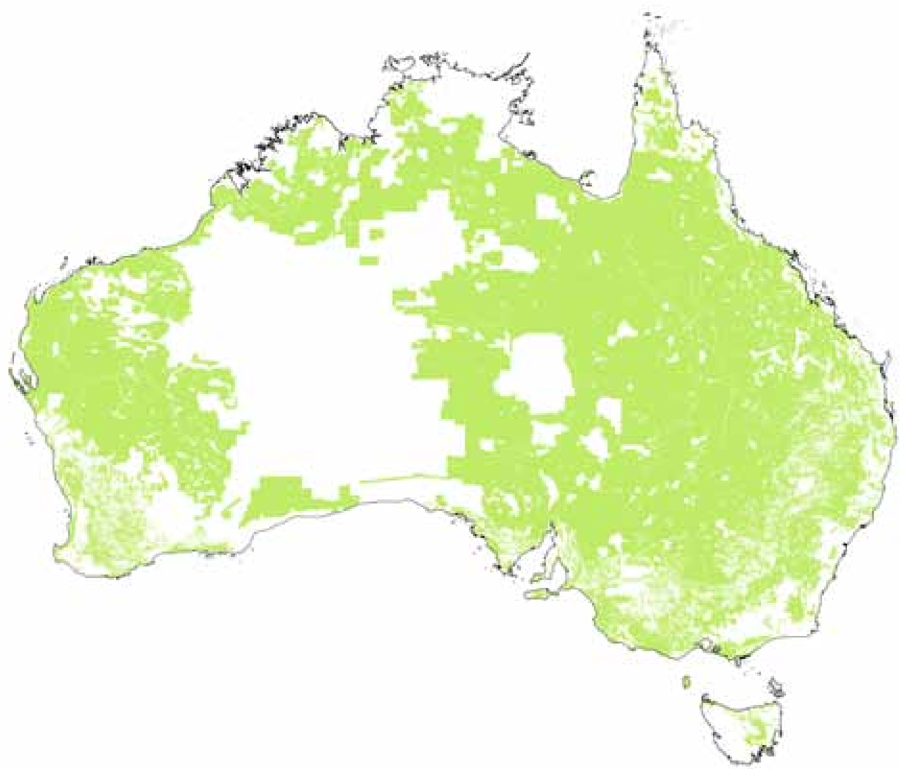
The *grassland remaining grassland* sub-category includes all areas of *grassland* that are not reported under *forest land converted to grassland*. Areas that are in rotational use between *grassland* and *cropland* are reported under either *forest land converted to cropland* or *cropland remaining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

The distribution of land areas in the *grassland remaining grassland* sub-category are estimated using the National Land Use 2001/2002 (Version 3) Summary Statistics provided by the Bureau of Rural Sciences (http://nlwra.gov.au/). In 2008 *grassland remaining grassland* covered an area of 436 million hectares (of the 449 million hectares of grassland reported in Table 7.5) which is evenly distributed around Australia (Figure 7.12). The remaining area of grassland is reported under the *forest land converted to grassland* sub-category.

There are three broad components to the *grassland remaining grassland* estimates – the grassland component, the shrubland component and the CO_2 emissions and post fire removals associated with savanna burning. Shrublands are areas that are not, by definition, 'forest'. Shrublands are typically sparse tree and shrub formations and are not separable into areas made up of uniquely tree or shrub plant types. Emissions from the *grassland remaining grassland* sub-category are estimated using interim methods. The Tier 3 *FullCAM* model is used to estimate emissions and removals of all pools (living biomass, dead organic matter and soil) for the grass only areas of the *grassland remaining grassland* sub-category. A Tier 2 method is used to estimate emissions and removals for the shrubland (sub-forest) areas for live biomass and dead organic matter. These methods are described in Appendix 7.H. The methods for estimating CO_2 emissions and removals associated with fires are described in section 7.12.1.2.

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

Figure 7.12 Distribution of Grassland remaining Grassland in 2001/02 from National Land Use Summary Statistics



Source: Bureau of Rural Sciences

7.7.1.2 Land Converted to Grassland

Forest land converted to grassland

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

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

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

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

7.7.2 Uncertainties and Time Series Consistency

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

7.7.3 Source Specific QA/QC

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

7.7.4 Recalculations Since the 2007 Inventory

The estimates of emissions and removals from *grassland remaining grassland* have been recalculated for the entire time series. This recalculation is due to the availability of a complete national map of sparse woody vegetation for 2002. This represents a significant improvement on the method applied in the previous inventory. This recalculation results in a 2535.0 Gg reduction to the 1990 sink estimate and a 39043.4 Gg increase in the 2007 emission estimate.

The estimates of the area of *forest land converted to grassland* from 2005 to 2007 have been revised with the provision of updated data from the NCAS. As the system randomly allocates the date of forest conversion between satellite overpasses in each update of the *FullCAM* model, this leads to small recalculations through the entire time-series although there have been no methodological changes. These recalculations result in a 762.0 Gg reduction to the 1990 emission estimate and a 7967.3 Gg reduction in the 2007 emission estimate.

Australia has also processed two years of remote sensing data (2008 and 2009) to allow reporting of 2008 emissions from the LULUCF sector in this inventory submission. This process will continue to ensure timely and accurate reporting of emissions and removals in all LULUCF sectors.

Table 7.11 5.C Grasslands: recalculation of total CO_2-e emissions, 1990–2007

	2009 submission	2010 submission	Change	
	($Gg\ CO_2$-e)		($Gg\ CO_2$-e)	(%)
1990	89087.55	90860.52	1772.97	2.0
2000	-12655.14	56635.42	69290.57	-547.5
2001	24847.46	39993.21	15145.75	61.0
2002	234992.57	276180.27	41187.71	17.5
2003	25173.82	36397.74	11223.92	44.6
2004	-31321.86	-36605.36	-5283.50	16.9
2005	214015.19	178101.20	-35914.00	-16.8
2006	103868.10	121496.04	17627.94	17.0
2007	282702.79	313778.88	31076.09	11.0

7.7.5 Source Speific Planned Improvements

A new grass growth model is being developed for integration with the existing inventory methods. It is envisaged that the new grass growth model will be available for the 2011 inventory submission.

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

In addition to the new modelling capabilities, Australia is completing a full national time series of change in sparse woody (shrub) vegetation cover from 1988 onwards using Landsat data. This will be available for the 2011 inventory submission (see Appendix 7.H for details).

7.8 Source Category 5D Wetlands

7.8.1 Methodology

7.8.1.1 Wetlands Remaining Wetlands

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

7.8.1.2 Land Converted to Wetlands

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

7.9 Source Category 5E Settlements

7.9.1 Methodology

7.9.1.1 Settlements Remaining Settlements

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

7.9.1.2 Land Converted to Settlements

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

7.10 Source Category 5F Other Land

7.10.1 Methodology

7.10.1.1 Other Land Remaining Other Land

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

7.10.1.2 Land Converted to Other Land

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

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7.11 Source Category 5G Other

7.11.1 Methodology

7.11.1.1 Harvested Wood Products

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

7.11.1.2 N_2O Emissions from N Fertilisation 5(I)

Nitrous oxide emissions associated with nitrogen fertilisers are reported under the agriculture sector (4D).

7.11.1.3 N_2O Emissions from Drainage of Soils 5(II)

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

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

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

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

7.11.1.5 CO_2 Emissions from Agricultural Lime Application 5(IV)

Limestone and dolomite are used in Australia to ameliorate soil acidity 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 limes dissolve and release biocarbonate which evolves into CO_2 and water.

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

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

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

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

$FracLime_{jk}$ = fraction limestone

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

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

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

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

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

7.11.2 Uncertainties and Time Series Consistency

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

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

7.11.3 Source Specific QA/QC

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

7.11.4 Recalculations Since the 2007 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 recalculated. The recalculation for *land converted to grassland* results in a minor decrease in the 1990 estimate and a 97.8 Gg CO_2-e increase to the 2007 estimate.

A number of parameters in the model used to estimate harvested wood products, have been modified. This has led to a recalculation of the entire time series. These changes result in a 409.3 and 366.1 Gg increase to the 1990 and 2007 sink estimates respectively.

The CO_2 emissions from agricultural lime application have been recalculated for the period 2003 to 2007. As 2008 data on limestone and dolomite is now available these values which were previously based on an extrapolation have been recalculated based on an interpolation between the 2002 and 2008 data. This recalculation results in a 437.9 Gg reduction in the 2007 estimate.

Table 7.12 5.G Other: recalculation of total CO_2-e emissions, 1990–2007

	2009 submission	2010 submission	Change	
	(Gg CO_2-e)		(Gg CO_2-e)	(%)
1990	-3909.64	-4324.94	-415.30	10.6
2000	-3041.13	-3764.58	-723.45	23.8
2001	-3092.97	-3285.50	-192.53	6.2
2002	-3176.98	-3343.89	-166.90	5.3
2003	-3109.34	-3650.52	-541.18	17.4
2004	-3480.61	-3997.60	-517.00	14.9
2005	-2986.49	-3955.50	-969.01	32.4
2006	-3034.00	-3792.85	-758.85	25.0
2007	-2642.64	-3348.84	-706.20	26.7

7.11.5 Source Specific Planned Improvements

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

7.12 Source Category 5(V) Biomass Burning

7.12.1 Methodology

7.12.1.1 Forest Land (5A.1)

Prescribed burning and wildfires

In *forest land*, burning occurs in Australia both anthropogenically and as a result of 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 often replace 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:

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

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 7.13 and Table 7.14),
Z_{jk} = burning efficiency (Table 7.15).

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

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

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 7.16),
EF_{ij} = emission factor for gas i from vegetation (Table 7.17),
C_i = factor to convert from elemental mass of gas species i to molecular mass (Table 7.18).

and total annual emissions for NO_x and N_2O are:

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

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 7.16),
NC_{jk} = nitrogen to carbon ratio in biomass (Table 7.16),
EF_{ijk} = emission factor for gas i from vegetation (Table 7.17),
C_i = factor to convert from elemental mass of gas species i to molecular mass (Table 7.18).

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 Appendix 7.D. The method uses the same data used to estimate non-CO_2 emissions.

Table 7.13 Fuel loads 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})							
Fuel load	17.6	18.2	4.1	9.7	9.6	20.0	17.9	12.0

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

Table 7.14 Fuel loads 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})							
Fuel load	35.2	36.4	7.2	19.4	19.2	40.0	35.8	33.4

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

Table 7.15 Burning efficiencies for Prescribed Burning and Wildfires in Australia

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

Tolhurst (1994)

Table 7.16 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 7.17 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 7.18 Elemental to molecular mass conversion factor (C_i)

CH_4	N_2O	NO_x	CO	NMVOC
1.33	1.57	3.29	2.33	1.17

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Slash burning

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

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

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

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

and for total annual emissions for NO_x and N_2O are:

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

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

EF_{ijk} = emission factor for gas i from vegetation (Table 7.17),

NC_{jk} = nitrogen to carbon ratio in biomass (Table 7.16),

C_i = factor to convert from elemental mass of gas species i to molecular mass (Table 7.18).

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

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

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

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

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

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

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

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

and for total annual emissions for NO_x and N_2O are:

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

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

EF_{ijk} = emission factor for gas i from vegetation (Table 7.17),

NC_{jk} = nitrogen to carbon ratio in biomass (Table 7.16)

C_i = factor to convert from elemental mass of gas species *i* to molecular mass (Table 7.18).

7.12.2 Uncertainties and Time Series Consistency

Uncertainties for biomass burning 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 difference in these uncertainty values is due to the more accurate fuel load estimates developed through the Tier 3 modelling used by the NCAS. Further details are provided in Annex 7. Time series consistency is ensured by the use of consistent methods and full recalculations in the event of any refinement to methodology.

7.12.3 Source Specific QA/QC

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

7.12.3.1 Methane emission factor

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

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

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

7.12.4 Recalculations Since the 2007 Inventory

Australia's interpretation of the current IPCC guidelines and good practice guidance is that they provide for reporting of the emissions and removal from forest fires as three year averages. As different interpretations of the guidelines on this issue are apparent, Australia has adopted the advice of the UNFCCC Expert Review Team and now reports these as annual emissions. This results in a recalculation to the entire time-series of emissions for wildfires and prescribed burning for *forest land remaining forest land*. In addition, areas of slash burning have been removed from the prescribed burning areas to avoid double counting across categories in *forest land remaining forest land*. Preliminary activity data on the areas of prescribed burning (New South Wales, Western Australia and South Australia) and wildfires (South Australia, Victoria, Queensland and Western Australia) have been replaced with actual estimates. The above recalculations result in a 285.1 Gg reduction to the 1990 estimate and a 2739.3 Gg increase to the 2007 estimate.

As the estimates for *forest land converted to cropland* and *grassland* have been recalculated so too have the emissions from biomass burning. This recalculation has resulted in a minor reduction to the 1990 estimate and a 375 Gg reduction to the 2007 estimate.

Table 7.19 5V Biomass Burning: recalculation of total CO_2-e emissions, 1990–2007

	2009 submission	2010 submission	Change	
	($Gg\ CO_2$-e)		($Gg\ CO_2$-e)	(%)
1990	6492.49	6206.86	-285.63	-4.4
2000	3698.96	3810.04	111.08	3.0
2001	4645.83	5091.15	445.32	9.6
2002	8279.79	6335.70	-1944.09	-23.5
2003	7547.25	14158.67	6611.43	87.6
2004	7234.74	4061.34	-3173.41	-43.9
2005	4698.81	5254.27	555.47	11.8
2006	5760.23	4711.30	-1048.92	-18.2
2007	5708.31	8071.80	2363.49	41.4

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7.12.5 Source Specific Planned Improvements

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

Appendix 7.A: Overview of the Development and Implementation of Australia's National Carbon Accounting System

7.A.1 Introduction

The National Carbon Accounting System (NCAS) was developed to provide a comprehensive system to estimate Australia's land-based greenhouse gas emissions and removals for both Australia's international reporting and national policy development. The NCAS integrates a wide range of spatially referenced data through a hybrid of process and empirical models to estimate carbon stock change and greenhouse gas emissions at fine spatial and temporal scales. Analysis and reporting includes all carbon pools (biomass, dead organic matter and soil), all principal greenhouse gases (CO_2, CH_4 and N_2O), covers both forest and agricultural land uses and can be applied at a variety of scales, from the project level through to regional and continental.

The NCAS was specifically designed for both annual national reporting and to support project-level estimates based on location specific management actions. To do this, the system was built to operate at fine temporal and spatial scales, leading to a bottom-up approach of aggregating 25 m grid resolution satellite data, ground inventory data and modelling into a national account. Even though the land cover change data (the principal driver) and modelling are performed at a 25 m resolution, not all data are available or needed at this fine scale for the bottom-up approach to be effective. A top-down approach to the national account, even with a relatively large sample over the entire continent, could not provide sufficient samples or resolution to support project-level estimates also provided by the NCAS.

The terrestrial ecosystem model implemented by the NCAS is the Full Carbon Accounting Model (*FullCAM*) (Richards, 2001; Richards and Evans, 2004). *FullCAM* is a carbon:nitrogen (C:N) ratio ecosystem model that calculates greenhouse gas emissions and removals in both forest and agricultural lands using a mass balance approach to carbon and nitrogen cycling. As most emissions and removals of greenhouse gases occur on transition between forests and agricultural land uses, the integration of agricultural and forestry modelling was essential. Model calibration and ongoing refinement programs are undertaken in parallel to the NCAS science and data collection programs and reporting activity. The continental spatial and temporal modelling capabilities of *FullCAM* help prevent errors of omission and commission (Brack *et al* 2006).

FullCAM also forms the basis of the publicly available National Carbon Accounting Toolbox (NCAT) which allows users to develop project-level carbon accounts using the same data as used for deriving national accounts, thus achieving consistency between national and project level accounting.

Although specifically developed to estimate greenhouse gas emissions, the *FullCAM* model and NCAS data have the potential to serve as a valuable framework for a range of land resource inventory and monitoring tasks. The national scale, fine spatial and temporal resolution, and breadth of data (climate, soils, productivity, land cover and management information) provide a comprehensive data and modelling capability not previously available in a single system. The process understanding generated through models allows for the development of management practices and land use policies with reliably estimated outcomes. Having such a capacity is fundamental to a cost:benefit analysis of mitigation actions and for optimising outcomes for multiple goals (e.g., maintaining production while reducing emissions). This Appendix reviews the ongoing development of *FullCAM* and NCAS. Appendix 7.J outlines in detail the quality assurance and quality control processes, calibration, verification and sensitivity analysis for the development and implementation of Australia's National Carbon Accounting System.

Method selection

Several possible methods were available for the development of the NCAS. These included direct measurement via a range of remote sensing techniques (e.g., optical, radar and lidar sensors), field sampling (e.g., stratified random or plot sampling inventory approaches), process modelling, or an integration of methods (e.g., combination of models, inventory data and remote sensing). The chosen method was an integrated approach combining ground data and remote sensing data with empirical and process models. Landsat satellite images are used to determine changes in land cover. An integrated suite of verified empirical and process models are then used to model the cycling of carbon and nitrogen in plant biomass, dead organic matter, soils and offsite products and to estimate the associated emission and removal of greenhouse gases.

A primary concern was the effect of changes in land cover and land use on greenhouse gas emissions. Therefore the modelling framework was designed to accommodate both forest and agricultural land uses, and any transitions between them. The model framework was fully integrated so that mass balance checks could be performed to ensure that all inputs, transfers and emissions were properly reconciled at each time step in the calculation.

A purely measurement approach to developing the NCAS may have provided a statistically robust national account, but at potentially greater cost than the model approach chosen. Given the limited amount of forest inventory data in Australia, particularly in the forests which are subject to the majority of deforestation, a measurement approach would also have limited Australia's capacity to develop a consistent time series of data on emissions and removals. A measurement approach would not have supported analysis of either project-level estimates or management decision making.

7.A.2 Land Cover Change

The importance of land cover change to the pattern of greenhouse gas emissions and removals led to the need to develop a national time series of land cover change maps showing both where and when change occurs. National coverages of Landsat satellite data (MSS, TM, and ETM+) across eighteen time epochs from 1972 to 2009 have been assembled and analysed for change. The historic cover and cover change information is important in two ways. Firstly, the effects on greenhouse gas emissions from land cover change are typically long lasting, and historic activities may still contribute to current estimates. Secondly, the emissions and removals by current activities will be affected by the site history.
For example, a current deforestation event will likely generate fewer emissions if the forest cleared is secondary forest (regrowth after a previous deforestation) rather than a primary (mature) forest.

7.A.2.1 Data Selection

Areas of land cover change[1] that contribute to emissions include those areas with lagged emissions from activities undertaken since the early 1970s. The ability to map land cover change over an extended period is therefore required for the emissions inventory. With Australia's land area of some 769 million hectares, establishing this record of activity presented many challenges, particularly as areas of change of less than one hectare need to be considered. In response to these requirements, a remote sensing approach using archival coverage of Landsat satellite data of Australia since the early 1970s was used.

The remote sensing options available for the land cover change program were limited by the retrospective and time-series consistency requirements to air photographs, National Oceanic & Atmospheric Administration (NOAA)/Advanced Very High Resolution Radiometer (AVHRR) data, or Landsat data. No other options met the temporal and spatial requirements outlined above. Investigation of these data sources showed that:

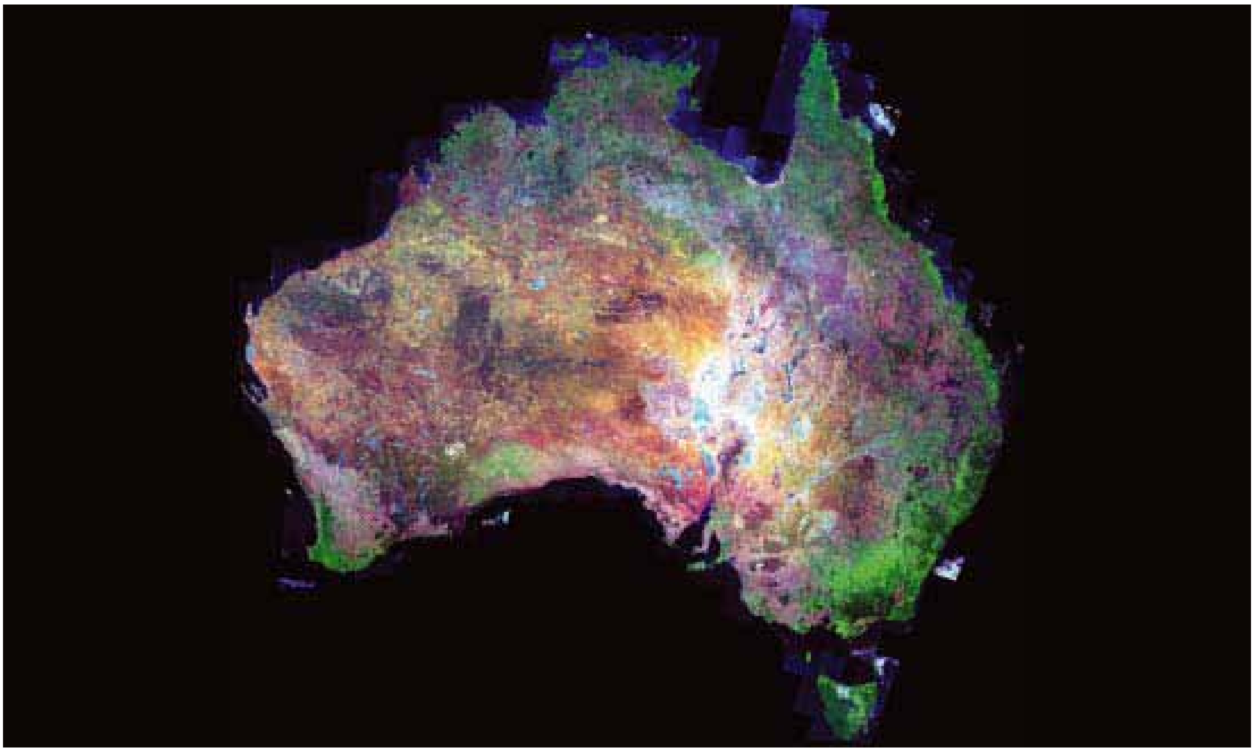
[1] Land Cover Change refers to a change from forest to non-forest (or vice-versa)

- Air photographs: The air photograph archive is not uniformly adequate and available across Australia. Also, the use of air photographs presented an excessively intensive analytic task due to the largely manual interpretation required. However, the archive of available air photographs provides a high-resolution calibration and verification tool to support other techniques when used as an independent sub-sample or as instrument 'training' data for satellite-based methods.
- NOAA/AVHRR: Data are generated at a nominal 1.1 km (approximately 120 ha) resolution. With accounting for Deforestation for the purposes of the Kyoto Protocol requiring monitoring at a sub-hectare scale, remote sensing at such a coarse resolution was not adequate.
- Landsat (MSS, TM and ETM+): Data, with comprehensive national coverage of areas with woody vegetation, are available through archives held in the USA and Australia since 1972. The Landsat MSS data (since 1972) can be effectively re-sampled to a 50 m pixel resolution (4 pixels per ha) and TM (since 1988) and ETM+ (1999-2002) can be re-sampled to 25 m pixel resolution (16 pixels per ha).

The use of Landsat data to analyse land cover change through time at a fine pixel resolution required a consistent geographically registered[2] and spectrally calibrated[3] reference base (Figure 7.A1). Also, standard specifications for processing and interpretation (including attribution[4]) of the sequence of Landsat data are needed to achieve a consistent national assessment of land cover change over the time-series.

It was important to move from the 50 m resolution MSS data to the 25 m resolution TM and ETM+ data without assessment of false land cover change being introduced due to instrumentation differences. To do this, a MSS equivalent 1989 image coverage was created from the TM images at 50 m resolution using a subset of the TM spectral bands corresponding to the MSS bands. Land cover change assessments bridging the switch from MSS to TM/ETM+ were then based upon MSS to MSS and TM/ETM+ to TM/ETM+, across similar image spectra and pixel size. The use of this overlap technique 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).

Figure 7.A1. The year 2000 mosaic registration and calibration base



[2] Registration uses stationary and identifiable ground features (ground control points) as constant reference points for the image sequence.
[3] 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.
[4] Attribution uses a combination of automation and visual inspection of the image sequence to determine the cause of land cover change and determine subsequent/existing land use.

7.A.2.2 Data processing

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

- image identification;
- image registration and calibration;
- mosaicing[5] of registered and calibrated images to the single map tiles for each time sequence (Figure 7.A3);
- sun-angle (terrain illumination) correction;
- thresholding[6] through all time sequences; and,
- attribution of change to direct human-induced change.

Figure 7.A2. Land Cover Change Program conceptual framework

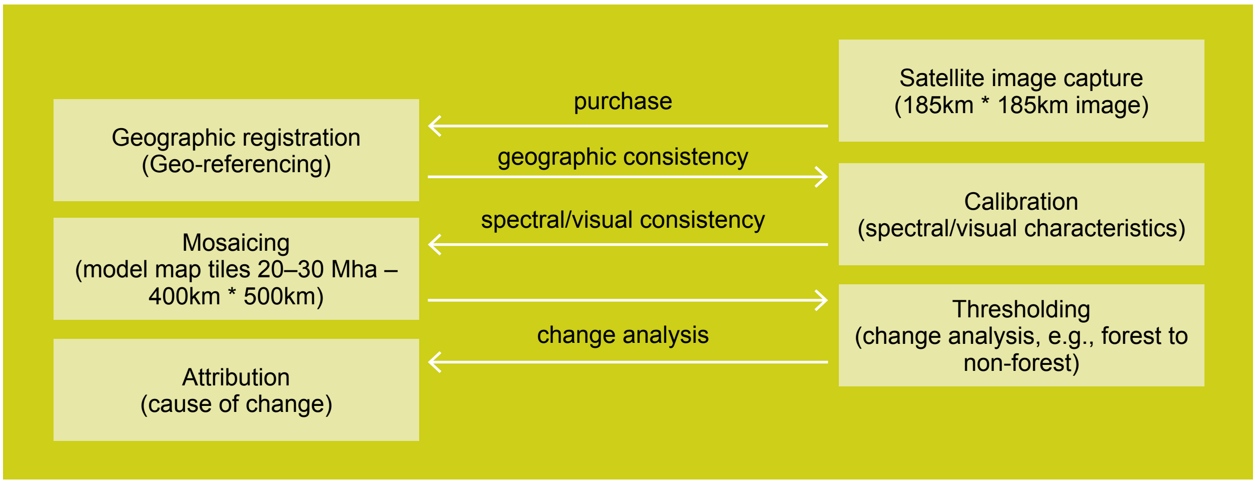
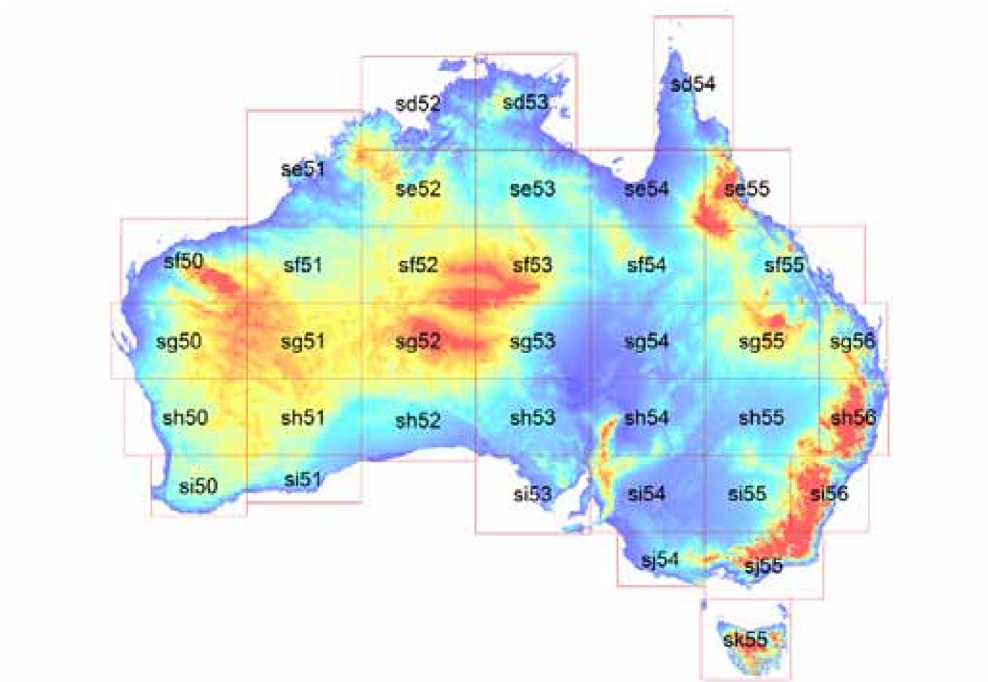


Figure 7.A3. The 37 1:1 million scale map tiles used in the NCAS program



5 Mosaicing aggregates images into the map tiles shown in Figure 7.A3, 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.

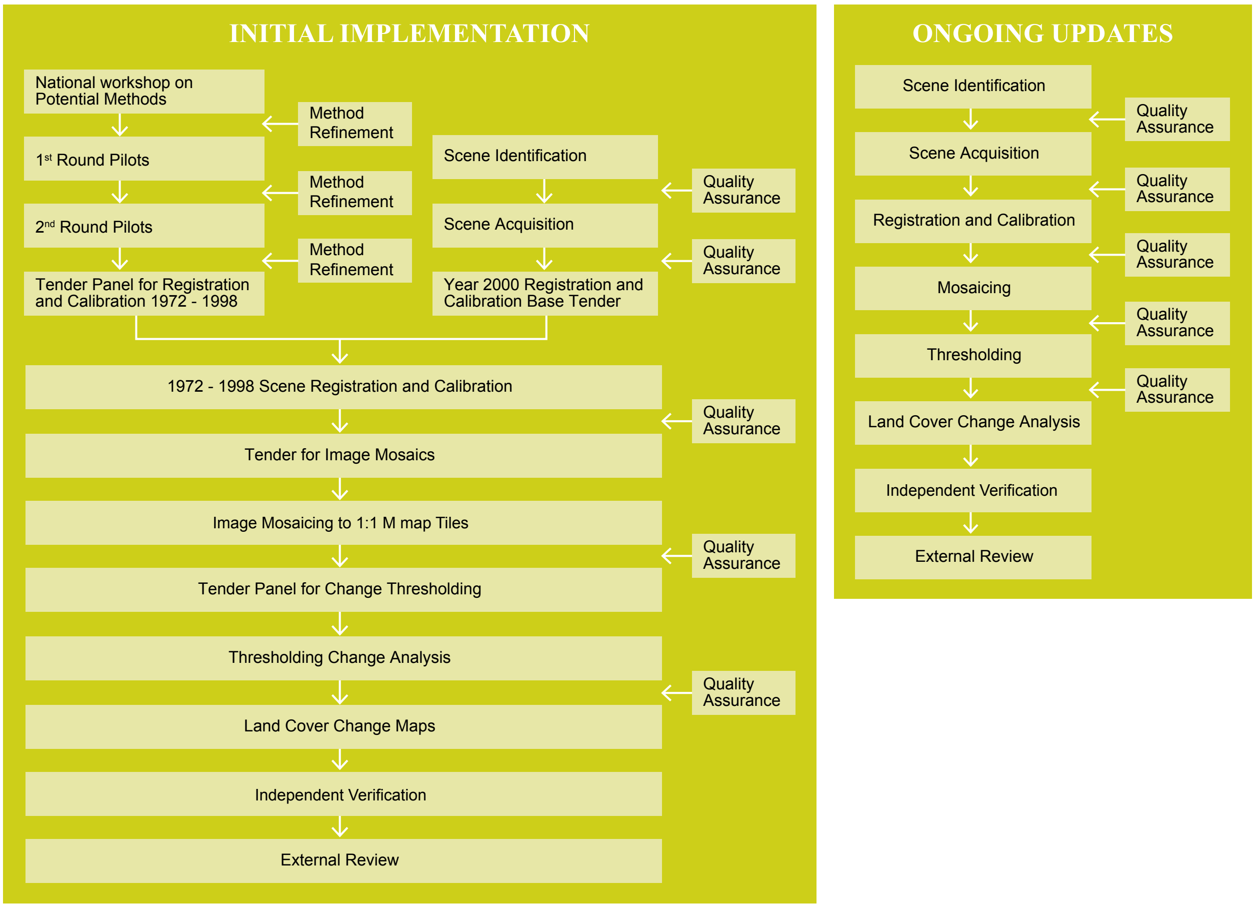
7.A.2.3 Program implementation

Pilot tests were used to train and develop industry capacity, refine methods and software and to develop logistical systems to maximise both output and opportunity for progressive quality assurance and quality control (QA/QC). The results of the pilot studies are published in Furby and Woodgate (2002). A full description of QA/QC, calibration, validation, verification and sensitivity and uncertainty analyses is reported in Appendix 7.J (section 7.J.3.1).

The approach to program administration provides for centralised progress monitoring and QA/QC at each stage in the processing of the Landsat data. Figure 7.A4 outlines the program stages and their sequence. Each processing stage is a regionally defined package of work based on 37 1:1,000,000 (1:1 M) map tiles of Australia (Figure 7.A3). The finalised program approach maximised quality assurance opportunities, expanded the use of competitive service acquisition and enhanced information flow. A set of 18 national coverages of Landsat data have been compiled at intervals between 1972 and 2009. The sequence of images shown in Table 7.A1 was designed to give maximum temporal resolution immediately before and after 1990, so as to achieve the best possible accuracy of emissions in 1990. The return to annual acquisition of data from 2004 onwards allows for the best possible accuracy for every year in the first Kyoto commitment period (2008–2012).

Though minimal in quantum, lagged emissions from land cover change events undertaken in the 1970s can persist through to the current inventory. These long-lagged emissions are largely insensitive to timing of land cover change events in early years (e.g., emissions in 1990 are generally insensitive to whether clearing occurred in 1972 or 1976) and therefore a lower, temporal resolution of early 1970s remote sensing images was considered acceptable for greenhouse accounting (post 1990) purposes. As well as identifying lagged emissions, the historic land cover change record also provides for initialisation of regrowth models, so that estimates of forest age are available for situations involving land cover change through removal of regrowth.

Figure 7.A4. Sequence of implementation of the Land Cover Change Program



The median of the actual capture dates of the approximately 5,000 185 km x185 km Landsat images processed for this project are summarised in Table 7.A1. The image selection criteria (Furby, 2002) require the images to be within three months of the nominated target date. The target dates vary between the north (winter or dry season) and south (summer) of the country and aim to provide the best possible forest discrimination. The precise date allocated to each land cover change (clearing and regrowth) pixel is randomly generated by the *FullCAM* model (see section 7.A.3), within the sequence of coverage dates for the relevant map tile. This method provides a random (unbiased over a large sample) distribution of initialisation dates (timing of land cover change event) for the carbon model, within the constraint of the two dates in the overall interval of the image sequence.

Table 7.A1. 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

Technical Specifications

The technical specifications for the land cover change program (Furby, 2002) evolved through two rounds of pilot testing undertaken by CSIRO and RMIT (Furby and Woodgate, 2002) and reflect the key technical decisions on method selection and implementation. These included:

- using a Landsat ETM+ national mosaic (year 2000) as the base for registration and calibration;
- using an orbital (earth surface) correction model as implemented through the PCI (PCI Geomatics 2000) software package;
- using a BRDF (Bi-Directional Reflectance Distribution Function) atmospheric correction model;
- applying a sun angle correction (Wu *et al.*, 2004);
- using an 'automated' change thresholding, using derived indices within zones based on specific vegetation and soil characteristics;
- digitising areas of fire scars, later using these as fire masks to differentiate change associated with fire from change associated with mechanical land clearing;

- applying a 'Conditional Probability Network' (CPN[7]) so that the probability of forested condition for each pixel at each time in the image sequence is placed in the context of the preceding and subsequent images; and,
- using the *FullCAM* model to interrogate the full change sequence of each pixel. The analysis of each pixel by *FullCAM* establishes whether a clearing or regrowth event has occurred between each image sequence for that pixel and allocates a time.

Selection of Indices

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

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

Conditional Probability Network

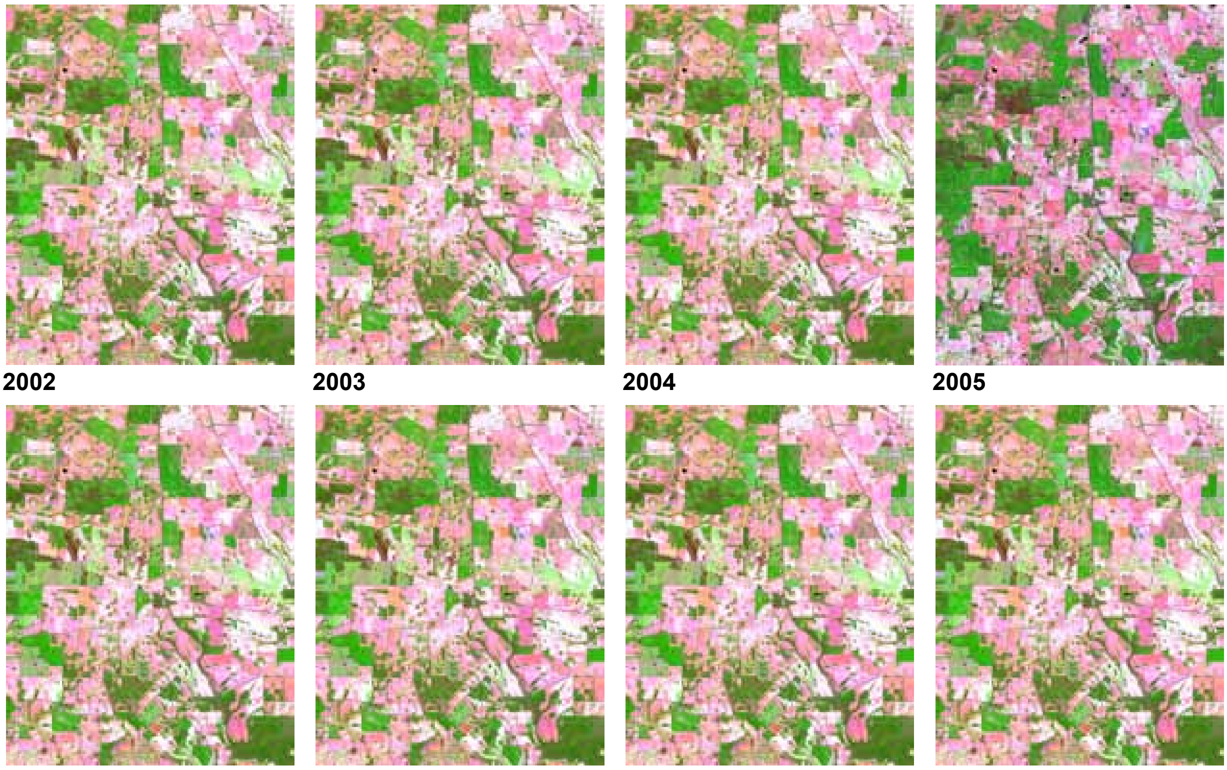
The multiple sequences of geographically referenced images are essential for the robust analysis of land cover change. The Conditional Probability Network (CPN) strengthened confidence in the 'forest' or 'non-forest' classification of a pixel by considering the previous and subsequent images in a sequence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

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

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

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

Figure 7.A5 Images of forest extent and change from NCAS CPN 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

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 flicker in scattered and edge forest 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.

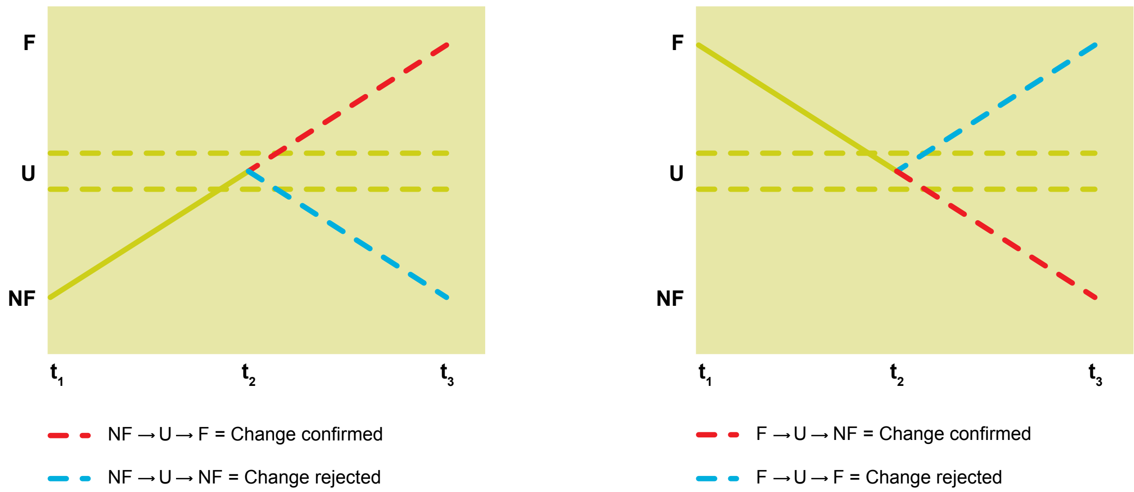
The area of land cover change is determined as the sum of the changed pixels through time. This approach avoids inclusion of pixels that represent gaps in the forest canopy. An independent study which looked at the implication of the inclusion or exclusion of forest canopy gaps in this way found that the resultant area estimate could vary significantly between approaches (ERIC, 2001). The approach used in the NCAS considers only 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 is introduced 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 uncertainties may be confirmed in a time-series update and CPN re-run (see Figure 7.A6). The three-class approach is most relevant to a multiple time series (as opposed to pair-wise) change analysis. It is this approach that leads to small adjustments to the areas cleared over the last 2 to 3 years of the time series as the CPN becomes more definitive as new images become available to confidently assign change from a prior condition.

Use of three-pixel clusters for forest extent

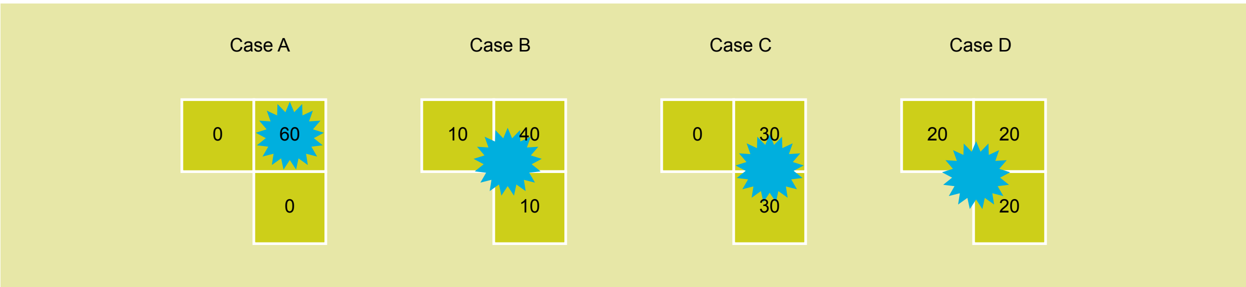
Australia uses the individual pixel (nominally 25 m x 25 m), that is approximately 0.0625 ha, as its analytic unit for the determination of forest (20% crown cover). To be classed as a forest (minimum area of approximately 0.2 ha) for the purpose of the land cover change analysis, three or more connected (at their edges or corners) pixels that meet this condition are required to form a forest area. Individual pixels are only assessed as to whether they meet or do not meet the height and canopy density criteria (Figure 7.A7). Individual pixels are assessed for their forest or non-forest (binary) condition and not percentage crown canopy cover, as the actual crown cover densities should not be added and averaged over any defined or undefined set of pixels (Figure 7.A7). Time-series canopy density analysis for individual pixels in an environment as spatially heterogeneous and with as much temporal variation as in Australia is not achievable with currently available data.

Figure 7.A6. Three class determination of forest cover and confirmation/rejection of change over time using the CPN. F- Forest, U – uncertain, NF – Not Forest



Defining rules to guide such an averaging of canopy density would likely lead to unknown error and also potential bias in the area estimates and almost certainly in emissions estimates. Figure 7.A7 shows how this could occur for area estimation and it assumes that pixels with no forest (0%) are not used when averaging.

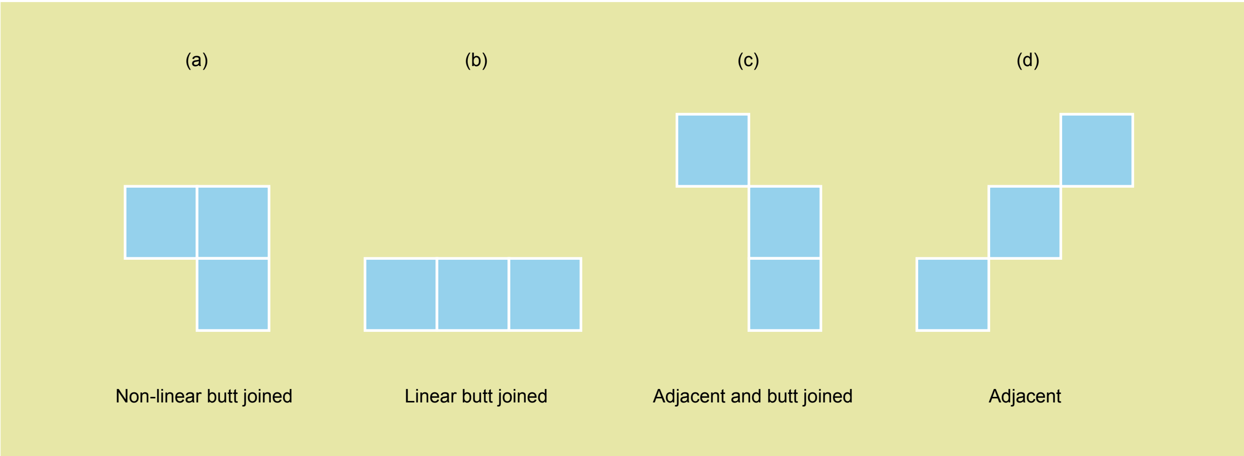
Figure 7.A7 Examples of the affects of 'averaging' over pixels on forest extent. Case A and C are not a forest, Case B and D are a forest. When pixels are not averaged, Case A, B and C are not a forest and Case D is a forest.



The random artefact that would arise from using averaging of canopy cover to determine a forest largely due to where the pixel boundaries were located in relation to the tree crown would not only provide erroneous estimates of the area of forest at any time, but also of the rates of deforestation and afforestation/reforestation. The criteria of each pixel in such a cluster having achieved greater than 20% crown canopy in each of three pixels is highly unlikely given the possible configurations of the pixels, and of the size of a tree crown that would be required to, by chance, have pixel boundaries fall to where Case B, C or D (Figure 7.A7) could occur.

An additional rationale for this approach was that, at a 25 m pixel scale, non-forest pixels (or low percentage forest cover pixel) were filtered out of the emissions analysis. This treatment accords with the estimates of biomass at forest sites where the data are taken to represent that of the areas of forest cover not the average of a forest to non-forest ratio. Therefore, the modelled estimate of biomass is accorded to only those pixels that have greater than 20% crown canopy cover. As the calibration data is not taken from plots with less than 20% crown canopy cover (independent of forest type/density e.g. a random plot which has only partial tree cover) there is the potential that a three pixel cluster, each at 20% canopy cover, may be accorded a higher biomass value than those conditions would infer. This could lead to some overestimation of emissions, but given the rarity of such events, would not be of consequence. Rarity arises from there being few three cluster pixels in Australia's forests and because the issue would only arise for Figure 7.A8 (a), of the possible configurations.

Figure 7.A8 Possible pixel configurations that meet the definition of forest (>0.2 ha) using 25 m x 25 m pixels.



If an area of forest made up of only three pixels is partially deforested, i.e., should one or two pixels be removed from a three pixel cluster by a deforestation event, then it no longer meets the definition of forest and emissions are only estimated for the one or two deforested pixels. The remaining tree covered pixels no longer form a forest and are not continued to be reported as forest. The emissions reported are only those released to the atmosphere from the pixels (area of forest) physically affected by deforestation and do not include those pixels (area of forest) left intact. This prevents the overestimation of emissions. The pixels subject to a land conversion (i.e., deforestation) are reported in the land conversion sub-category. The pixels not subject to a land conversion are transferred to the appropriate land remaining sub-category, e.g., *grassland remaining grassland* (see Appendix 7.H). It is appropriate for the areas of land conversion presented in the lands matrix to be aligned with the basis used to calculate emissions so that the average emissions per unit area converted is transparent and not confounded by residual unaffected pixels that did not contribute to emissions. The emissions and removals from the residual pixels described above are estimated and reported under their new land remaining category.

Approximately 0.05% of Australia's forest area is made up of three pixel clusters. The percent of the total area cleared that occurs in three pixel clusters is 0.123%, half of which cleared all three pixels. Therefore, the area affected by partial clearing of three pixel clusters is only 0.06% of the total area cleared. The three pixel clusters also typically occur in areas of sparse forest cover (low productivity areas) and are much less influential on emissions estimates than even their percent representation would suggest by area when converted to emissions.

For lands converted to *forest land*, a reversal of the process for deforestation is applied. This ensures the symmetrical treatment of emissions (loss of forest) and removals (gains of forest) in the national accounts. Many areas of reforestation and native forest regrowth are observed to 'fill-in' over time as pixels reach the 20% threshold, eventually achieving complete aerial coverage. This may lead to some delay in reporting of removals for a particular forest stand, but given the range of age classes in the national estate, this is not an issue and would result in a conservative estimate of removals.

7.A.2.4 Attribution of Change

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

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

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

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

7.A.2.5 Plantation typing

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

7.A.2.6 Quality Assurance and Quality Control

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

7.A.3 FullCAM Model Framework

7.A.3.1 Overview of model framework

A considerable challenge was presented by the requirement for the NCAS to provide an integrated, transparent and verifiable framework for data management and modelling. A fundamental requirement was that the framework needed to be capable of implementing an integrated suite of models within a geographic information system (GIS). A purpose-built model framework was developed for the NCAS as there was no integrated framework capable of carrying out this task and producing the results in a manner required for national inventory reporting.

The model framework and its development are described in Richards (2001) and Richards and Evans (2004). In addition to the major development of providing the complex modelling in a spatial (GIS) framework, the model also provided for mixes and transitions between forest and agricultural systems and to change plant species and management over both space and time. *FullCAM* (Full Carbon Accounting Model) 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, transitional (afforestation, reforestation and deforestation) and mixed (e.g., agroforestry) 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.A9) (Attachment A1). The five sub-models integrated to form *FullCAM* are:

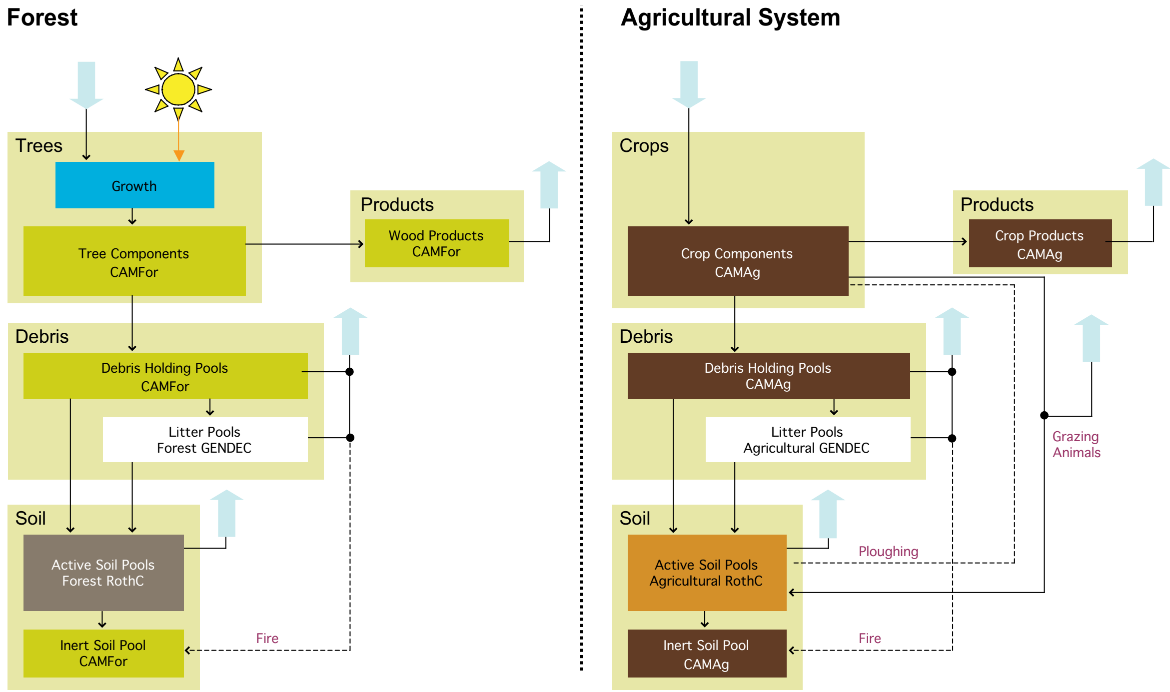
- a variant of the physiological growth model for forests, *3–PG* (Landsberg and Waring, 1997, Coops *et al.*, 1998, Coops *et al.*, 2001);
- the carbon accounting model for forests, *CAMFor* (Richards and Evans, 2000a);
- the carbon accounting model for cropping and grazing systems, *CAMAg* (Richards and Evans, 2000b);
- the microbial decomposition model *GENDEC* (Moorhead and Reynolds, 1991; Moorhead *et al.*, 1999); and,
- the Rothamsted Soil Carbon Model, Roth-C (Jenkinson, *et al.*, 1987, Jenkinson *et al.*, 1991).

These models have been independently developed for the various purposes of predicting:

- soil carbon change associated with agriculture and forest activities (in the case of *Roth–C*);
- rates of decomposition of litter (in the case of *GENDEC*); and,
- rates of growth in trees (in the case of *3–PG*).

The integration of the component models into *FullCAM* served two primary goals. The first was to provide a capacity to be able to operate at a level of conservation of carbon (i.e., closed cycle or mass balance) at a site or other specified area. This includes all pools and transfers (net of atmospheric uptake and emissions) between pools to ensure that there are no significant instances of double counting or omissions in accounting. Potentially, such errors could occur if the dominant carbon pools (soil carbon, biomass and litter) were considered independently. The second goal is to provide a model with the capability to operate continentally as a fine resolution grid-based spatial application. A single efficient model is required to analyse the large input data sets, in a multi-temporal spatial context.

Figure 7.A9: Simplified diagram of the *FullCAM* model pool structure



7.A.3.2 Sub-Model development

As part of the development of the NCAS, an implementation plan was developed by the Australian Government which included extensive consultation with national experts. The details of the implementation plan and results of the International review of the plan are reported in NCAS technical report 11 (AGO, 2000b). One of the key recommendations of the review was to take a holistic approach, with modelling and measurement continuous across all carbon pools and cognisant of the transfers between pools. Other, more specific recommendations from the Review which had direct implications for the development of the NCAS, and therefore *FullCAM* were:

- the adoption of a generic and widely applicable physiological growth model for forests (*3–PG*);
- the adoption of a microbial litter decomposition model, with a suggestion to consider the *GENDEC* model of Moorhead *et al.*, (1999); and,
- support for national calibration of the *Roth–C* soil carbon model.

In selecting the models for integration, priority was given to the use of existing models that had a proven track record in Australia. In addition to model development, strategies for data accumulation and assimilation to allow spatially and temporally explicit carbon accounting and modelling at both continental and project scale (largely directed at satisfying the requirements of the Kyoto Protocol) were developed. Strategies were also developed to guide the fundamental data collections (field and analytic protocols), research program (targeted research objectives) and model calibration (including sensitivity and uncertainty analysis). As part of this development two new sub-models were developed by the NCAS; *CAMFor* and *CAMAg*. These carbon accounting models make it possible to assess the impacts of management practices, such as fire, decomposition, harvest, cropping, and grazing on externally generated growth and decomposition rate inputs.

3–PG

A modified version of *3–PG* was implemented into *FullCAM* to estimate the plant productivity in turn used to model forest growth. This version is a simplified, spatial version of *3–PG* based on the work of Coops and Waring (2001) and described in Kesteven *et al.*, (2004). Further details are provided in section 7.A.4.

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

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

CAMFor

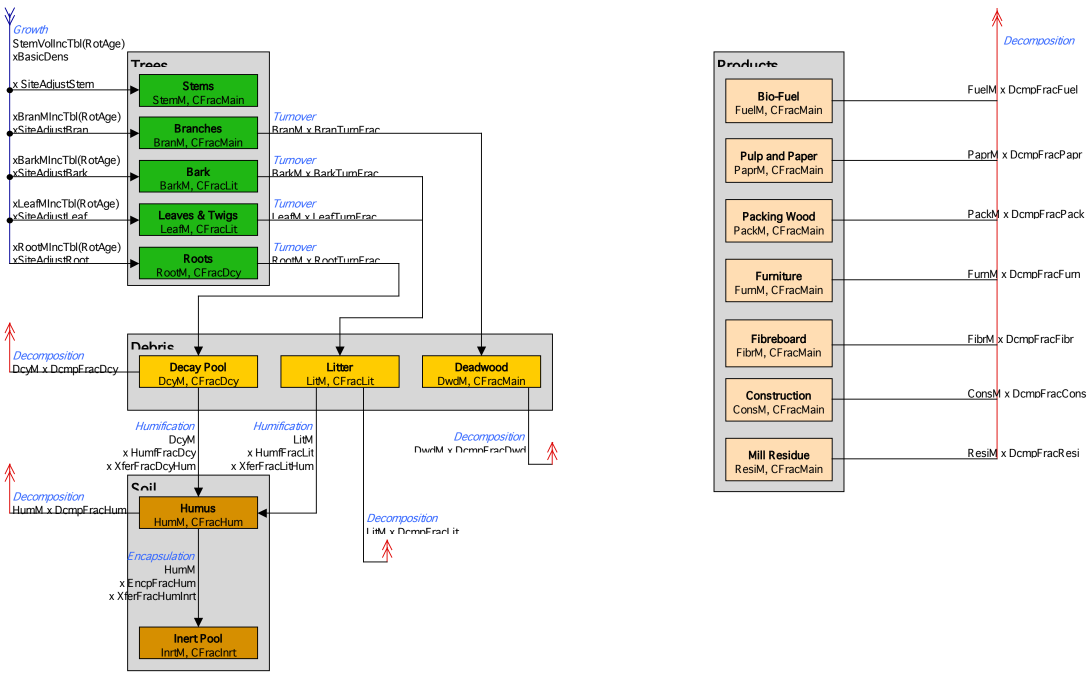
CAMFor (Carbon Accounting Model for Forests) (Richards and Evans, 2000a) was developed within the NCAS to provide capacity for both project and continental scale accounting (Figure 7.A10). *CAMFor* primarily focused on carbon sequestration in forests using basic species information and standard forestry yield tables entered by the user, with limited debris and soil carbon modelling capabilities. *CAMFor* has its origins in the 1990 CO_2 Fix model of Mohren and Goldewijk (1990). The published Fortran code for this model was converted to an Excel spreadsheet (sheet based, formula driven) format as reported in Richards and Evans (2000a). A subsequent series of modifications were made including:

- the introduction of an inert soil carbon pool, recognizing the nature of the carbon in Australian mineral soils, the high charcoal content and the potential long-term protection of fine organic matter through encapsulation and absorption by clays;
- addition of a fire simulation capacity that could deal with stand-replacing and/or regenerating fires, being either forest floor fires largely removing litter, or crown fires affecting the whole tree;
- enhancement of the wood products model to reflect the pool structures and life cycles described in the NCAS technical report number 8 (Jaakko Pöyry Consulting, 1999) (biofuel, pulp and paper, packing wood, furniture and poles, fibreboard, construction wood, and mill residue);
- the ability to move carbon in the on-site plant or debris pools to the relevant product pools at any harvest or thinning event;
- inclusion of the transfer of forest products to landfill and in-landfill decay parameters;
- greater resolution to the component distinctions of the standing tree material, splitting coarse and fine roots, branch and leaf material; and,
- an added capability to use aboveground mass increment for accounting, as an alternative to stem volume increment.

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

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

Figure 7.A10: The *CAMFor* model pool structure



CAMAg

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

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

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

GENDEC

GENDEC is a microbial decomposition model developed by Moorhead *et al.*, (1999) which considers the environmental and biological drivers of microbial activity, namely temperature, moisture and substrate quality. *GENDEC* addresses both carbon and nitrogen, relying on nitrogen-to-carbon ratios throughout the decomposition process and using available nitrogen as a factor which may constrain the rate of microbial activity. When *GENDEC* is brought into operation with *FullCAM*, it can replace the empirical decomposition routines which deal with the resistant decomposable fraction of each tree component embedded in both the *CAMFor* and *CAMAg* components of the model.

The impact of invertebrate activities on the breakdown of debris is addressed within *FullCAM*, whereby the microbial decomposition of *GENDEC* is paralleled by a breakdown factor which can account for losses in aboveground litter due to factors such as macro-invertebrate activity. Root material is incorporated directly into the soil carbon pools, and therefore is subject to the decomposition activities of the *Roth–C* component of the *FullCAM* model. *GENDEC* is not currently applied for reporting changes in carbon stocks, but is a key component of the ongoing nitrogen cycle development. As such *GENDEC* is the subject of ongoing calibration studies and will undergo further testing prior to implementation for the national accounting.

Roth–C

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

GORCAM

Further to the product decomposition modelling, *FullCAM* also incorporates *GORCAM* (Schlamadinger *et al.*, 1997) which allows modelling of the displacement of fossil fuel emissions due to use of bioenergy products and displacement due to the use of alternative products. This allows the relative merits of various types of forest and agricultural products to be assessed against other products (e.g., steel or cement) that may be used as a substitute. The inclusion of *GORCAM* allows *FullCAM* to consider a life cycle approach in carbon accounting.

7.A.3.3 Sub-model integration

The sub-models described above were fully integrated into the *FullCAM* model (Richards, 2001; Richards and Evans, 2004) which was developed in the programming language C++ with a graphical user interface. The individual sub-models can be applied independently or in various combinations within the *FullCAM* framework. The integration of the agricultural and forest models helps ensure conservation of mass during carbon and nitrogen cycling by including all pools and transfers between pools, thus ensuring that there are no instances of double counting or omissions in accounting. The ability to change agricultural and forest species over time was also introduced into *FullCAM*. Further, by embedding both the forest and agricultural models within *FullCAM*, it is possible to represent completely transitional activities – afforestation, reforestation and deforestation (change at one site) – or a mix of agricultural and forest systems (e.g., agroforestry, discrete activities at separate sites) in a single, mass-balance model framework.

The integration into a single compendium model was initially undertaken in Excel as a test version. The prototype forest model derived, *GRC3* (Richards and Evans, 2000c) (Figure 7.A11), 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.

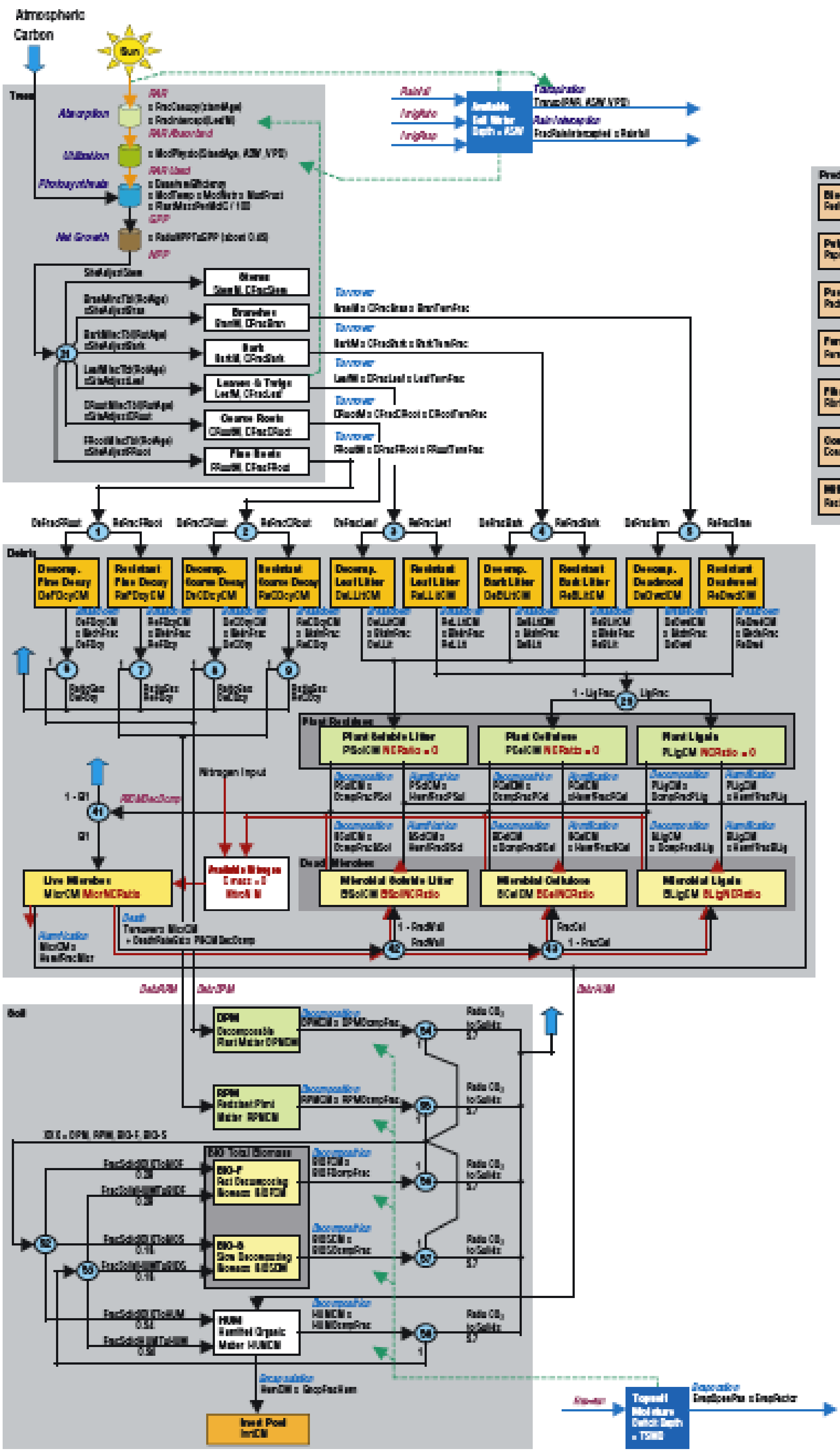
In addition to the integration of the sub-models *FullCAM* also provides the capacity for spatial (grid–based GIS) application, driven by data on land use change, climate, management and site conditions. The *FullCAM* model provides the framework for the integration of the model program calibration and verification activities, land use and management systems, remotely sensed land cover change information and collated (tabular) data such as crop yield.

Model calibration

The NCAS provided considerable investment into the calibration of each of the models for the range of conditions and management practices present throughout Australia. Over a 2 to 3 year period the total investment, including the data collection and process understanding for model calibration needed to prepare and complete the model for initial national application, was in the order of $9M AUS.
Model calibration included the collation of a series of previous (quality audited) site measurements and the undertaking of additional field work and laboratory analyses. Separate data sets were maintained for model calibration and verification of model results. The subsequent implementation of the calibrated

model into a spatial application requires the use of a range of spatially continuous and often multi-temporal input data layers. This includes data such as that on land cover change, climate and soil type described in previous sections. A full description of the quality assurance, quality control, calibration, validation, verification and sensitivity and uncertainty analyses for the model component and data are reported in Appendix 7.J.

Figure 7.A11. The forest 'side' of the *FullCAM* model



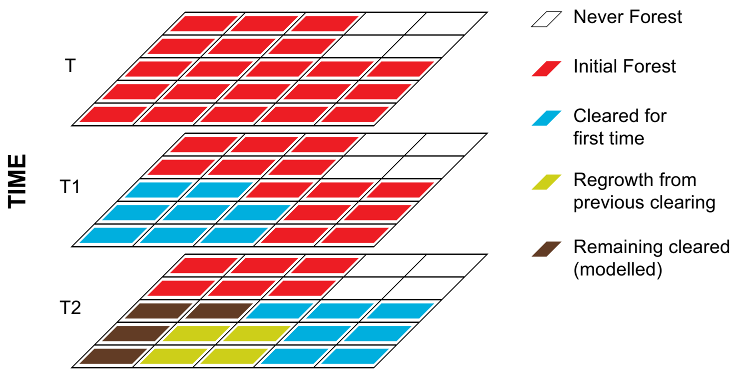
7.A.3.4 Spatial application of *FullCAM*

Entry of lands into the model

The fundamental analytic unit of the NCAS model is the land cover change pixel (25 m x 25 m) derived from the satellite remote sensing program. There are approximately 240 million pixels that are each individually modelled in *FullCAM* as part of the *forest land converted to cropland* and *forest land converted to grassland* sub-categories. The Approach 3, spatially explicit modelling method applied by the NCAS is shown in Figure 7.A12. 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 modelling of that pixel commences (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 in the modelling. Therefore, in any given year, there will be three classes of forest pixels represented in the model.

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 that year (blue). The pixel now enters the model and remains there in future years. The model proceeds to calculate the emissions and removals on that pixel from the moment that the pixel becomes active and the accounting continues each year into the future (purple and green). The third class of forest pixel is for pixels that 'remain active in the model due to an earlier land clearing event'. This class represents the accumulated set of active pixels from previous years back to 1972. 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.A12. Diagrammatic representation of the fully spatially explicit modelling approach used in *FullCAM*



Modelling emissions and removals

Once lands enter the model through a land clearing event, as seen from one satellite image to the next, *FullCAM*:

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

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

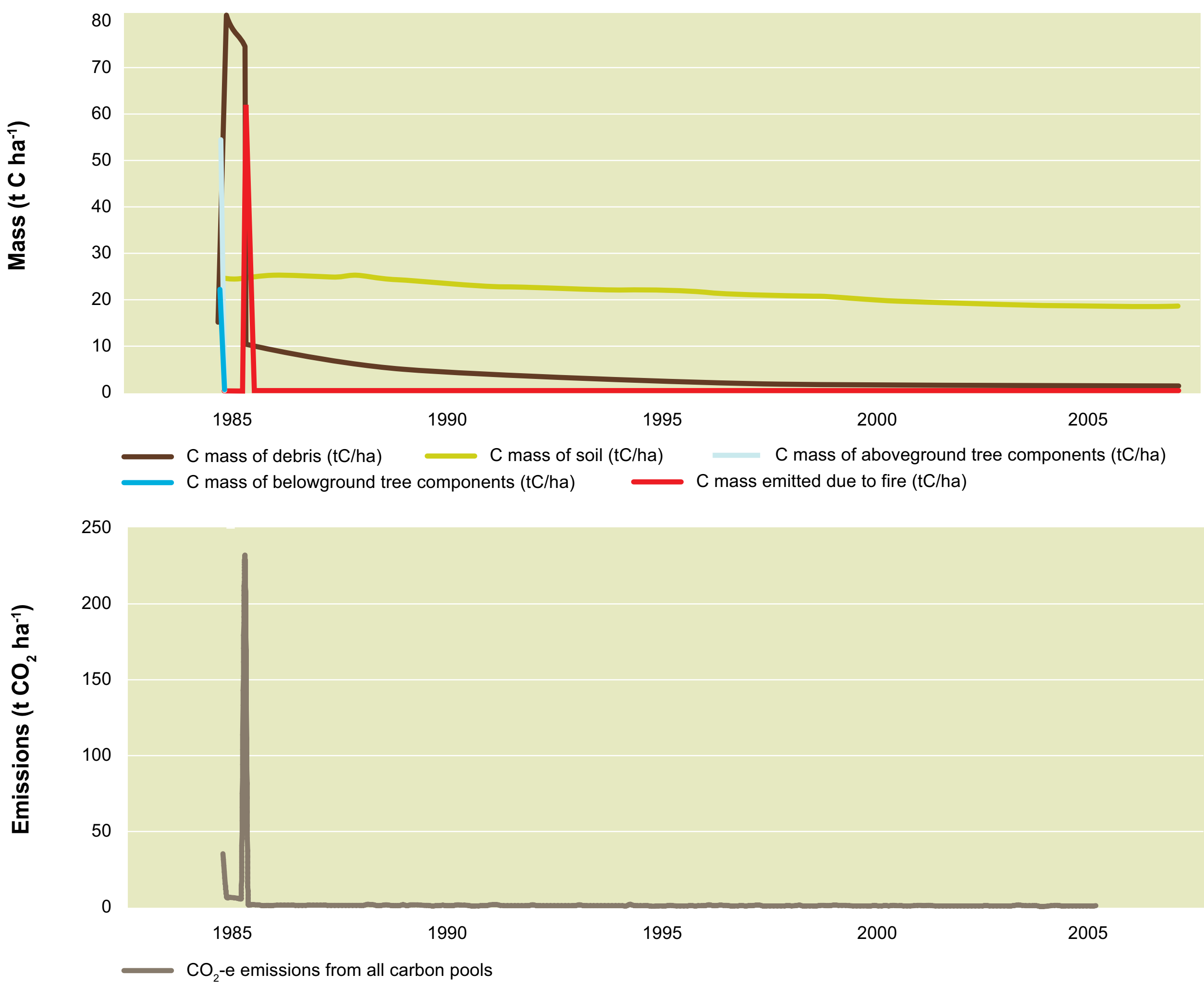
Accounting for lagged emissions

Lagged emissions are emissions in any given year that result from a land clearing event in previous years. These lagged emissions are associated with biomass, debris and soil.

As the NCAS tracks individual pixels through time, from the time of the initial clearing event, any lagged emissions are reported in the account in the years subsequent to the clearing event when the lagged emissions actually occur. 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.A13 shows that the greatest impact of lagged emissions on overall emissions estimates occurs within the first two years following a land clearing event.

Figure 7.A13. *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



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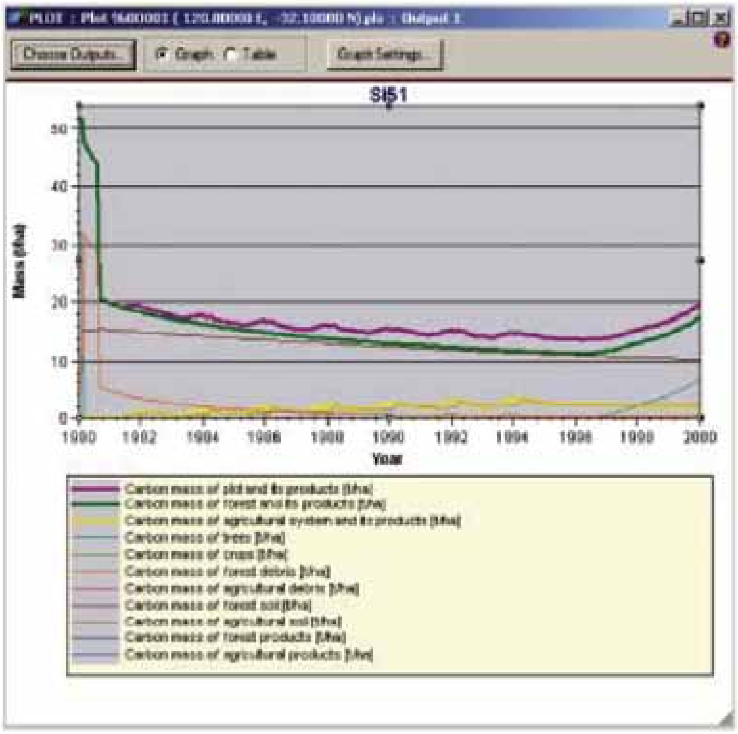
7.A.3.5 Model Outputs

The *FullCAM* model provides a variety of outputs, developed with particular regard to the requirements of the *1996 IPCC (Revised) Guidelines* and the *2003 IPCC Good Practice Guidance*. Depending on the model configuration there are currently over 700 possible outputs available. The outputs can be used for reporting emissions and removals by specific pools as well as for model testing and validation.

There are three general types of outputs from *FullCAM*: point-based, tabular (from spatial analyses) and spatial (grids). As well as being able to operate independently as a point-based model, when applied spatially (Figure 7.A13) *FullCAM* is able to generate point-based models (Figure 7.A14) from the spatial surfaces to produce files at a user specified frequency that are used for verification of the spatial model implementation.

Figure 7.A14. An example point-based (25 m grid) model output from Western Australia



The point-based models provide detail of all data drawn from spatial layers as well as constants set through the model interface and those parameters drawn from the relational database. Outputs can be graphical or tabular and can (optionally) describe the carbon stock in all pools, all pool transfers and atmospheric losses from each pool for each monthly time step.

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Figure 7.A15. Spatial carbon stock change output

Note: Each 100 m grid (sums of 16 25 m * 25 m pixels) has a unique carbon stock change value. The spatial array of source and sink values generally represents the 'proportions' of agricultural practices applied.

Tabular results outputted by the *FullCAM* model include summaries of input data across the spatial surface, e.g., the areas of land cover change (clearing, regrowth, re-clearing[8]) each year. The tabular carbon outputs include the total change in carbon stock (including all onsite and offsite carbon pools) due to the modelled activities for each 25 m pixel under consideration. Other carbon outputs of interest from a reporting perspective include the change in tree mass (of both above- and belowground pools), crop mass (total), soil carbon and offsite carbon mass. The amount of biomass burnt is also reported. These tabular outputs are in a form that can be readily used to report into Common Reporting Format (CRF) tables.

Spatial outputs (25 m or 100 m grids) are made up of the results from each 25 m pixel being modelled. This produces a 'map' of the output of interest for a point in time (Figure 7.A15). These grid files can be easily read in most GIS systems and provide a visual check of the results. Change over a period of time can be determined by calculating the difference between carbon stock maps at the beginning and end of the period under consideration. Any *FullCAM* output can be produced as a spatial file.

Having outputs of both the areas of land cover change and carbon stocks allows for consideration of the lagged emissions that arise from forest conversion. This is crucial to understanding the nexus between rates of land cover change and rates of carbon stock change, as policy response strategies against carbon losses typically focus on the reduction of rates of land cover change. The modelling of lagged emissions and their effect is discussed in section 7.A.3.4. The output information on areas of land cover change distinguishes between first-time and repeat events on a land unit. Spatial overlays can be performed to consider a range of factors such as land cover change pressures on various locations, vegetation types, soil types and under particular climate patterns.

7.A.3.6 Model coherence and validation

As previously noted, the fundamental analytic unit of the NCAS model is the land cover change pixel (25 m x 25 m) of which there are approximately 250 million in the land use change account. The results from each pixel are added together to give the total emissions account in the format of the CRF tables.
The average estimate per hectare for the overall account (the implied emissions factor or; IEF) will not reflect any individual, or cluster of individual pixels. As the number of pixels active in the account accumulates over time, the IEFs for each of the accounts for each year will reflect a mix of area change and change in pixel output. The change in pixel output is also strongly affected by the amount of time since the land was cleared and climate variability.

As there are multiple variable factors, the implied emissions factors from the overall inventory cannot be used to test the model's coherence as the model processes can no longer be observed in anything like their original analytic unit.

[8] Re-clearing is clearing for a second time on a land unit, subsequent to regrowth of an area identified as clearing in the land cover change record.

Testing for coherence in a Tier 3 (Approach 3) model-based pixel by pixel inventory method requires very different techniques to those applied to checks on trends and emissions factors in Tier 1 and Tier 2 models. Tests of model coherence and validation can only be meaningfully undertaken at the pixel level. This is the approach taken and is consistent with the good practice recommendations of the *2006 IPCC Guidelines*. As the robustness of the national account simply flows from the correct summing of the outputs of the individual pixels, testing the results at the individual pixel scale will test 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 the NCAS model 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 biomass and soil carbon calibration results are shown in sections 7.A.4 and 7.A.5, respectively, and quality assurance, quality control, validation and verification are given in Appendix 7.J.

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

7.A.4 Biomass Estimation

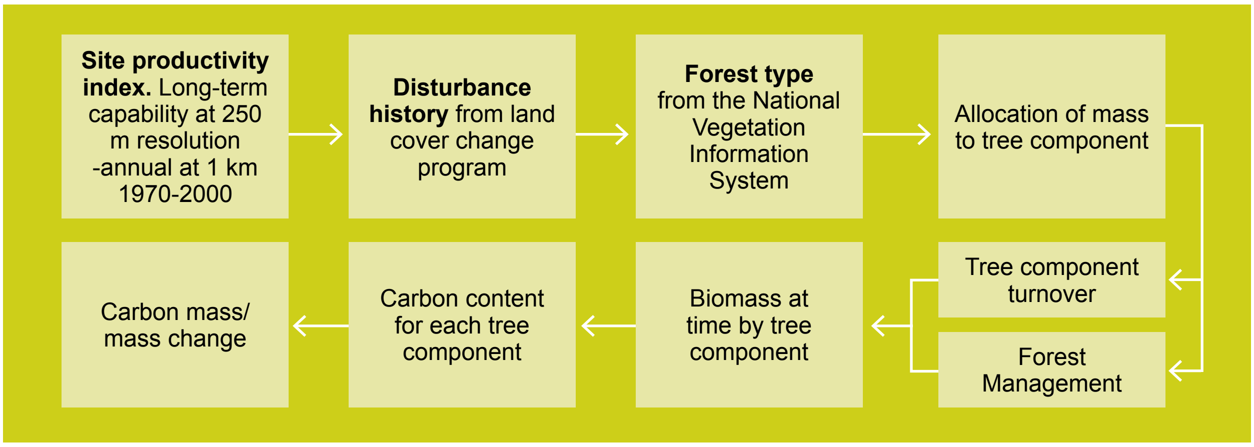
One key part of the NCAS is the ability to estimate the carbon stocks of mature forests and the rates of carbon accumulation in any forest regrowth, inclusive of both spatial and temporal variability. At the start of the NCAS program there was no comprehensive growth data or growth modelling capability (empirical or process-based, as either bole volume or total mass) available to support either biomass stock estimation or growth estimates with the required temporal and spatial disaggregation to develop a robust account.

Providing a dynamic, disturbance and management responsive forest growth model for all of Australia's forests was particularly challenging. Eventually, a spatial modelling approach was used that combines the strengths of both empirical and process-based modelling. The forest growth model component of *FullCAM* can be described as either a hybrid of process and empirical modelling, or an empirically constrained process model. In the hybrid system, process models estimate the initial aboveground biomass, forest growth, relative movements between pools and account for climatic variability while empirical data set the constraints within known ranges (Figure 7.A16). It is the empirical data that constrains the model to reflect extensive field data (both existing and specifically collected).

To derive the spatial and temporal patterns of forest growth the derivative 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 corrections to account for belowground (fine and coarse root) material.

[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. These are not a linear relationship with biomass growth increment.

Figure 7.A16. Overview of the forest biomass programs



Source: AGO 2002

7.A.4.1 Forest Productivity Index

The *3–PG* spatial model, as used in this study, is a truncated version of the full *3–PG* model (Landsberg and Waring, 1997), retaining the essential features of biomass net primary production (*NPP*) estimation, without the carbon partitioning procedures. The essence of the model is the calculation of the amount of photosynthetically active radiation absorbed by plant canopies (*APAR*). *APAR* is calculated (Equation 1) as half the amount of short-wave (global) incoming radiation (*SWRadn*) absorbed by plant canopies.

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

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 0 (complete restriction of growth) and 1 (no restriction). Modifiers used in this way are discussed by Landsberg (1986), McMurtrie *et al.*, (1992) and Landsberg and Waring (1997).

The modifying factors are:

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

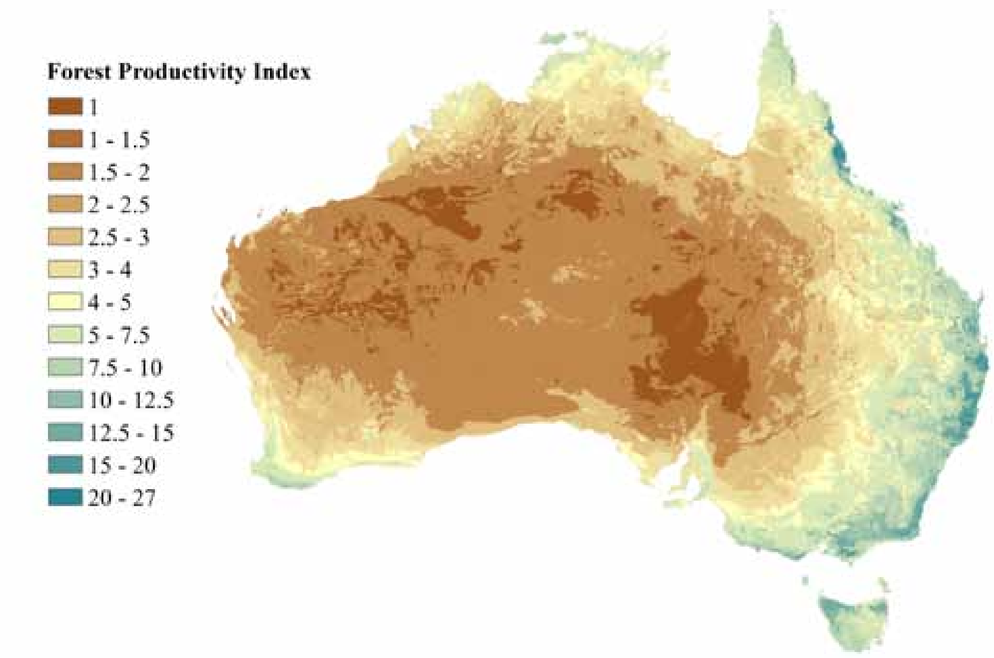
A frost modifier is included, using the simple assumption that frost temporarily inactivates the photosynthetic mechanism in foliage, so there is no growth on a frost day. The modifier is, therefore, simply the ratio of number of frost days/month to the number of days in the month.

Calculation of the Forest Productivity Index

The Forest Productivity Index (FPI) is calculated both temporally and spatially using the monthly (since 1968) 1 km grid climate and site information described in section 7.A.6. A further 250 m long-term average FPI is also calculated, using a slope and aspect corrected APAR calculation (Figure 7.A17).

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

Figure 7.A17 250 m slope and aspect corrected productivity index map



7.A.4.2 Initial assumed biomass

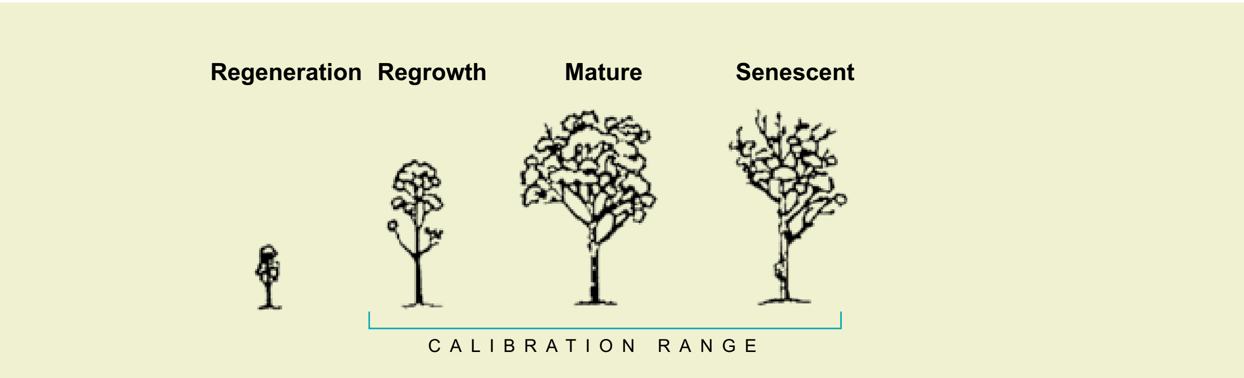
Calibration

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

The assumed initial biomass for a pixel which is subject to first time land clearing is calculated from the site productivity of that forest pixel. Field biomass measurements used in the calibration represent all forest conditions except those with visible evidence of recent disturbance. Mature forests were defined as having no identifiable major disturbance events since 1970 such as clearing, harvest or fire (Raison *et al.*, 2003; Richards and Brack, 2004a). The lands may, however, have an ongoing low level disturbance such as grazing and low intensity fires. As the NCAS model assigns an actual value to regrowth of forest cleared after 1972, forests containing young regrowth were excluded from the assumed initial biomass calibrations to avoid an underestimate of biomass.

The calibration data covers the mix of age classes from regrowth to senescent (old-growth) (Figure 7.A18) and therefore the potential variation in field biomass conditions. To develop this relationship a collation of available biomass data for forests was conducted by CSIRO (Raison *et al.*, 2003). These data combine all the field studies that were available and of the required standard at the time the NCAS methodology was built.

Figure 7.A18: 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).

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

To determine the initial forest biomass for an individual forest site the geo-referenced calibration data set was fitted to the productivity map. The solid red line in Figure 7.A19 is the line of best fit for predicting the initial forest biomass of an individual forest site.

A regression found a significant correlation ($p < 0.01$, $r^2 = 0.68$) between the stand biomass measures (M) and the Long-Term Forest Productivity Index (P) (Equation 10). A square root transformation was required to meet assumptions of normality and homogeneity (Figure 7.A19).

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

Figure 7.A19 The assumed initial biomass relationship

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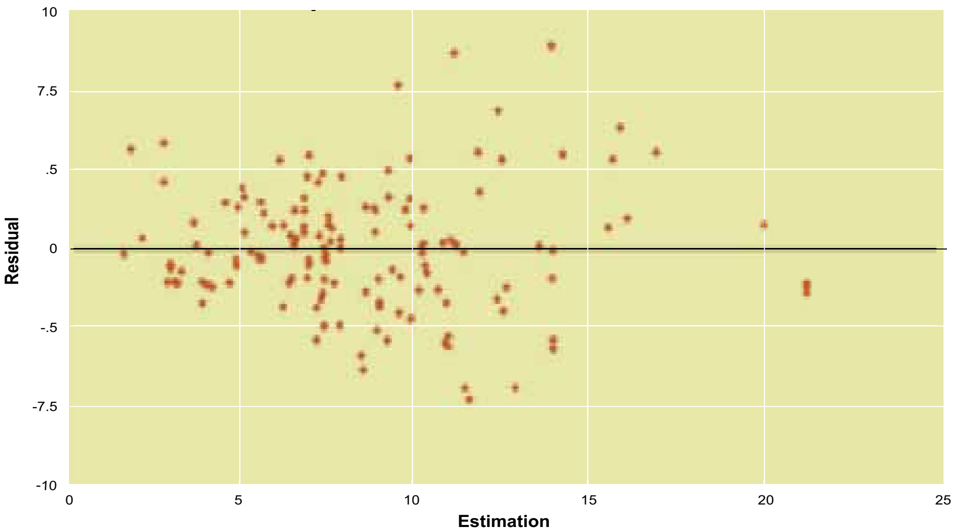
The goodness of fit of Equation (10) ($r^2 = 0.68$, $p < 0.01$) to the measured data confirms that a robust relationship exists between the productivity mapping and measured aboveground biomass estimates. The outer 95% confidence limits (outer pair of dotted lines) show the reliability for predicting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

The initial assumed biomass at a chosen resolution for the entire continent can then be calculated by applying Equation (10) to the FPI mapping. A key benefit of the hybridisation of process modelling (through the productivity mapping) and empiricism (through known measures), is that estimates will be constrained to actual conditions (measured mass estimates) and actual growth, not that of optimal growth without factors such as insect predation taken into account.

While the goodness of fit and lack of bias in error estimates (Figure 7.A20) provides confidence in the application of Equation (10) as a model to predict biomass at maturity, there is an obvious scatter in the data. This is attributable to the range of age classes and forest histories used in the model, the differing methods used in the field estimation and to an inherent variability between the 'plot' locations used to scale to one hectare mass estimates compared to the average condition reflected in the 250 m resolution productivity estimation.

Figure 7.A20. Error distribution for equation 10



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

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

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

Key Terms used in the biomass model

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

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

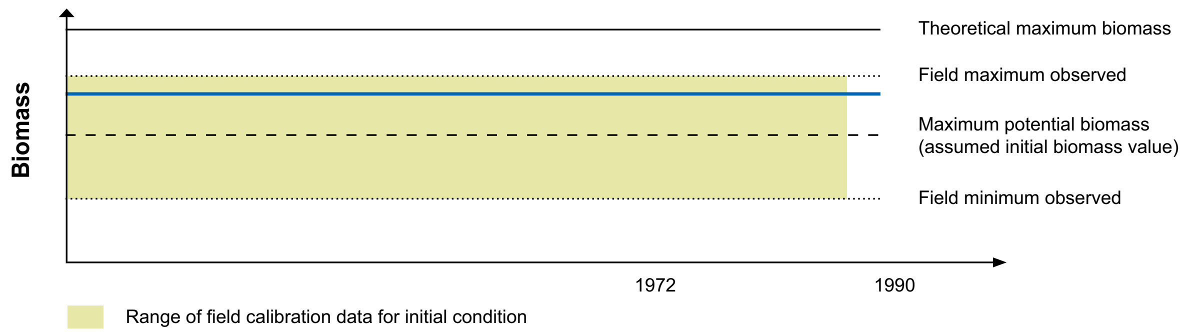
Field maximum and minimum observed values – reflect the range of measured biomass for any point along the site productivity continuum. The maximum measured values typically represent situations that are least disturbed. The minimum values represent a higher degree of disturbance (but exclude young regrowth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

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

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

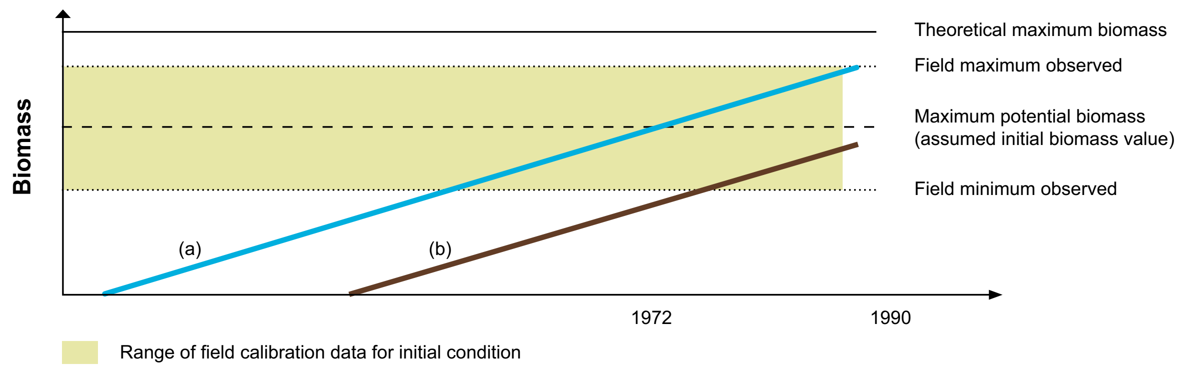
Figures 7.A21 (a) to (c) (below) show the relationship between the model's assumed initial biomass and the likely biomass in each of the three historical disturbance cases. In Case 1 (Figure 7.A21 (a)) the forest site was undisturbed prior to 1972, (as represented by the continuous blue line) and remains 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.A21 (a) Biomass of forest undisturbed prior to 1972



In Case 2 (Figure 7.A21 (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.A21 (b) Biomass of forest cleared prior to 1972



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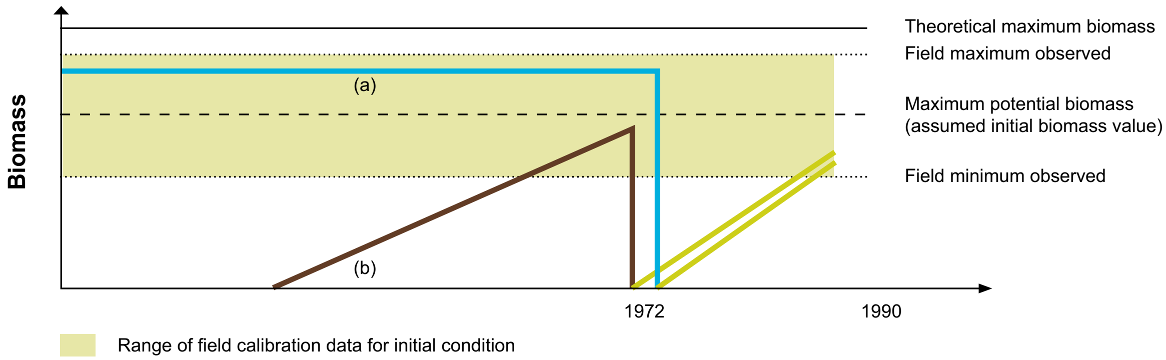
For Case 2 (a) the actual biomass for the site may exceed what would be assigned as the assumed initial biomass condition by the model. This is because of the length of time that the forest has had to regrow means that it resembles the Case 1 scenario. Where the initial clearing occurred soon before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

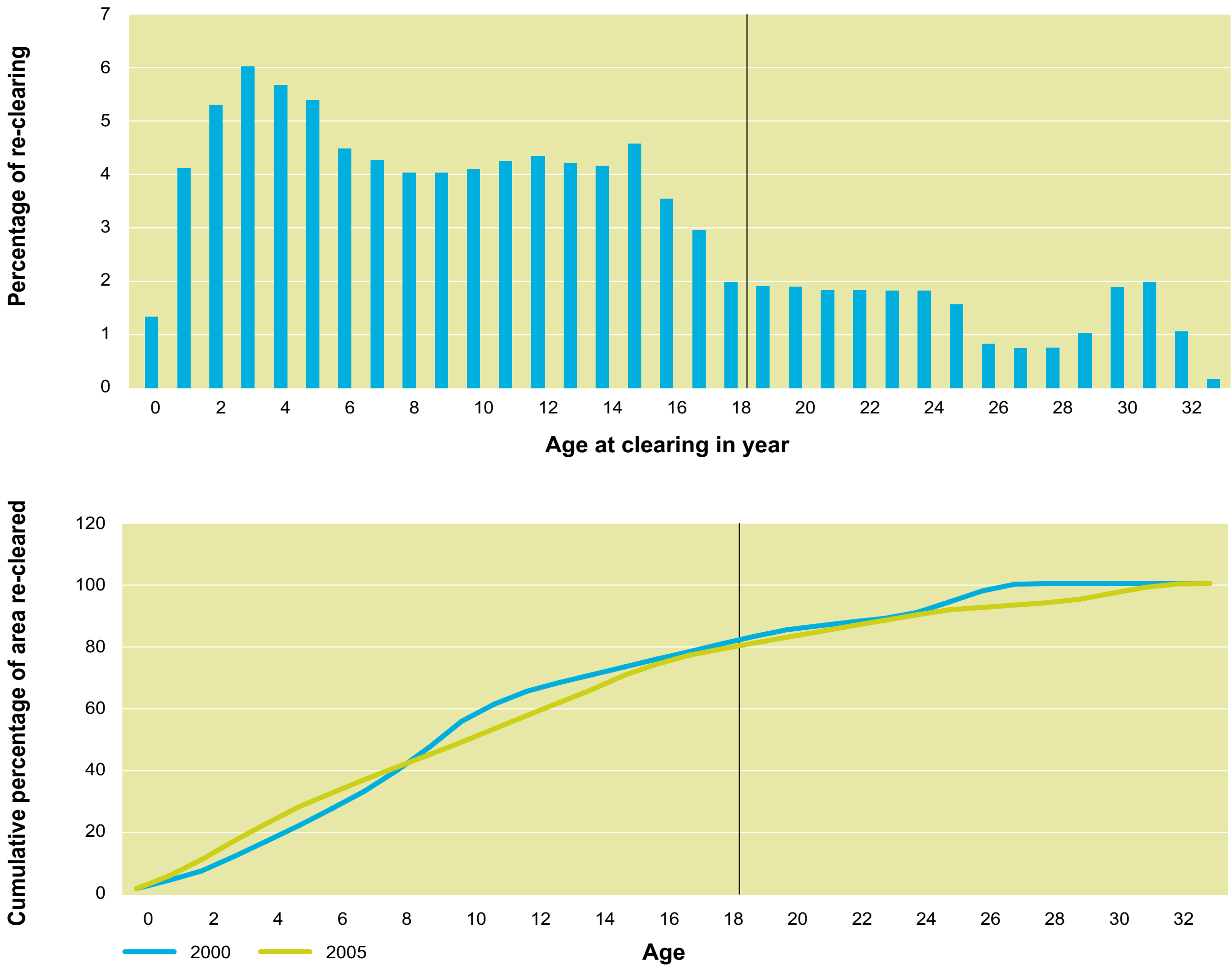
Both Cases 2 (a) and 2 (b) are relatively rare occurrences. This is because the average re-clearing cycle is 8 to 11 years, with 80% of re-clearing happening within 18 years of the last regrowth event (Figure 7.A22). This means that of the forests possibly in Case 2 (a) and 2 (b) (that is previously 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 (Figure 7.A21 (c)). 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.A21 (c) Biomass of forest cleared post–1972



In Case 3 (Figure 7.A21 (c)) the forest is interpreted from the post-1972 remote sensing data to have been 'cleared for the first time' after 1972 (Case 3 (a)) and has subsequently regrown. In this case the age of the forest is known and the biomass is modelled directly using the age of the forest and site productivity (see biomass growth increments section 7.A.4.4). The green lines in both (a) and (b) represent biomass that can be calculated by the model because the age of regrowth can be observed. The assumed initial biomass is not used for any subsequent re-clearing event as the age of regrowth forest is known at the time of re-clearing. Prior to 1972, the forest may have been undisturbed (represented in the blue line (a)) or disturbed (represented in the red line (b)). Regardless of whether the situation was (a) or (b) the initial biomass assumption at time of first clearing will not affect the biomass estimates for a re-clearing event after an initial clearing has been identified.

Figure 7.A22: Percentage of re-clearing by age



7.A.4.4 Biomass increment for regrowing forests

As not all forest areas are in a ‘mature’ state, the remote sensing of land cover change is used to identify disturbance history and, therefore, forest age. The forest type mapping is subsequently spatially overlaid on the multi-temporal productivity maps to determine, for every 25 m pixel, the forest type, productivity and age (inferred from disturbance history using the land cover change data). The following formula (Equation 11) is then used to provide an estimate of growth of those forests which have regrown since 1972 using the spatial productivity index (mass at maturity and forest type) and multi-temporal spatial data (productivity and land cover change).

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

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

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

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

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

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

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

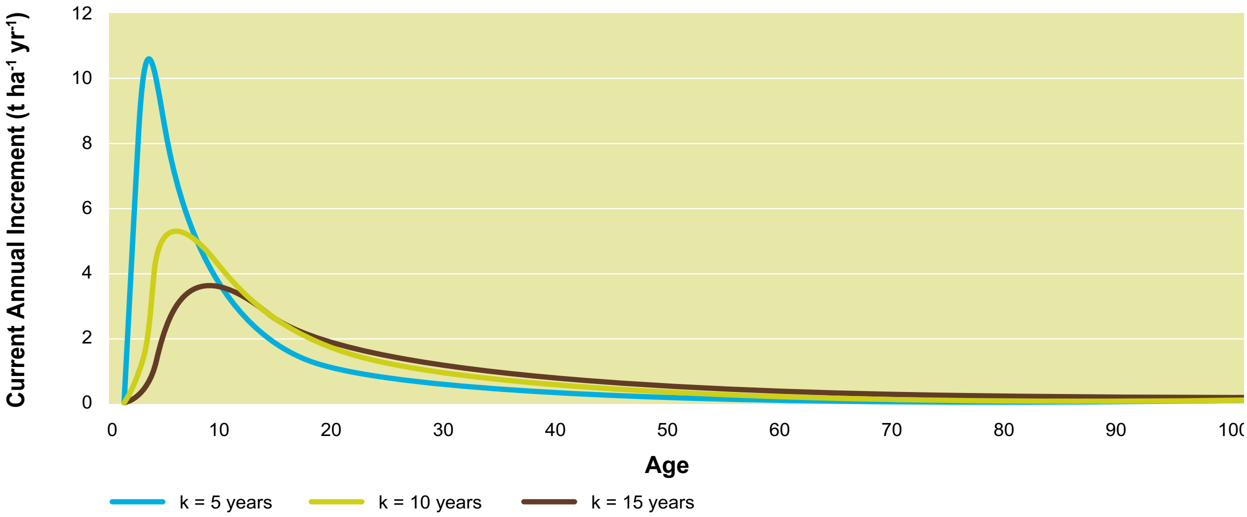
However, as productivity in any given year may vary around the average due to non-average weather or other factors, the average annual increment may be adjusted by the productivity in a given year (P_a) as a ratio with the average productivity (*P*):

$$I_a = I_a \times P_a/P \qquad (13)$$

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

Figure 7.A23 provides an analysis of the effects of varying age of maximum aboveground biomass increment between the ranges of 5 to 15 years. While the early age growth increments are very sensitive to BI_a, even by age 18 there is little difference in the annual aboveground biomass growth increment. The effect of BI_a on any modelling at the national scale will depend on the age, quantity and location of regrowing forest and is discussed separately in Appendix 7.F.

Figure 7.A23. Effects of varying age of maximum current annual increment



7.A.5 Estimating Changes in Soil Carbon

To perform spatially and temporally disaggregated accounting for soil carbon, it was necessary to calibrate and verify a robust and widely applicable soil carbon model. On the basis of previous successful testing in a range of environments in Australia, the *Roth–C* (Jenkinson *et al.*, 1987, Jenkinson *et al.*, 1991) soil carbon model was chosen (Webbnet Land Resources Services Pty. Ltd., 2000) for implementation in the NCAS and integrated into the *FullCAM* model. The structure of the model is represented in Figure 7.A24.

The overall soil carbon program developed both resource inventory (mapping) descriptions and model calibration and verification. The integrated soil carbon program for the NCAS is shown in Figure 7.A25. The background to the selection of methods and design of the program can be found in Webbnet Land Resource Services Pty. Ltd. (2000).

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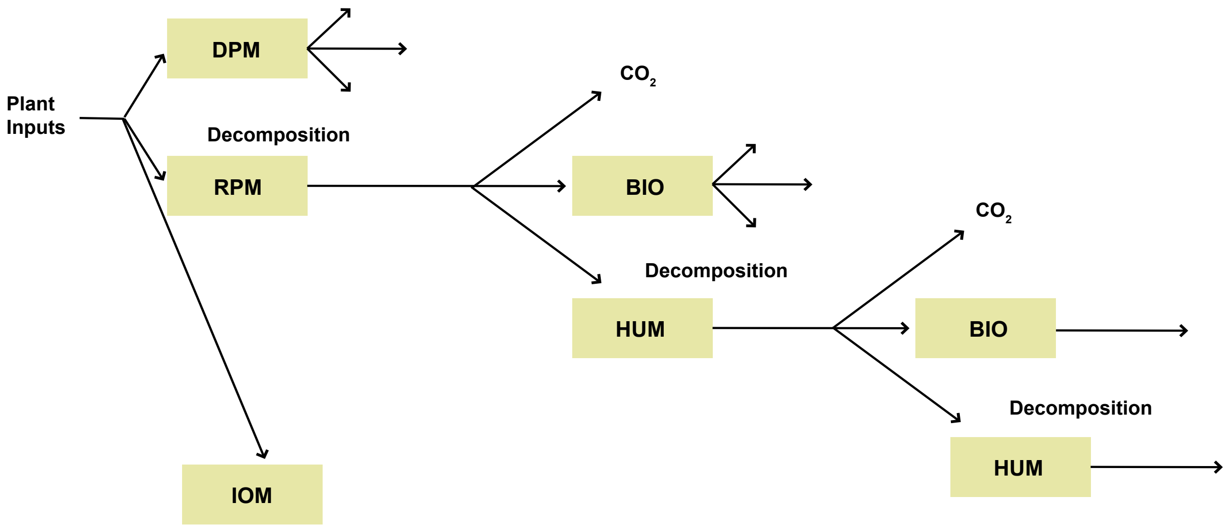
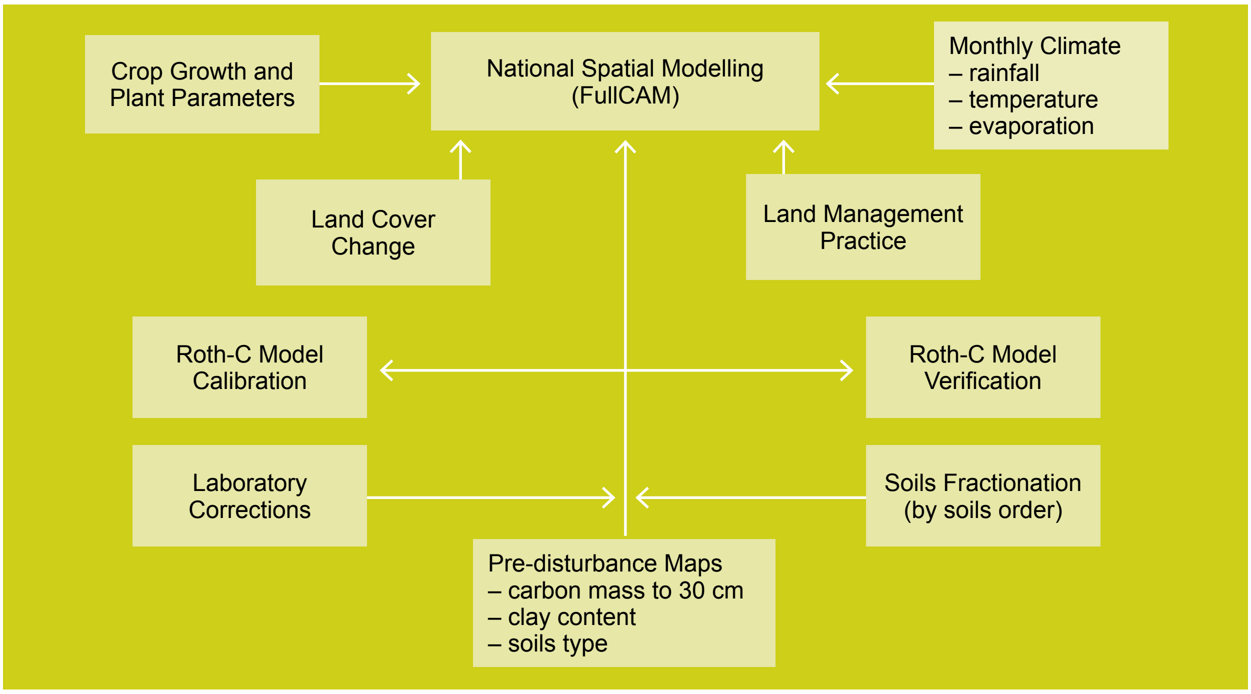
Figure 7.A24: Structure of the *Roth–C* soil carbon model as implemented in *FullCAM*



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

Figure 7.A25. The NCAS Soils Program



Source: AGO 2002

7.A.5.1 Soil Mapping and Inventory

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

The mapping of soil units was completed at a level of precision which could be supported by available data. This approach led to variable resolutions in the mapping, generally determined by the regional data availability and heterogeneity of soil landscapes. The results of this project are reported in Webbnet Land Resource Services Pty. Ltd. (2002). Figure 7.A26 shows the derived pre-disturbance soil carbon map.

In conjunction with the development of the pre-disturbance soil carbon map, a map of clay content was also developed (Figure 7.A27) using the same map base. The mapped soil units provide pre-disturbance carbon (organic) content, clay content and soil type. The soil types (Table 7.A2) allow for the initial soil carbon values from the mapping to be partitioned into carbon pools used by the soil carbon model via a relational database. These pools are defined by their differences in turnover times (i.e., the resistant versus decomposable). The proportion of material in each soil pool (fractionation) was established by laboratory analysis of soil samples held in CSIRO and State/Territory Government archives.

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

Figure 7.A26. Pre-disturbance soil carbon map

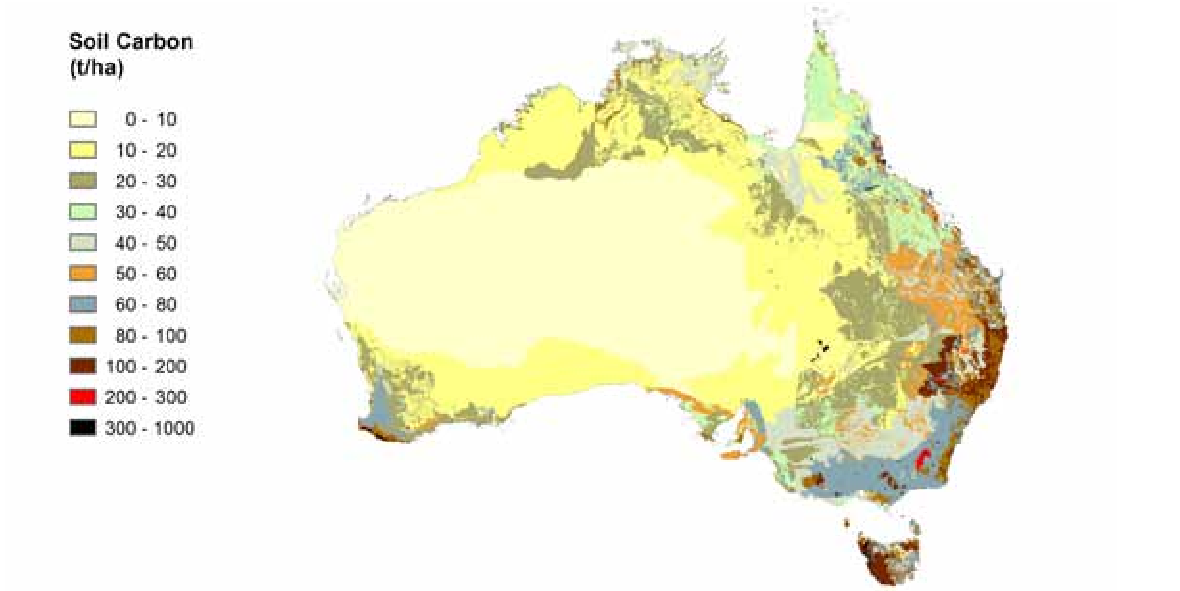


Figure 7.A27. Clay content map

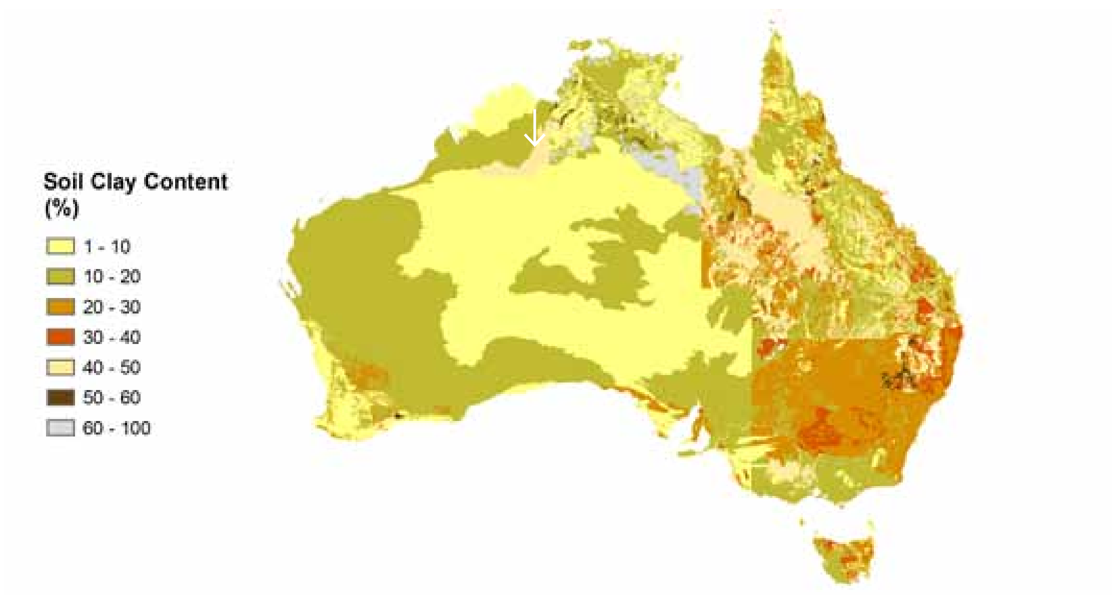


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Table 7.A2. Soil classification used in the modelling

Soil no.	Location	Soil type
s1	TAS	Structured earths
s2	TAS	Bleached sands with subsoil pans
s3	TAS	Other soils
s4	NSW	Clay
s5	NSW	Loam
s6	NSW	Sand
s7	QLD	Duplex – woodland
s8	QLD	Clay – brigalow and gidgee
s9	QLD	Clay – open downs
s10	QLD	Clay – brigalow and belah
s11	QLD	Gradational
s12	QLD	Clay
s13	QLD	Other soils
s14	QLD	Gradational – spinifex
s15	QLD	Clay – mitchell grass (30%) and gidgee
s16	QLD	Duplex – black spear grass & a\b woodland
s17	QLD	Duplex
s18	QLD	Gradational and duplex
s19	QLD	Clay – gidgee
s20	QLD	Open downs
s21	QLD	Earths
s22	QLD	Sands and loams
s23	QLD	Clays and red loams
s24	NT	Kandosol
s25	NT	Other
s26	NT	Tenosol
s27	SA	Sub area 1 – DD
s28	SA	Sub area 2 – Lb5
s29	SA	Sub area 3 – Sandy
s30	SA	DD2/Lb5/E6
s31	VIC	Deep sands
s32	VIC	Calcarosols
s33	VIC	Cracking clays
s34	VIC	Yellow duplex soils
s35	VIC	Leached sands
s36	VIC	Brown duplex soils
s37	VIC	Black duplex and gradational soils
s38	VIC	Red-brown earths
s39	VIC	Bleached sands
s40	VIC	Organic soils
s41	VIC	Gradational Red earths
s42	VIC	Non-cracking clays
s43	VIC	Red duplex soils
s44	VIC	Organic loams
s45	VIC	Red earths
s46	VIC	Brown earth
s47	VIC	Grey cracking clays
s48	WA	Coloured sands
s49	WA	Gravels
s50	WA	Loams and clays
s51	WA	Non saline wet
s52	WA	Other
s53	WA	Pale sands
s54	WA	Sandy duplexes
s55	WA	Saline

7.A.5.2 Soil Carbon Model Calibration and Validation

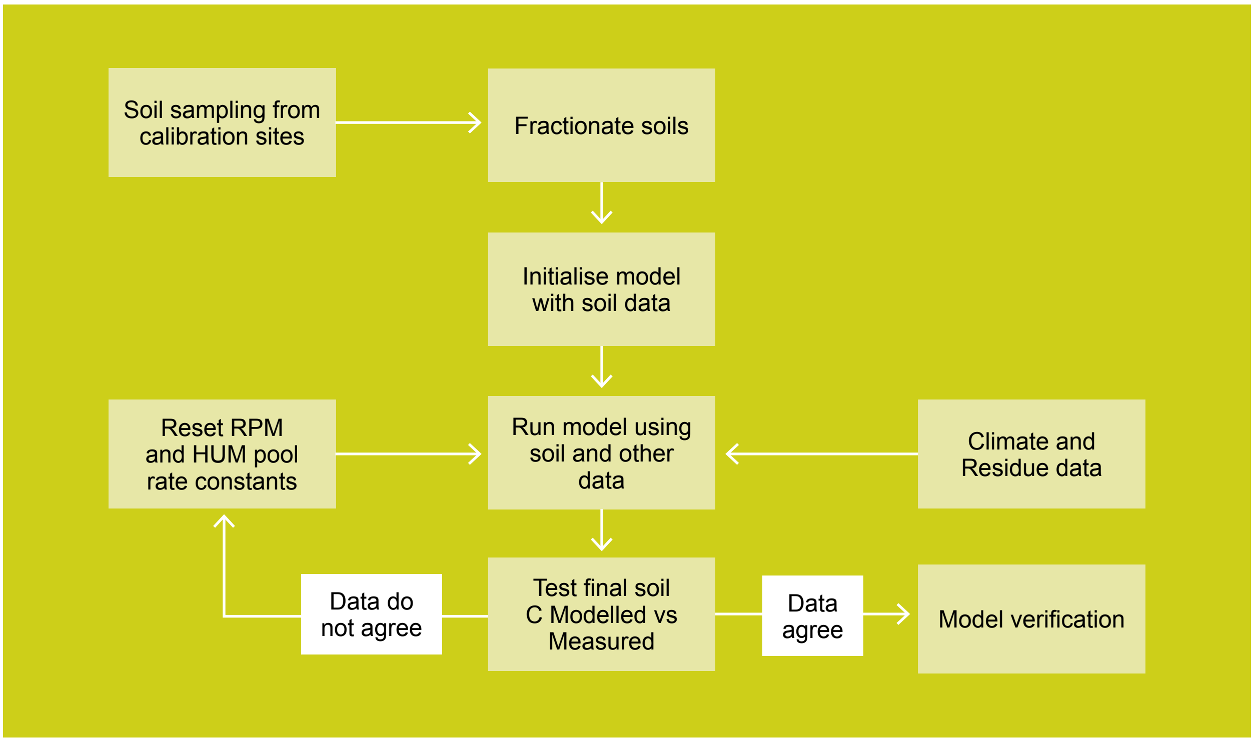
Early policy and technical analysis of the requirements for the carbon accounting under the IPCC inventory guidelines, the Kyoto Protocol, and of the national data and methodological capacity available for the task, led to the development of a model-based methodology underpinned by the *Roth–C* soil carbon model. The model calibration and verification program identified available long-term field trial data, a subset of which had sufficiently detailed and complete long-term data to enable calibration of the model against long-term field measurements. Only a minimum of data supplementation was accepted at these calibration sites. Other sites with incomplete long-term data, but providing a robust temporal pattern of carbon change under known management and climate, were used for model validation and verification (Skjemstad and Spouncer, 2002) (see Appendix 7.J).

In addition to this long-term trial data, approximately 75 new soil pairs (an undisturbed site paired with a cleared site) were sampled to provide a range of verification targets for model testing. Sites were established, in collaboration with State Agencies in Queensland, New South Wales and Western Australia, in the areas of major forest conversion activity. Sites were selected to cover a variety of crop type, soil type and time since change (e.g., clearing) in areas subject to most intensive activity. Sampling of sites was completed according to the standardised soil sample protocol developed for the NCAS (McKenzie *et al.*, 2000b).

Calibration of the soil carbon model was completed around a structured procedure as shown in Figure 7.A28.

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

Figure 7.A28: Procedure for the calibration of the *Roth–C* soil component of *FullCAM*



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7.A.6 Data Sources

An initial task in the implementation of the NCAS was to bring together all the available data, review its utility and synthesise data of various origins. Pre-existing national data, such as the vegetation groups of the National Vegetation Information System (NLWRA, 2001) were used where available. Where such national compilations were not available (e.g., soil carbon content and clay content), national collation and synthesis of available inventory and research data was undertaken by the NCAS (Skjemstad *et al.*, 2000; Webbnet Land Resource Services Pty. Ltd., 2002).

7.A.6.1 Climate

Model sensitivity testing for the NCAS 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, the NCAS obtained weather station data from the Bureau of Meteorology for rainfall, minimum and maximum temperature, evaporation and solar radiation. Monthly climate surfaces (maps) at 1 km resolution for each variable were then derived using the ANUCLIM (McMahon *et al.*, 1995) techniques.

Raw Data

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

Derived Outputs

The weather station climate data are interpolated (modelled) using mathematical (multivariate spline) functions that reflect influences on micro-climate such as elevation. Climate maps are derived at variable resolutions (grid sizes), again using the ANUCLIM software (Kesteven *et al.*, 2004). The list of outputs and their resolution is shown in Table 7.A3. Figures 7.A29 to 7.A32 illustrate national long-term average annual climate maps generated using the ANUCLIM software, noting that the NCAS methods apply the climate maps at the specific spatial and temporal resolutions as presented in Table 7.A3.

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

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

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Table 7.A3. List of climate and productivity maps developed for the NCAS

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

Figure 7.A29. Long-term average annual rainfall

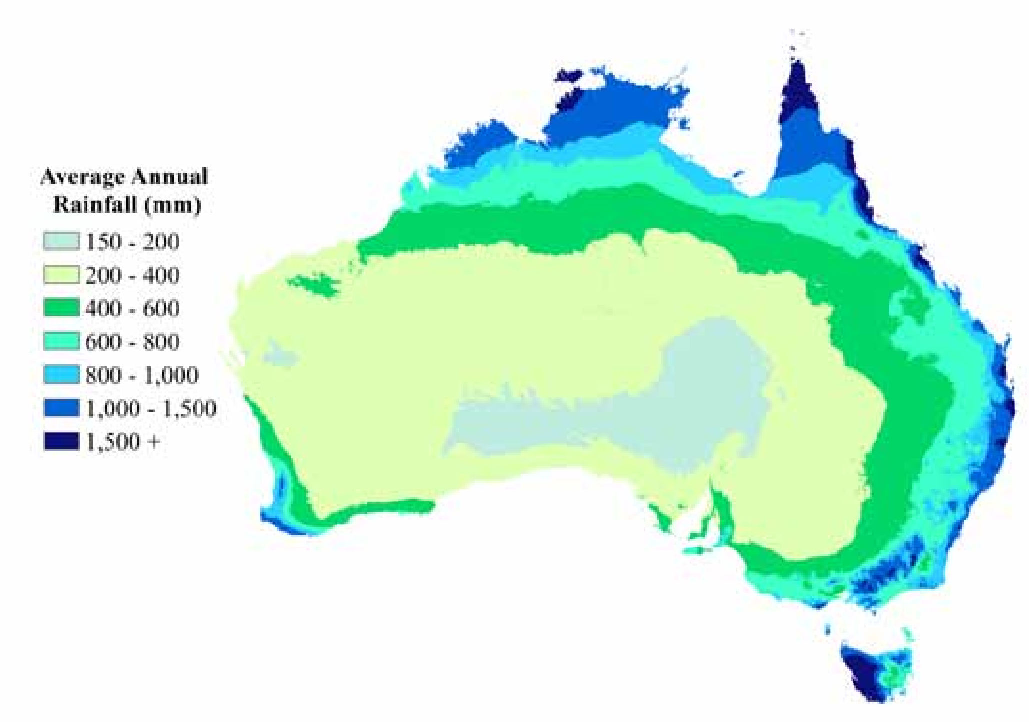

Figure 7.A30. Long-term average annual temperature

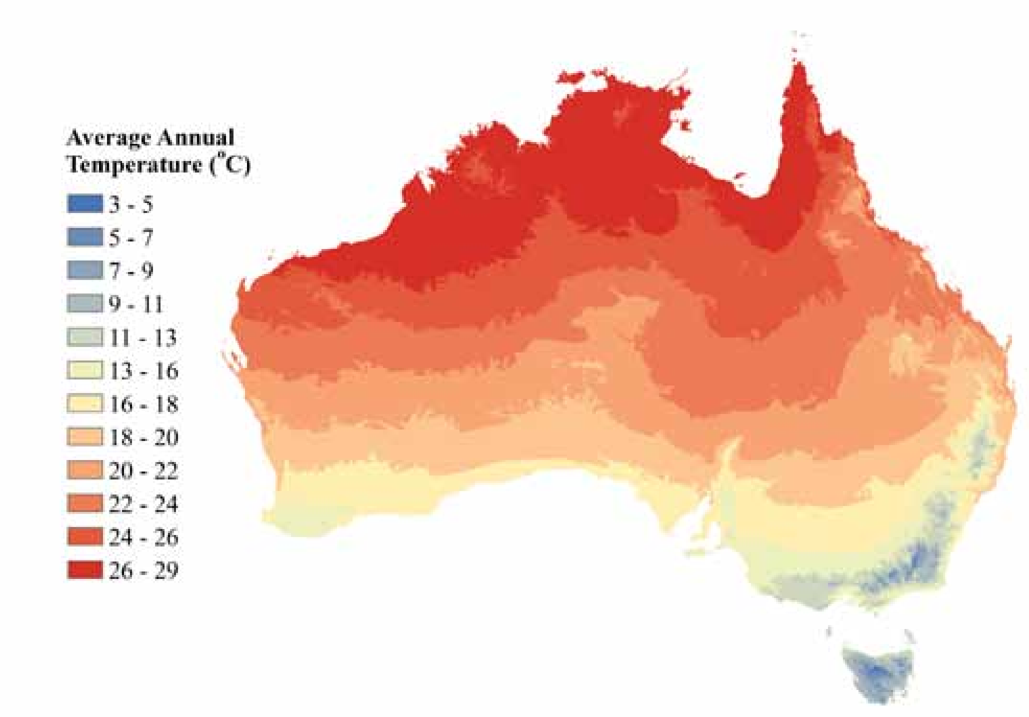

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Figure 7.A31. Long-term average annual evaporation

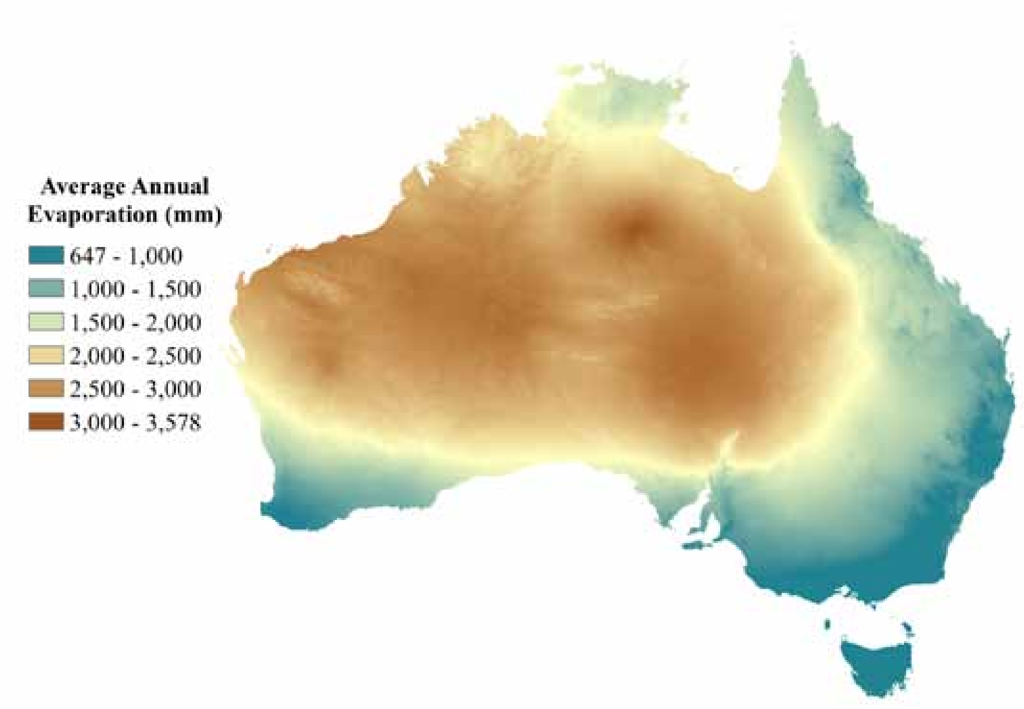
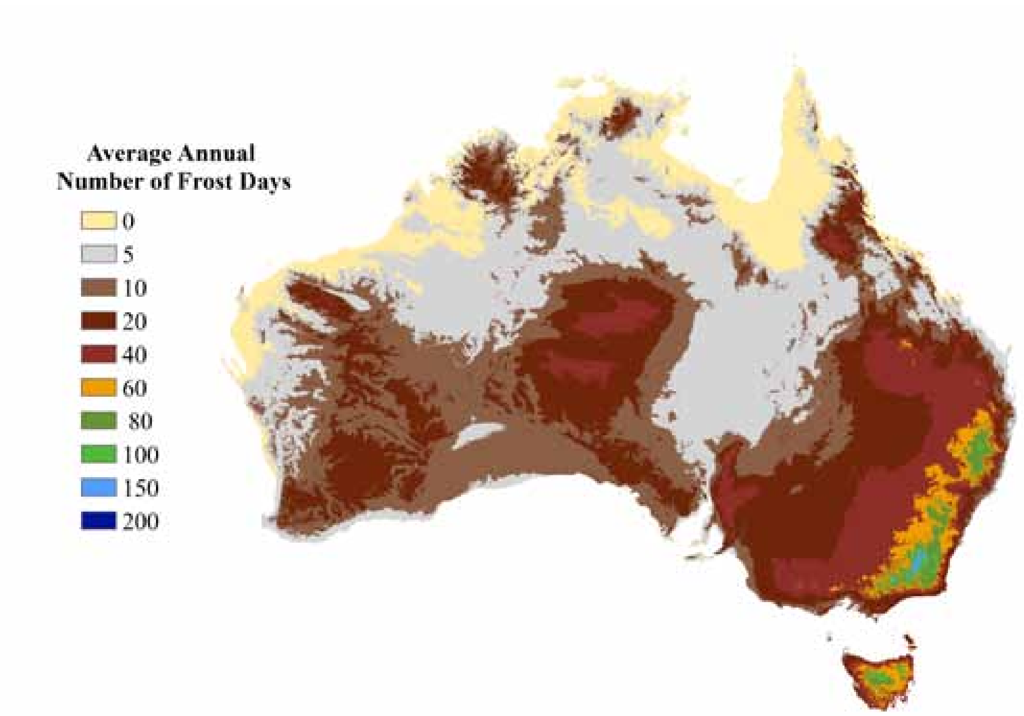


Figure 7.A32. Long-term average number of frost days per year



7.A.6.2 Soils and other spatial data

Soils

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

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

Land tenure

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

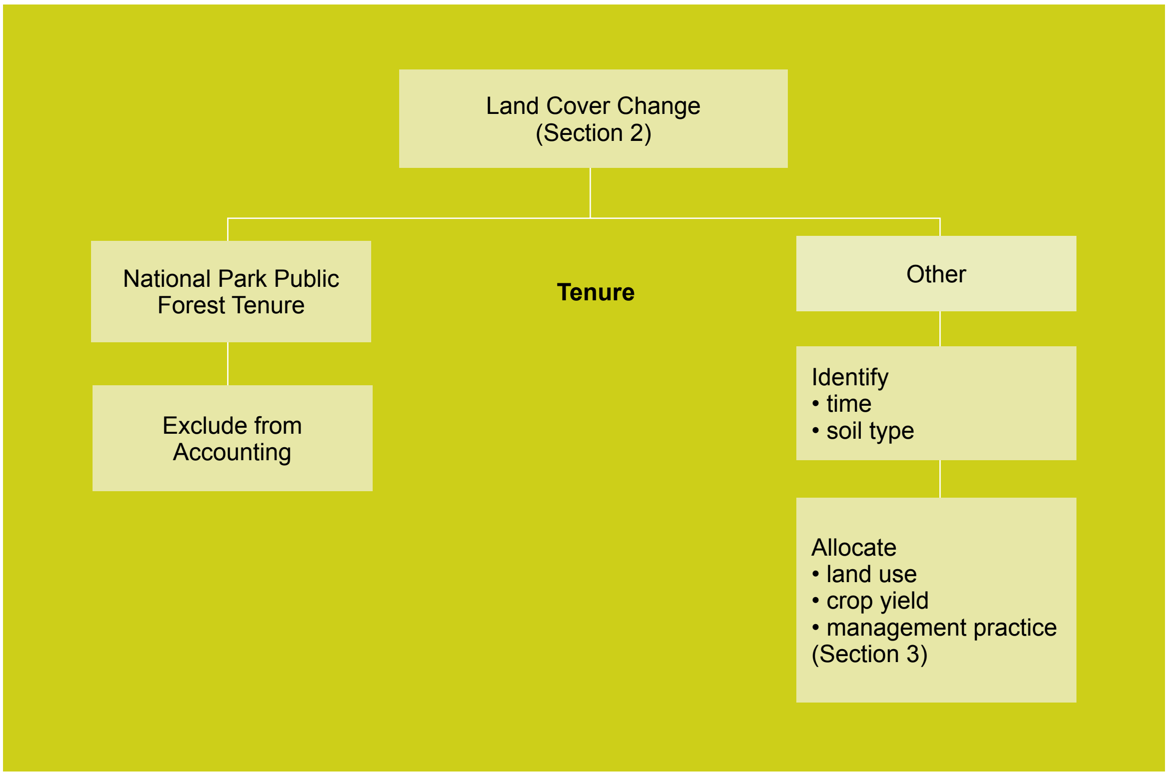
7.A.6.3 Land Use and Management Data

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.

The NCAS 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 derived for the NCAS 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.A33).

Figure 7.A33. Overview of the land use and management program



To obtain the agricultural land use and management information, the NCAS commissioned CSIRO Land and Water to collect relevant growth and management information via survey and literature searches for each Interim Biogeographic Regionalisation of Australia (IBRA) (Thackway and Cresswell, 1995) region, based on soil type, crop type and crop regime (rotations), management type and time (Table 7.A4). This included time-based crop yield estimation for each identified land use and management type. The results of this study can be found in Swift and Skjemstad (2002), reported by IBRA regions (Figure 7.A34) 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.

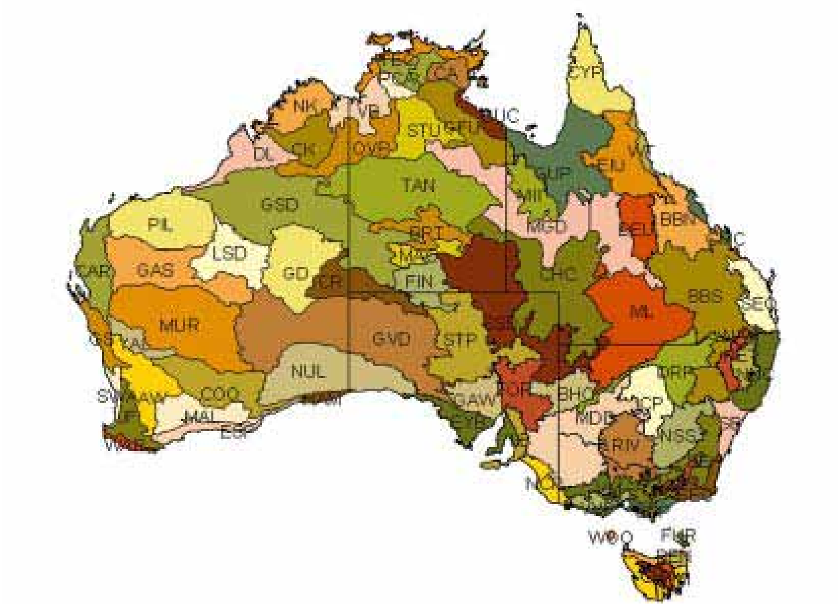
Table 7.A4. Example land use table

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.A34. IBRA regions



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

Crop yield

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

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

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

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

7. A.6.4 Other non-spatial data

Plant characteristics

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

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

Coarse woody debris and litter

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

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

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

7.A.7 Planned Improvements

Development of the NCAS 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* sub-categories and implementation of the full Tier 3, spatially explicit modelling approach to lands converted to *forest land*.

Development of a comprehensive estimation capability for future reporting is ongoing and will be released once the national implementation has been fully calibrated, verified, quality assured and peer reviewed. This is consistent with the approach to inclusion of NCAS results in the national inventory only after all appropriate cross-cutting processes have been completed.

Remote sensing

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

- areas of plantation established prior to 1988 using Landsat MSS data;
- areas subject to harvest in the *harvested native forests*, and
- areas of sparse vegetation and change in sparse vegetation since 1988.

Modelling

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

The carbon cycling approaches used in the *FullCAM* model are similar to those implemented in the *Century* model (Parton *et al.*, 1987). This has allowed *FullCAM* to be further developed to include nitrogen cycling, using the *Century* approach as a basis. Inclusion of nitrogen cycling serves two functions. The first is to constrain growth where there is insufficient nitrogen available to plants to support that growth. This is often important in Australian conditions (Dalal *et al.*, 2002). The second is to estimate the amount of nitrogen volatilised, or lost to nitrification and denitrification. These estimates are of specific interest for modelling emissions of N_2O under differing management. The N-cycle component of *FullCAM* is currently in the final stage of development prior to final testing.

FullCAM software flexibility

For the 2008 inventory submission the output structure of the *FullCAM* model has been revised so as to provide for sub-category reporting for (i) the separation of lands into a category of either less than 20 years or 20 to 50 years since conversion, and (ii) a category of transition from lands converted to lands remaining after 50 years. For each new inventory year in a Tier 3, Approach 3 model, the land units converted each year and the emissions from those land units are reported separately and tabulated to report the converted lands and their emissions, by land category, for each year that conversions occur.

Australia is currently developing more 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. Australia anticipates that this will be enabled for the 2011 inventory.

The effect will result in a complex time-series of reporting tables. One table will list the emissions for a given year and the second table will list emissions for a given year of the land conversions sub-category of which the emission for that year is catalogued to the year when the land entered the land converted sub-category. For example, to report emissions for the year 2007, land may have entered the land converted sub-category from 1972 onward. The emissions for that land converted sub-category will then be broken into the 35 years from which the land conversion may have occurred. To report this since 1990, some 477 reporting lines will be created for each land conversion sub-category.

7.A.8 Public Tools and Data Availability

As part of the NCAS program a public release version of *FullCAM* combined with electronic copies of the technical report series and Landsat imagery (the DataViewer) has been made available. This provides a valuable resource to land managers while ensuring greater transparency for the NCAS.

The DataViewer contains five of the eighteen national composite Landsat satellite sensor images (1972, 1980, 1989, 2000, 2004) obtained and registered by the NCAS; continental maps of long-term average rainfall; minimum, average and maximum temperatures; evaporation; and number of frost days. Recent improvements in image compression technology allowed all of these data to fit onto a single DVD. The associated program allows users to locate and zoom into any area of Australia and compare images to help determine changes in land use from 1972-2004. All of these images can be easily imported into more complex GIS systems.

Although a useful tool, the image compression used in the DataViewer does lead to some reduction in visual quality. The archive of Landsat data has been made publicly available through Geoscience Australia (www.ga.gov.au) for the cost of data transfer.

The National Carbon Accounting Toolbox (NCAT) contains a public release version of *FullCAM* and the NCAS technical reports which outline how and why the system was established, the data used in the development of the system and the results of continental simulations. The public release version does not contain nitrogen cycle modelling capabilities or other model aspects currently under development.

As part of the NCAT development, *FullCAM* was fitted with a Databuilder function. A single *FullCAM* plot file typically requires over 1,500 inputs, including monthly climate records and species and management information making it difficult and time consuming to develop a single model. The Databuilder function simplifies this process by downloading all the required data for a point from a webserver that contains all the climate, species and management data as used in NCAS continental simulations. Users simply select the type of system they wish to model (forest only, agriculture only or transitions between the two), enter a latitude and longitude (obtainable from the Dataviewer) and click a button to download the spatial data. The model then accesses the webserver and obtains the required climate and site information for the specific location from either 250 m or 1 km grids depending on the data type. Users then further decide what species and management actions they wish to model and further download the required parameters from the server. Hence users can quickly build a *FullCAM* plot using the best available data at the national level. These models can then be saved, shared with other users and run at any time without a web connection. As the full model is provided, advanced users can also adjust any parameter in the model to better fit their exact circumstances.

All the data and models are publicly available via the internet and they form the basis of many scientific and commercial programs – more than 10,000 copies of the model and supporting documentation (user manual, technical publications and functional specifications) have been distributed. The wide distribution and accessibility of the data and model means that there is an informal ‘test’ community numbering in the thousands, a share of which represent well developed scientific and commercial interests. Therefore, for any one specific pixel or group of pixels in Australia, anyone could model the changes as would be represented in the national model by testing them against field measurements that meet the standards prescribed in the NCAS sampling protocols.

Attachment A1:The *FullCAM* Model

Naming Conventions

Abbreviations used in names

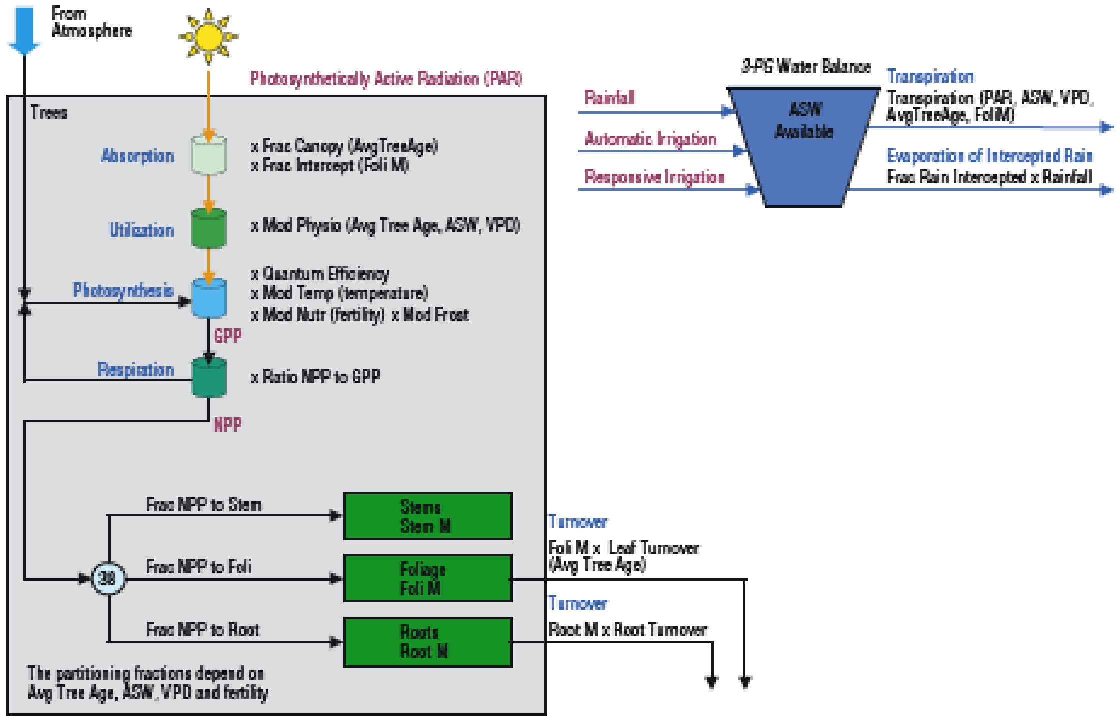
Actv	Active soil carbon
Avg	Average B = Microbes (dead) (see P, Micr)
Bkdn	Breakdown C = Carbon Material whose every atom has six protons
C	Coarse (see Dcy, Root)
Cel	Cellulose (see Lig, Sol)
CM	Carbon mass of material Mass of carbon atoms in the material
Conp	Consumption (of fodder by animals,which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

Root	Root, either CRoot (coarse root) or FRoot (fine root)
RotAge	Rotation age (years since trees were planted)
Sol	Soluble litter (see Cel, Lig)
Tbl	Table
Temp	Temperature
Turn	Turnover
Wall	Microbe cell wall

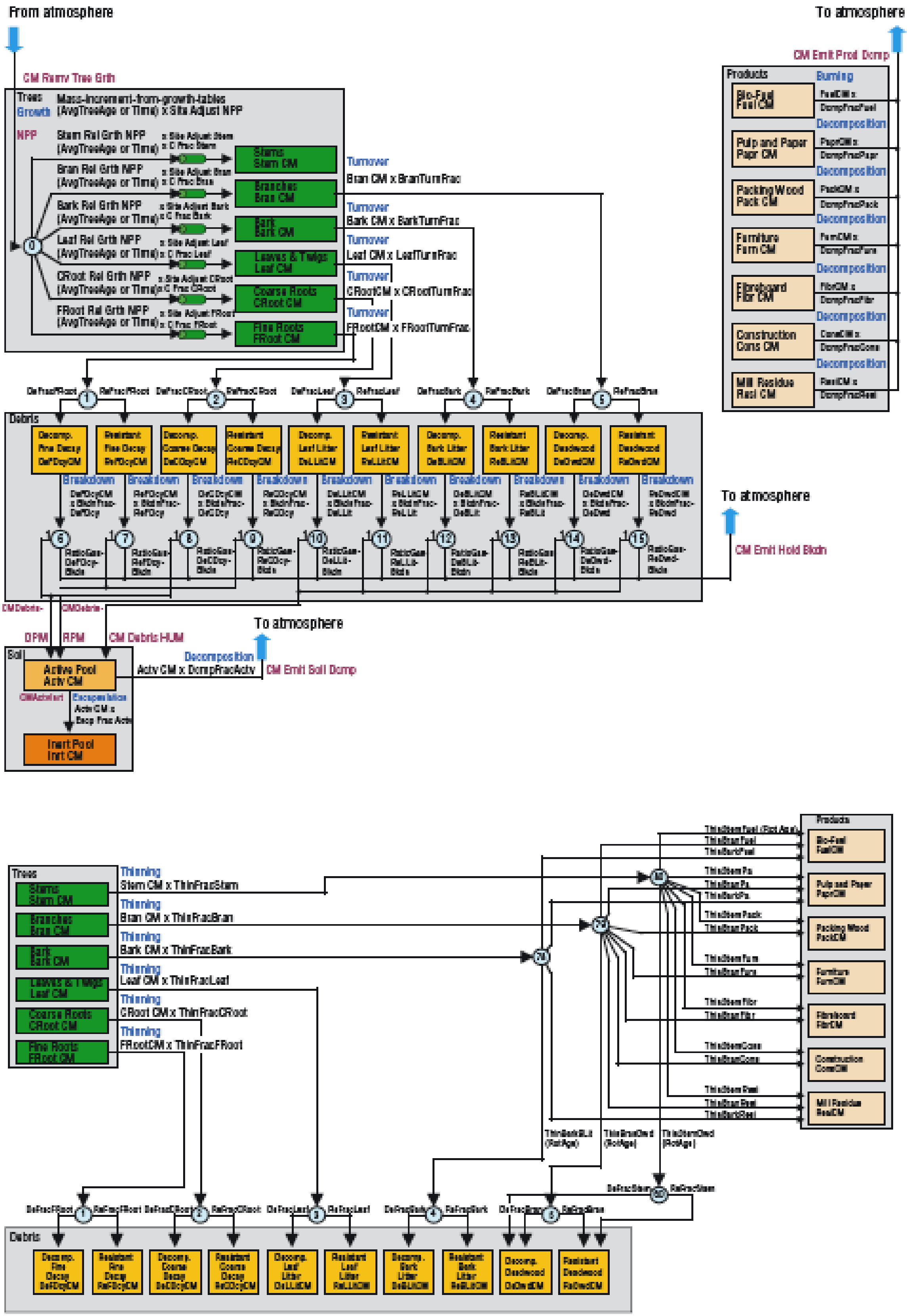
Abbreviated Quantities

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

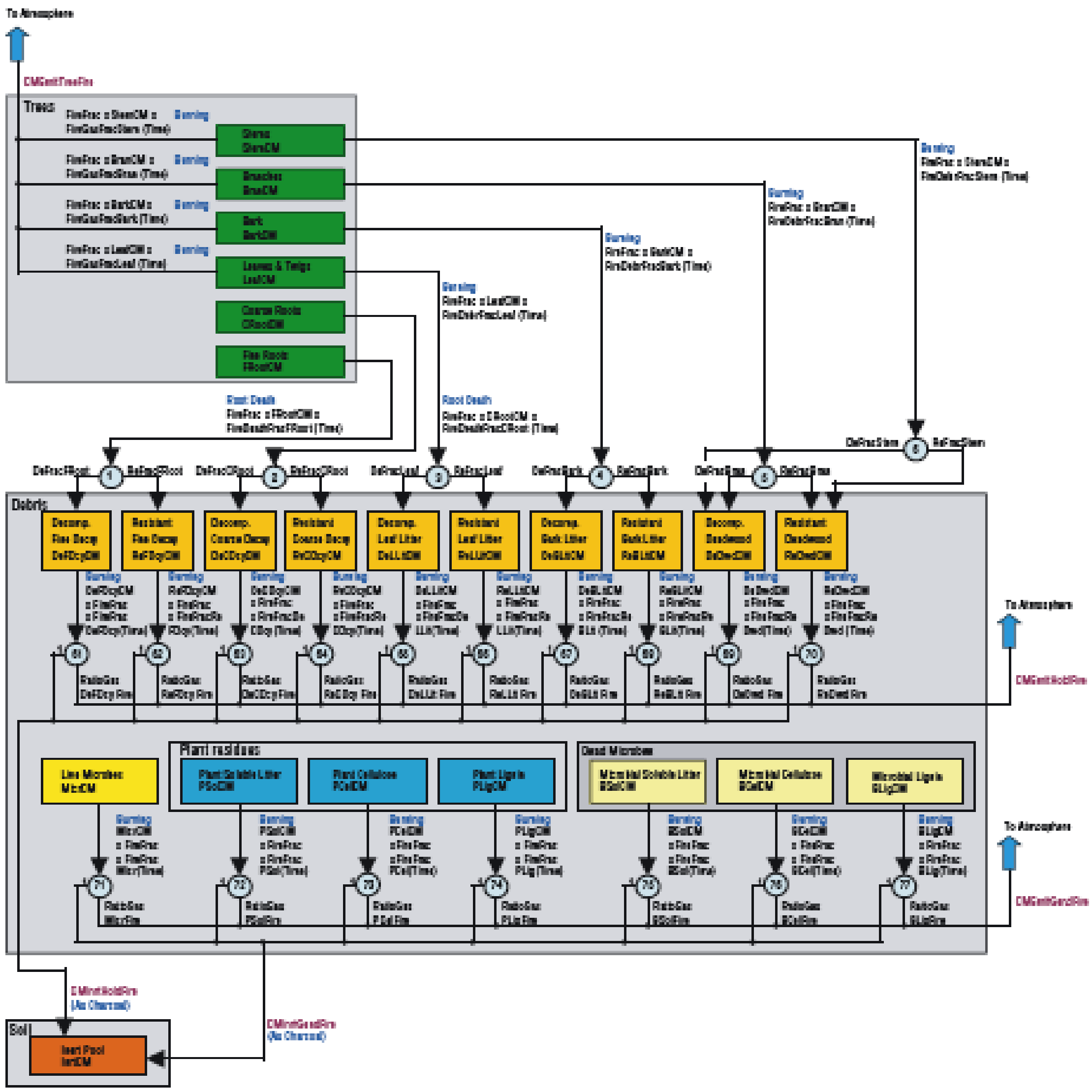
The *3–PG* Model



The *CAMFor* Model (a) Thinning



The *CAMFor* Model (b) Fire



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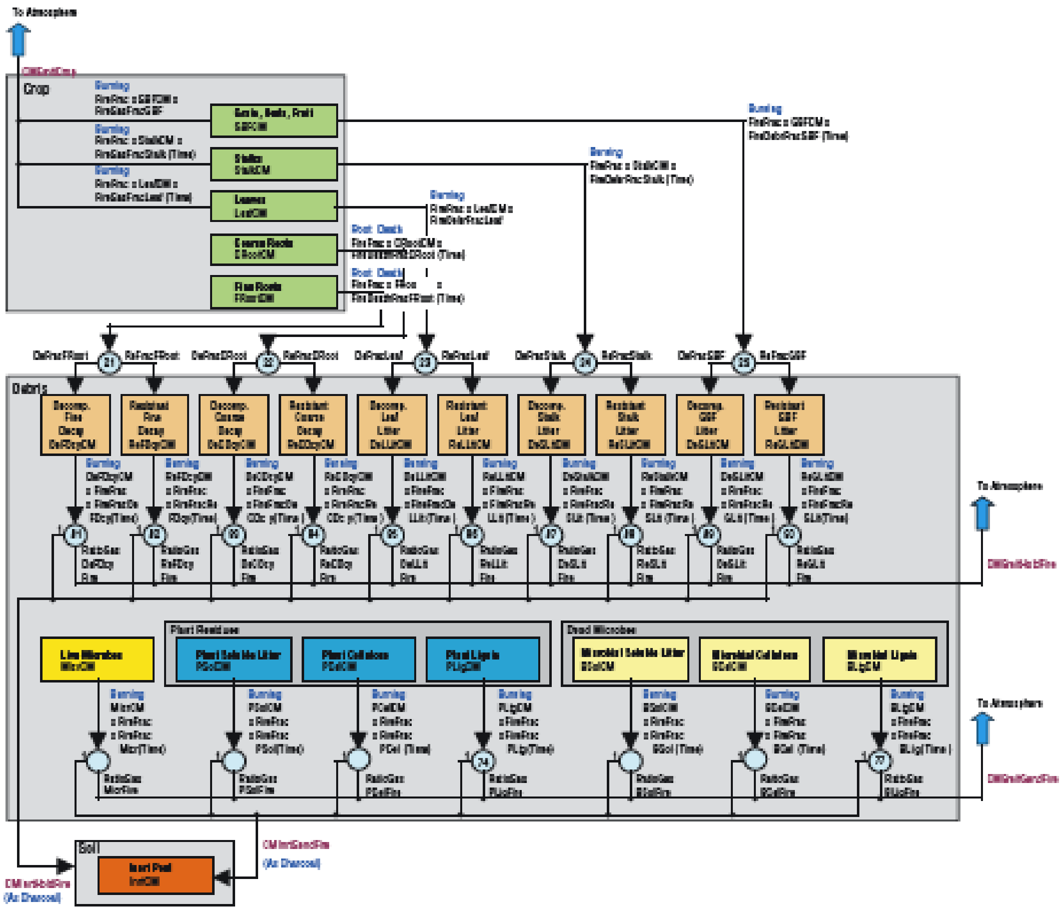
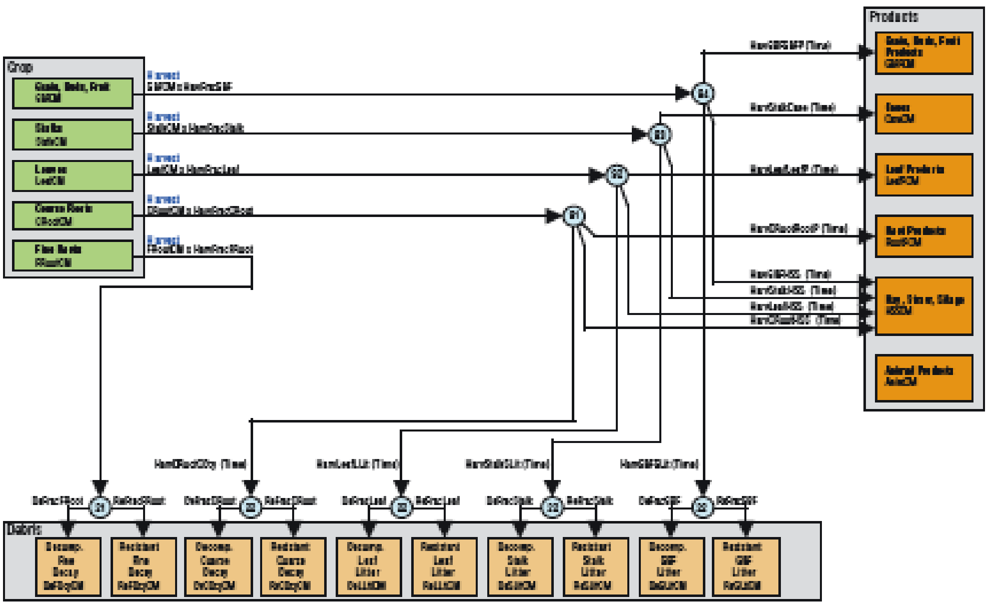
The *CAMAg* Model



The *CAMAg* Model (a) Fire



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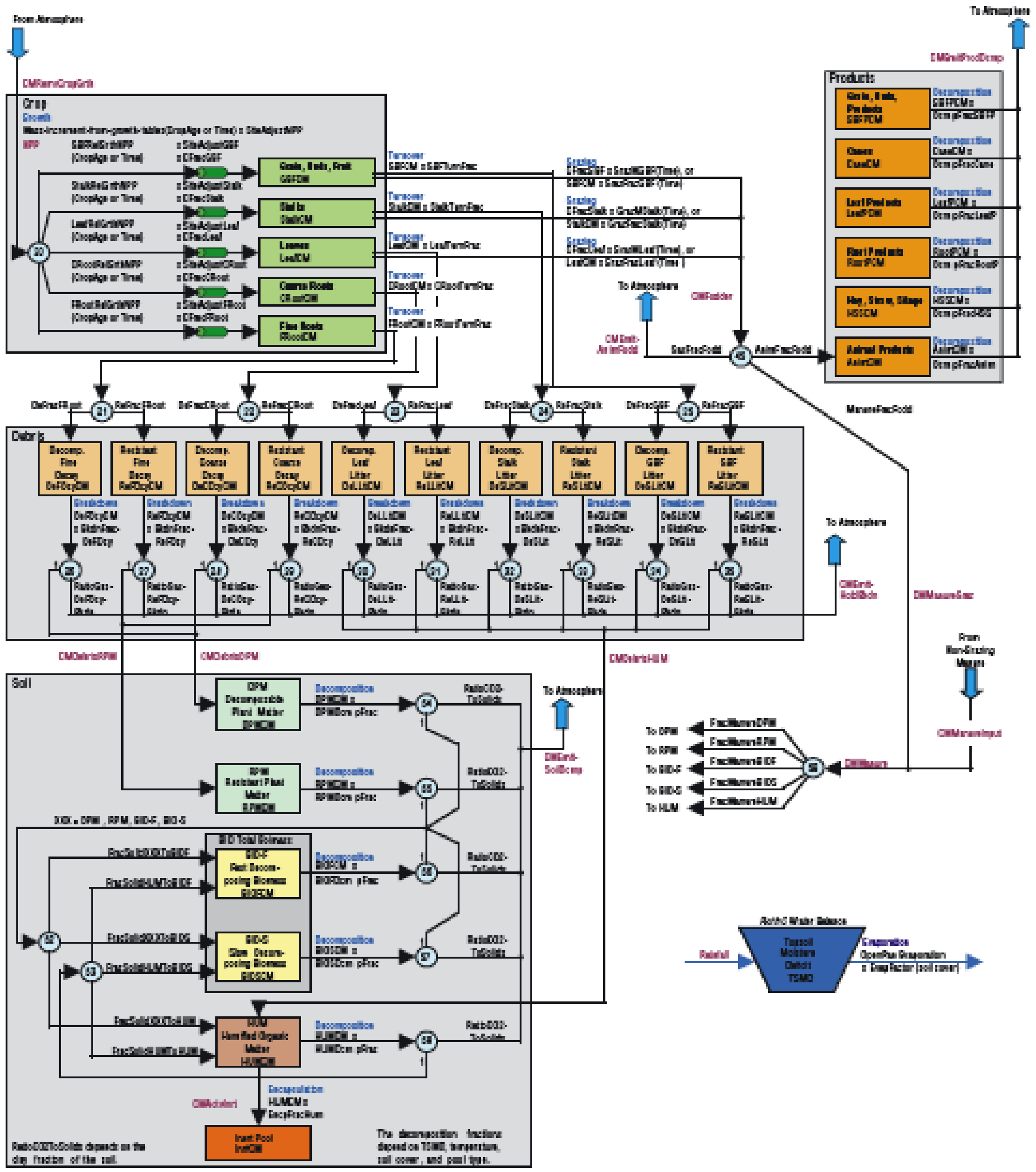
The *CAMAg* Model (b) Harvest



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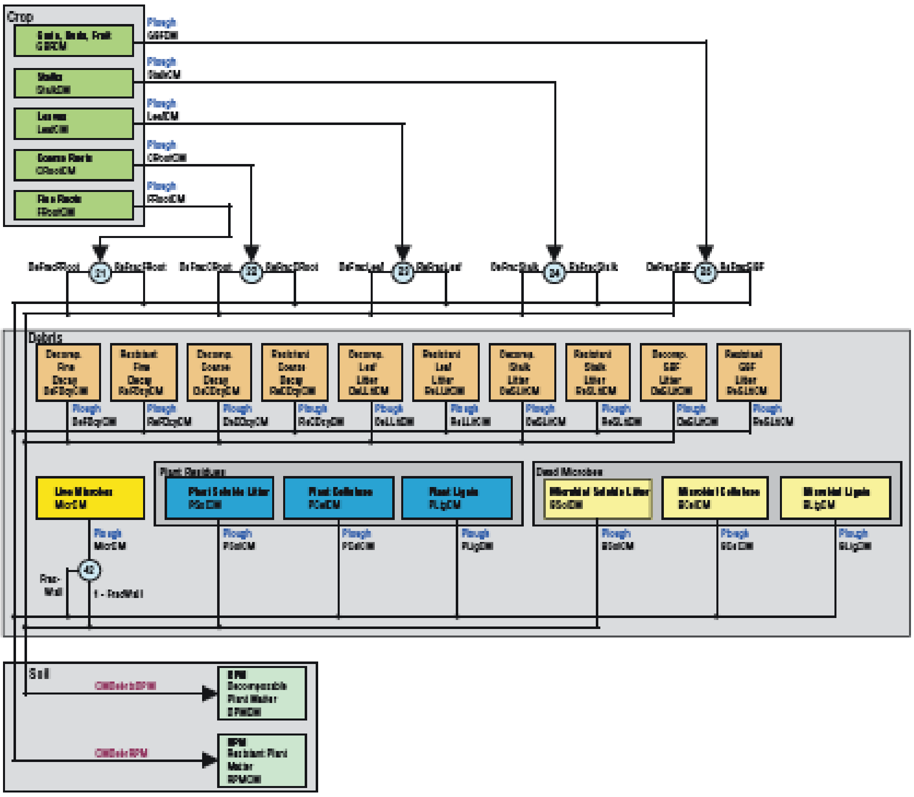
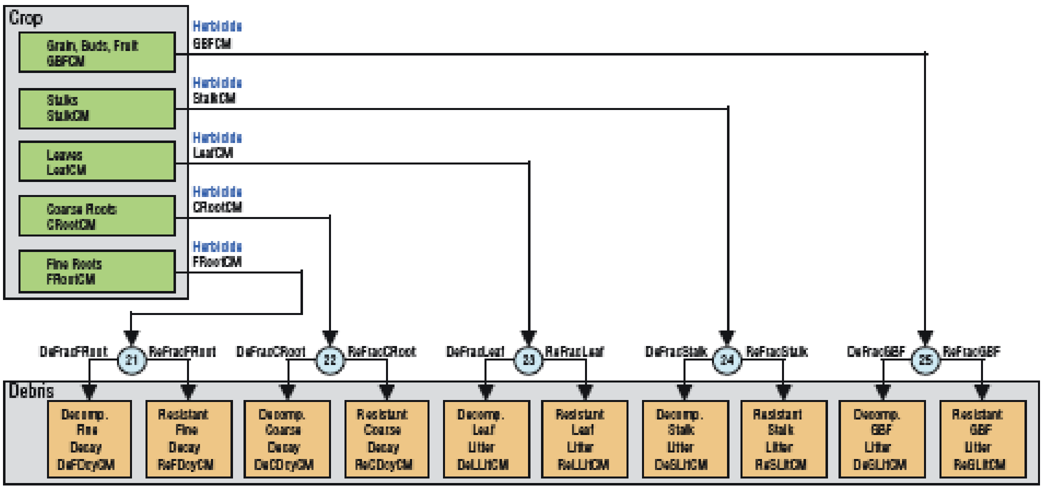
The *CAMAg* Model (d) Herbicide

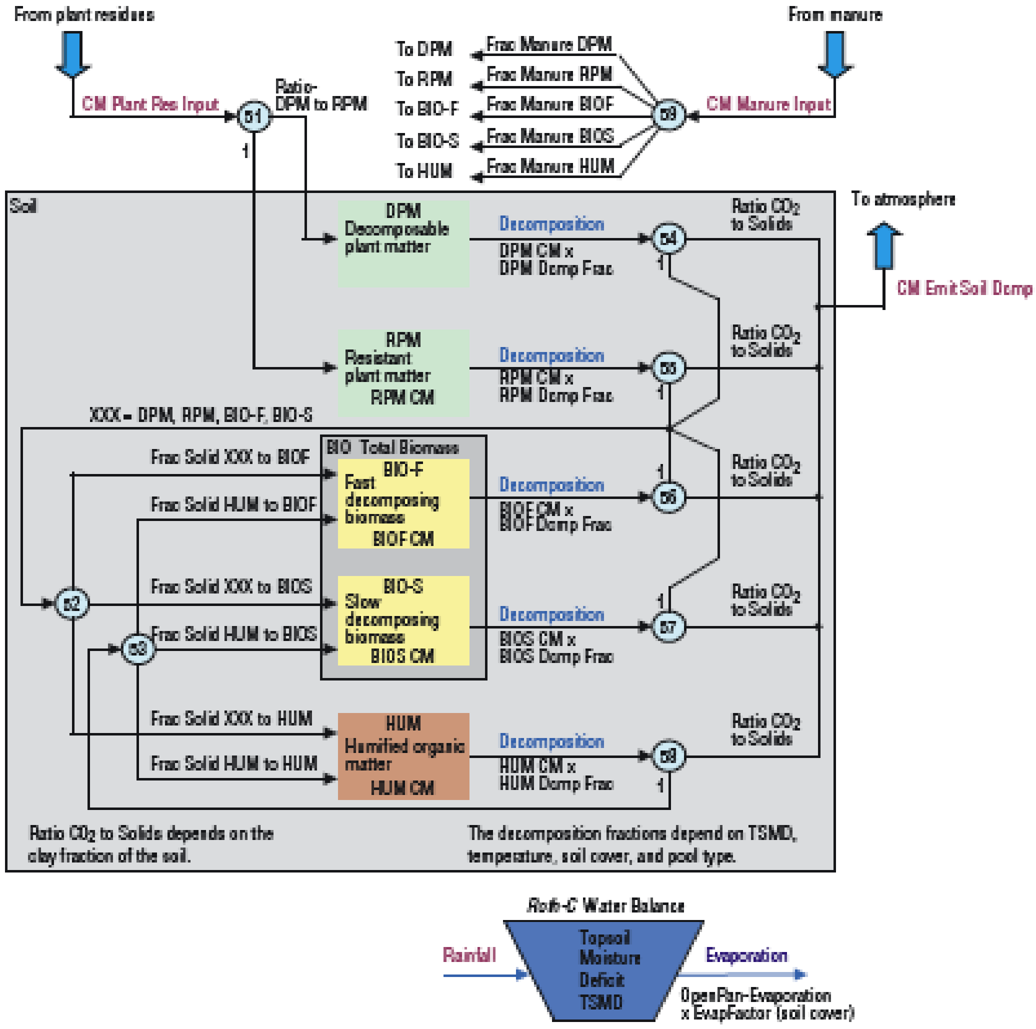


The *CAMAg* Model (c) Plough

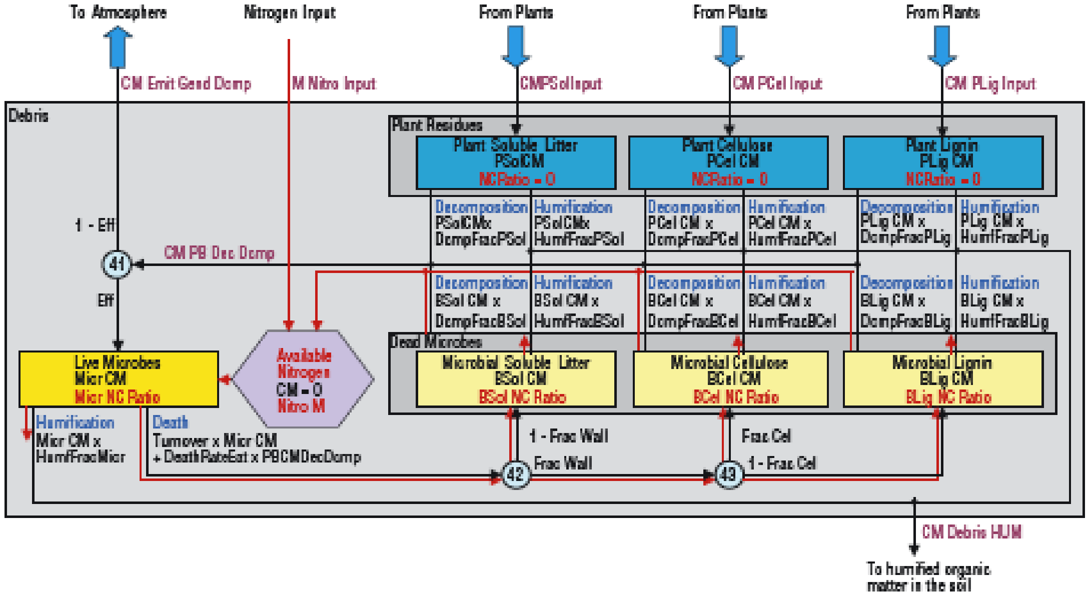


APPENDICES

The *GENDEC* Model



The *Roth–C* Model



APPENDICES

Appendix 7.B: Harvested Native Forests

Background

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

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

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

Area of Harvested Native Forests

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

Growth Modelling

The growth rates of harvested native forests (in t C ha^{-1} yr^{-1}) are modelled by broad forest types and age classes (Table 7.B1) based on work done under the National Forest Inventory by Lucas *et al.*, (1997). The initial carbon stock in 1990 is calculated based on the area of each forest type and age class. The age-based growth data are entered into the *FullCAM* model. *FullCAM* then allows the forests to age and for forest age to be reset following harvest, resulting in a dynamic representation of forest growth. 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 rates determined for Australia's National Forest Inventory do not provide age-based growth curves for rainforests, which tend to be climax communities (Jackson, 1968). Therefore, the growth rate of rainforests was assumed to be constant at 0.58 t C ha^{-1} yr^{-1} as per Lucas *et al.*, (1997). The growth rate of Medium sparse Eucalypt forests, Cypress pine forests and 'Other' forests is also assumed to be constant based upon the data in Lucas *et al.*, (1997) (see Table 7.B2).

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

Table 7.B1: Areas by forest type and age classes in 1990 (ha)

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

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

Table 7.B2: Aboveground growth rates by forest type and age class (t C ha^{-1} yr^{-1})

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

Forest debris

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

Table 7.B3: Turnover for tree components

Tree component	Turnover percent per year
Branches	6.5
Bark	9.5
Leaves	40
Coarse Roots	6.5
Fine Roots	73

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

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

Table 7.B4 Decomposition rates for debris pools used in the harvested native forests model.

	Breakdown % yr^{-1}	
Debris component	Decomposable	Resistant
Deadwood	5	5
Bark litter	50	50
Leaf litter	80	80
Coarse dead roots	40	10
Fine dead roots	100	100

Carbon fraction of biomass

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)(Table 7.B5).

Table 7.B5: Carbon Fraction of biomass for each tree component based on Gifford (2000a and 2000b)

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

Partitioning of biomass to tree components

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

Table 7.B6: Partitioning of biomass to each of the tree components

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

Carbon to CO_2 Conversion

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

Area Harvested and Type of Harvest

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

Table 7.B7: Estimated total area of native forest harvested

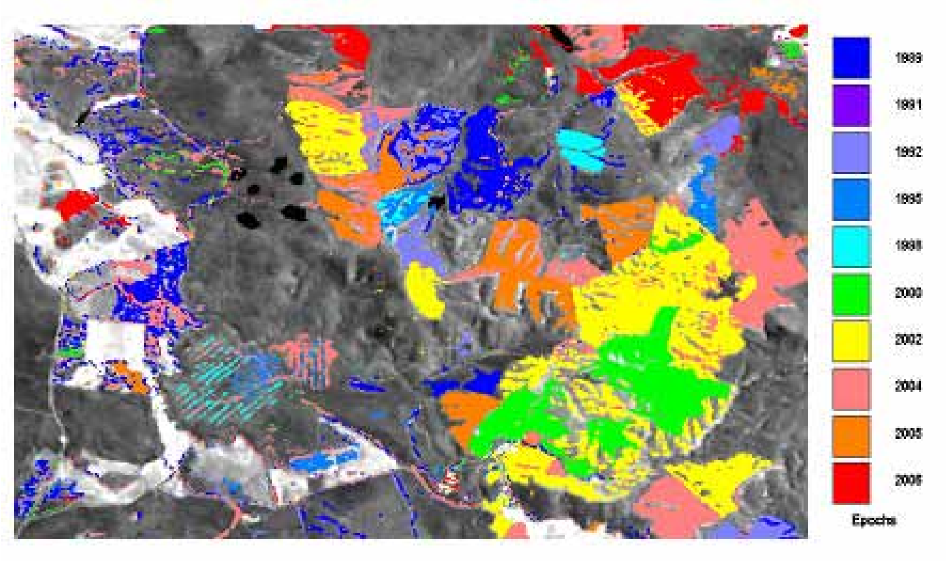
Year	Area Harvested (ha)
1990	144,339
1991	138,121
1992	143,953
1993	147,513
1994	155,258
1995	153,648
1996	148,438
1997	142,436
1998	143,609
1999	135,798
2000	141,317
2001	151,957
2002	117,594
2003	112,802
2004	113,358
2005	102,074
2006	100,247
2007	104,923
2008	113,607

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

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

Figure 7.B1: An example of harvested area detection using the NCAS time-series remote sensing data. Coloured areas represent detected harvest areas in a particular epoch



Silvicultural systems

Ten broad silvicultural systems are represented in the model (Table 7.B8). These systems are designed to represent the range of harvesting systems employed in Australia throughout the 1990s and up to 2008. Each silvicultural system is modelled based on the unique combinations of forest age and forest type (Table 7.B5 and Table 7.B8) to which it is associated. This produces 73 unique silviculture, forest age, and forest type combinations. These are simulated annually according to the area that was estimated to be occurring under each particular combination. Examples of the carbon mass in trees and debris for the models developed for each of the silvicultural systems are presented in Figure 7.B2.

Table 7.B8: Broad silvicultural systems used in the *harvested native forests* model

Forest type	Silviculture	Percent of trees removed	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

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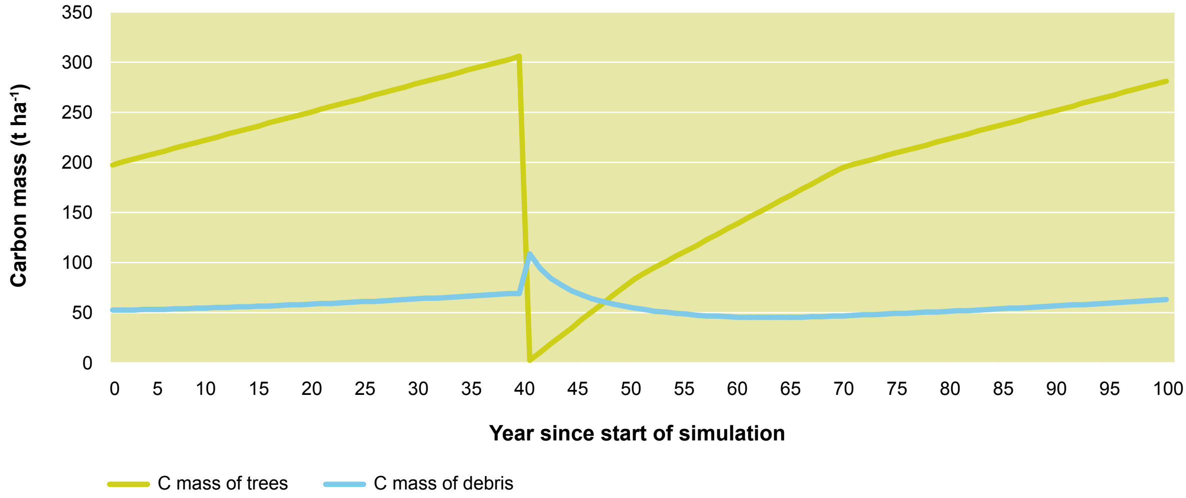
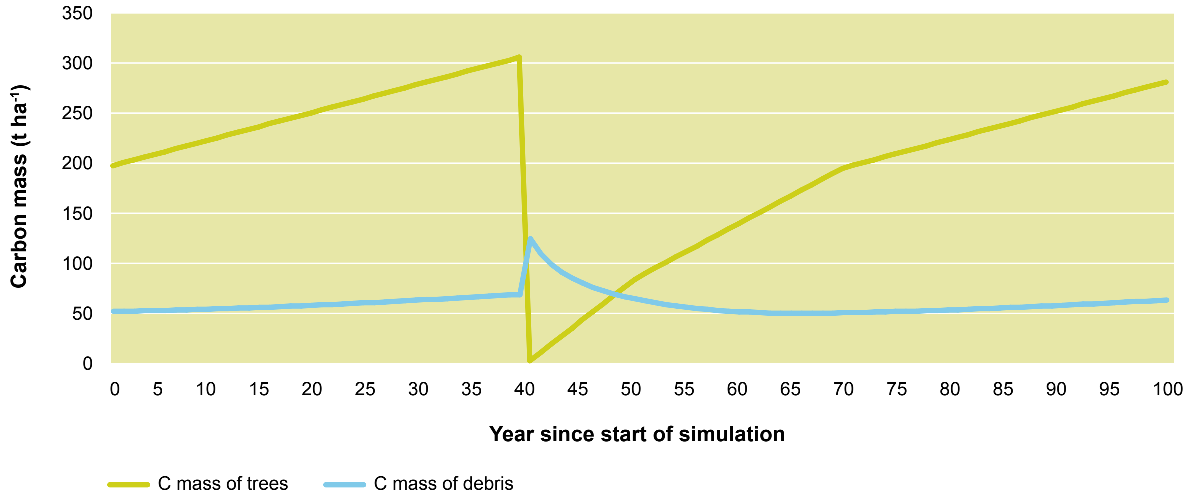
Figure 7.B2: Examples of the tree and debris carbon mass change for the ten silvicultural systems

(a) Tall dense eucalypt forest clearfell with pulpwood



(b) Tall dense eucalypt forest clearfell without pulpwood



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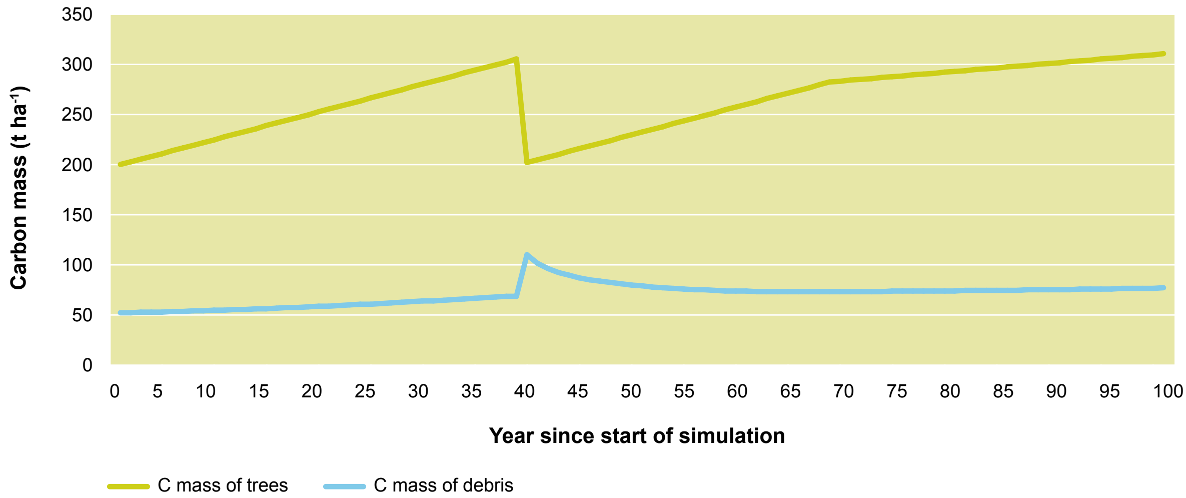
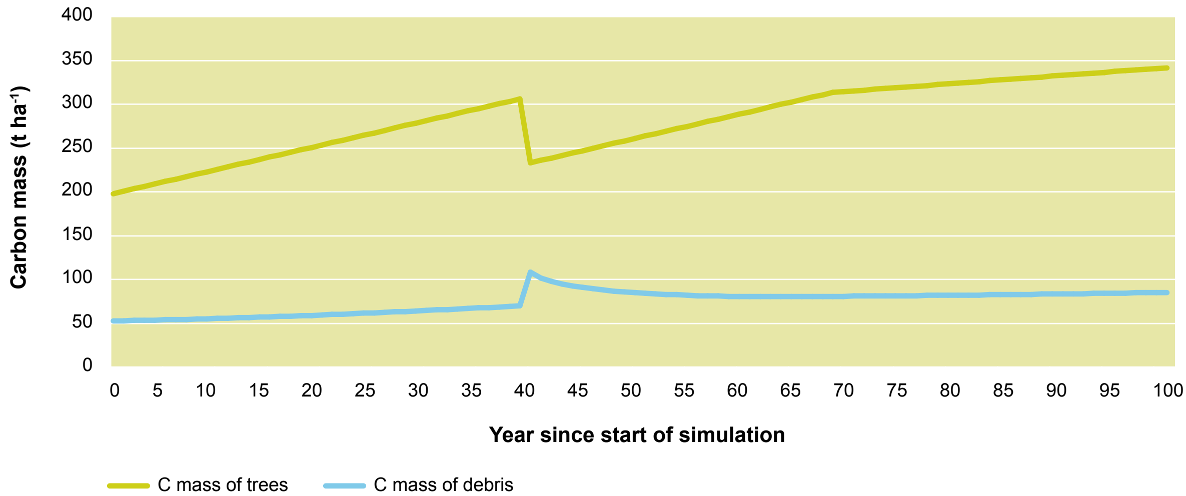
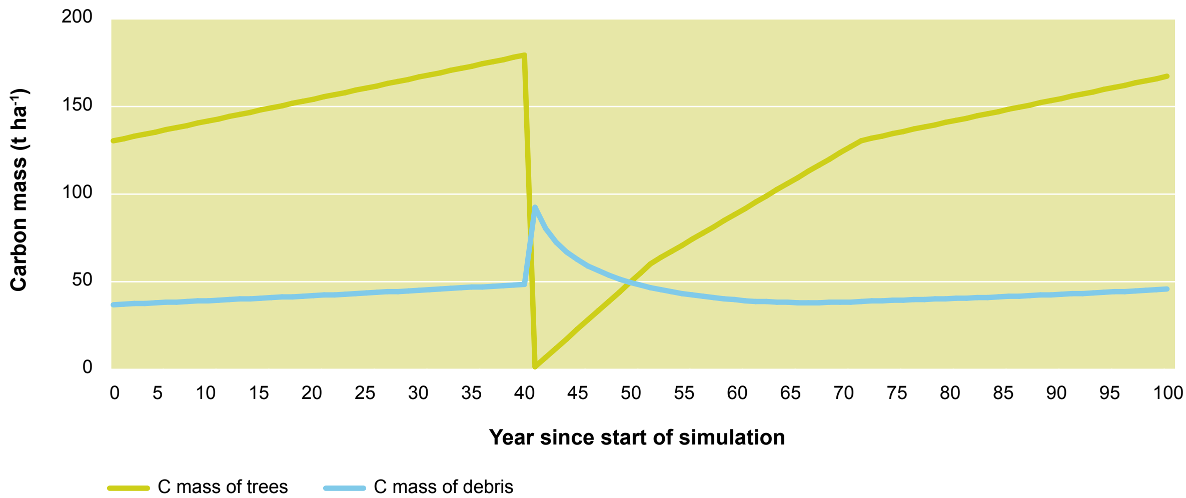
(c) Tall dense eucalypt forest partial harvest with pulpwood



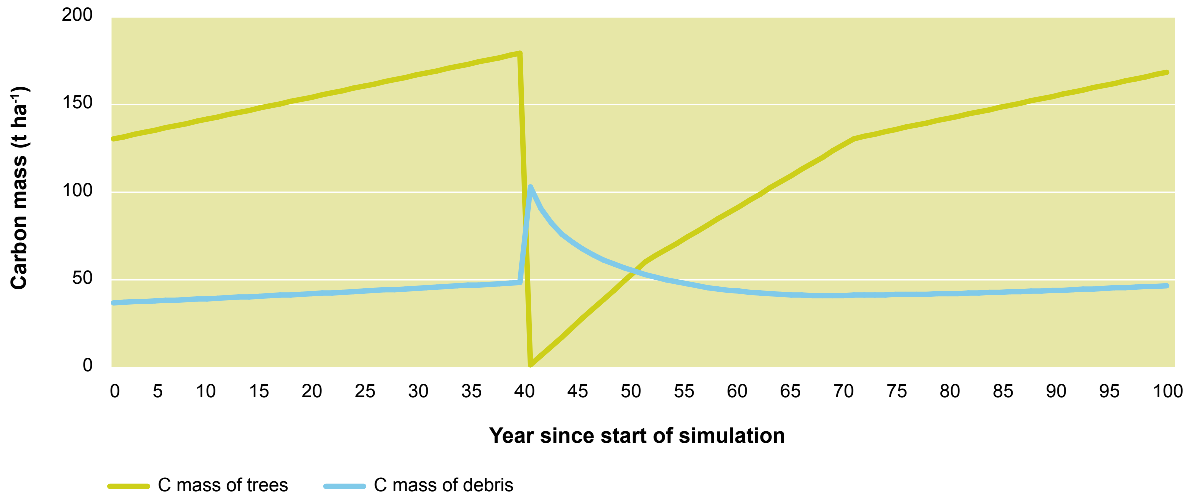
(d) Tall dense eucalypt forest partial harvest without pulpwood



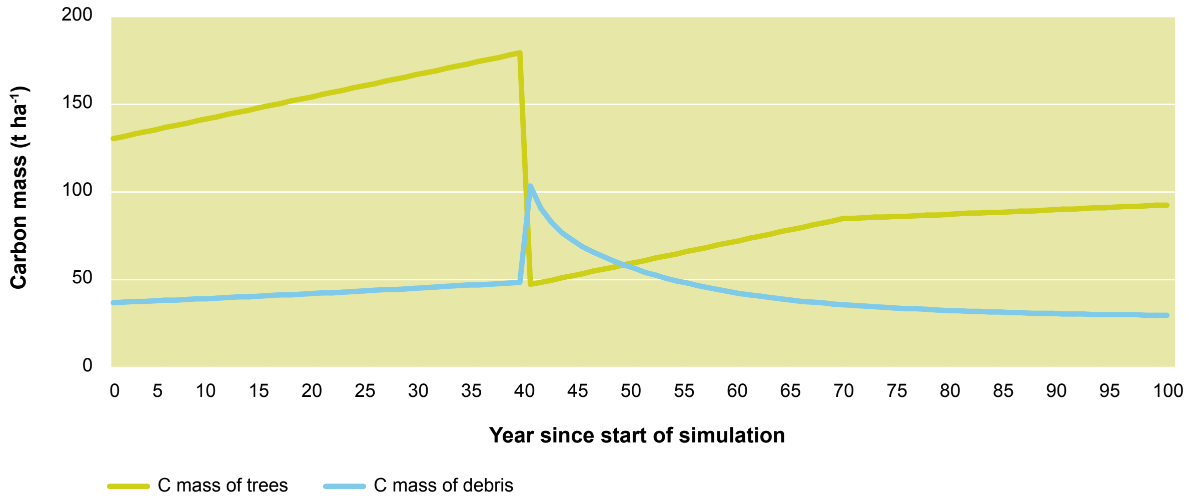
(e) Medium dense eucalypt forest clearfell with pulpwood



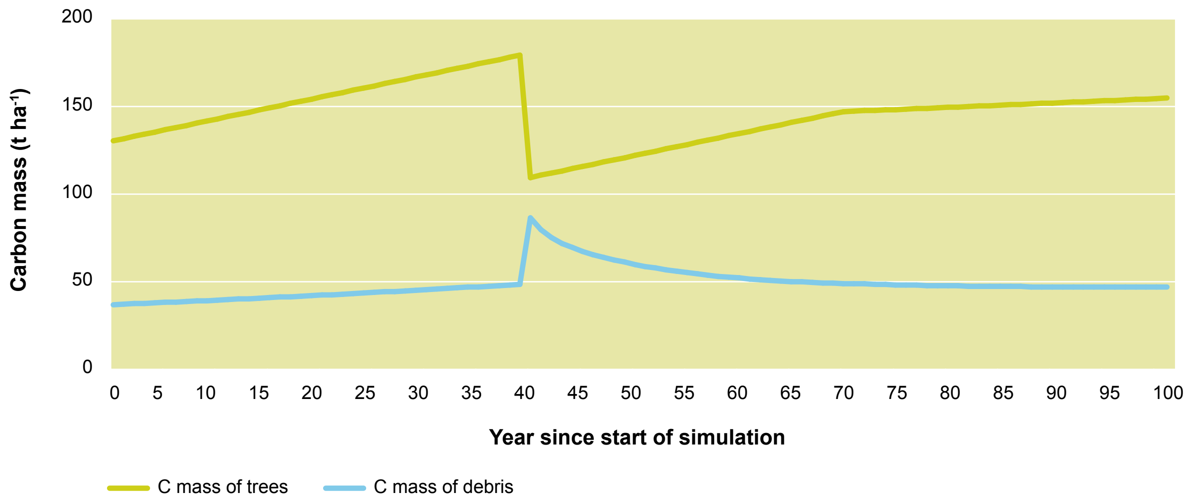
(f) Medium dense eucalypt forest clearfell without pulpwood



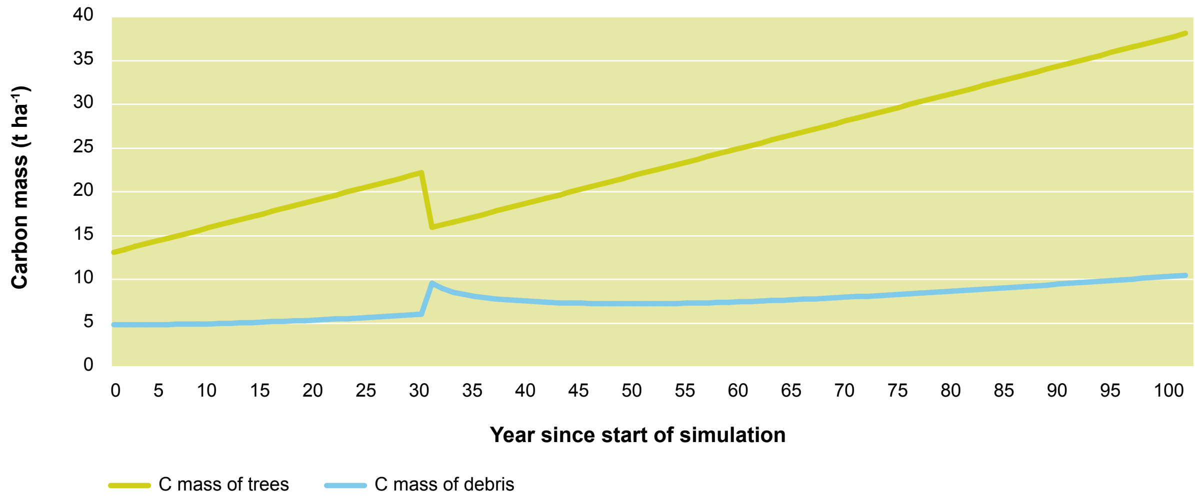
(g) Medium dense eucalypt forest partial harvest with pulpwood



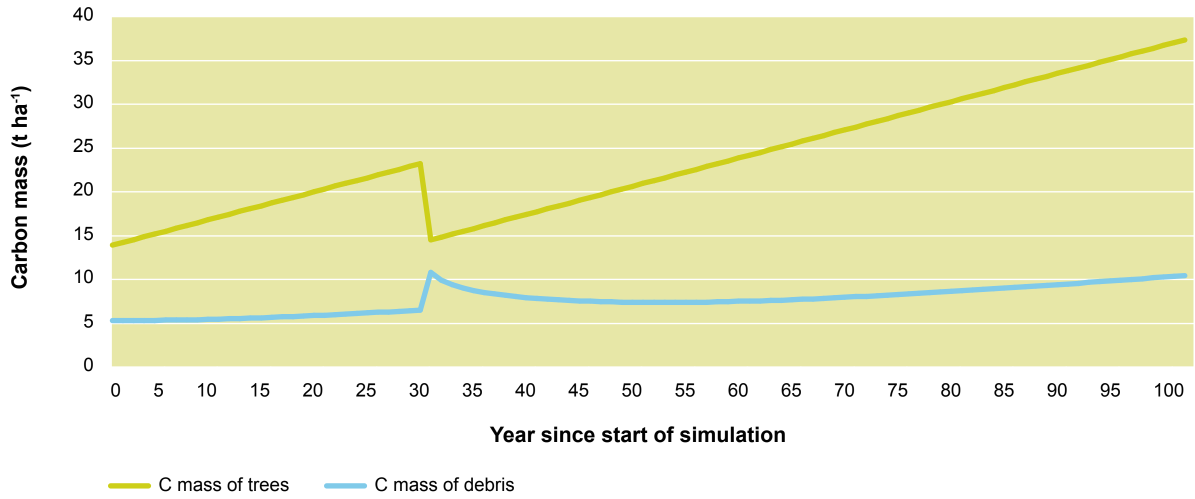
(h) Medium dense eucalypt forest partial harvest without pulpwood



(i) Medium sparse eucalypt forest partial harvest without pulpwood



(j) Cypress pine partial harvest without pulpwood



APPENDICES

Emissions due to harvest and harvest slash

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 oxidisation. Wood products removed from *harvested native forests* are included in the *harvested wood products* modelling (see Appendix 7.I).

The amount of slash produced by a harvest is also dependent upon the harvest type, forest age, and forest type. Information on the production of harvest slash 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 slash production (Ximenes and Gardner, 2005, Ximenes *et al.*, 2005). Following harvest the slash decomposes and is also impacted by management actions taken post-harvest such as regeneration fire treatments.

Calculation of emissions and removals in *harvested native forests*

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

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 lag emissions due to the ongoing decay and management of slash from harvesting in previous years.

Appendix 7.C: Pre–1990 Plantations

Introduction

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

The Australian Government's capacity for carbon accounting in pre-1990 *plantations* has been developed as a part of Australia's National Carbon Accounting System (NCAS). The development of the NCAS includes four principal program areas; remote sensing of land cover change; biomass estimation; soil carbon estimation; and information system development. The capability developed for these programs is being progressively implemented for national reporting. The results presented in this Appendix represent an implementation of the Tier 3 emissions estimation and Approach 2 land representation capability of the NCAS. The form of Tier 3 emissions estimation and Approach 3 land representation, as used for the post-1990 *plantations*, will be implemented in future inventory submissions.

Growth Modelling and Management

Plantation growth and the effect of management on emissions and removals for the pre-1990 *plantations* sub-category are modelled using the Full Carbon Accounting Model (*FullCAM*). For the *plantations* sub-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* thirty-four *FullCAM* models representing the National Plantation Inventory regions, key species and management practices of pre-1990 *plantations* were developed. In addition to the growth tables and thinning regimes of Turner and James (2002) the models require parameters for:

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

Table 7.C1 and Attachment 7.C1 show the relevant inputs, and the resultant carbon balances on a per hectare basis from each of the plantation types. These snapshots are incorporations of the information collated by the NCAS as individual model implementations for each plantation type.

Growth Tables and Thinning/Harvest Regimes

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

The empiricism of the estimates masks the influences of climate variability resulting in estimates which represent average performance over the time of measurement. It has been shown that a variable climate will cause variability in growth over time (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) for the NCAS. 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, there is potential that the adopted wood densities are over-estimates for the early stages of plantation growth. However, the overall effect is unlikely to be significant as lower densities occur when mass is least, that is, during early growth stages. Table 7.C1 and Attachment 7.C1 show the wood density values used for the major plantation species in the plantation types.

Stem to Whole Tree Mass Conversions

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

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

Carbon Contents

The carbon contents of various tree components below and aboveground were examined in Gifford (2000a) and Gifford (2000b) respectively, in studies for the NCAS. Carbon contents were tested for various species and growing conditions, with recommended estimates given within the range of values yielded in test results. There was little variability in the results and more importantly no cause to suspect bias in any set of environmental conditions or plant groups. These results could be considered as robust and reliable estimates, providing little source of uncertainty in the carbon models. The carbon contents are listed in Table 7.C3.

Turnover and Decomposition Rates

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

The turnover rate of leaves and fine roots affects both the amount of fine litter on the forest floor and subsequently most of the contribution to soil carbon. As this implementation of the model does not include soil carbon (which is estimated using a Tier 2 method), the rates of turnover of both leaves and fine roots are relatively unimportant. The key attributes of the assigned rates are that they are realistic and do not operate at rates 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.C1: 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) for the NCAS. Table 7.C2 shows the decomposition rates applied.

Table 7.C2: Debris decomposition rates

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

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

Table 7.C3: Plantation types, wood densities, carbon contents and management regimes

Region(s)	Species	Density	CC% Leaf	CC% Branch	CC% Wood	CC% Bark	CC% Fine Roots	CC% Coarse Roots	Regime Description
Green Triangle	*Pinus radiata*	440	52	51	52	53	46	49	Average Sites – 54% thinning @ 13 years, 25% @ 18, 28% @ 23, CF @ 30
Green Triangle	*Pinus* (other than radiata)	440	52	51	52	53	46	49	Average Sites – 54% thinning @ 13 years, 25% @ 18, 28% @ 23, CF @ 30
NSW Northern Tableland	Southern Pine (*P. elliotti*, *P. taeda*, *Araucaria cunninghamii*)	440	52	51	52	53	46	49	Average Sites – 27% thinning @ 14 years, 47% @ 20, CF @ 30
NSW	Eucalyptus plantations	550	52	47	52	49	46	49	All Sites – 67% @ 20 years, 47% @ 35, CF @ 45
NSW	Eucalyptus plantations	550	52	47	52	49	46	49	All Sites – CF @ 20
Qld	Eucalyptus plantations	550	52	47	52	49	46	49	All Sites – 67% @ 20 years, 47% @ 35, CF @ 45
Qld	Eucalyptus plantations	550	52	47	52	49	46	49	All Sites – CF @ 20
Qld	Southern Pine (*P. elliotti*, *P. taeda*, *Araucaria cunninghamii*)	440	52	51	52	53	46	49	All Sites – 35% @ 18 years, CF @ 35
South Australia	Eucalyptus plantations	550	52	47	52	49	46	49	All Sites – CF @ 20
South Australia	Eucalyptus plantations	550	52	47	52	49	46	49	All Sites – CF @ 15
South Australia	Eucalyptus plantations	550	52	47	52	49	46	49	All Sites – CF @ 25
South Australia	*Pinus* (other than radiata)	440	52	51	52	53	46	49	Average Sites – 54% thinning @ 13 years, 25% @ 18, 28% @ 23, CF @ 30
Tasmania	*Eucalyptus nitens*	550	52	47	52	49	46	49	All Sites – CF @ 30
Tasmania	*Eucalyptus nitens*	550	52	47	52	49	46	49	All Sites – CF @ 15
Tasmania	*Eucalyptus nitens*	550	52	47	52	49	46	49	All Sites – CF @ 25
Tasmania	*Pinus radiata*	440	52	51	52	53	46	49	Average Sites – CF @ 35
Tasmania	*Pinus* (other than radiata)	440	52	51	52	53	46	49	All Sites – CF @ 35
Victoria (Central)	*Pinus radiata*	440	52	51	52	53	46	49	Average Sites –34% thinning @ 15 years, 18% @ 22, 24% @ 28, CF @ 35
Victoria (Central)	*Pinus radiata*	440	52	51	52	53	46	49	Average Sites – CF @ 30
Victoria (Central Gippsland)	Eucalyptus plantations	550	52	47	52	49	46	49	All Sites – CF @ 25
Victoria (Central Gippsland)	Eucalyptus plantations	550	52	47	52	49	46	49	All Sites – CF @ 20
Victoria (Central Gippsland)	Eucalyptus plantations	550	52	47	52	49	46	49	All Sites – CF @ 30
Victoria (Central Gippsland)	Eucalyptus plantations	550	52	47	52	49	46	49	All Sites – CF @ 35
Victoria (Central Gippsland)	*Pinus radiata*	440	52	51	52	53	46	49	Average Sites – 33% thinning @ 15 years, 37% @ 20, CF @ 30
Murray Valley	*Pinus radiata*	440	52	51	52	53	46	49	Average Sites – 47% thinning @ 14 years, 35% @ 22, 29% @ 29, CF @ 30
Murray Valley	*Pinus radiata*	440	52	51	52	53	46	49	Average Sites – 47% thinning @ 14 years, 35% @ 22, CF @ 30
Murray Valley	*Pinus radiata*	440	52	51	52	53	46	49	Very Good Sites – 44% thinning @ 14 years, 31% @ 18, 27% @ 23, CF @ 30
Victoria and NSW	*Pinus radiata*	440	52	51	52	53	46	49	Average Sites – CF @ 30 years
Victoria and NSW	*Pinus radiata*	440	52	51	52	53	46	49	Average Sites – 65% thinning @ 16 years, CF @ 30
Victoria and NSW	*Pinus radiata*	440	52	51	52	53	46	49	Average Sites – 65% thinning @ 16 years, 57% @ 24, CF @ 30
Victoria and NSW	*Pinus radiata*	440	52	51	52	53	46	49	Average Sites – 65% thinning @ 16 years, 57% @ 24, 27% @ 30, CF @ 35
Victoria and NSW	*Pinus radiata*	440	52	51	52	53	46	49	Poor Sites – 26% thinning @ 18 years, 32% @ 24, CF @ 30
Victoria and NSW	*Pinus radiata*	440	52	51	52	53	46	49	Poor Sites – CF @ 30 years
Western Australia	*Eucalyptus globulus*	550	52	47	52	49	46	49	Clear fall @ 10
Western Australia	*Pinus pinaster*	470	52	51	52	53	46	49	Average Sites – 65% thinning @ 18 years, 37% @ 25, CF @ 40
Western Australia	*Pinus radiata*	440	52	51	52	53	46	49	Average Sites – 51% thinning @ 12 years, 39% @ 18, 32% @ 24, CF @ 35

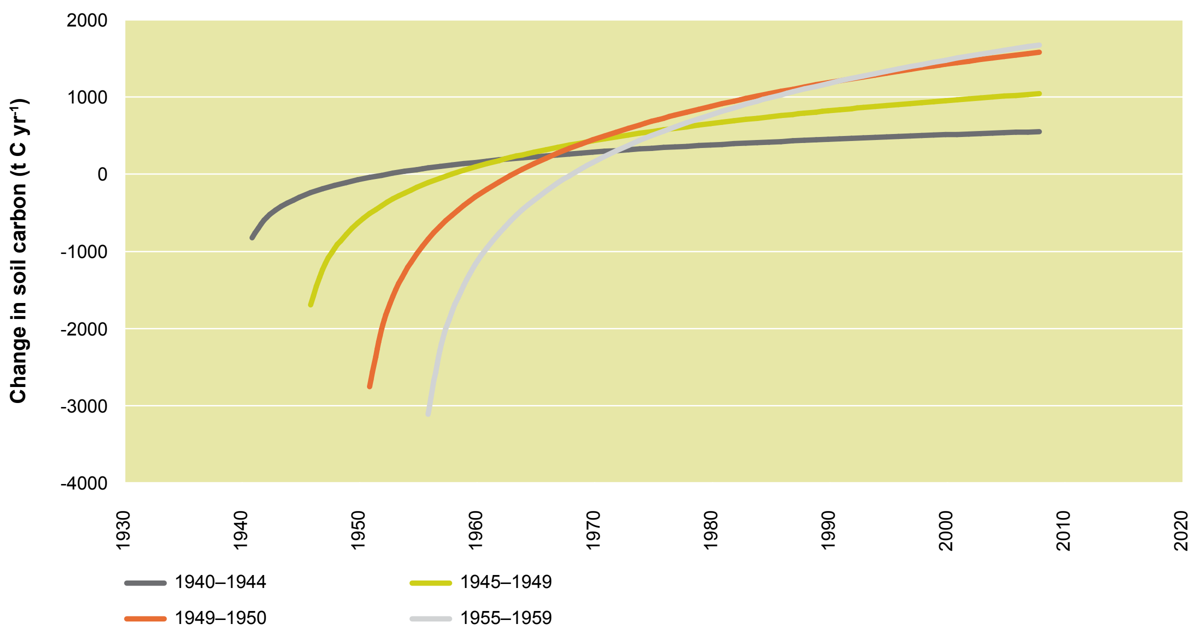
Soil Carbon Modelling

While it has been shown that in the medium to long term, soil carbon does not change for most plantations (Polglase *et al.*, 2000), it has also been identified that there are frequently short term losses (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*. Initial work (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 0 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 percent change per year (% yr^{-1}) to tonnes of carbon change per year (t C yr^{-1}). The age of the plantation was calculated as the time since plantation establishment. Figures 7.C1 and 7.C2 show the estimated change in soil carbon (t C yr^{-1}) following plantation establishment between 1940 and 1959 and 1960 and 1989, respectively.

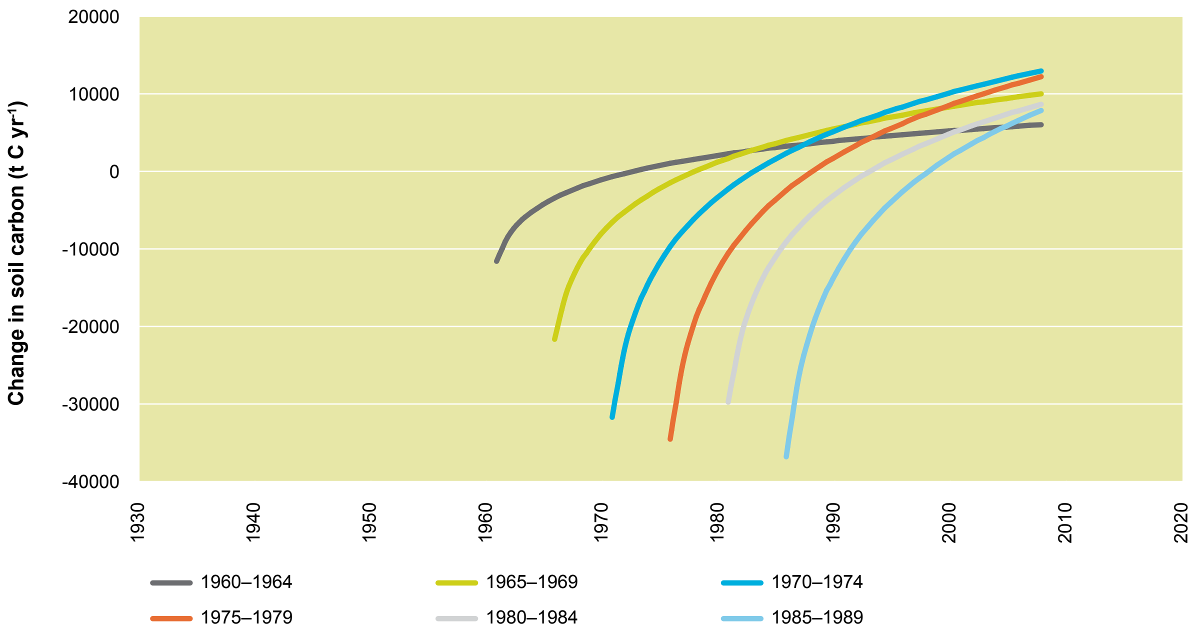
The change in soil carbon was estimated for the total area of plantation established per year; therefore, the large estimated change in soil carbon stock from one year to the next is due to the increase in the area of the plantation estate; by 1985, the total pre-1990 *plantation* estate had expanded to over 40 times the area initially established in 1940. The change in soil carbon following plantation establishment does not explicitly incorporate the effects of factors such as site preparation, previous land use, climate, soil texture, site management and plantation harvesting during the time since planting. However, the data used to develop the model covers a wide range of conditions and management practices and can therefore be considered representative at the national scale.

Figure 7.C1 Change in soil carbon (t C yr^{-1}) following plantation establishment from 1940 to 1959



APPENDICES

Figure 7.C2 Change in soil carbon (t C yr⁻¹) following plantation establishment from 1960 to 1989



Activity Data

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

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

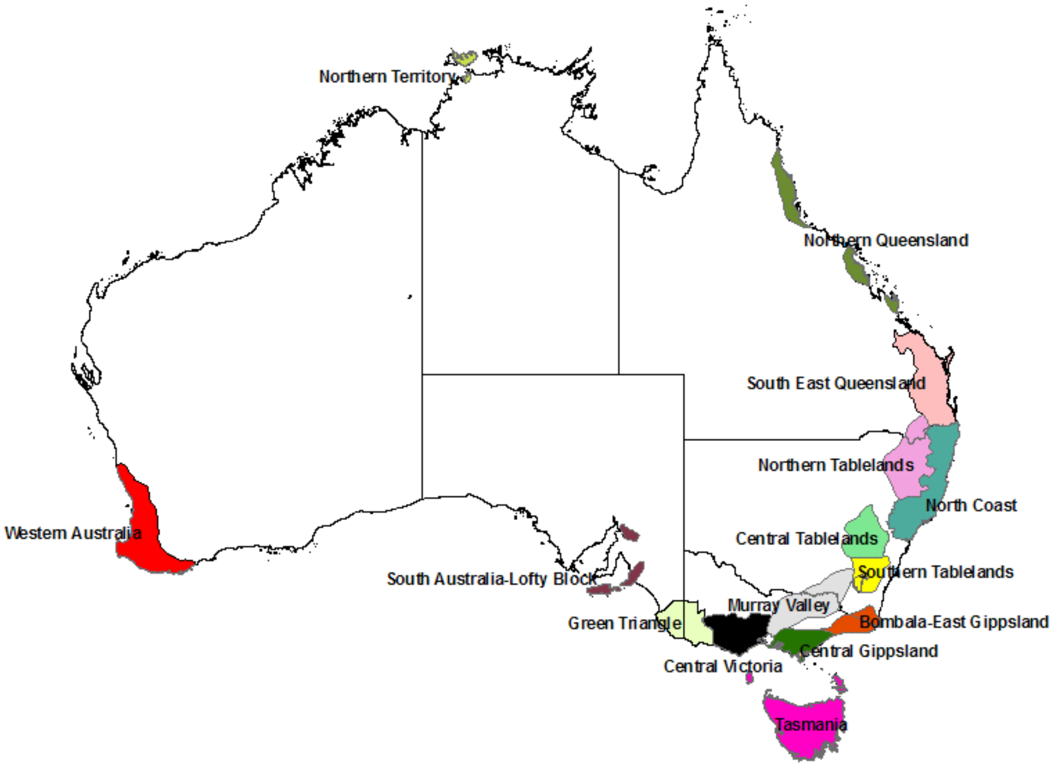
Allocations of the Short Rotation Hardwood (SRH), Long Rotation Hardwood (LRH) and Softwood (SW) classes are made to the region and species specific Plantation Types as described by Turner and James (2002).

Table 7.C4. 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

Further improvements of the analysis is planned 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 from 1972 to 1989 using Landsat MSS data.

Figure 7.C3: The National Plantation Inventory regions

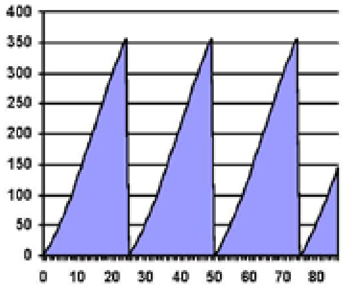
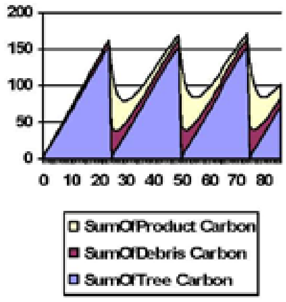


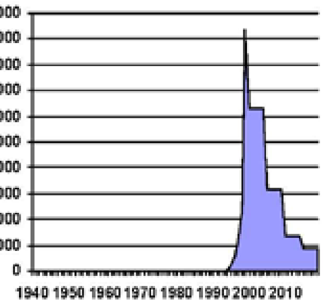
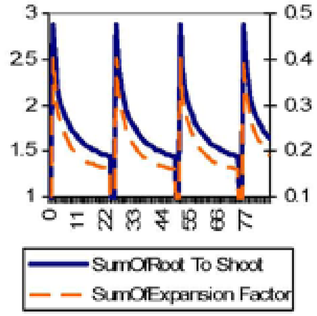
Calculations of total emissions and removals

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

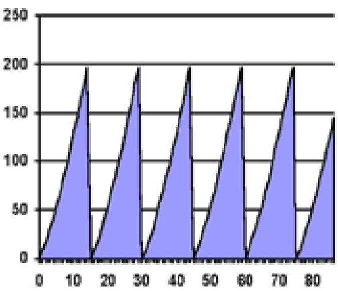
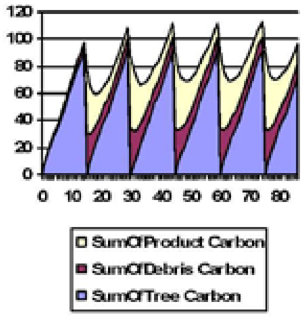
APPENDICES

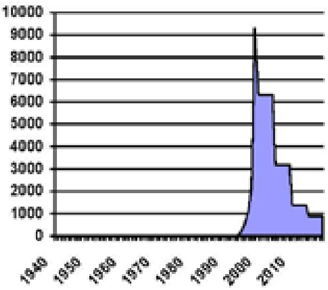
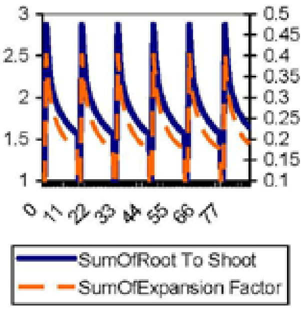
Attachment 7.C1: Plantation Type Model Parameters and Outcomes

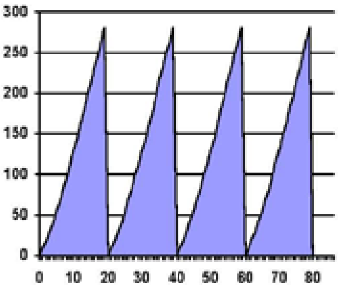



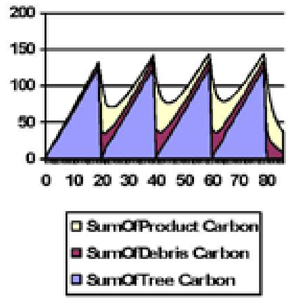
LookUp	Region(s)	Species	Density	CC% Leaf	CC% Twig	CC% Branch	CC% Sapwood	CC% Wood	CC% Bark	Regime Description
SA4 Euc 3	South Australia	Eucalyptus plantations	550	52	52	47	52	52	49	All Sites - CF @ 25

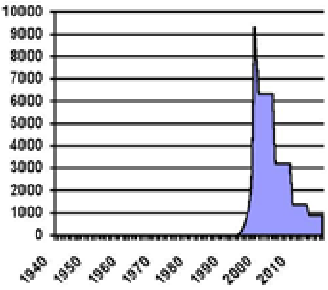



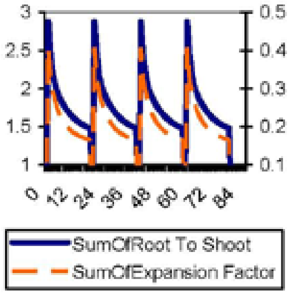



LookUp	Region(s)	Species	Density	CC% Leaf	CC% Twig	CC% Branch	CC% Sapwood	CC% Wood	CC% Bark	Regime Description
SA4 Euc 2	South Australia	Eucalyptus plantations	550	52	52	47	52	52	49	All Sites - CF @ 15

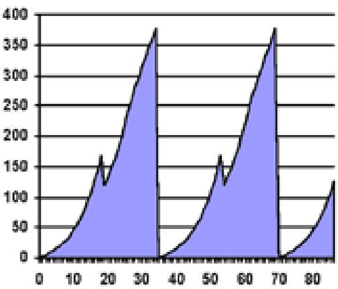


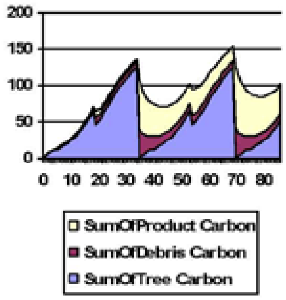


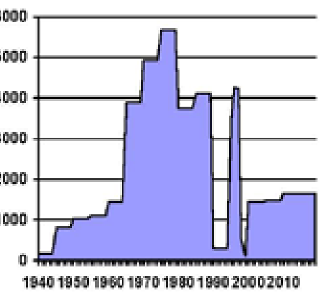


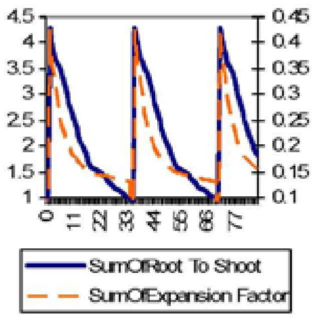


LookUp	Region(s)	Species	Density	CC% Leaf	CC% Twig	CC% Branch	CC% Sapwood	CC% Wood	CC% Bark	Regime Description
SA4 Euc 1	South Australia	Eucalyptus plantations	550	52	52	47	52	52	49	All Sites - CF @ 20

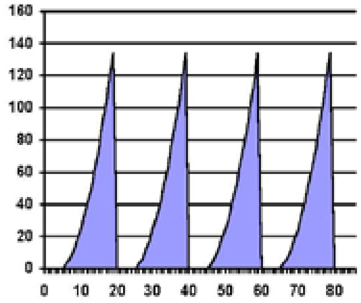


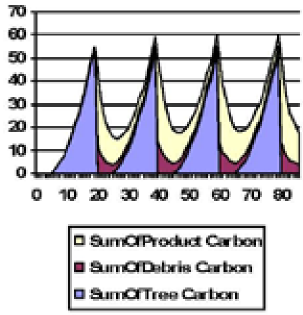


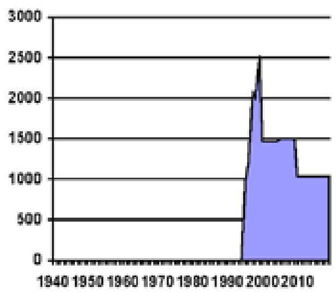


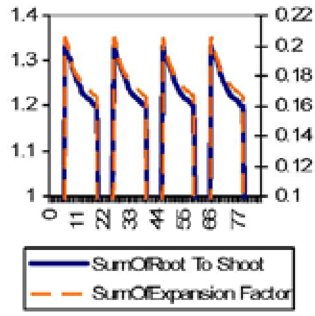


LookUp	Region(s)	Species	Density	CC% Leaf	CC% Twig	CC% Branch	CC% Sapwood	CC% Wood	CC% Bark	Regime Description
Qld1314 SthPine	Queensland	Southern Pine (*P. elliotti, P. taeda, Araucaria cunninghamii*)	440	52	52	51	51	52	53	All Sites - 35% @ 18 years, CF @ 35

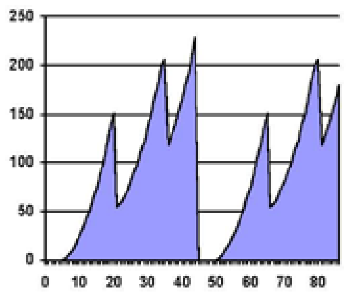


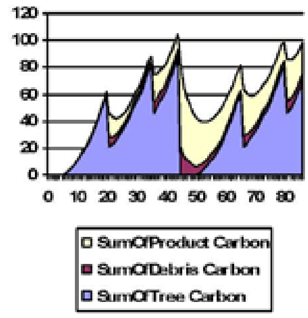


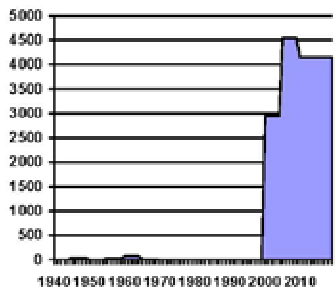


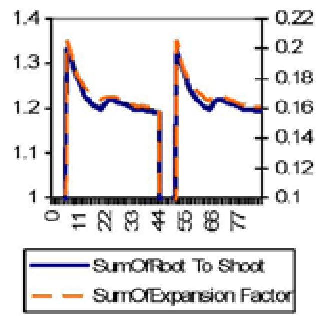


LookUp	Region(s)	Species	Density	CC% Leaf	CC% Twig	CC% Branch	CC% Sapwood	CC% Wood	CC% Bark	Regime Description
Qld1314 Euc 2	Queensland	Eucalyptus plantations	550	52	52	47	52	52	49	All Sites - CF @ 20









LookUp	Region(s)	Species	Density	CC% Leaf	CC% Twig	CC% Branch	CC% Sapwood	CC% Wood	CC% Bark	Regime Description
Qld1314 Euc 1	Queensland	Eucalyptus plantations	550	52	52	47	52	52	49	All Sites - 67% @ 20 years, 47% @ 35, CF @ 45

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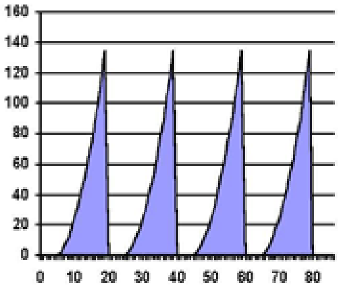
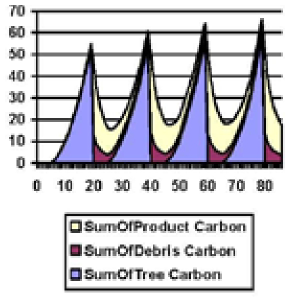
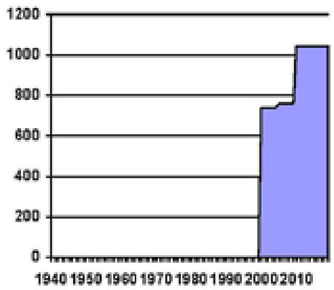
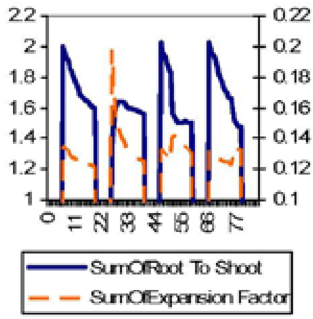
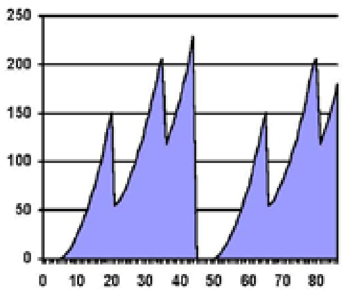


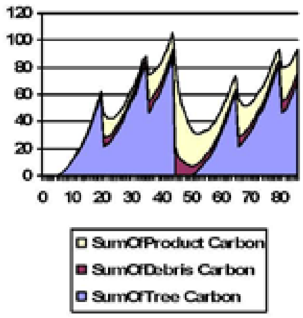


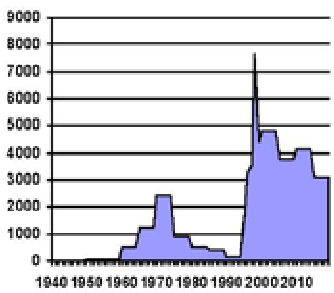


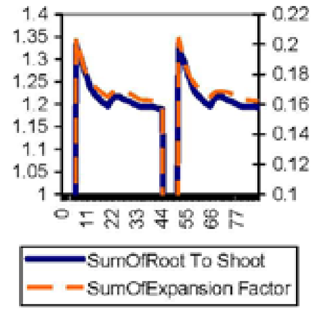


LookUp	Region(s)	Species	Density	CC% Leaf	CC% Twig	CC% Branch	CC% Sapwood	CC% Wood	CC% Bark	Regime Description
NSW9101112 Euc 2	NSW	Eucalyptus plantations	550	52	52	47	52	52	49	All Sites - CF @ 20

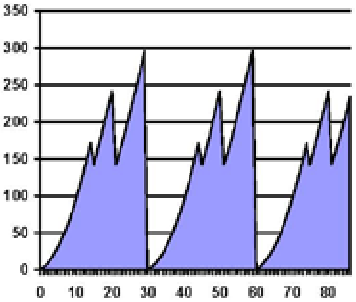


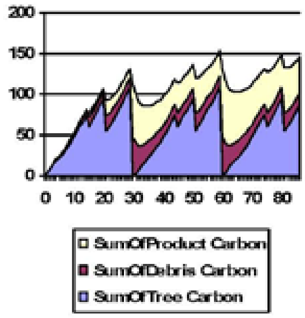


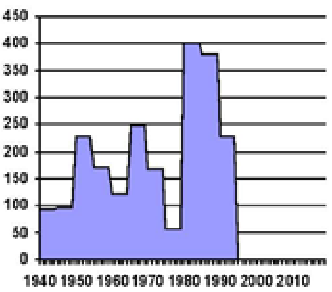


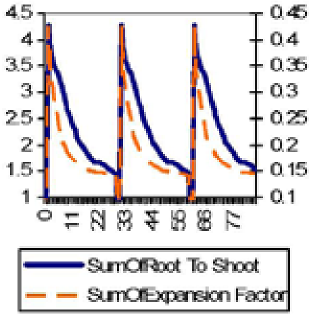


LookUp	Region(s)	Species	Density	CC% Leaf	CC% Twig	CC% Branch	CC% Sapwood	CC% Wood	CC% Bark	Regime Description
NSW9101112 Euc 1	NSW	Eucalyptus plantations	550	52	52	47	52	52	49	All Sites - 67% @ 20 years, 47% @ 35, CF @ 45

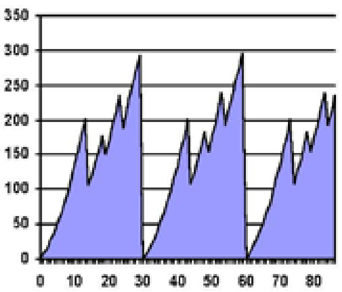


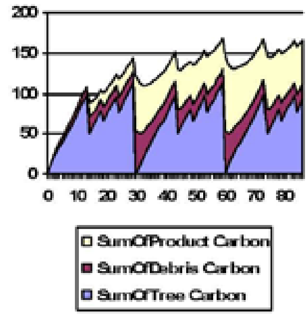


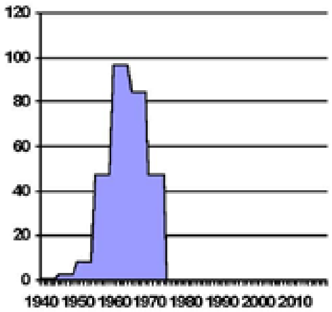


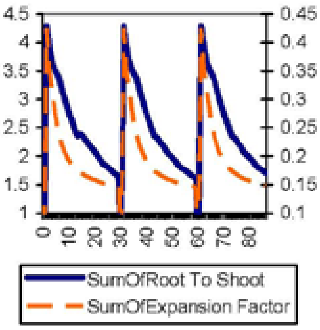


LookUp	Region(s)	Species	Density	CC% Leaf	CC% Twig	CC% Branch	CC% Sapwood	CC% Wood	CC% Bark	Regime Description
NSW11 SthPine 1	NSW Northern Tableland	Southern Pine (*P. elliotti, P. taeda, Araucaria cunninghamii*)	440	52	52	51	51	52	53	Average Sites - 27% thinning @ 14 years, 47% @ 20, CF @ 30









LookUp	Region(s)	Species	Density	CC% Leaf	CC% Twig	CC% Branch	CC% Sapwood	CC% Wood	CC% Bark	Regime Description
GrnTri3 Pinus 1	Green Triangle	Pinus (other than radiata)	440	52	52	51	51	52	53	Average Sites - 54% thinning @ 13 years, 25% @ 18, 28% @ 23, CF @ 30

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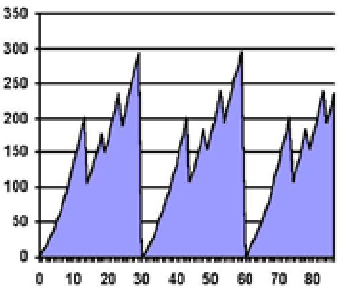
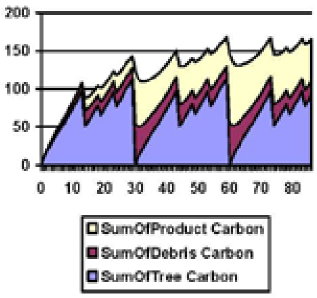
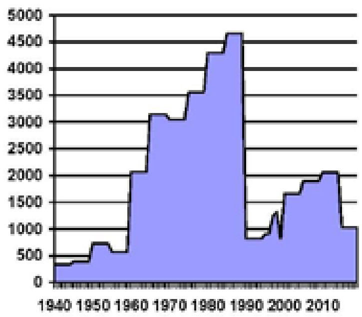
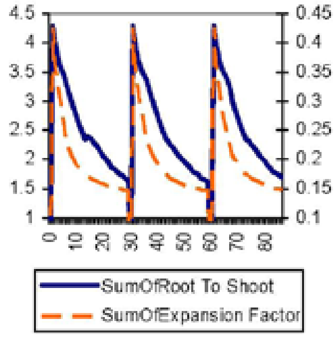
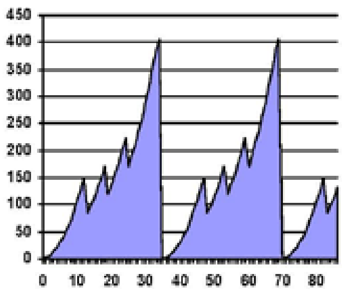


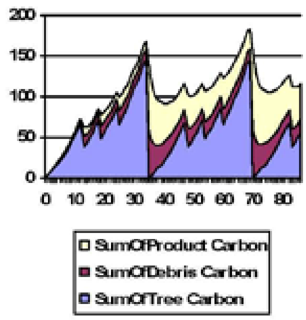


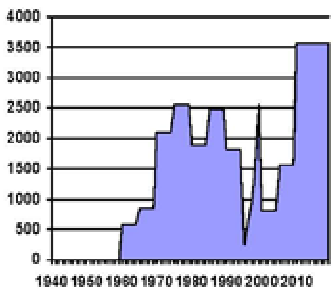


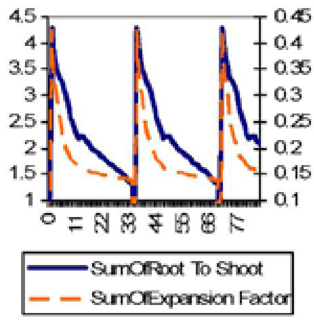


LookUp	Region(s)	Species	Density	CC% Leaf	CC% Twig	CC% Branch	CC% Sapwood	CC% Wood	CC% Bark	Regime Description
GrnTri3 P.rad 1	Green Triangle	*Pinus radiata*	440	52	52	51	51	52	53	Average Sites - 54% thinning @ 13 years. 25% @ 18. 28% @ 23. CF @ 30

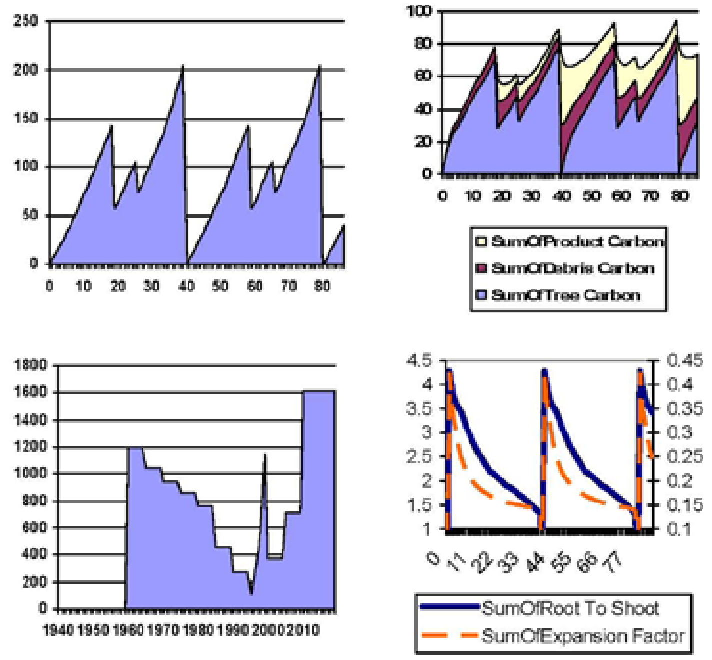




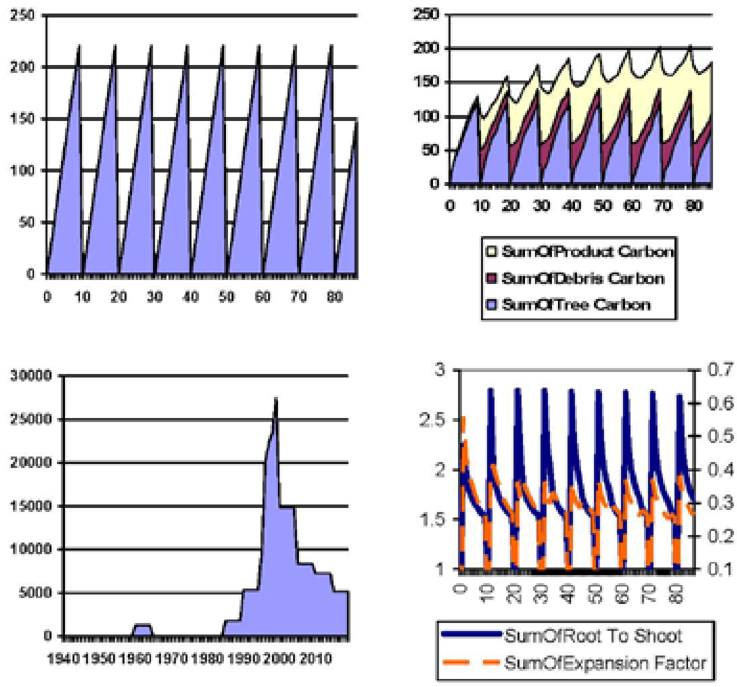




LookUp	Region(s)	Species	Density	CC% Leaf	CC% Twig	CC% Branch	CC% Sapwood	CC% Wood	CC% Bark	Regime Description
WA1 P.rad 1	Wester Australia	*Pinus radiata*	440	52	52	51	51	52	53	Average Sites - 51% thinning @ 12 years, 39% @ 18, 32% @ 24, CF @ 35



LookUp	Region(s)	Species	Density	CC% Leaf	CC% Twig	CC% Branch	CC% Sapwood	CC% Wood	CC% Bark	Regime Description
WA1 P.pin 1	Wester Australia	*Pinus pinaster*	470	52	52	51	51	52	53	Average Sites - 65% thinning @ 18 years, 37% @ 25, CF @ 40



LookUp	Region(s)	Species	Density	CC% Leaf	CC% Twig	CC% Branch	CC% Sapwood	CC% Wood	CC% Bark	Regime Description
WA1 E.glob 1	Wester Australia	*Eucalyptus globulus*	550	52.8	49.8	47	48.7	50.7	49	Clear fall @ 10

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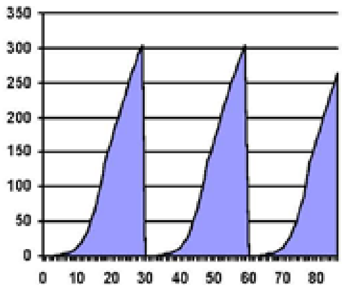
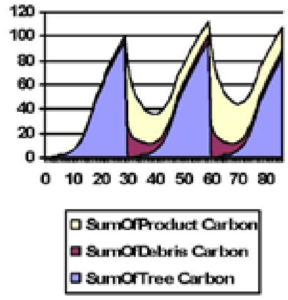
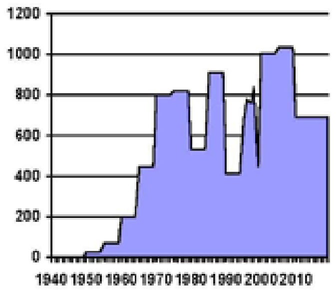
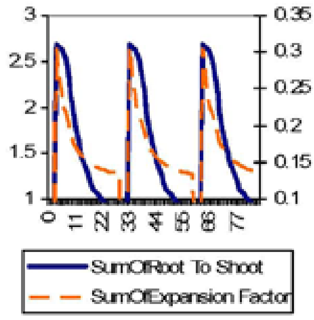
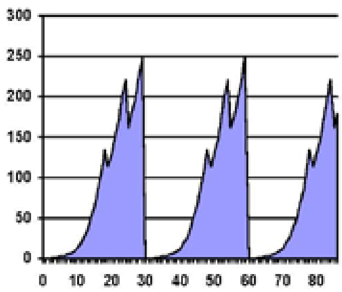


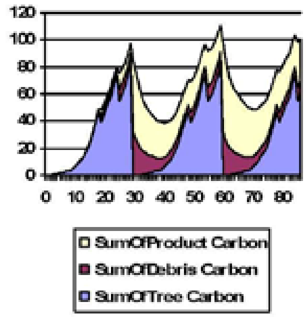


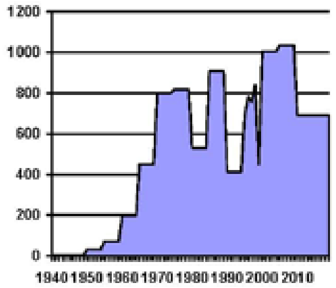


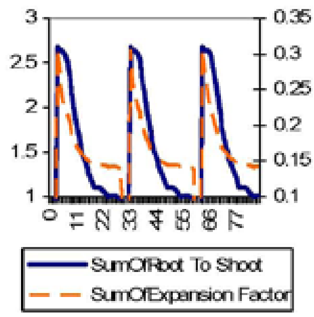


LookUp	Region(s)	Species	Density	CC% Leaf	CC% Twig	CC% Branch	CC% Sapwood	CC% Wood	CC% Bark	Regime Description
VicNSW891011 P.rad 6	Victoria and NSW	*Pinus radiata*	440	52	52	51	51	52	53	Poor Sites - CF @ 30 years









LookUp	Region(s)	Species	Density	CC% Leaf	CC% Twig	CC% Branch	CC% Sapwood	CC% Wood	CC% Bark	Regime Description
VicNSW891011 P.rad 5	Victoria and NSW	*Pinus radiata*	440	52	52	51	51	52	53	Poor Sites - 26% thinning @ 18 years, 32% @ 24, CF @ 30

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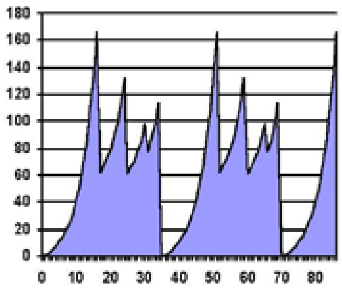
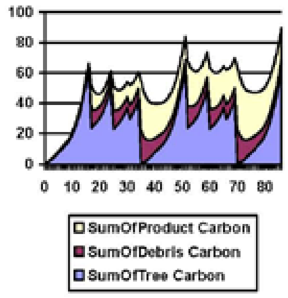
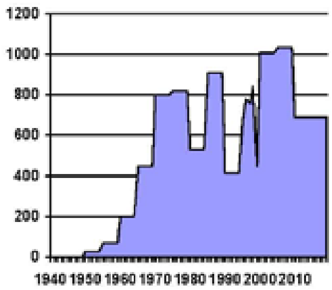
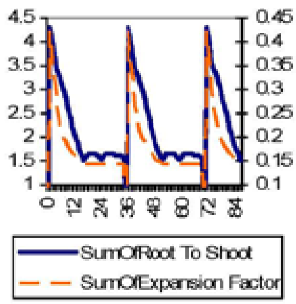
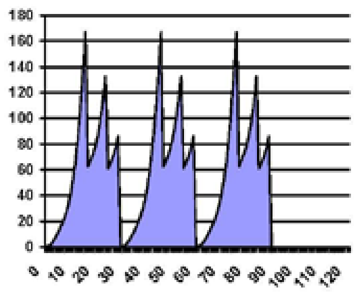


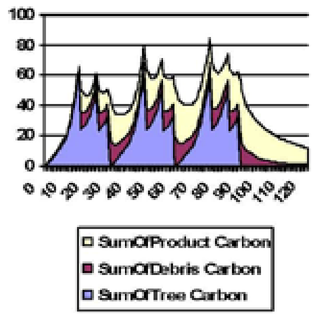


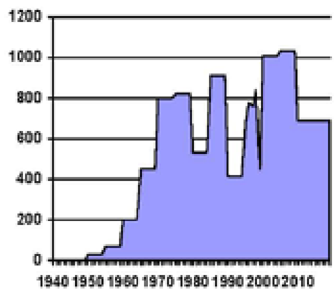


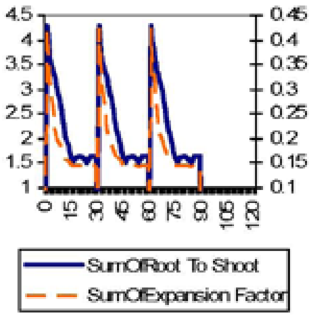


LookUp	Region(s)	Species	Density	CC% Leaf	CC% Twig	CC% Branch	CC% Sapwood	CC% Wood	CC% Bark	Regime Description
VicNSW891011 P.rad 4	Victoria and NSW	*Pinus radiata*	440	52	52	51	51	52	53	Average Sites - 65% thinning @ 16 years, 57% @ 24, 27% @ 30, CF @ 35









LookUp	Region(s)	Species	Density	CC% Leaf	CC% Twig	CC% Branch	CC% Sapwood	CC% Wood	CC% Bark	Regime Description
VicNSW891011 P.rad 3	Victoria and NSW	*Pinus radiata*	440	52	52	51	51	52	53	Average Sites - 65% thinning @ 16 years, 57% @ 24, CF @ 30

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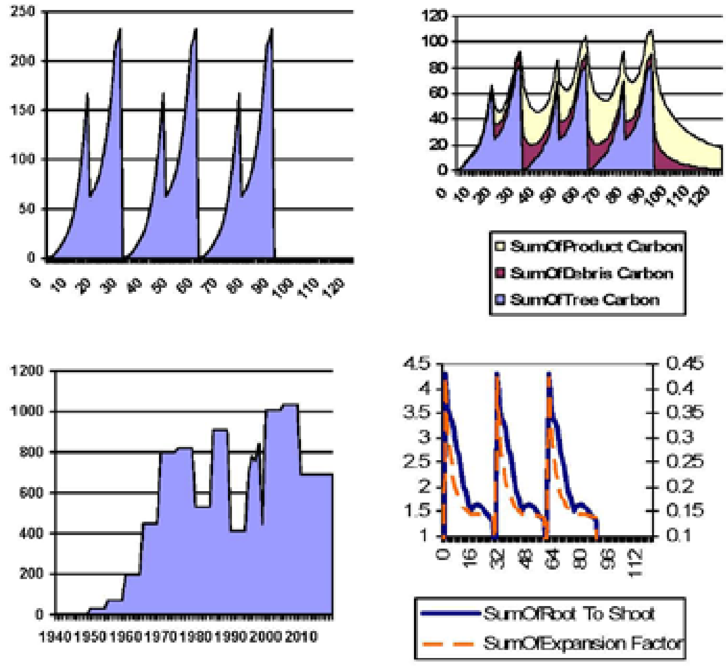

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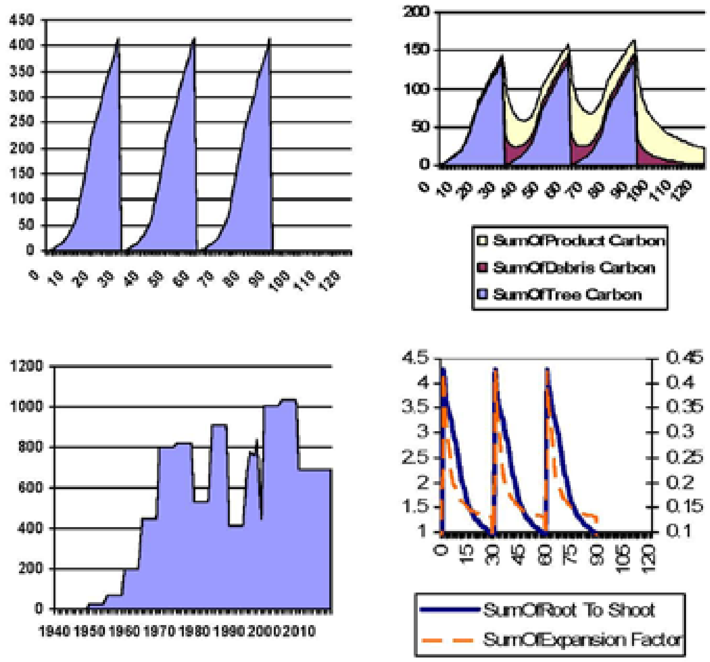
VicNSW891011 P.rad 2	Victoria and NSW	*Pinus radiata*	440	52	52	51	51	52	53	Average Sites - 65% thinning @ 16 years, CF @ 30



LookUp	Region(s)	Species	Density	CC% Leaf	CC% Twig	CC% Branch	CC% Sapwood	CC% Wood	CC% Bark	Regime Description
VicNSW891011 P.rad 1	Victoria and NSW	*Pinus radiata*	440	52	52	51	51	52	53	Average Sites - CF @ 30 years

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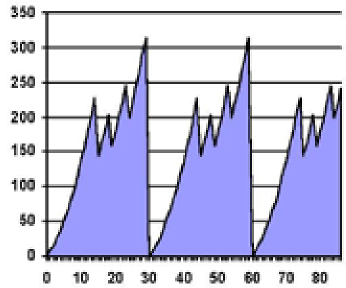
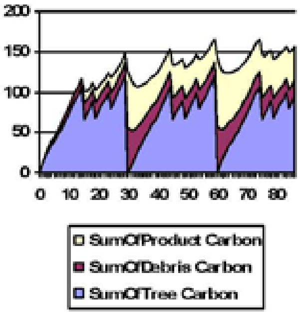
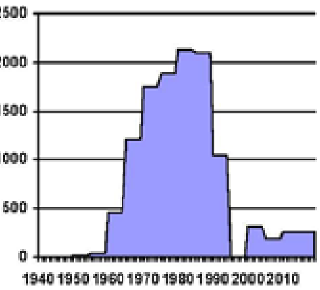
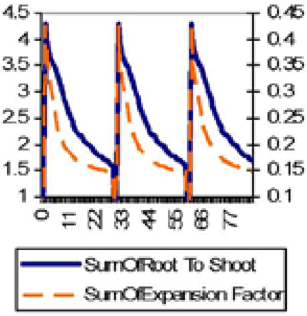
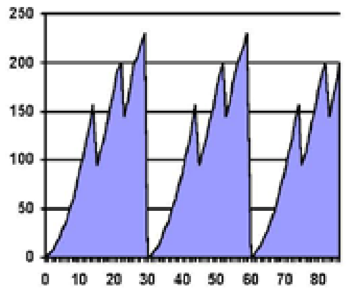


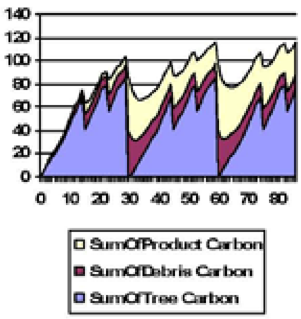


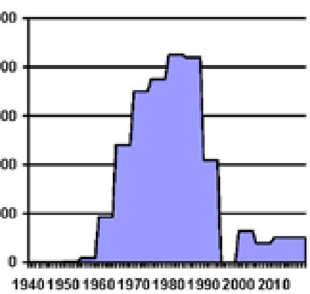


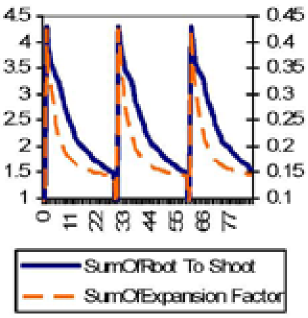


LookUp	Region(s)	Species	Density	CC% Leaf	CC% Twig	CC% Branch	CC% Sapwood	CC% Wood	CC% Bark	Regime Description
VicNSW6 P.rad 3	Murray Valley	*Pinus radiata*	440	52	52	51	51	52	53	Very Good Sites - 44% thinning @ 14 years, 31% @ 18, 27% @ 23, CF @ 30









LookUp	Region(s)	Species	Density	CC% Leaf	CC% Twig	CC% Branch	CC% Sapwood	CC% Wood	CC% Bark	Regime Description
VicNSW6 P.rad 2	Murray Valley	*Pinus radiata*	440	52	52	51	51	52	53	Average Sites - 47% thinning @ 14 years, 35% @ 22, CF @ 30

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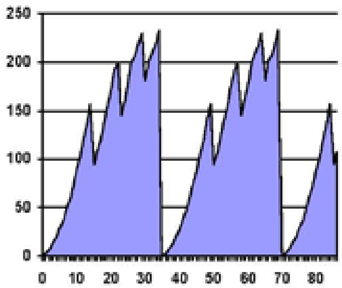
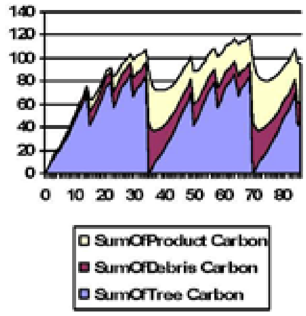
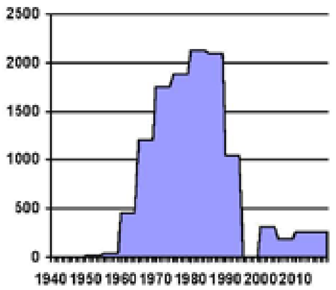
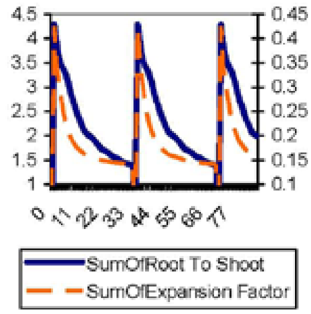
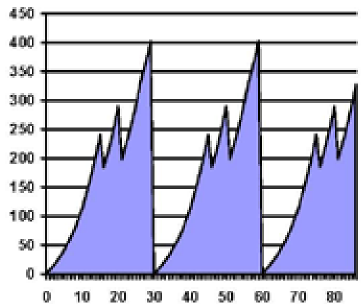


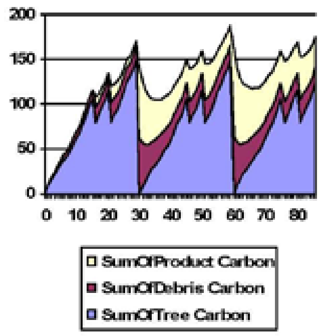


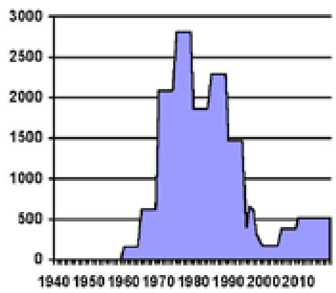


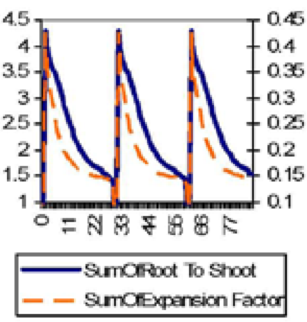


LookUp	Region(s)	Species	Density	CC% Leaf	CC% Twig	CC% Branch	CC% Sapwood	CC% Wood	CC% Bark	Regime Description
VicNSW6 P.rad 2	Murray Valley	*Pinus radiata*	440	52	52	51	51	52	53	Average Sites - 47% thinning @ 14 years, 35% @ 22, CF @ 30









LookUp	Region(s)	Species	Density	CC% Leaf	CC% Twig	CC% Branch	CC% Sapwood	CC% Wood	CC% Bark	Regime Description
Vic7 P.rad 1	Victoria (Central Gippsland)	*Pinus radiata*	440	52	52	51	51	52	53	Average Sites - 33% thinning @ 15 years, 37% @ 20, CF @ 30

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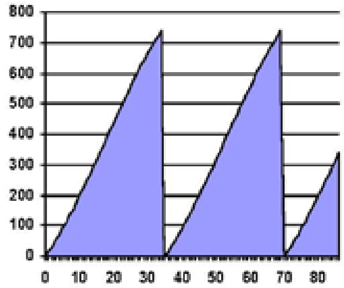
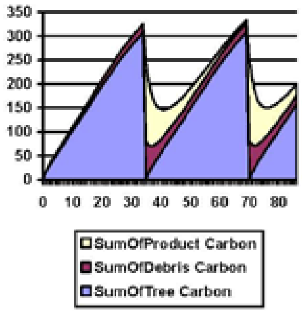
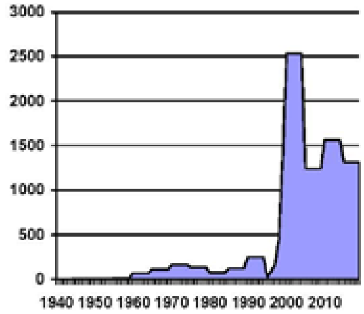
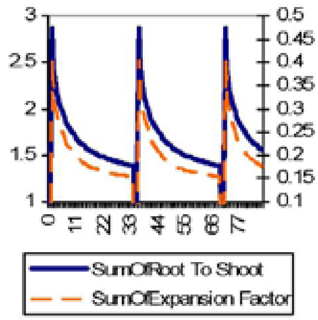
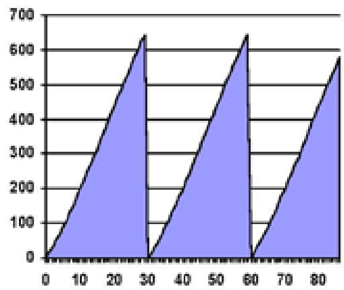


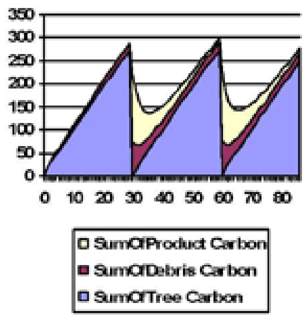


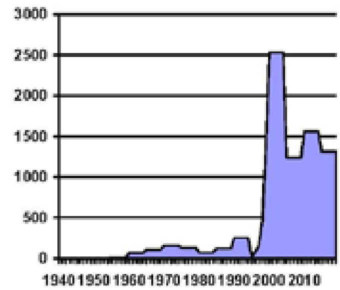


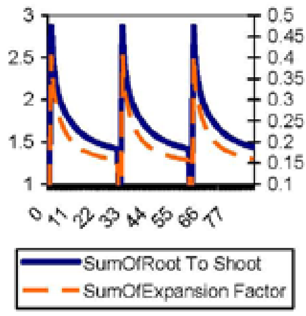


LookUp	Region(s)	Species	Density	CC% Leaf	CC% Twig	CC% Branch	CC% Sapwood	CC% Wood	CC% Bark	Regime Description
Vic7 Euc 4	Victoria (Central Gippsland)	Eucalyptus plantations	550	52	52	47	52	52	49	All Sites - CF @ 35



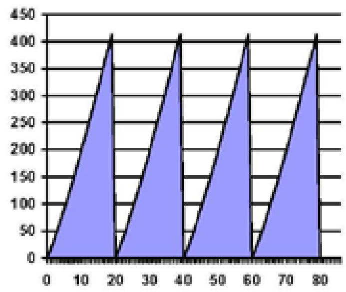


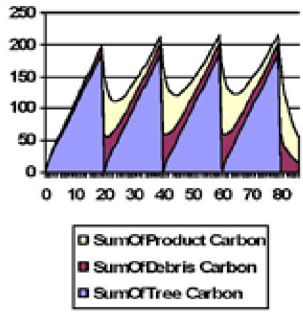


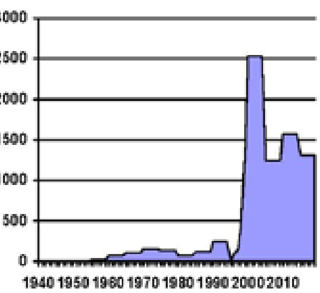


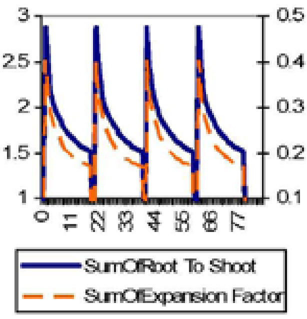
LookUp	Region(s)	Species	Density	CC% Leaf	CC% Twig	CC% Branch	CC% Sapwood	CC% Wood	CC% Bark	Regime Description
Vic7 Euc 3	Victoria (Central Gippsland)	Eucalyptus plantations	550	52	52	47	52	52	49	All Sites - CF @ 30

APPENDICES

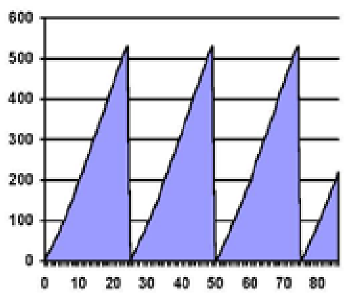


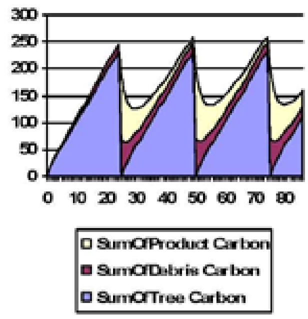


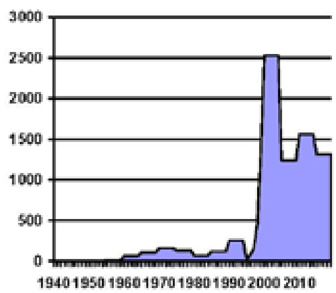


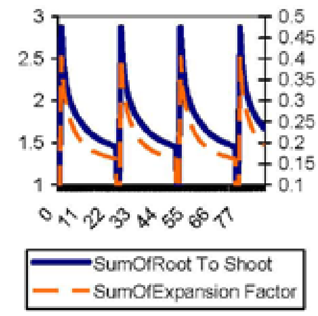


LookUp	Region(s)	Species	Density	CC% Leaf	CC% Twig	CC% Branch	CC% Sapwood	CC% Wood	CC% Bark	Regime Description
Vic7 Euc 2	Victoria (Central Gippsland)	Eucalyptus plantations	550	52	52	47	52	52	49	All Sites - CF @ 20

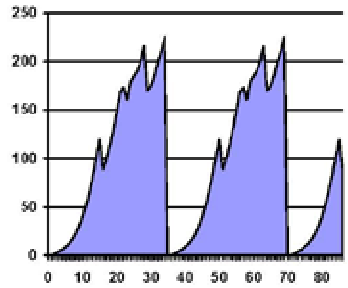


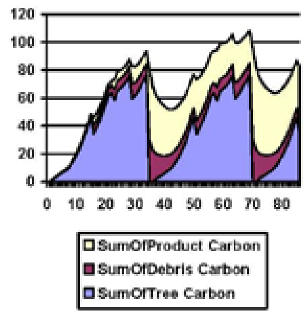


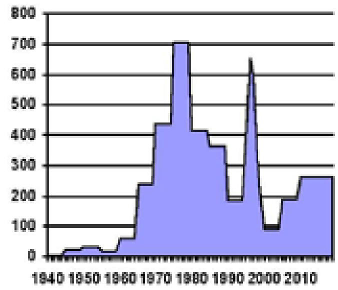


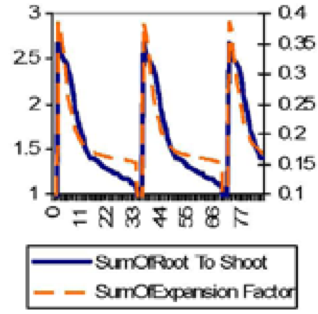


LookUp	Region(s)	Species	Density	CC% Leaf	CC% Twig	CC% Branch	CC% Sapwood	CC% Wood	CC% Bark	Regime Description
Vic7 Euc 1	Victoria (Central Gippsland)	Eucalyptus plantations	550	52	52	47	52	52	49	All Sites - CF @ 25

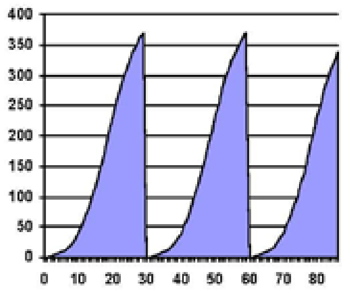


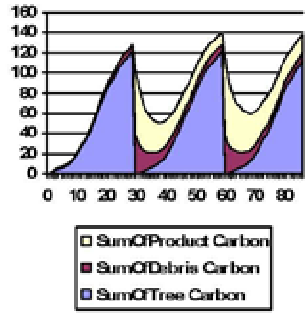


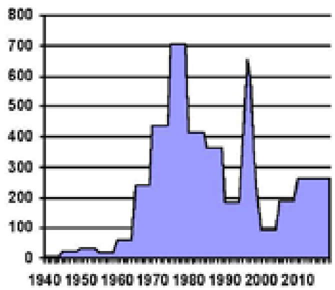


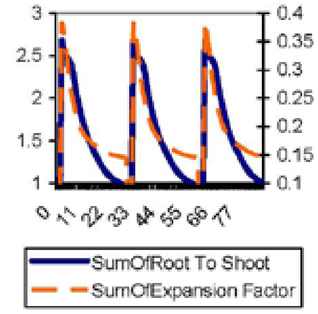


LookUp	Region(s)	Species	Density	CC% Leaf	CC% Twig	CC% Branch	CC% Sapwood	CC% Wood	CC% Bark	Regime Description
Vic5 P.rad 2	Victoria (Central)	*Pinus radiata*	440	52	52	51	51	52	53	Average Sites - CF @ 30









LookUp	Region(s)	Species	Density	CC% Leaf	CC% Twig	CC% Branch	CC% Sapwood	CC% Wood	CC% Bark	Regime Description
Vic5 P.rad 1	Victoria (Central)	*Pinus radiata*	440	52	52	51	51	52	53	Average Sites - 34% thinning @ 15 years, 18% @ 22, 24% @ 28, CF @ 35

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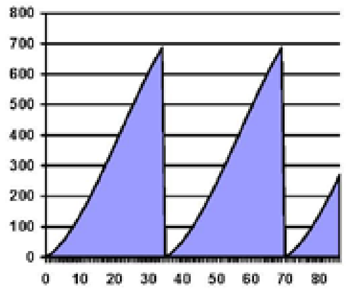
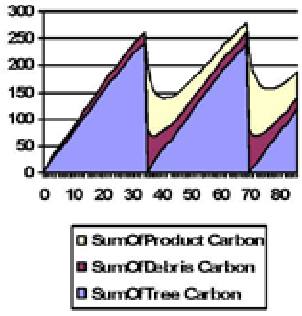
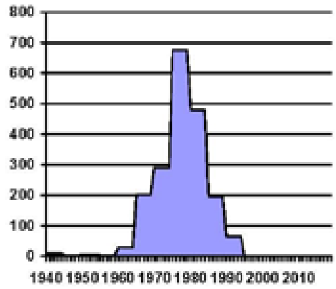
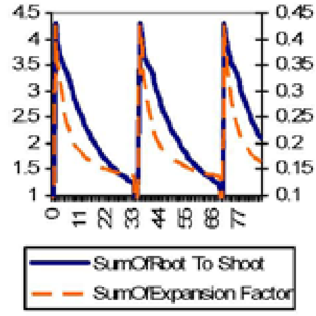
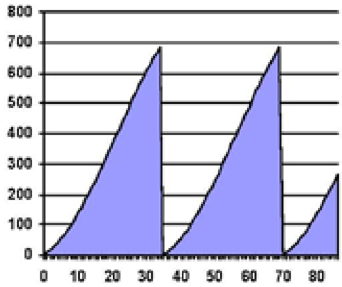


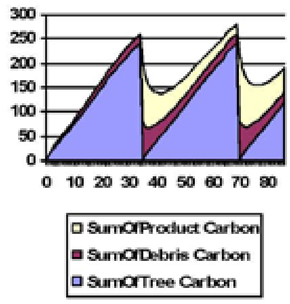


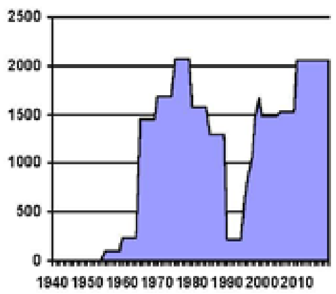


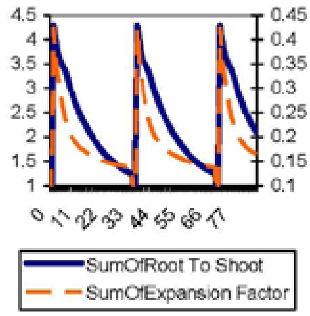


LookUp	Region(s)	Species	Density	CC% Leaf	CC% Twig	CC% Branch	CC% Sapwood	CC% Wood	CC% Bark	Regime Description
Tas2 Pinus 1	Tasmania	Pinus (other than radiata)	440	52	52	51	51	52	53	All Sites - CF @ 35









LookUp	Region(s)	Species	Density	CC% Leaf	CC% Twig	CC% Branch	CC% Sapwood	CC% Wood	CC% Bark	Regime Description
Tas2 P.rad 1	Tasmania	*Pinus radiata*	440	52	52	51	51	52	53	Average Sites - CF @ 35

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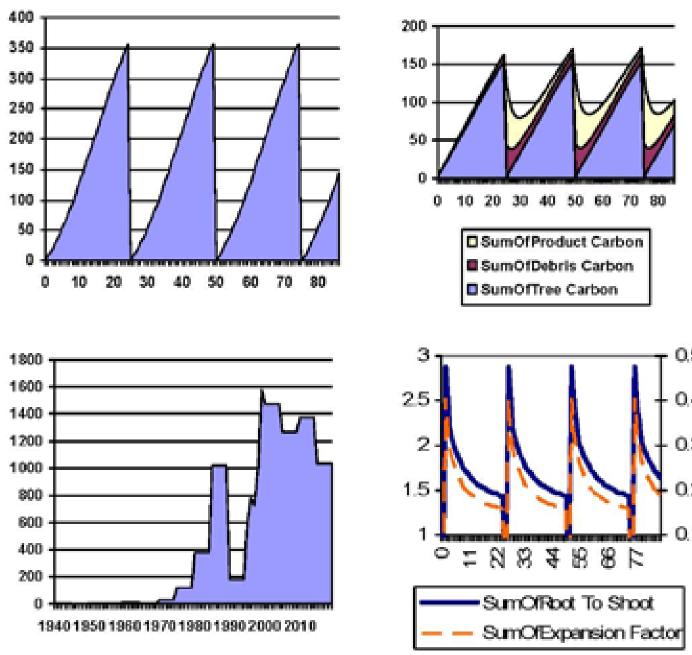
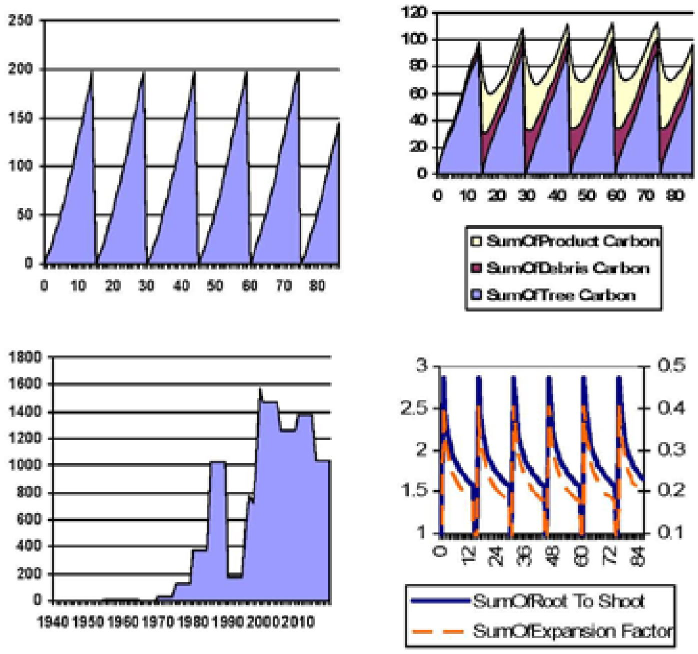


LookUp	Region(s)	Species	Density	CC% Leaf	CC% Twig	CC% Branch	CC% Sapwood	CC% Wood	CC% Bark	Regime Description
Tas2 E.nit 3	Tasmania	*Eucalyptus nitens*	550	52	52	47	52	52	49	All Sites - CF @ 25



LookUp	Region(s)	Species	Density	CC% Leaf	CC% Twig	CC% Branch	CC% Sapwood	CC% Wood	CC% Bark	Regime Description
Tas2 E.nit 2	Tasmania	*Eucalyptus nitens*	550	52	52	47	52	52	49	All Sites - CF @ 15

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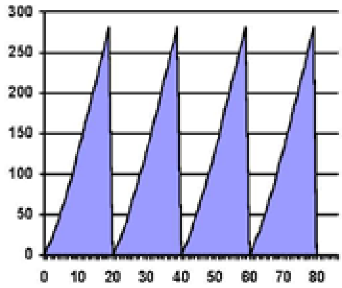
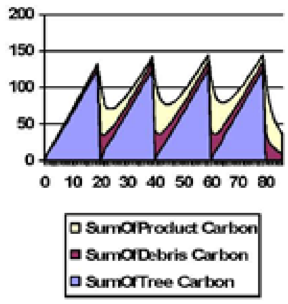
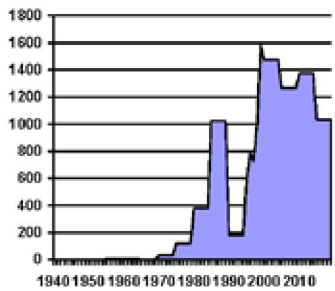
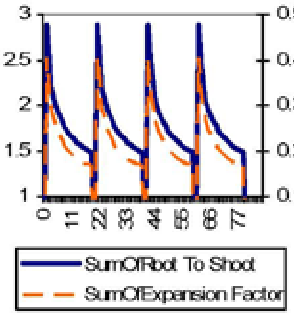
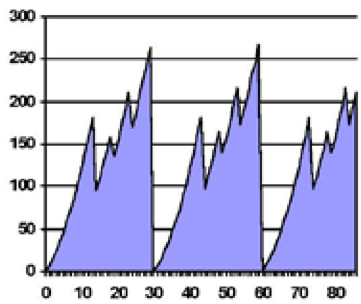


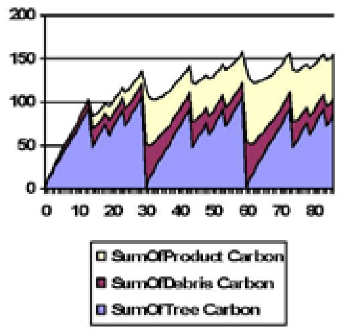


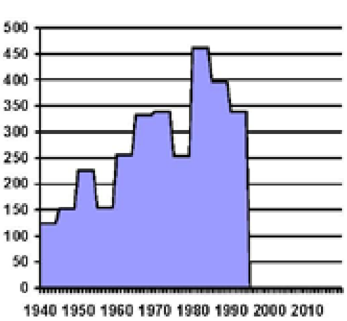


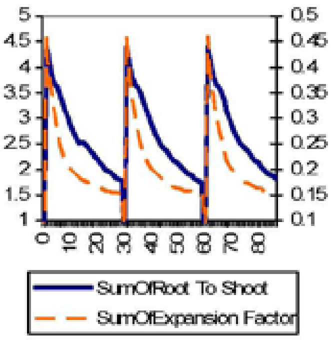


LookUp	Region(s)	Species	Density	CC% Leaf	CC% Twig	CC% Branch	CC% Sapwood	CC% Wood	CC% Bark	Regime Description
Tas2 E.nit 1	Tasmania	*Eucalyptus nitens*	550	52	52	47	52	52	49	All Sites - CF @ 30









LookUp	Region(s)	Species	Density	CC% Leaf	CC% Twig	CC% Branch	CC% Sapwood	CC% Wood	CC% Bark	Regime Description
SA4 Pinus 1	South Australia	Pinus (other than radiata)	440	52	52	51	51	52	53	Average Sites - 54% thinning @ 13 years, 25% @ 18, 28% @ 23, CF @ 30

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Appendix 7.D: Post–1990 Plantations

Introduction

The Australian Government's capacity for carbon accounting in post-1990 *plantations* has been developed through Australia's National Carbon Accounting System (NCAS). The development of the NCAS system to allow modelling of post-1990 *plantations* includes five principal program areas; remote sensing of land cover change; remote sensing of plantation type; biomass estimation (including the effects of ongoing management); soil carbon estimation; and information system development.

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

Model Configuration

The methods used to estimate emissions and removals in post-1990 *plantations* reflect an implementation of the full form of Tier 3 emissions estimation and Approach 3 land representation capabilities of the NCAS. The model covers all carbon pools: living biomass, dead organic matter and soil. These pools can be further divided as necessary for reporting under the Kyoto Protocol. A full description of the NCAS modelling system is provided in Appendix 7.A.

Growth Modelling and Management

Forest growth model

Understanding spatial and temporal variation in forest growth is important to developing accurate carbon accounts. Rainfall, temperature and soil fertility are significant determinants of the potential total biomass carrying capacity and the rate at which the forest approaches carrying capacity. Growth estimates over short periods (< 5 years) are sensitive to climate variability and forest age. Growth rates are also affected by management, age, forest type and forest structure. It is necessary to account for all of these factors when estimating emissions and removals over short reporting periods (e.g., annual) over an entire continent.

Purely empirical modelling methods using methods based purely on yield or increment tables (Richards and Brack, 2004a; Lewis *et al.*, 1976; Turner and James, 2002) do not reflect short-term climate variability and cannot easily account for management effects.

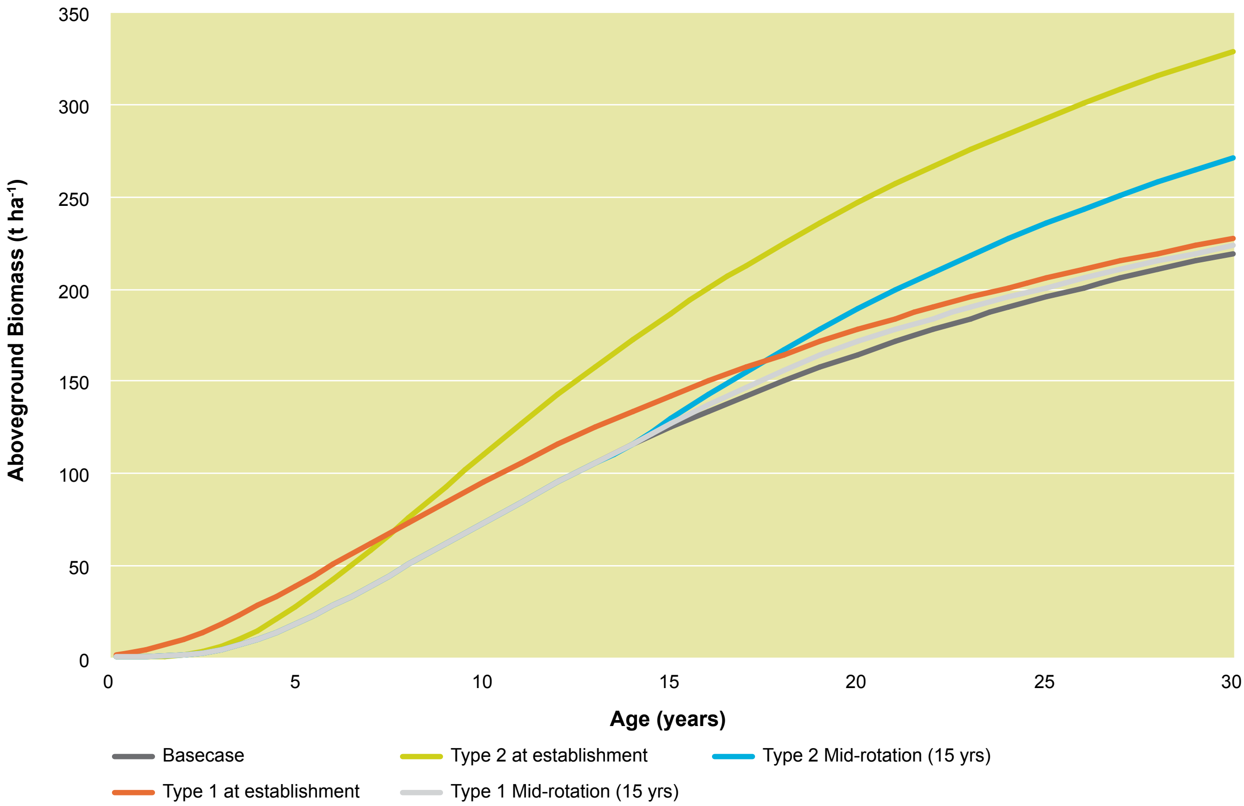
Plantations commonly produce more biomass than native forest systems in Australia, at least in the short to medium term (15-40 years). For example, Baker and Attiwill (1985) showed that *Pinus radiata* achieved 70-100% of the biomass of an 80 year old native forest, grown under similar conditions, in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

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

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

Figure 7.D1 Effect of Type 1 and Type 2 management practices on (a) cumulative and (b) annual growth

(a)



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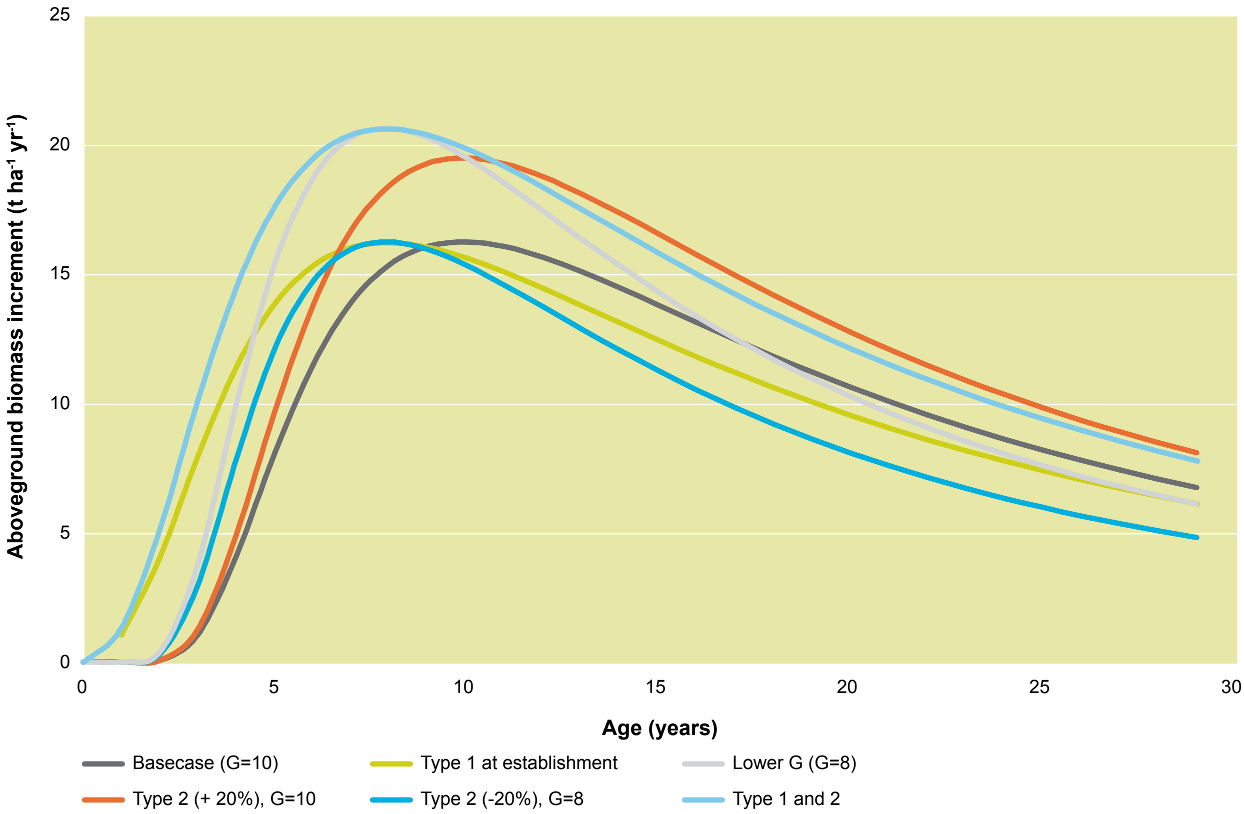
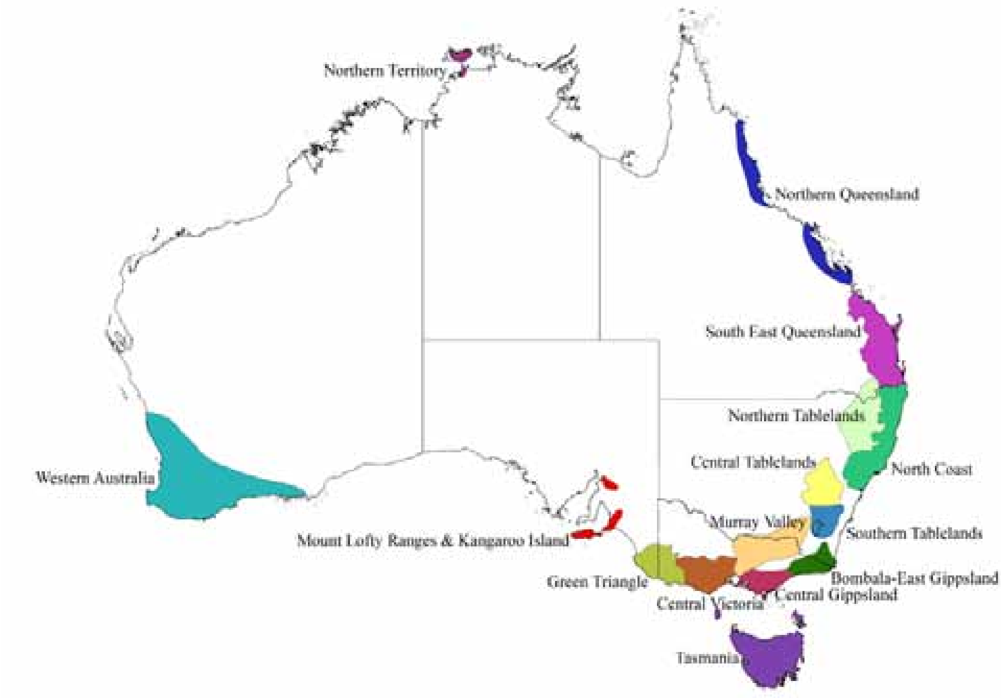
(b)



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

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

Figure 7.D2: The National Plantation Inventory regions



Calculation of r

The plantation species multiplier (*r*) was determined for each major plantation species on a regional basis. *P* 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 NCAS 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 and amenity 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 the NCAS 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), the *P* for the dominant species was set values from regions with similar species and conditions, with the other species ranging from the minimum to the lowest value of the dominant species. The MAVI and *P* data used for calibrating *r* are shown in Table 7.D1.

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The *r* value required to adjust the base case native forest growth model to the documented plantation MAVI growth rates and the estimated minimum and maximum MAI's for each State, NPI region and species was calculated based on assumptions of species characteristics and forest management (Equation 1). As the MAVI growth data is not spatially explicit it was assumed that low *P* values represent low MAVI values and high *P* values represent high MAVI values. This is justified through the strong relationship between *P* data and native forest biomass stocks (see Appendix 7.A), and preliminary 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 based on expected rotation length equations from Snowdon *et al.*, (2000). 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.D1 Range of FPI (*P*) values on which plantation types occur, the minimum, average and maximum growth rates (Mean Annual Volume Increment, $m^3\ ha^{-1}\ yr^{-1}$) and rotation length

NPI	Plantation type	Species	FPI low	FPI mean	FPI high	Min MAI	Average MAI	Max MAI	Rotation length
Western Australia	Softwood	Pinus radiata	5.0	7.0	11.2	12	20	30	30
Western Australia	Softwood	Pinus pinaster	3.8	5.5	8.0	6	11	16	35
Western Australia	Hardwood	Eucalyptus globulus SR	4.0	6.7	11.9	12	17	30	12
Western Australia	Hardwood	Eucalyptus globulus LR	5.0	7.0	11.9	12	18	27	25
Tasmania	Softwood	Pinus radiata	5.3	10.0	15.3	12	19	30	30
Tasmania	Hardwood	Eucalyptus globulus SR	6.0	11.5	15.5	14	23	30	10
Tasmania	Hardwood	Eucalyptus nitens SR	5.3	10.0	14.5	12	15	27	15
Tasmania	Hardwood	Eucalyptus nitens LR	6.0	11.5	15.5	14	19	27	25
Green Triangle	Softwood	Pinus radiata	4.8	7.4	11.5	12	21	30	35
Green Triangle	Hardwood	Eucalyptus globulus SR	4.8	7.7	11.5	12	17	27	12
Green Triangle	Hardwood	Eucalyptus globulus LR	6.0	8.2	11.5	14	20	25	25
South Australia – Lofty Block	Softwood	Pinus radiata	5.3	6.6	10.6	12	21	27	35
South Australia – Lofty Block	Hardwood	Eucalyptus globulus SR	4.3	6.5	10.4	12	17	27	12
South Australia – Lofty Block	Hardwood	Eucalyptus globulus LR	5.0	7.5	10.4	12	20	25	25
Central Victoria	Softwood	Pinus radiata	5.5	8.0	14.1	12	18	27	35
Central Victoria	Hardwood	Eucalyptus globulus SR	5.3	7.3	13.9	12	18	27	12
Central Victoria	Hardwood	Eucalyptus globulus LR	6.0	8.0	13.9	14	18	25	25
Murray Valley	Softwood	Pinus radiata	5.3	9.4	12.4	12	20	27	30

NPI	Plantation type	Species	FPI low	FPI mean	FPI high	Min MAI	Average MAI	Max MAI	Rotation length
Murray Valley	Hardwood	Eucalyptus globulus SR	5.3	8.6	13.0	12	16	25	13
Murray Valley	Hardwood	Eucalyptus globulus LR	6.5	9.0	13.0	12	18	25	25
Central Gippsland	Softwood	Pinus radiata	5.9	9.0	16.6	12	20	30	30
Central Gippsland	Hardwood	Eucalyptus globulus SR	5.8	10.4	16.9	12	18	27	12
Central Gippsland	Hardwood	Eucalyptus nitens LR	7.0	13.0	16.9	12	18	27	25
Bombala-East Gippsland	Softwood	Pinus radiata	6.4	11.0	14.9	12	16	27	35
Bombala-East Gippsland	Hardwood	Eucalyptus globulus SR	6.4	9.5	15.1	12	19	27	12
Southern Tablelands	Softwood	Pinus radiata	5.1	7.0	12.4	12	16	27	30
Central Tablelands	Softwood	Pinus radiata	5.3	9.0	11.7	12	16	25	30
Northern Tablelands	Softwood	Pinus radiata	6.2	9.9	16.6	12	16	25	30
Northern Tablelands	Hardwood	Eucalyptus globulus SR	4.7	8.4	16.1	12	16	25	14
Northern Tablelands	Hardwood	Nth Coast Eucs LR	7.4	11.7	16.1	12	14	20	30
North Coast	Softwood	SouthernPines	8.1	12.5	22.3	12	15	25	30
North Coast	Softwood	Hoop pine	8.1	12.5	22.3	9	13	20	40
North Coast	Hardwood	Nth Coast Eucs SR	7.6	10.8	19.6	12	18	27	12
North Coast	Hardwood	Nth Coast Eucs LR	8.0	10.8	19.6	12	18	25	35
South East Queensland	Softwood	SouthernPines	6.3	11.1	21.2	12	13	25	30
South East Queensland	Softwood	Hoop pine	6.3	11.1	21.2	8	13.4	20	40
South East Queensland	Hardwood	Nth Coast Eucs SR	6.0	9.0	21.0	12	18	27	12
South East Queensland	Hardwood	Nth Coast Eucs LR	7.0	11.5	21.0	12	18	25	35
Northern Queensland	Softwood	SouthernPines	6.7	10.4	17.5	12	13	25	30
Northern Queensland	Softwood	Hoop pine	6.7	11.8	25.0	8	13.4	20	50
Northern Queensland	Hardwood	Nth Coast Eucs SR	6.6	10.2	20.9	12	18	27	12
Northern Queensland	Hardwood	Nth Coast Eucs LR	9.0	15.0	20.9	12	18	25	35
Northern Territory	Hardwood	Acacia	6.4	8.4	11.0	20	25	35	8
Northern Territory	Hardwood	NT eucs	6.4	8.5	11.0	8	12	20	30

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

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

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

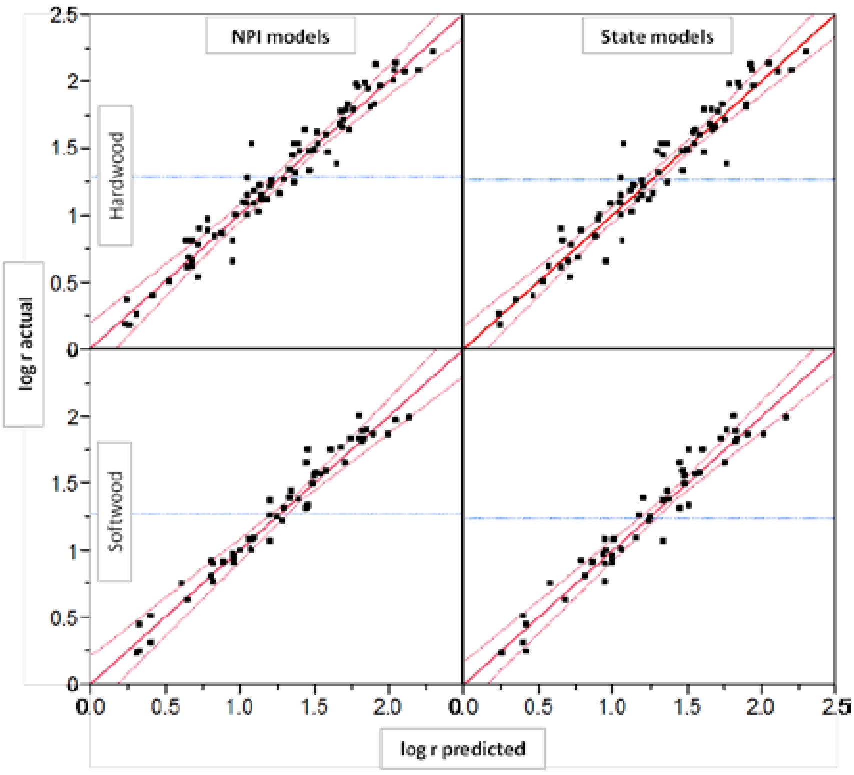
Where r = non-endemic species multiplier

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

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

P = long-term average FPI value.

Figure 7.D3 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 (G) can be modified through direct manipulation of G or through applying Type 1 effects prior to G (see Appendix 7.A; Equation 5). Varying G affects both the age and magnitude of Max I_B. Where a Type 1 response is applied prior to G (i.e. between ages 0 and G), the effective age of Max I_B is lowered without affecting the magnitude of growth. The majority of management effects on early age growth, such as weed control and good site establishment methods, are modelled by applying Type 1 effects at planting. This also provides extra flexibility in adjusting stand growth based on specific management regimes. Hence, the unaffected G value (i.e., that with little or no management) can be calculated based on the actual age of Max I_B and the sum of Type 1 effects on early age growth due to management (Equation 3):

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

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

Calibration of G

Values for the multiplier to account for site productivity (s) and the region/species dependent intercept (c) were calculated for each species within each NPI region based on rotation length and the approximate sum of Type 1 effects at planting.

Snowdon and James (2008) state that canopy closure (and hence G_{man}) in *P. radiata* established within the last 20 years generally occurs between the ages of 7 and 12 depending on site quality and management. 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 1970s, have reduced the age of canopy closure by about 2 to 3 years (Boomsma and Hunter, 1990; Snowdon and James, 2008) and were modelled as Type 1 effects. Equation (4) was calibrated based on 'unaffected stands' by adding 2 years of Type 1 effect to the current age of canopy closure (Equation 3), resulting in a range of 9 to 14 years for G. Regionally specific data for G and G_{man} was not available so this range was applied for all long rotation systems. 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.

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).

To account for the effect of site productivity on *G* a simple linear relationship between *G* and *M* was included (Equation 4). The results of the calibration are shown in Waterworth *et al.*, (2007).

$$G = s * M + c \qquad \text{(Equation 4)}$$

Where G = age of maximum biomass increment of unaffected stand

s = multiplier to account for site productivity

M = unadjusted maximum biomass value

c = region/species dependant intercept

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

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

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

a = Age of trees

r = non-endemic species multiplier

M = maximum aboveground biomass (calculated from P)

y_1 =Type 2 site multiplier at age, a

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

$k = 2 * G$

where G = Tree age of maximum growth

d = Adjusted age of the trees, in years

= a + sum over each treatment of

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

where, for each Type 1 treatment,

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

U = the advancement period, in years

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

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

P_{av} =Long term average FPI value

Stem to Whole Tree Mass Conversions

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

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

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

Carbon Contents

Studies of the carbon fractions of above and 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.

Table 7.D2 Carbon percent (%) of tree components

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

Turnover and Decomposition Rates

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

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

Table 7.D3: 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) for the NCAS. Table 7.D4 shows the decomposition rates applied.

Table 7.D4: Debris decomposition rates

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

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

Soil Carbon

Soil carbon is estimated using the fully spatially explicit approach described in Appendix 7.A with some modifications to the base input data to suit the modelling for post-1990 *plantations*. The initial soil carbon map used for the *forest land converted to cropland* and *grassland* analyses is based on pre-clearing conditions. While this is well suited for 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* (Table 7.D5) is drawn from the NCAS remote sensing program (see Appendix 7.A). The remote sensing data allows the location, plantation type and time of establishment to be determined with a high degree of accuracy. The methods applied also ensure that the post-1990 *plantations* modelled in the account are directly human induced, that a conversion from another land use (grassland) has occurred (i.e., not simply recovers from previous harvest) and that only plantings after 1989 are included. This is achieved by:

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

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

Table 7.D5. Areas of land converted to forest

Year	Area (ha)
1990	53,078
1991	50,315
1992	54,103
1993	56,082
1994	53,635
1995	38,656
1996	36,778
1997	36,586
1998	45,384
1999	46,056
2000	76,275
2001	81,186
2002	80,232
2003	78,985
2004	78,892
2005	54,846
2006	46,229
2007	55,285
2008	50,124

Management Information

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

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

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

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

To allow the effects of ongoing management to be represented within the Tier 3, Approach 3 NCAS 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.D6.

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. This data allows *FullCAM* to model forest growth for any point based on the site and climate data using the methods described previously.

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

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

Calculation of Emissions and Removals

The estimates of emissions and removals for post-1990 *plantations* are modelled using the full Tier 3, Approach 3 capabilities of the NCAS. Each individual 25 m x 25 m pixel identified as being a post–1990 *plantation* is modelled through time from the time of establishment. Each 25 x 25 m model takes into account the age, plantation type, management and site conditions to estimate emissions and removals. The national account for any one year is the sum of all the pixels being actively modelled. A full description of this form of spatially explicit modelling is provided in Appendix 7.A.

Table7.D6 Management actions, the FullCAM events used to represent them and the choices available through parameterisation of the FullCAM event (Source: Waterworth and Richards, 2008)

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 (agricultural)	Moves herbaceous species carbon to debris, mulch and soil	Spot cultivation
			Strip cultivation
			Broadcast cultivation
Forest thin and harvest and pruning	Forest thin (forest)	Moves tree components to products or debris, debris to bioenergy	Varies by time, species and region
Fertiliser 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})

[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.

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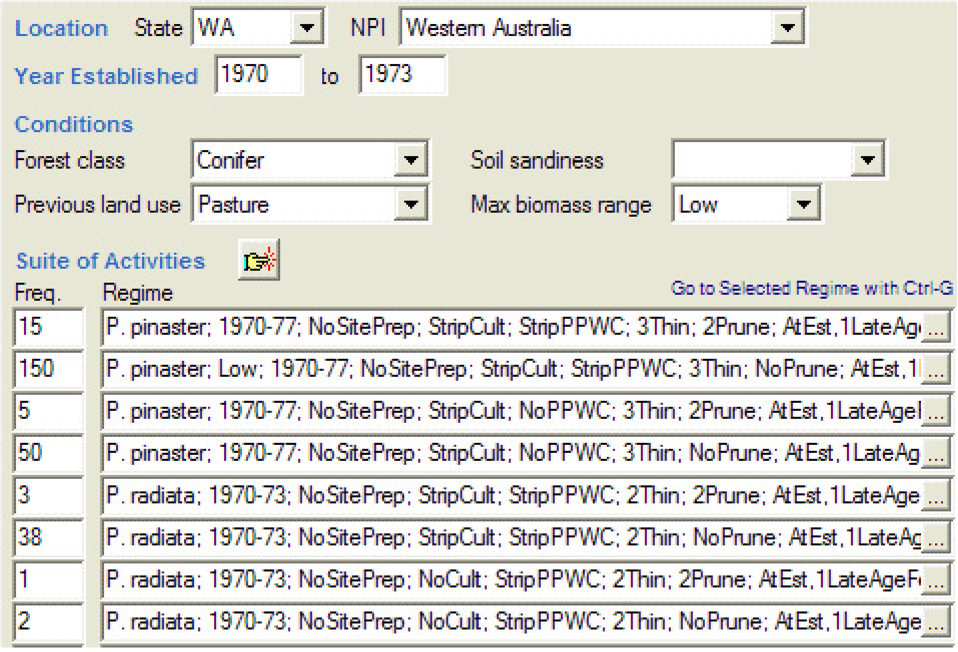
Figure 7.D4 Examples of (a) the activities table through which pixels are assigned a regime based on their location, type and time; and (b) a time series of management practices which make up a regime

(a)



Source: Waterworth and Richards, 2008.

(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

Source: Waterworth and Richards, 2008.

APPENDICES

Appendix 7.E: Other Native Forests

Background

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

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

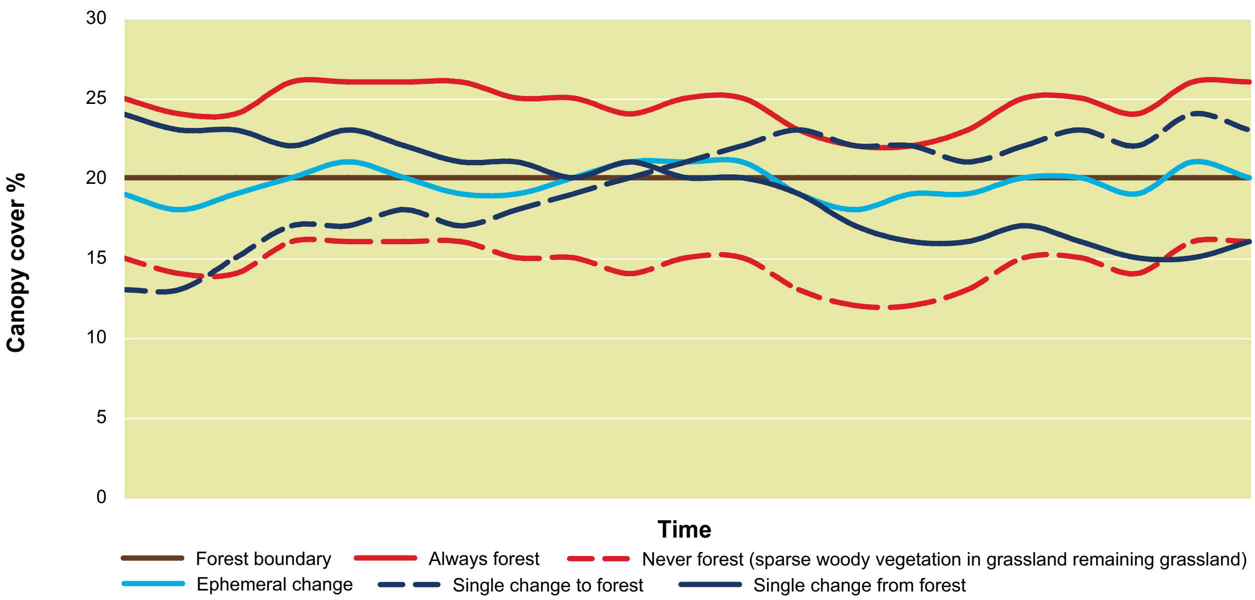
As most of the emissions and removals from these activities are driven by natural variability and natural disturbance, the effects are:

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

Trends in Forest Vegetation Cover in Other Native Forests

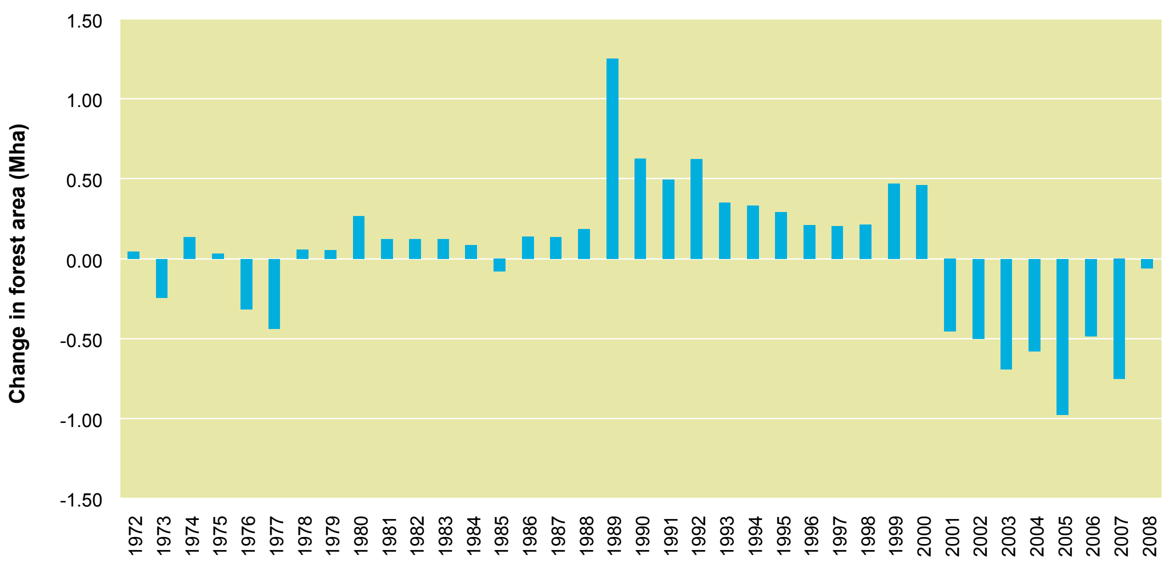
The mixture of climate effects, grazing, fire and recovery from land use change, and the regional differences in these processes gives rise to variability in forest cover over time. Figure 7.E1 shows the typical fluctuations in forest cover that occur around the prescribed canopy cover definition of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

Figure 7.E1 Patterns of change in forest cover in areas of *other native forest*



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

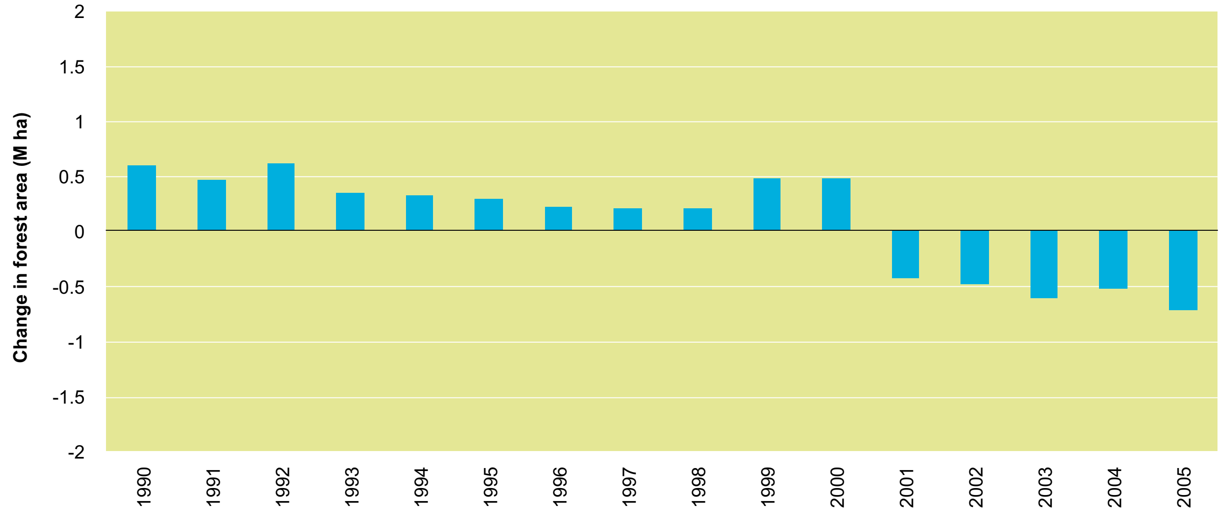
Figure 7.E2 Change in forest area (Mha) not attributable to land use change and included in *other native forests*, since 1972



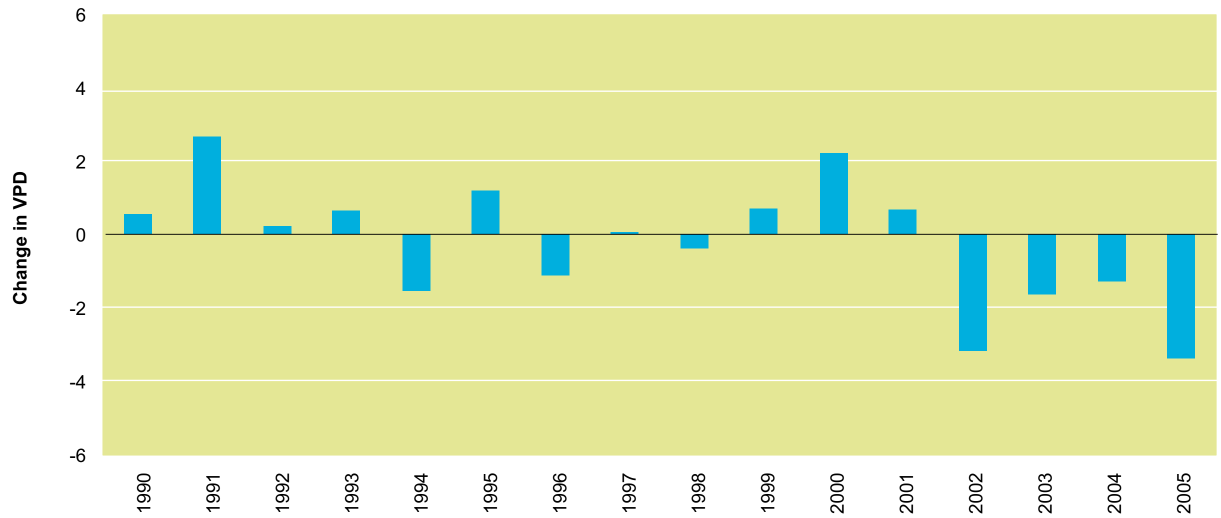
One of the first ways to contemplate attribution to a ‘cause’ for loss or gain is to look at the correlation of change with climate variation. This can be done at a national scale by comparing the gains and losses of forest area not attributable to anthropogenic land use change with a key climate variable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

Figure 7.E3 (a) Annual change in forest area and (b) variation of vapour pressure deficit (VPD) from long term average

(a)

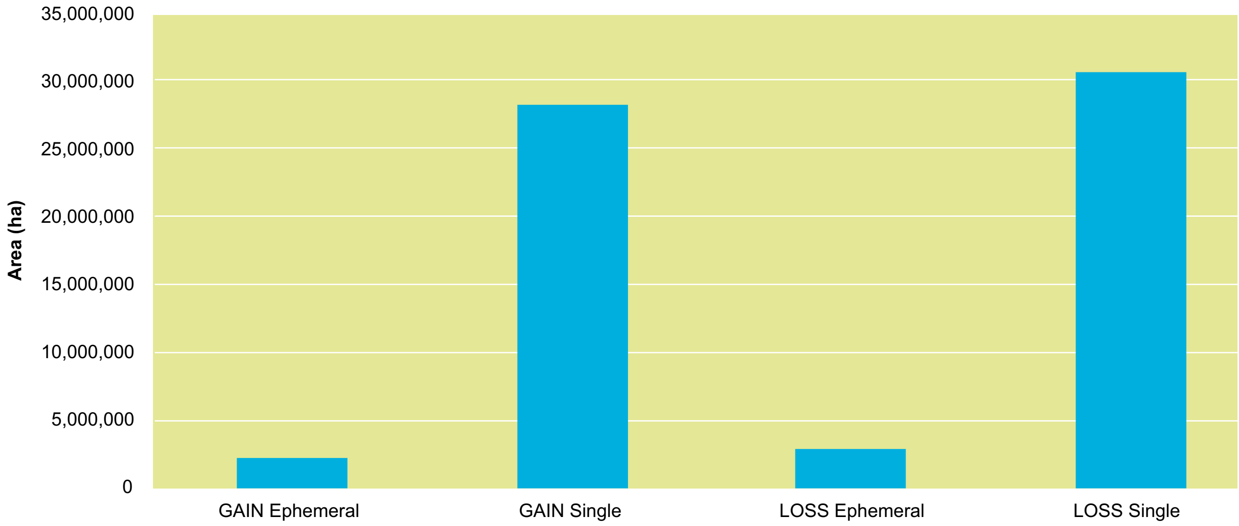


(b)



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

Figure 7.E4: Areas of forest to non-forest transitions that are single (one transition only) and ephemeral (more than one transition) at some time in the time series of remotely sensed data



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

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

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

Methodology

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

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

Annual Changes in Foliage Mass

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

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Ephemeral, intermittent change in forest cover

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

Changes in leaf area of continuous forest cover

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

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

Table 7.E1 Parameters used to estimate emissions and removals from changes in leaf mass in areas of forest cover

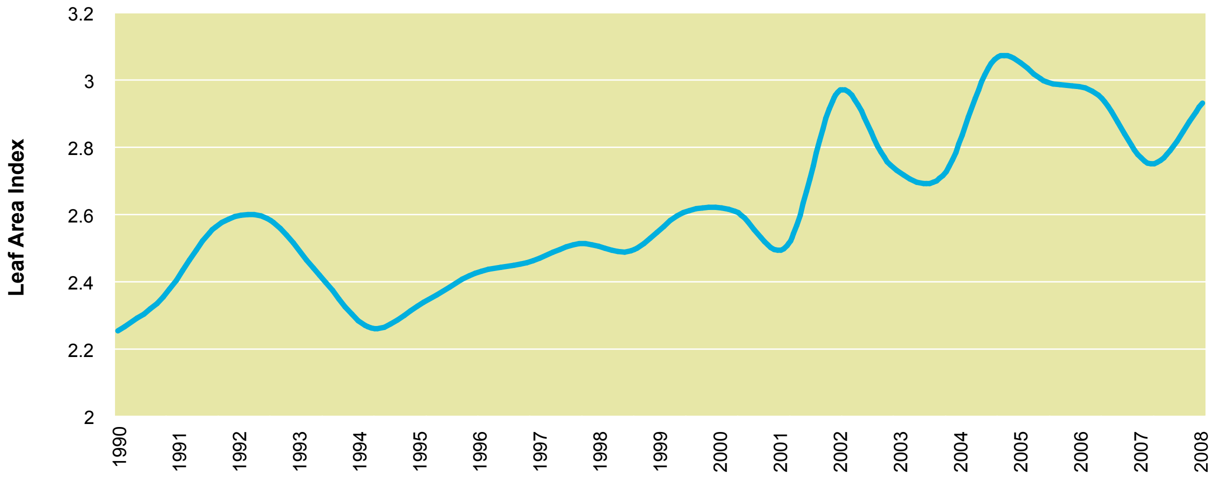
Parameter	
Max LAI	3.05
Min LAI	2.23
LAI range	0.82
Leaf mass range (t C ha^{-1})	0.20

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

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

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

Figure 7.E5 Time-series national annual leaf area index



Permanent loss and gain of forest cover

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

Table 7.E2 Parameters used in the model of single change in forest cover

Parameter	
Total C loss/gain from single change	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

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Woody thickening

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

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

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

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

Fire

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

The emissions caused by fire are affected by the areas burnt, the combustion efficiency of fires and micro-scale climate condition (e.g., wind, local temperatures and topography). The rates of recovery (removals) after fire vary with climate, ecosystem type, previous fire history and site conditions. As fires often remove only fine debris and leaves from live biomass, the recovery can be quite rapid. The estimation of CO_2 emissions from forest fires and CO_2 removals from recovery in *other native forests* is based on the areas burnt (Figure 7.E6), and parameters and input data developed for the estimation of non-CO_2 emissions from forest land in section 7.12.1.1. The debris mass recovers within 5 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 7.8 and 7.9),

Z_{jk} = burning efficiency (Table 7.10).

Annual CO_2 emissions are calculated as:

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

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

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

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

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

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Annual CO_2 removals are calculated as:

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

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

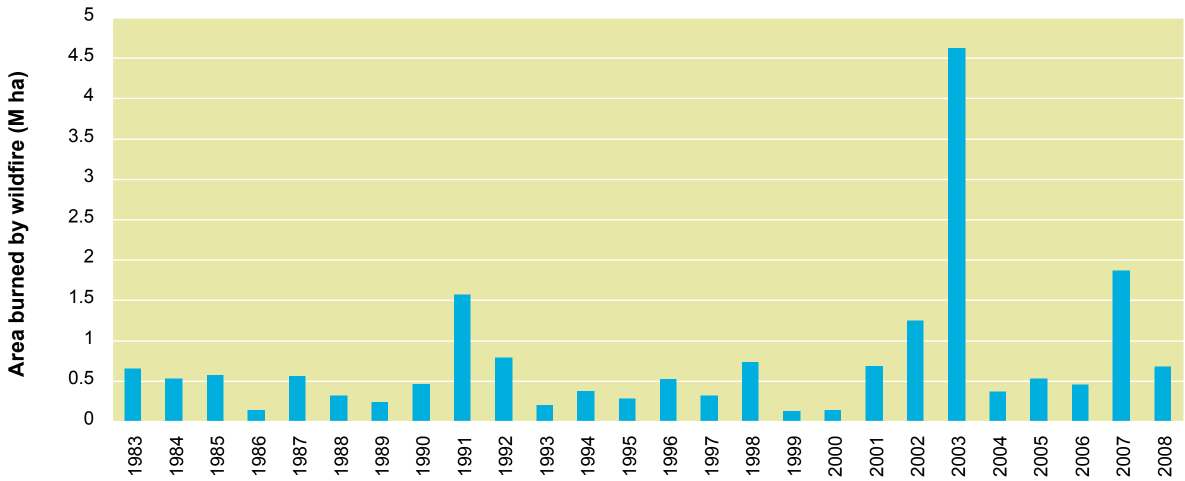
M_{jk} = mass of fuel burnt over period t,

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

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

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

Figure 7.E6 Areas burned by wildfire 1983–2008



Results

The annual emissions and removals from *other native forests* are highly variable due to the effects of natural variability and disturbance (Table 7.E3). Emissions and removals from the change in leaf area (leaf mass) of continuous forests are highly variable, responding on annual timescales to climate variability. For the period 1990 to 2008 emissions estimation for the single change in forest cover, the model indicates a net removal (sink) due to the increase in new forest area from the late 1970s until 2000 (Figure 7.E2). The decrease in forest area since 2000 is yet to offset the area gains of the previous 20 years. Emissions from fire are highly variable and contribute the majority of variation in emissions and removals for the *other native forests* category.

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Table 7.E3 Results of the estimates of annual emissions and removals in *other native forests*

Emissions (Mt CO_2)						
Year	Ephemeral change in forest	Leaf mass change in continuous forest	Single change in forest	Woody Thickening	Fire	Total
1990	-0.01	-2.19	-3.98	-12.20	4.59	-13.79
1991	-0.01	14.38	-4.74	-12.20	58.77	56.20
1992	-0.01	13.50	-5.72	-12.20	5.40	0.97
1993	-0.01	-6.53	-6.72	-12.20	-23.62	-49.08
1994	-0.01	-7.37	-7.06	-12.20	-10.53	-37.17
1995	-0.01	-2.78	-7.51	-12.20	-18.28	-40.78
1996	0.00	-4.77	-8.39	-12.20	-4.89	-30.25
1997	0.00	1.86	-9.47	-12.20	-3.03	-22.85
1998	0.00	-9.84	-9.73	-12.20	14.47	-17.30
1999	-0.01	-0.29	-10.44	-12.20	-15.99	-38.93
2000	-0.01	8.79	-10.77	-12.20	-11.17	-25.36
2001	0.01	-39.12	-9.80	-12.20	13.46	-47.65
2002	0.01	18.54	-8.76	-12.20	39.40	37.00
2003	0.02	2.61	-7.40	-12.20	188.64	171.66
2004	0.01	-28.66	-6.28	-12.20	-46.88	-94.01
2005	0.02	5.47	-4.78	-12.20	-40.71	-52.19
2006	0.01	3.13	-3.74	-12.20	-49.17	-61.97
2007	0.02	16.33	-2.25	-12.20	24.88	26.78
2008	0.00	-14.30	-1.84	-12.20	-42.26	-70.60

Appendix 7.F: Forest Conversion to Cropland and Grassland

Introduction

Emissions estimates from forest land converted to a non-forest land use apply the full capability of Australia's National Carbon Accounting System (NCAS). This capability uses a mass balance, process-based ecosystem model (Tier 3) in a fully spatially explicit land representation (Approach 3). The areas and timing of forest conversion are identified through a national time-series of Landsat satellite data.

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

Model Configuration

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

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

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

Maps

- seventeen sequences of both clearing and regrowth 1972-2008 (25 m);
- an initial 1972 forest/non-forest mask (25 m);
- monthly rainfall maps of Australia since 1968 (1 km);
- monthly average temperature maps of Australia since 1968 (1 km);
- annual top-soil moisture deficit maps of Australia since 1970 (1 km);
- a long-term average productivity (index) map of Australia (250 m);
- annual productivity maps of Australia since 1970 (1 km);
- a soil clay content map of Australia (250 m);
- a pre-disturbance soil carbon content map of Australia (250 m);
- a maximum forest biomass (biomass at maturity) map of Australia (250 m); and,
- a forest type (MVG) map of Australia (200 m).

Tabular data (from the FullCAM relational database)

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

Table 7.F1 *FullCAM* configuration used for the *forest land converted to cropland* and *grassland* sub-categories

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

Data Used

Land Cover Change

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

Climate and Soil Inputs

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

Crop Growth and Plant Parameters

Crop yield and residue (CAMAg)

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

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

Figure 7.F1 Overview of the crop growth and plant parameters program

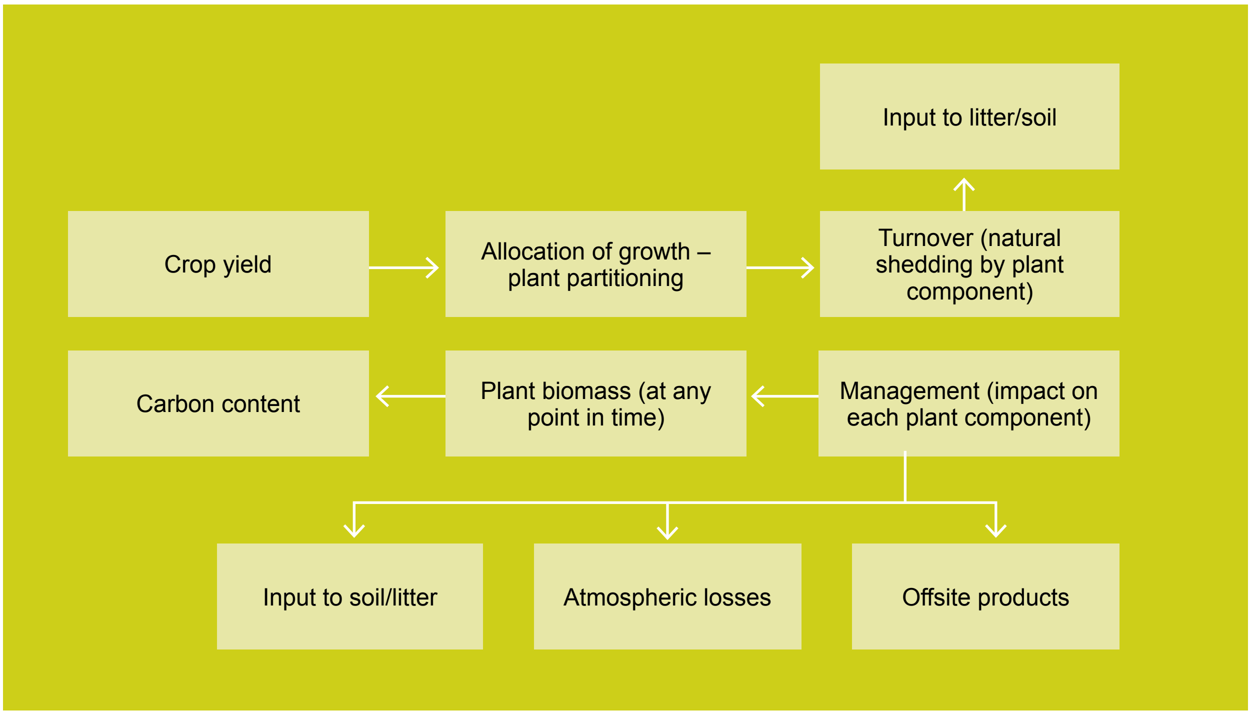


Table 7.F2. Plant partitioning by crop type

Name	Yield Allocation to Grains, Buds or Fruit (fraction)	Yield Allocation to Stalks (fraction)	Yield Allocation to Leaves (fraction)	Yield Allocation to Coarse Roots (fraction)	Yield Allocation to Fine Roots (fraction)
Agricultural crops	0.28	0.00	0.42	0.00	0.30
Annual pasture	0.00	0.00	0.50	0.00	0.50
Annual pastures	0.00	0.00	0.50	0.00	0.50
Barley	0.30	0.00	0.40	0.00	0.30
Canola	0.27	0.00	0.51	0.00	0.22
Cereal	0.27	0.00	0.43	0.00	0.30
Cereal forage	0.00	0.00	0.60	0.00	0.40
Cereals	0.26	0.00	0.43	0.00	0.31
Cleared improved pasture	0.00	0.00	0.50	0.00	0.50
Continuous pasture	0.00	0.00	0.50	0.00	0.50
Crop	0.27	0.00	0.43	0.00	0.30
Cropping (e.g. barley)	0.24	0.00	0.46	0.00	0.30

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)
Fallow	0.20	0.20	0.20	0.20	0.20
Grain sorghum	0.29	0.00	0.41	0.00	0.30
Grass pasture	0.00	0.00	0.50	0.00	0.50
Horticulture	0.00	0.00	0.30	0.60	0.10
Improved pasture	0.00	0.00	0.50	0.00	0.50
Irrigated cotton	0.25	0.25	0.30	0.10	0.10
Legume	0.00	0.00	0.50	0.00	0.50
Legume crop	0.30	0.00	0.48	0.00	0.22
Lucerne	0.00	0.00	0.50	0.00	0.50
Lupins	0.23	0.00	0.55	0.00	0.22
Maize	0.34	0.32	0.09	0.00	0.25
Pasture	0.00	0.00	0.50	0.00	0.50
Pasture permanent	0.00	0.00	0.50	0.00	0.50
Peanut	0.35	0.00	0.35	0.00	0.30
Poppies	0.25	0.20	0.35	0.00	0.20
Pulse	0.30	0.00	0.48	0.00	0.22
Root vegetables	0.00	0.00	0.30	0.60	0.10
Roughly cleared pasture	0.00	0.00	0.50	0.00	0.50
Sugar cane	0.00	0.75	0.15	0.00	0.10
Sugarcane	0.00	0.75	0.15	0.00	0.10
Sunflower	0.32	0.39	0.20	0.00	0.10
Unimproved or native pasture	0.00	0.00	0.50	0.00	0.50
Wheat	0.26	0.00	0.44	0.00	0.30
Winter grain (wheat)	0.28	0.00	0.42	0.00	0.30

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

Carbon content of crop and grass species

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

Initial crop litter mass and decomposition rates

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

Table 7.F3. 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 high given that they are primarily annual by nature. Within this annual constraint, the litter and soil carbon modelling is relatively insensitive to turnover rate. For continuous (perennial) systems such as grazed pastures, root sloughing in response to grazing is included in the model which maintains the relative ratio of aboveground to belowground plant mass with grazing. The turnover rates used are shown in Table 7.F4.

Table 7.F4. Turnover rates applied to the crop systems

Plant Component	Turnover Rates yr^{-1}
Grains, Buds, Fruit	0.8
Stalks	0.8
Leaves	0.8
Coarse Roots	0.8
Fine Roots	0.8

Forest Growth and Tree Parameters

Forest growth in the *forest land converted to cropland* and *forest land converted to grassland* sub-categories is modelled using the fully spatial, hybrid process-empirical method described in Appendix 7.A and detailed in Richards and Brack (2004a) and Waterworth *et al.*, (2007). To parameterise the model a program of consolidation and synthesis of available national data on relevant forest and tree parameters was conducted. These data were then supplemented with additional research where required. The results of this work are provided in Appendix 7.A and in the NCAS technical report series (www.climatechange.gov.au) and only a brief summary is provided here.

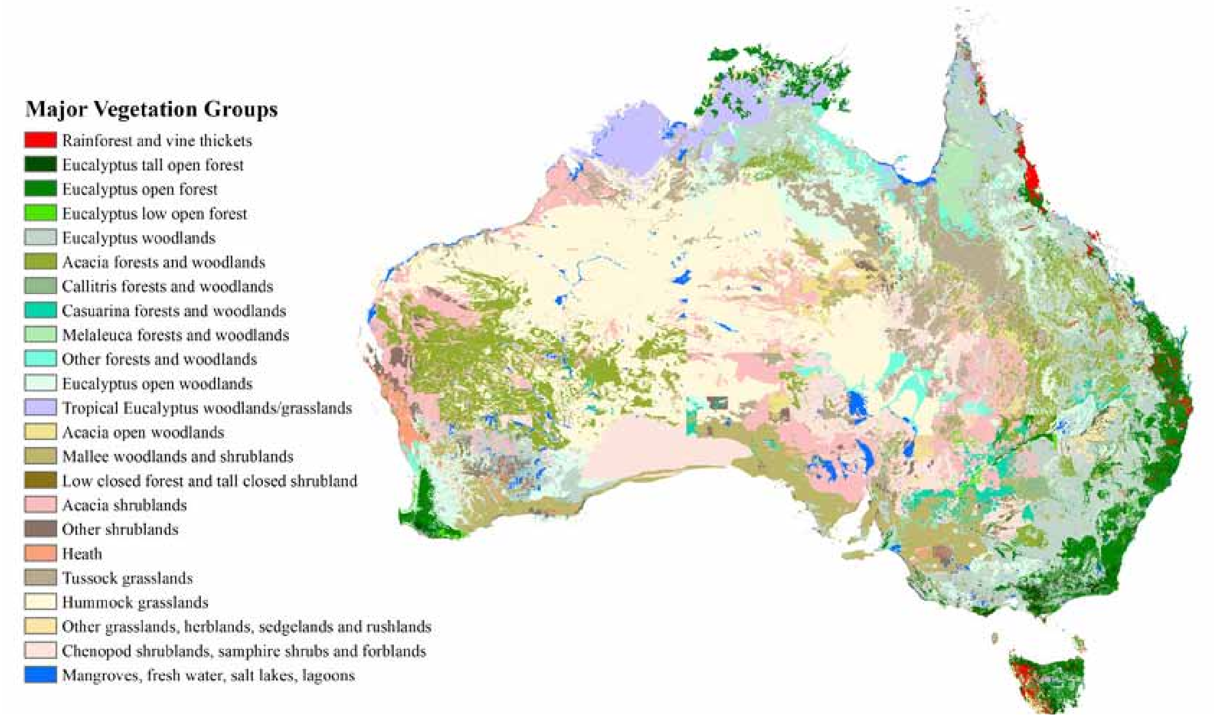
Forest type mapping

The National Vegetation Information System (NVIS, see NLWRA, 2001) provides a composite of the best available vegetation mapping in Australia. For the *forest land converted to cropland* and *forest land converted to grassland* sub-categories, various forest characteristics (e.g., forest floor coarse woody debris and litter) are associated with the forest types extracted from the NVIS. The NVIS collates and provides, in a consistent taxonomy and classification, the best available vegetation maps from all available sources. Six levels of information are available (Table 7.F5). For the purposes of carbon accounting the Level III Major Vegetation Grouping (MVG) categories were applied (Figure 7.F2). These vegetation types are described in Attachment 7.F1.

Table 7.F5. National Vegetation Information System (NVIS) hierarchical classifications

Hier-archical Level	Description	National Vegetation Information System structural/floristic components required
I	Class	Dominant growth form for the ecologically dominant stratum
II	Structural Formation	Dominant growth form, cover and height for the ecologically dominant stratum.
III	Broad Floristic Formation	Dominant growth form, cover, height and broad floristic code usually dominant land cover Genus for the upper most or dominant stratum.
IV	Sub-Formation	Dominant growth form, cover, height and broad floristic code usually dominant Genus and Family, for the three traditional strata.(i.e. Upper, Mid and Ground)
V	Association	Dominant growth form, height, cover and species (3 species) for the three traditional strata. (i.e. Upper, Mid and Ground)
VI	Sub-Association	Dominant growth form, height, cover and species (5 species) for all strata.

Figure 7.F2. Major vegetation groups (MVG)



APPENDICES

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 the NCAS land cover change program pre-dated the current vegetation mapping (which was generally based on data from 1990 onwards). This meant that areas identified as cleared land in the NVIS could have been forested between 1972 and the date used in the NVIS mapping. In these instances, the vegetation type allocation was drawn from the 1770 modelled (inferred) vegetation map.

While the forest potential maximum (at maturity) biomass and growth rates are largely independent of forest type, other tree characteristics are specific to forest type. Wood density, partitioning of mass to different tree components, the belowground to aboveground biomass ratios and the initial debris stocks are forest type dependent. These are described in the sections below.

Wood basic density

One of the key benefits of the direct biomass (rather than volume) modelling approach used in the *forest land converted to cropland* and *forest land converted to grassland* sub-categories, is that the considerable uncertainty in wood basic density values for various forest types and species does not affect the model results, as would be the case for volume based inventories. Although volume, and hence basic density, is not used in the carbon modelling, it is back calculated during the analysis to assist in comparisons between modelled estimates and measured plot data for verification purposes.

The wood basic density information used for the back calculation of wood volume was drawn from Ilic *et al.*, (2000), a national compendium of wood basic density information prepared for the NCAS. The data of Ilic *et al.*, (2000) are presented on a species basis. The wood basic density assigned to each forest type is an approximate average of the values for species typically represented in each class. The wood basic density values used are shown in Table 7.F6.

Table 7.F6. Wood basic density values for the Major Vegetation Group (MVG) classes

MVG Class	Wood Density (Basic) (kg dry matter m^{-3})
Rainforest and Vine Thickets	500
Eucalypt Tall Open Forest	550
Eucalypt Open Forest	625
Eucalypt Low Open Forest	550
Eucalypt Woodland	890
Acacia Forest and Woodland	940
Callitris Forest and Woodland	650
Casuarina Forest and Woodland	860
Melaleuca Forest and Woodland	660
Other Forests and Woodland	800
Tropical Eucalypt Woodland/Grassland	830
Eucalypt Open Woodland	890
Acacia Open Woodland	940
Mallee Woodland and Shrubland	1,060
Low Closed Forest and Closed Shrubland	1,000
Acacia Shrubland	940
Other Shrubland	940
Heath	900
Chenopod Shrub, Samphire Shrub and Forbland	900
Unclassified Native Vegetation	780

Age of maximum biomass increment

Where an area that has previously been cleared begins to re-grow to forest, the forest biomass increment is modelled using the simple empirical growth model described in Appendix 7.A. and Richards and Brack (2004a), Brack *et al.*, (2006) and Waterworth *et al.*, (2007). One of the key parameters in this model is the age of maximum aboveground biomass increment (BI_a).

Available national data and literature sources were analysed to estimate BI_a for regrowth forests (i.e., those identified by remote sensing as recovering from clearing since 1972). This work was conducted by the Australian National University and was based largely on the work of West and Mattay (1993). This was a challenging task due to the lack of growth data for Australia's native forests, in particular for the drier woodlands. This was noted by Richards and Brack (2004a) who suggest that understanding *"…growth patterns in lower productivity (generally non-commercial forest types…)."* could be enhanced by further sampling because *"…few yield tables are available for these types of forests"*.

Available data, such as that reported by West and Mattay (1993), suggest that the age of maximum current annual increment (CAI) for stem volume is within a small range (12-20 years) for most species and is largely independent of site productivity. For the *forest land converted to cropland* and *forest land converted to grassland* sub-categories the age of maximum aboveground biomass increment is set to 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 1to 2 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 1 to 2 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 10 is equivalent to an effective age of maximum current annual increment in stemwood volume of around 14 years. A BI_a of 10 is higher than that found in most eucalypt plantations, which reach this peak between 2 to 7 years. Plantation management aims to achieve maximum growth rates as quickly as possible and probably represent the best achievable early age growth rates when compared to natural forests.

Tree partitioning

The partitioning of mass to different tree components has limited effect on the carbon modelling for forest conversion, but robust data are required for model accuracy. The NCAS initiated a number of studies to collect data relevant to partitioning (Keith *et al.*, 2000, Eamus *et al.*, 2000, Grierson *et al.*, 2000 and Burrows *et al.*, 2001). Snowdon *et al.*, (2000) provides a synthesis of the available data. While in harvested forests, tree components will likely be treated independently (e.g., stemwood being removed from the site as wood product and crowns burnt or left to decay onsite); such differential management does not occur in land clearing activity to any degree of significance, except for some removal of firewood. A national study on firewood collection indicated that limited activity is associated with forest conversion (Driscoll *et al.*, 2000).

The most important attribute in partitioning is the ratio of belowground biomass to aboveground biomass (the root:shoot ratio), which is estimated using available data (Snowdon *et al.*, 2000). There is also a need to apportion materials to different decomposition pools from aboveground components. As land cover change is frequently cyclic (including removal of regrowth), any over- or underestimates in growth due to the root-to-shoot ratio applied will be largely compensated for by an equivalent over– or underestimate in amounts of regrowth removed. The partitioning ratios used are drawn from the best available data, largely taken from the synthesis of data compiled by Snowdon *et al.*, (2000) for the NCAS. The partitioning used for each forest type is shown in Table 7.F7.

Table 7.F7. Partitioning of biomass by Major Vegetation Group (MVG) class

Name	Yield Allocation to Stems (fraction)	Yield Allocation to Branches (fraction)	Yield Allocation to Bark (fraction)	Yield Allocation to Leaves (fraction)	Yield Allocation to Coarse Roots (fraction)	Yield Allocation to Fine Roots (fraction)
Rainforest and vine thickets	0.78	0.06	0.06	0.01	0.06	0.03
Eucalyptus Tall Open Forest	0.67	0.09	0.10	0.02	0.08	0.04
Eucalyptus Open Forest	0.45	0.12	0.10	0.02	0.25	0.06
Eucalyptus Low Open Forest	0.45	0.12	0.10	0.02	0.25	0.06
Eucalyptus Woodland	0.44	0.15	0.10	0.02	0.23	0.06
Acacia Forest and Woodland	0.42	0.15	0.10	0.02	0.25	0.06
Callitris Forest and Woodland	0.42	0.15	0.10	0.02	0.16	0.15
Casuarina Forest and Woodland	0.42	0.15	0.10	0.02	0.25	0.06
Melaleuca Forest and Woodland	0.42	0.15	0.10	0.02	0.25	0.06
Other Forests and Woodland	0.42	0.15	0.10	0.02	0.25	0.06
Eucalyptus Open Woodland	0.41	0.18	0.10	0.02	0.23	0.06
Tropical Eucalyptus woodland/grassland	0.41	0.18	0.10	0.02	0.23	0.06
Acacia Open Woodland	0.22	0.165	0.10	0.025	0.42	0.07
Mallee Woodland and Shrubland	0.22	0.165	0.10	0.025	0.42	0.07
Low Closed Forest and Closed Shrubland	0.22	0.165	0.10	0.025	0.42	0.07
Acacia Shrubland	0.22	0.165	0.10	0.025	0.25	0.24
Other Shrubland	0.22	0.165	0.10	0.025	0.25	0.24
Heath	0.00	0.3	0.18	0.03	0.25	0.24
Chenopod Shrub, Samphire Shrub and Forbland	0.00	0.3	0.18	0.03	0.25	0.24
Mangrove, tidal mudflat, samphire and bare areas, claypan, sand, rock, salt lakes, lagoons, freshwater lakes	0.167	0.167	0.167	0.167	0.167	0.167
Unclassified Native vegetation	0.39	0.14	0.09	0.02	0.25	0.11

Tree carbon contents

The carbon content of the estimated biomass (dry matter) is needed to derive a carbon mass equivalent from the biomass modelling. Studies by Gifford (2000a) and Gifford (2000b) for the NCAS considered the carbon content of various tree components, for a range of species and across a range of environments. Drawing on this work, the carbon contents used in this analysis are shown in Table 7.F8.

Table 7.F8. Carbon content of tree components

Tree Component	Carbon Content (fraction of dry matter)
Stems	0.50
Branches	0.47
Bark	0.49
Leaves and Twigs	0.52
Coarse Roots	0.50
Fine Roots	0.48

Tree component turnover rates

Tree component turnover rates determine the inputs to litter, while soil organic matter is largely derived from root turnover (the balance coming from litter decomposition). The tree component turnover rates have little effect on the *forest land converted to cropland* or *forest land converted to grassland* categories except for areas under trees that are part of the cyclic regrowth cycle. Litterfall (leaf), branch and bark shed and root turnover have been determined from available literature. The rates applied are in Table 7.F9. These draw heavily on the rates determined by Paul *et al.*, (2002b) in a model calibration study for the NCAS.

Table 7.F9. Tree component turnover rates

Tree Component	Turnover rate yr^{-1}
Leaf	0.0470
Branch	0.0056
Bark	0.0083
Coarse Roots	0.0560
Fine Roots	0.1042

Forest litter

Initialisation of the forest litter stock in the model (coarse woody debris and fine litter) draws upon assessments carried out for the NCAS in conjunction with the soils measurement program (Murphy *et al.*, 2002; Griffin *et al.*, 2002; Harms and Dalal, 2003; Harms *et al.*, 2005) and a separate study by Mackensen and Bauhus (1999). Sites used in these studies were widespread throughout the areas primarily cleared for agricultural purposes. Additional data were drawn from literature where available. The values used are shown in Table 7.F10. Debris mass is converted to carbon assuming a carbon fraction of 0.45.

Forest residue management

The principal methods of land cover change for forest conversion involve the extraction of root material (e.g., tree pulling) to allow for subsequent cultivation for pasture and cropping. Limited use of tree poisons, with subsequent standing decomposition (by microbial and invertebrate activity) also occurs.

Table 7.F10. Initial forest litter values (t dry matter ha^{-1})

Major Vegetation Group (MVG) Class	Decomposable Fine Decay	Resistant Fine Decay	Decomposable Coarse Decay	Resistant Coarse Decay	Decomposable Leaf Decay	Resistant Leaf decay	Decomposable Bark Decay	Resistant Bark Decay	Decomposable Deadwood Decay	Resistant Deadwood Decay
Rainforest and Vine Thickets	30	18	14	10	5	2	0.5	2	18	100
Eucalypt Tall Open Forest	30	18	14	10	12	5	1	5	18	100
Eucalypt Open Forest	20	9	7	5	10	4	1	5	9	56
Eucalypt Low Open Forest	10	5	4	3	7	3	0.75	3	5	30
Eucalypt Woodland	5	2	1	1	4.5	2	0.5	2	2	12
Acacia Forest and Woodland	5	2	1	1	4.5	2	0.5	2	2	12
Callitris Forest and Woodland	5	2	1	1	4.5	2	0.5	2	2	12
Casuarina Forest and Woodland	5	2	1	1	4,5	2	0.5	2	2	12
Melaleuca Forest and Woodland	5	2	1	1	4.5	2	0.5	2	2	12
Other Forests and Woodland	5	2	1	1	4.5	2	0.5	2	2	12
Tropical Eucalypt Woodland/Grassland	6	3	2	1.5	4	2	0.5	2	2	15
Eucalypt Open Woodland	5	2	1	1	4.5	2	0.5	2	2	12
Acacia Open Woodland	1	0.2	0.1	0.1	3	1	0.2	1	1	2.5
Mallee Woodlandand Shrubland	1	0.2	0.1	0.1	3	1	0.2	1	1	2.5
Low Closed Forest and 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

APPENDICES

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. The *FullCAM* model 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 per cent, leaving 2 per cent of all biomass unaffected by burning. Further residue is left to decompose following incomplete combustion, with combustion efficiencies set at 90 per cent for stems, 95 per cent for bark, 95 per cent for leaf litter, 80 per cent for coarse dead roots and 70 per cent for fine dead roots.

Litter decomposition rates have been extracted from available information including the study undertaken by Mackensen and Bauhus (1999) for the NCAS. The rates applied are shown in Table 7.F11. There are few studies in Australia of litter decomposition rates with most work being focused on wood product longevity trials. The data were supplemented with some limited chronosequence work on paired sites. However, the main focus of this work was on modelling rates that coincided with measures of litter mass when the models were run over extended periods so that a reasonable balance between turnover (input to litter pools) and decomposition of litter pools was achieved.

Table 7.F11. Litter decomposition rates for tree components

Plant Component	Decomposition Rate (yr^{-1})
Decomposable Leaf	1.0
Resistant Leaf	1.0
Decomposable Deadwood	0.1
Resistant Deadwood	0.1
Decomposable Bark	0.5
Resistant Bark	0.5
Decomposable Coarse Root	0.4
Resistant Coarse Root	0.1
Decomposable Fine Root	0.3
Resistant Fine Root	0.4

Soil Carbon parameters

The soil carbon model (*Roth–C*) parameters did not vary from those developed as part of the NCAS development programme. A full description of the programme and the parameterisation of the model is provided in Appendix 7.A.

Attachment 7.F1: Major Vegetation Groupings Classified by the National Vegetation Information System

Group 1. Rainforest and Vine Thickets

Rainforest communities in Australia are mostly confined to the wet and cooler areas or climatic refuges in eastern Australia, apart from the semi-evergreen vine thickets of the Brigalow Belt and the monsoonal vine thickets that are found in the tropics in Western Australia and the Northern Territory. Community types include cool temperate rainforest, sub-tropical rainforest, tropical rainforest, vine thickets, and semi-deciduous and deciduous vine thickets. Rainforests were cleared extensively in the late 19th or early 20th centuries for high value timbers, dairying, tobacco/sugar cane or other agricultural production.
The best known examples of this are the "Big Scrubs" of Illawarra and northern New South Wales and the Atherton Tableland in north Queensland.

Group 2. Eucalyptus Tall Open Forest

These communities are restricted to all but the wetter areas of eastern Australia from the margins of the wet tropical rainforests of north Queensland to Tasmania, and the south west of Western Australia, often in rugged mountainous areas. At their maximum development in Tasmania and parts of Victoria, they contain the world's tallest flowering plants, with some trees rising to heights in excess of 100 m.
These communities are typified by a well-developed often broad-leaved shrubby understorey or sometimes tree ferns and are mostly found adjacent to, or in association with, rainforest communities. Extensive areas of these communities were cleared for agriculture and grazing early in the 20th century, particularly where they occurred in association with rainforests. Major areas remain today in crown reserves as State Forests or National Parks.

Group 3. Eucalyptus Open Forest

Widespread along the sub-coastal plains and 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

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 does 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.G: Cropland Remaining Cropland

Background

Cropland by definition is land on which crops are grown and harvested. The *cropland remaining cropland* sub-category covers an area of over 20 million hectares and includes lands under rotational crop-pasture systems that change between grassland and cropland on a regular basis. Land that is categorised as *cropland remaining cropland* has been under a cropping system 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 converted to *forest land* or *grassland* but remain as *cropland*.

Australian croplands range over a longitude of 40^{o} and latitude of 25^{o} resulting in significant geographical variation in the types of crops grown and climatic conditions (Unkovich *et al*, 2009). Climate variability is an important factor affecting changes in Australian crop production, with rainfall variation the main contributor to changes in crop yields from one year to another (ABARE, 2009e). Croplands are generally located along a broad inland fringe across the southern and eastern areas of Australia, with the highest yields commonly obtained in the south west and eastern regions. In the southern regions, cropland is dominated by wheat production, with barley, oats, lupins and canola being the other dominant crops. In the north wheat, sugarcane, sorghum and cotton production dominate.

Pasture and grass systems that have never been cropped (annual, perennial, improved, native, permanent and lucerne) are reported under the *grassland remaining grassland* sub-category. Pasture and grass systems that are incorporated as part of a crop-pasture rotation, are reported under the *cropland remaining cropland* sub-category.

Cropland Management Practices

The climate in Australia has a strong influence on agricultural land use. For example, the tropical north is suited to extensive grazing (principally cattle) as well as, in some areas, intensive production of fruit, sugarcane and grain crops which are grown during the summer wet season (Dec – Apr), but also include regions where winter crops can also be grown. The temperate regions support grain cropping and livestock production. In the drier central regions, low-density grazing (mostly cattle) is found (Swift & Skjemstad, 2002). In the southeast of Australia, the Murray-Darling Basin has a large irrigation infrastructure to support the production of fruit, vegetables, rice, and other intensive agricultural activities including irrigated broadacre crops (DAFF, 2005).

Irrigation

The nature of Australian cropping systems is predominantly rainfed whereby the amount and distribution of rainfall are important determinants of crop selection, growth and yield. The majority of crops grown in Australia are winter dominant given that they are predominantly reliant on winter rainfall with 55% of the cropping area receiving winter dominant rainfall (southern Western Australia, South Australia and Victoria), 40% receiving equiseasonal rainfall (New South Wales), and 5% receiving summer dominant rainfall (Queensland) (Unkovich *et al.*, 2009). In addition, crop yields vary according to the annual distribution of rainfall and the types of crops grown within a region. Irrigation of cropping systems only accounts for approximately 1 million hectares of field crops (approximately 5% of the total cropped area), most of which (92%) occurs in New South Wales and Queensland.

Some farmers in Australia use irrigation water, where available, to supplement rainfall in agricultural production systems, largely due to Australia's variable and unpredictable rainfall; however, irrigation practices differ between farms according to water availability, soil type, topography, state legislation and water costs, to name a few (ABS, 2008e). Some crops are almost totally dependent on irrigation, while for others irrigation water supplements natural rainfall or provides moisture at critical periods of plant growth (ABS, 2007).

Water sources for irrigation are mostly drawn from surface water, such as rivers, lakes, weirs and dams with most water used for irrigation originating from Australia's major river systems, the Murray-Darling system in eastern Australia and the Ord River in the Kimberley region of Western Australia together with other significant river and dam systems in Queensland, Western Australia and Victoria (ABS, 2008e). Another large source of water is ground water from the Great Artesian Basin which covers irrigation for north-eastern Australia (ABS, 2008e).

Fertiliser application

Australian soils are geologically old, highly weathered, fragile and naturally nutrient deficient and need extra nutrients to maximise crop yields. The application of nitrogen- and phosphorus-based fertilisers to Australian soils aid in increasing soil fertility and hence agricultural productivity. The most common types of fertiliser used in Australia are urea and single superphosphate, however ammonium phosphates and manufactured fertilisers are also commonly used (ABS, 2009d).

Crop residue management

The crop residue management practices used in Australia include leaving crop residue intact, removing crop residue by baling or heavy grazing, burning crop residue, ploughing crop residue into the soil, and mulching crop residue (ABS, 2009d). The burning of crop residue was a widespread practice in Australia in the early 1970s generally occurring prior to sowing of the next year's crop (Swift & Skjemstad, 2002), although there has been a widespread move away from burning, it is still practised in some regions to control weeds. Nowadays, there is a tendency to retain crop residue for soil protection over the summer months (i.e., retention of soil water and minimise erosion). Subsequent crops are sown directly into the stubble residues which help to retain soil moisture. In the Western Australia cropping region more than 86% of growers now adopt this practice (Llewellyn *et al.*, 2009). However, burning of crop residue is still used as a strategy to control weeds, diseases and pests than to remove bulky straw. The main crop residue management practices now undertaken in Australia include leaving residue intact, grazing residues over the summer months, removing crop residues by baling, and ploughing crop residues into the soil.

Methodology

The *cropland remaining cropland* sub-category includes emissions and removals due to the effect of climate, the effects of management regimes (including residue burning), and the effect of grazing on crop-pasture rotation systems. The key drivers of the emissions and removals in *cropland remaining cropland* are:

- Annual variability (gains or losses) in biomass due to climate variability, particularly rainfall and frost;
- Management practices (in particular fertiliser application and residue management);
- Crop-pasture rotations; and
- Grazing of stubble or pasture within crop-pasture rotations;

The reporting of *cropland remaining cropland* includes all on-site carbon pools (living biomass, dead organic matter and soil). Emissions and removals are estimated using the Tier 3, Approach 3 NCAS mass balance, process-based ecosystem model *FullCAM*, as described in Appendix 7.A.

For this sub-category, it is presumed that land in the *cropland remaining cropland* area entered this category following deforestation between 1940 and 1971. The date of deforestation of each pixel is randomly allocated between these years. The model is then 'run-in' for a period from 1972 to 1989, for the initial reporting year of 1990, to stabilise the soil carbon stocks therefore reflecting soils under long term cropping management. As the lands in the *cropland remaining cropland* sub-category are retained under a similar land use for several years (i.e., the land has been *cropland* since 1972), changes in carbon stocks are affected primarily by land management practice and climate. These two factors largely determine the amount of live biomass and therefore the residues in dead organic matter that subsequently become incorporated into the soil carbon (Janik *et al*, 2002).

Management regimes are allocated to areas of cropland based on their location and soil type. The allocation ensures that the crop types being modelled represent the range of management practices described in the Land use mapping (see later). For the current *cropland remaining cropland* estimates management is not dealt with as comprehensively as for the *forest land converted to cropland* sub-category because spatially and temporally explicit management data for all of Australia's croplands is not yet available. This will be included once data is collected and incorporated in the model databases. Hence variation in the live biomass, dead organic matter and soil pools is largely driven by crop production, which varies due to climate and improved breeding. Therefore emissions and removals from this sub-category follow climate affects on crop production

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

Crop Biomass Change (Transitions)

The variability in gains and losses in cropping systems are highly affected by climate variability, particularly the variability in rainfall. Rainfall variability in Australia is very high relative to global patterns and often results in lengthy periods without rain (ABS, 2008e). Most recently in 2002-03 and 2006-07, Australia experienced two of the worst droughts on record, and in some regions the drought has lasted several years. These drought conditions resulted in highly variable (mostly losses) crop productivity levels, which are reflected in the degree of variation in emissions and removals of CO_2 (ABS, 2008e; Swift & Skjemstad, 2002).

The variability and seasonality of rainfall in Australia has been recorded as far back as the early 20th century (www.bom.gov.au) with records of droughts and very wet events being felt in most States and agricultural regions (at different times and for different lengths of duration). Major drought events often result in major yield declines in dryland (rainfed) crops contrasting with very wet periods during which crop yields increase (Swift & Skjemstad, 2002). Due to erratic rainfall events and the increasing failure of summer and winter crops to establish and yield, 'opportunity cropping' is becoming more prevalent in rainfed farming systems (Swift & Skjemstad, 2002). That is, the increased uncertainty in seasonal rainfall means that there is a large degree of 'opportunity cropping' rather than set rotations.

The agricultural regions of south-western Australia consist mainly of farms that rely on dryland grain crop production and livestock grazing in a ley-farming system (Swift & Skjemstad, 2002). More permanent grazing systems predominate in the wetter districts (> 750 mm annual rainfall) and the more permanent cropping systems predominate in the drier districts (< 400 mm annual rainfall). Increasingly, in drier districts, farmers are moving away from livestock and into cropping-only systems which has become a more viable option (Swift & Skjemstad, 2002) and national herd numbers for sheep have declined over the past 20 years whereas cattle numbers have increased slightly (ABARE, 2008d).

Mapping of Cropland Remaining Cropland Systems

The mapping of the extent of *cropland remaining cropland* systems is estimated using the National Land Use 2001/2002 (Version 3) Summary Statistics provided by the Bureau of Rural Sciences (http://nlwra.gov.au/). The area of cropping includes areas of both continuous cropping and areas under crop-pasture rotations. Areas of cropland that are included in the *forest land converted to cropland* sub-category are excluded from this mapping to prevent double counting of land areas.

Estimation of CO_2 Emissions and Removals

Carbon dioxide (CO_2) emissions and removals from *cropland remaining cropland* are estimated using the Tier 3 NCAS *FullCAM* model which introduces into the estimates both natural and anthropogenic emissions and removals in living biomass, dead organic matter and soil associated with land management practice and annual climate variability. The models use the same climate, site and management data as that used in the *forest land converted to cropland* estimates as described in Appendix 7.F. Emissions and removals are calculated by summing the results of all modelled pixels for each year.

Results

Having been retained under a similar land use over the period since at least 1972, changes in carbon stocks will largely be affected only by land management and climate (particularly rainfall). These factors determine the amount of live biomass and dead organic matter, as well as the amount of residues and fertiliser inputs to soil carbon.

The emissions estimation of the *cropland remaining cropland* sub-category is reported in Table 7.G1 which show strong variability due to climate.

Table 7.G1 Net CO_2 emissions and removals estimates for *Cropland remaining Cropland*

Year	Net CO_2 emissions (Mt CO_2)
1990	-22.92
1991	-23.78
1992	-4.59
1993	-24.58
1994	-37.39
1995	-10.58
1996	-4.93
1997	-18.28
1998	8.60
1999	-6.22
2000	-16.02
2001	-24.10
2002	38.65
2003	-27.24
2004	-37.28
2005	-51.13
2006	9.57
2007	18.05
2008	-18.77

Appendix 7.H: Grassland Remaining Grassland

Background

The *grassland remaining grassland* sub-category covers around 440 million hectares of land. The vast majority of this area occurs in inland Australia and is used for extensive grazing of both sheep and cattle. In Australia, grazing occurs across very diverse climate, ecosystem and management systems. The pasture types and associated management intensities range from highly improved and sometimes irrigated pastures to extensive rangeland systems in the semi-arid and arid regions of Australia. Native or naturalised pastures are the major pasture type, occupying approximately 17% of Australia's land area with sown and fertilised pastures occupying only 4% of the land area. Sown pastures are represented by mixed annual grasses and legumes as well as mixed perennial grasses and legume species depending upon rainfall and regional location. Irrigated pastures represent about 1% of all pastures and are generally confined to the dairy and feedlot industries.

Pasture productivity determines the amount of live biomass that is produced, while the effects of grazing and fire determine transition of the living biomass into carbon stock pools over a reporting period. In addition, the dead organic matter and soil carbon pools will be influenced by pasture utilisation (grazing management), and interventions such as burning. The introduction of an improved pasture system may lead to a moderate increase or decrease in soil carbon, and this may vary (increase or decrease) on an annual basis according to annual climate variability.

Methodology

The *grassland remaining grassland* sub-category includes emissions and removals in both shrub (non-forest forms of perennial woody vegetation) and grass systems, including the effects of grazing, grass and shrub transitions and the effects of fire. This comprehensive approach therefore also captures the losses and uptake of carbon associated with savanna burning, both anthropogenic and natural. The key drivers of the emissions and removal in *grassland remaining grassland* are:

- grazing intensity;
- annual variability in biomass due to climate variability;
- land management (in particular burning practice);
- natural disturbances (wildfire); and,
- shrub and grass transitions (due to both natural effects and anthropogenic cause).

The distribution and area of land in *grassland remaining grassland* was estimated using the National Land Use 2001/2002 (Version 3) Summary Statistics prepared by the Bureau of Rural Sciences (www.nlwra.gov.au). The subset of areas of *grassland remaining grassland* that were shrub vegetation was established by the methods described below. The area that was only grasses was established by removing the areas of shrubland from the total *grassland remaining grassland* area.

Grass component

The reporting for the grass component includes all on-site carbon pools (living biomass, dead organic matter and soil). Emissions and removals are estimated using the Tier 3, Approach 3 NCAS mass balance, process-based ecosystem model *FullCAM*, as described in Appendix 7.A. The calibration and verification of this model, along with the associated quality assurance and quality control program are described in Appendix 7.J. The data used in the model runs include plant growth rates, grazing intensity and pasture management practices such as burning. These data are described in Appendices 7.A and 7.F.

For the *grassland remaining grassland* sub-category, it is presumed that land in the grass component (i.e., not sparse woody vegetation) entered this category following deforestation between 1924 and 1971.

The date of deforestation of each pixel is randomly allocated in the period between these two years with the amount of clearing approximately evenly distributed in each year. The model is then 'run-in' for a period from 1972 to 1989, for the initial reporting year of 1990, which is used to stabilise the soil carbon stocks therefore reflecting soils under long-term grazing management, i.e., soil carbon is not significantly affected by the initial pasture establishment or former land use. This run-in allows the model to represent both areas which have always been grassland and those cleared for grazing prior to 1972.

For the current *grassland remaining grassland* grass component estimates, management data are not varied because comprehensive data for all of Australia's *grassland* are not yet available (as opposed to the *forest land converted to grassland* sub-category where data are available). Hence variation in the live biomass, dead organic matter and soil pools is largely driven by variations in the climate.

Grass and Shrub Transitions

There are many processes that lead to transitions between shrubs and grasses in Australian ecosystems. These processes are driven by factors that include how palatable the shrubs are to herbivores, and whether they are resistant or susceptible to fire, drought and waterlogging. The species concerned may be endemic, native (but not endemic), or introduced.

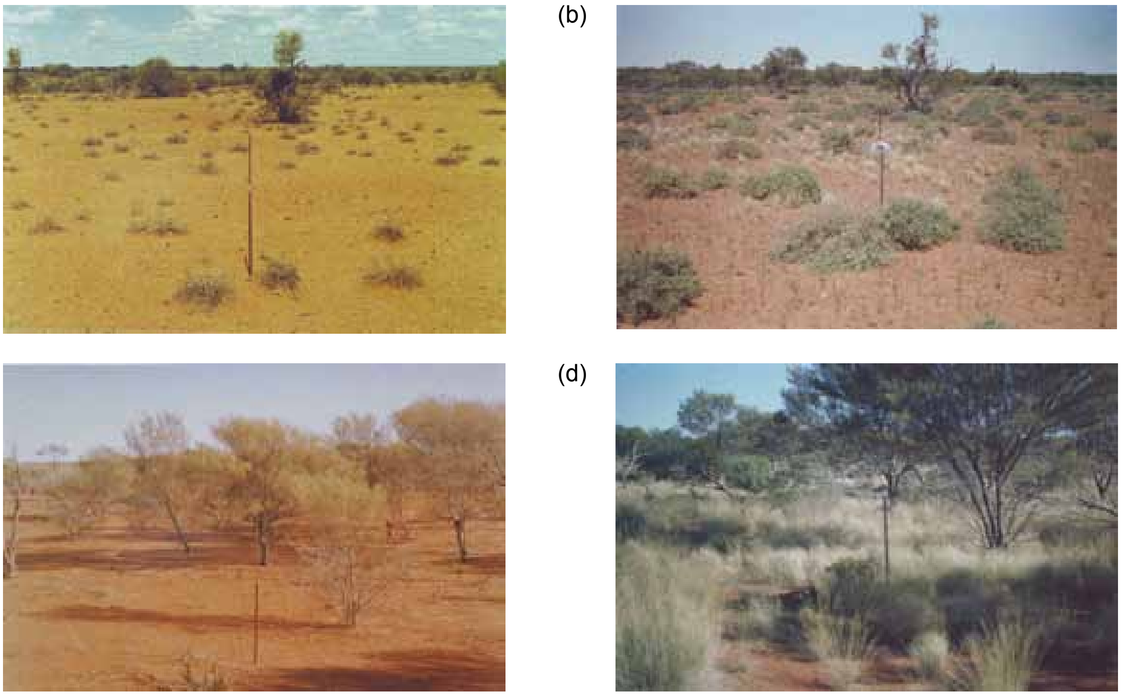
The direct anthropogenic transitions between shrub and grass systems, such as land clearing and the subsequent establishment of shrub plantations (e.g., saltbush for grazing and tea-tree for oils), are readily the 'cause' for the transition. Equally, losses due to natural and managed fires are also straight forward to interpret. Another natural phenomenon that impacts carbon stocks and transitions between grasses and shrubs is climate driven changes in the shrub condition. While the climate driven process is well understood, quantifying its effects is not straight forward. Figure 7.H1 highlights how the presence of shrubs can be affected by climate variability with 'flushing' in standing plants following a rainfall event.

Figure 7.H1 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) (b)

(c) (d)



Transitions that are not in response to a direct human intervention are difficult to assign a cause to, although they may occur in response to the combination of past or current land management and climate. These transitions are predominately a shift from grass to shrubs in a process often described as 'woody weed invasion'. Woody weed invasion has been reported in many areas of Australian rangelands and savannas. Woody weed invasion is often associated with changed fire regimes (lower frequency and less intensive) that have accompanied the introduction of grazing.

A range of land management practices are used to treat woody weed invasion and include:

- prescribed burning;
- mechanical control (e.g., ploughing); and,
- chemical control.

Mapping of extent and change in shrubs

Mapping of the extent, and change in extent in forest systems (as reported in other forest related emissions categories) is now relatively straight-forward using data from the Landsat satellite data archives (see Appendix 7.A). To supplement the forest mapping a national mapping program is currently underway to assess both the extent, and changes in extent, of sub-forest forms of woody vegetation. The results of the program to date are that:

- reliable extent and change mapping is possible (Caccetta and Furby, 2004) by supplementing the techniques applied to forest mapping to deal with the impact of low signal (proportion of woody vegetation of interest) to noise (other vegetation) ratio;
- the low signal to noise ratio leads to a variable lower detection limit. 'False change' (i.e., change only in the lower detection limit threshold) can occur and this must be addressed by enforcing a constant lower limit, which is in the order of 5-7% woody cover; and
- the analysis can only be applied to the more recent (since 1988) Landsat TM and ETM+ data. Data from the earlier Landsat MSS sensors is not able to deal with the low signal to noise ratio in these systems.

This inventory has seen the completion of a national coverage of shrubland extent 'base' maps (see Figure 7.H2) for a single point in time (2002). A further subset of areas (see Figure 7.H3) includes change analysis which has been applied and verified for the period 1991 to 2004.

Figure 7.H2 Extent of sparse vegetation in 2002 (Sparse vegetation shown in green)

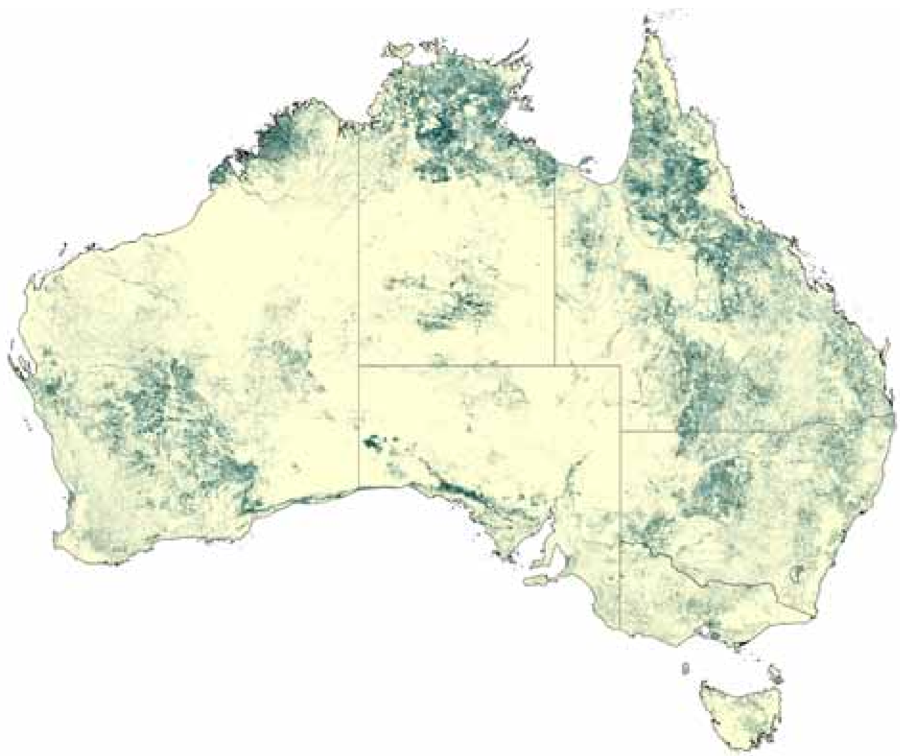
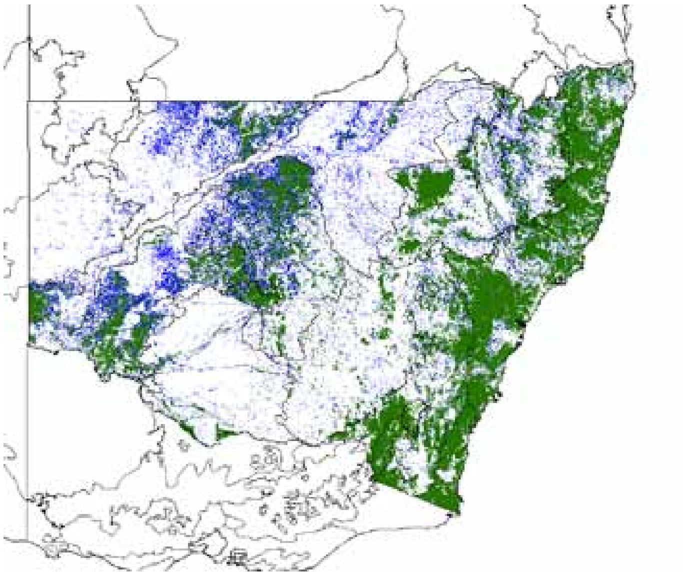


Figure 7.H3 Map of forest (green) and sub-forest woody vegetation (blue) for the area where the sparse change analysis has been verified



To use these preliminary data to derive an estimate of the emissions from grass to shrub transitions Australia has:

- used the recently completed shrubland extent base maps to determine the sub-forest woody vegetation extent; and
- used the time-series trends for change in areas where change is available (see Figure 7.H3) and applied this to the national extent.

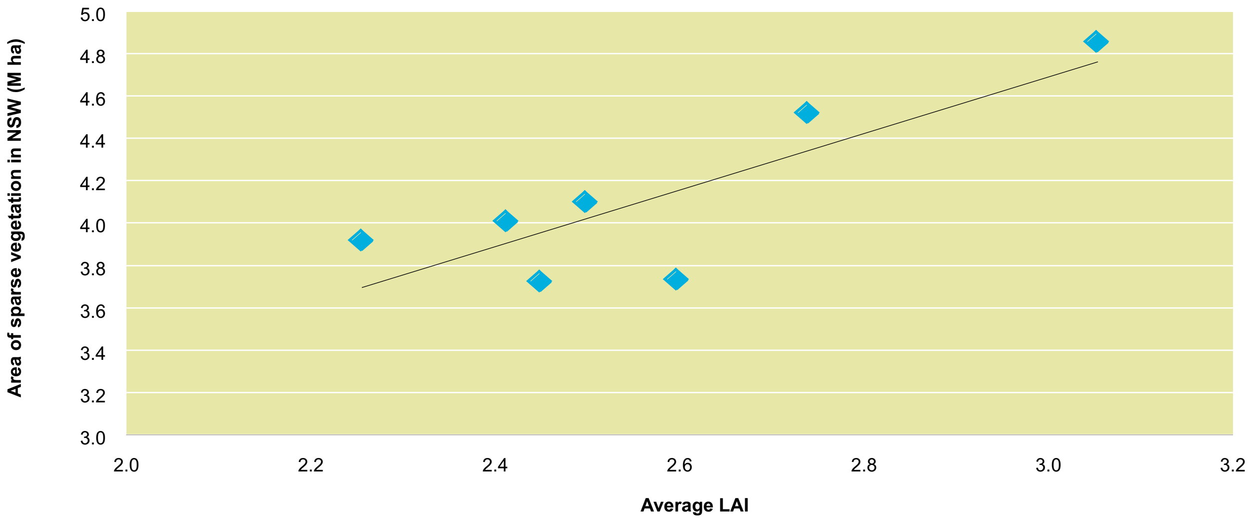
As the data on the transitions between shrubs and grasses were only available for a sample of the country since 1991, it was necessary to extrapolate the data so that an emissions estimate for 1990 could be derived. To do this, a relationship between the observed transitions (change) in the sample area and the national trends in leaf area index (derived from satellite data) was developed (Figure 7.H4; $r^2 = 0.65$). The robustness of this relationship allows for extrapolation of the observed shrub and grass transitions to the date of the first leaf area index (LAI) data in 1987. Prior to 1987 no net change in extent of shrub vegetation is assumed.

Estimation of emissions and removals

To estimate the change in shrub biomass due to the change in shrub area, the net annual change in area was placed in a simple Tier 2 model. The model uses an average woody biomass of 10 t DM ha^{-1} (Raison *et al.*, 2003) and presumes a loss of that amount in the years of net area loss. Where the area of shrubland increases it is assumed that these will regrow to 10 t DM ha^{-1} over 5 years (i.e., a growth rate of 2 t DM ha^{-1} yr^{-1}). The results of this analysis are shown in Table 7.H2.

APPENDICES

Figure 7.H4 The relationship between leaf area index and sparse woody vegetation change



Fires

Fires are the major natural disturbance in grasslands, and area burned varies from year to year. Fire in grass areas of the *grassland remaining grassland* sub-category are modelled as part of the Tier 3 *FullCAM* analysis. Fires in the shrubland component of the *grassland remaining grassland* sub-category are modelled using a Tier 2 method. The fire activity data and model parameters (see Table 7.H1) applied in the Tier 2 model are the same as those used for the estimation of non-CO_2 gases from the *prescribed burning of savannas* (4.E). Following burning, shrub biomass is presumed to recover over a four year period.

For some States (Victoria, New South Wales and Tasmania) the area burnt data used for the *prescribed burning of savannas* (4.E) do not include a differentiation between shrubland and grassland. For these States it was assumed that the areas reported represent shrubland. Since 1983 (when data in all states first become available) the areas burnt in these states represent less than 1% of the total area burnt. Therefore the effect of this assumption is considered insignificant.

Table 7.H1 Model parameters for the *grassland remaining grassland* fire emissions and removals estimation

Parameter	NSW	Tas	WA	SA	VIC	QLD	NT
Fuel load	6.9	9.0	8.3	3.0	11.7	3.0	4.1
Burn Efficiency	0.72	0.72	0.72	0.72	0.72	0.72	0.72
C%	0.46	0.46	0.46	0.46	0.46	0.46	0.46
C loss ha^{-1}	2.29	2.98	2.75	0.99	3.88	0.99	1.36
Years to recover	4	4	4	4	4	4	4

Results

Having been retained under a similar land use over the period since at least 1972, changes in carbon stocks will largely be affected only by land management, natural disturbances and climate. These factors largely 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 emissions estimation of the grassland dynamics from the areas of grassland showed an overall trend of being a source of emissions, with strong variability due to climate and fire. The results are reported in three parts (Table 7.H2) to reflect the three elements of the emission estimation:

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

Table 7.H2 Emissions and removals (Mt CO_2) for *grassland remaining grassland*

	Emissions Mt CO_2			
Year	Grass	Sparse	Fire	Total
1990	-0.60	-16.43	1.30	-15.73
1991	61.30	23.13	-31.89	52.55
1992	56.83	20.64	-11.24	66.23
1993	14.65	-14.59	-0.07	-0.02
1994	0.90	-8.85	8.68	0.74
1995	36.65	-9.17	88.14	115.62
1996	-15.23	-11.79	20.50	-6.52
1997	18.09	-6.68	-19.51	-8.10
1998	62.05	-13.63	47.37	95.79
1999	23.32	-9.73	0.27	13.85
2000	-69.89	15.97	44.78	-9.14
2001	-64.57	-27.30	67.97	-23.90
2002	146.59	24.60	40.89	212.09
2003	68.39	-14.49	-70.28	-16.38
2004	43.54	-38.10	-101.48	-96.04
2005	37.34	-22.21	85.78	100.90
2006	181.95	-7.22	-121.55	53.18
2007	142.99	32.01	76.80	251.80
2008	61.30	-24.89	101.41	137.82

Appendix 7.I: Harvested Wood Products

Introduction

Harvested wood product CO_2 emissions are considered under the 1996 (Revised) IPCC *Guidelines* for the United Nations Framework Convention on Climate Change (IPCC 1997) and associated *Good Practice Guidance* (IPCC 2003) and are reported in the *land use, land use change and forestry* component of Australia's National Greenhouse Gas Inventory where they arise from the service life of products. Emissions from landfill are reported under the *waste* sector of the inventory.

A national database of domestic wood production, including import and export quantities, has been maintained in Australia since the 1930s. This consistent and detailed collection of time-series data provides a sound basis for the development of a national wood products model. Jaakko Pöyry Consulting were initially engaged by the National Carbon Accounting System (NCAS) to develop a national carbon accounting model for wood products, and that work provides the precursor model to that adapted and described here. The model development is reported in detail in NCAS technical reports, 8 (Jaakko Pöyry Consulting, 1999) and 24 (Jaakko Pöyry Consulting, 2000). Updates and model refinement were subsequently undertaken by MBAC Consulting in conjunction with the NCAS. Jaakko Pöyry Consulting subsequently provided a quality assurance review of the model (see Appendix 7.J). The refined model and its sensitivity analysis are reported in Richards *et al.*, (2007). The independent quality assurance for the model is in Appendix 7.J (section 7.J.3.8).

Accounting Approaches

Accounting approaches for carbon emissions from timber harvesting and wood products include emissions from wood products in Australia (wherever the source). This approach accounts for emissions from all wood products within Australia, regardless of their country of origin. Exported wood products are not accounted for and are the responsibility of the importing country. The amount of material exported is deducted from the total production, with total imports added, to derive the amount of material available for emissions within Australia. The origin of imported wood products is not tracked. However, the total flow of imported wood products into various pools within Australia is monitored.

Model Components

Information has been obtained and examined under the following components of the model:

- log flow from the forest: current annual production data were obtained by species groupings, and product classes, e.g., sawlogs, veneer logs, pulp logs, roundwood and other, e.g., sleepers;
- fibre flow from processing: data on the intake of raw materials to the various processing options and the output of products and by-products have been used in the model to estimate the total tonnes of carbon produced each year under various end product classes;
- import and export quantities of wood products;
- recycling;
- entry and decomposition in landfill;
- use for bioenergy; and,
- other losses to atmosphere.

Life Cycles and the Wood Products Carbon Pool

Estimates of the life cycles appropriate for each class of wood product have been made and methods for estimating the initial pool of carbon, as represented by wood products in use since 1943, have been proposed. Annual log removals data are available through the Australian Forests Products Statistics published quarterly by the Australian Bureau of Agricultural and Resource Economics (ABARE 2009c). Data are also available through the Levies Management Unit of the Department of Agriculture, Fisheries and Forests, on behalf of the Forest and Wood Products Research and Development Corporation (FWPRDC). Log removals data are also published by the relevant State Forest Services and these provide a valuable crosscheck on ABARE data.

Cypress pine removals are included under the total for coniferous logs and a separate figure is not provided. It is necessary to extract cypress pine volume and analyse separate from softwood sawmilling because:

- Cypress pine is a significant source of wood products;
- Cypress pine is a native conifer and softwood sawmilling largely refers to exotic species plantations; and,
- Cypress pine is a denser wood than exotic pines and is used by a totally separate industry supplying different products to the market.

A Cypress pine figure can be developed from the ABARE information by applying a conversion factor to sawn-wood consumption and applying a conversion factor to 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”% sawdust, shavings or sander dust for on-site energy generation or compost, “y”% woodchips for other manufacturing processes, “z”% of sawn timber products, panel products and paper;
- an estimate of the proportion of products by product categories, depending on whether their expected end use is long-term or short-term; e.g., framing timber, dry dressed boards, cases and pallet stock, panel products for use in house construction, panel boards for use in furniture and cabinets, newsprint paper, and writing and printing paper;
- a final figure for total Australian consumption by end use categories, converted to wood fibre content (oven-dry weight) and to tonnes of carbon; and
- import and export data obtained from the ABARE (2009c) by end use categories.

Details of the flows are shown in Attachment 7I.1.

Treatment of Bark

There has been no accounting for bark in this study. All bark is regarded as being a component of logging slash (harvesting residue) and accounted for under in-forest logging operations, for the following reasons:logs are sold with log volumes recorded on an underbark basis;

- in most hardwood operations, logs are debarked in the field;
- in softwood operations, it is estimated that some bark is lost prior to the logs reaching the mill. Most of this loss occurs during the mechanised de-limbing and log docking operations; and,
- most softwood bark recovered at the mill is used for garden mulch which it is considered would have decay characteristics similar to that of logging slash.

Softwood bark is a significant source of carbon with total bark varying from about 35% of underbark log volume (not oven dry weight) in Caribbean pine to 20% in radiata pine and hoop pine. It is likely that, in the future, an increasing proportion of softwood bark will be used in the co-generation of energy and it may be reasonable to review this proposal should the situation change.

Basic Density and Carbon Content

Basic wood density and carbon content estimates are relevant to all of the processing options and the choice of values adopted has a significant bearing on the final outcome. In the case of all sawn timber, and treated softwood and hardwood poles, weighted basic densities for the species involved have been applied across each category. Basic density is defined as oven dry weight divided by green volume and the values adopted have been based on Ilic *et al.*, (2000). For board products and paper, however, the situation is different because all have been subjected to varying amounts of compression during manufacture and to compensate for this, their basic densities have been adjusted accordingly from the air-dry density of the finished products.

Carbon content is defined variably throughout the literature with values ranging from 0.4 to 0.53 of the oven dry (bone dry) weight. A figure of 0.5 has been adopted for use in the model as a median value extracted from Gifford (2000a).

Apart from the assumptions concerning basic density and carbon content, the other manufacturing assumptions were developed from interviews with representatives from the various industry associations and individual sawmilling companies. The issues addressed included:

- recoveries of green sawn timber, sawdust and chip;
- actual sawn sizes and corresponding dressed sizes; and,
- the range and proportions of products produced.

For the softwood sawmilling industry, for example, weighted averages of the information received have provided realistic assumptions. The same applies to the other species/industry sectors, with the exception of hardwood sawmilling.

Table 7.I1: Basic densities, moisture and carbon contents

Carbon Fractions	
Description	**Value**
Fraction of softwood sawmilling dry matter that is carbon, by weight	0.50
Fraction of particleboard dry matter that is carbon, by weight	0.40
Fraction of MDF dry matter that is carbon, by weight	0.40
Basic Densities[a]	
Description	**Value kg m^{-3}**
Density of softwood sawmilling	460
Density of hardwood sawmilling	630
Density of cypress sawmilling	600
Density of plywood (softwood and hardwood) and veneer	540
Density of particleboard	520
Density of MDF	600
Density of hardboard	930
Density of softboard	230
Density of pulp and paper: Paper	1,000
Density of pulp and paper: Softwood	430
Density of pulp and paper: Hardwood	500
Density of pulp and paper: Waste paper	1,000
Density of pulp and paper: Pulp	1,000
Density of paper and paperboard imports and exports, on average	1,000
Density of chips and logs for export: Softwood logs	415
Density of chips and logs for export: Hardwood logs	630
Density of hardwood poles, sleepers and miscellaneous	790
Moisture Content of Green Wood	
Description	**Value**
Ratio of weight of water to weight of wood substance in softwood chips	1.10
Ratio of weight of water to weight of wood substance in hardwood chips	0.90

(a) Basic density = (mass of oven dry wood in kg) / (volume of green wood in m^3)

Wood Flows from Processing

Wood flows in the various wood products produced in Australia have been developed under the following species/industry headings:

- Softwood sawmilling;
- Hardwood sawmilling;
- Cypress sawmilling;
- Plywood;
- Particleboard and medium density fibreboard (MDF);
- Pulp and paper;
- Preservative treated softwood;
- Hardboard;
- Hardwood poles, sleepers and miscellaneous; and,
- Export of woodchips and logs.

Softwood sawmilling

The softwood sawmilling industry in Australia is largely based on plantations of exotic pines, although the native pine, hoop pine, is grown in southern Queensland. Most plantations were initiated around the 1930s. Early development was slow, but momentum was gained in the 1960s and 1970s.

Softwood processing has become very efficient, highly mechanised and a well integrated industry, comparable with any of its overseas counterparts. Most softwood mills are large, with up to 500,000 m^3 yr^{-1} log intake. Most of the sawn timber is seasoned and dressed. Value-adding options such as machine stress grading, glue lamination and finger jointing are common.

Nearly all softwood mills are now operating on zero waste, with all slabs and edgings being chipped for paper pulp or panel board feedstock and the sawdust and shavings being used for boiler fuel to provide energy for kiln drying. In some cases, some of this material is sold for composting, but this is unlikely to continue if the co-generation of electricity becomes more financially attractive.

A basic density of 415 kg m^{-3} is used. This is sourced from Ilic *et al.*, (2000) and Gardner and Ximenes (*pers. comm.*); and is based on a weighted average of the respective densities of radiata pine, slash pine, Caribbean pine and hoop pine that are harvested.

The destinations of sawlogs and sawn timber products were sourced from representative sawmills in South Australia, Tasmania, Queensland and the Australian Capital Territory and from Pine Australia. Import and export figures were derived from ABARE (2009c).

Hardwood sawmilling

The hardwood sawmilling sector is quite different from the softwood sector being characterised by a large number of small mills; even the very few large hardwood mills are much smaller than the average softwood mill. In recent years, the hardwood industry has undergone considerable change in response to reductions in their traditional resource base and to the impact that softwood framing has had on the traditional green hardwood framing market and also due to growing restrictions in the utilisation of native hardwood forests.

As indicated earlier, the hardwood plantation resource is expanding and removals from hardwood plantations have been included in the total hardwood removals. Most of this material is currently of pulp log quality, but more sawlogs will be harvested as the resource matures. There is a reasonable degree of integration in the hardwood industry; however integration is difficult for the smaller more remote mills.

The hardwood sawmilling industry is far more complex and varied than any of the other sectors. There are at least 10 major species throughout the country, all having different densities and shrinkage rates, and to a great extent having different end uses. This sector has not been addressed in nearly the same detail as was applied to the softwood sawmilling sector and the outcome should be regarded as indicative only.

Assumptions on the product out-turn from hardwood sawmilling were sourced from the Victorian Association of Forest Industries and a large sawmilling company operating mills in Queensland, New South Wales and Tasmania. Sawlog volumes produced and import/export data have been sourced from ABARE (2009c).

A basic density of 630 kg m^{-3} is assumed for hardwood sawlogs. This is an average of the following ten commonly logged hardwoods: spotted gum (*Corymbia maculata*), blackbutt (*Eucalyptus pilularis*), rose gum (*E. grandis*), jarrah (*E. marginata*), karri (*E. diversicolor*), mountain ash (*E. regnans*), alpine ash (*E. delegatensis*), silvertop (*E. sieberi*), brown barrel (*E. fastigata*) and messmate stringybark (*E. obliqua*). The basic density assumed for poles and sleepers is 790 kg m^{-3}. This is an average of spotted gum, ironbark and blackbutt – the main species used.

Hardwood chips are lower in average density than either sawlogs or poles and sleepers as they contain a wider range of species as well as younger regrowth and plantation material. An average basic density of 570 kg m^{-3} is assumed. This is sourced from Chin (*pers. comm.*) of CSIRO.

Cypress sawmilling

The Cypress sawmilling industry is restricted to the native cypress pine forests in Queensland and New South Wales. The quantity of logs removed is small and the data are currently included in the coniferous forest information in the ABARE quarterly reports (ABARE 2009d).

The industry consists of several relatively small, low technology mills operating on a scattered resource. Because of the distances involved, integration with other processing sectors is difficult; however some Cypress pine chips are being used in panel board manufacture. The products are principally green framing and high value flooring and dressed panelling.

Plywood (softwood and hardwood) and veneer

The Australian plywood industry is based principally on plantation grown softwoods and about 8% hardwoods, both native and plantation grown. Large, high quality logs, for which premium prices are paid, are preferred. In volume terms, the plywood industry is small, but it uses high technology and produces a variety of products.

In addition to plywood veneer, sliced or rotary peeled decorative veneer is produced in small quantities for furniture, door and panel overlays. This production is not recorded separately by ABARE. Jaakko Pöyry Consulting (2000) estimated annual production is less than 10,000 m^3. Data sources used in the model for plywood was from ABARE (2009c) and the Plywood Association of Australia.

Particleboard and Medium Density Fibreboard (MDF)

The characteristics of these two wood panel boards are different, but their feedstock and end use product categories are similar. Their densities are, however, different. Particleboard and MDF plants are large-scale operations and they are usually located close to their resource. Either require low cost material as input using either small logs unsuited to sawmilling, or woodchips produced as a by-product of sawmilling. Most of the feedstock is from softwood plantations, although some regrowth hardwood is being used in a plant in Tasmania and some cypress pine is being used in a plant in Queensland. In terms of trade, Australia is a net exporter of particleboard and MDF. The industry source used for information on processing assumptions in the model was the Australian Wood Panels Association.

Pulp and paper

Pulp and paper plants are very large-scale industries requiring large volumes of low cost resource. Plantation grown softwood fibre provides the major resource but hardwood and recycled fibre is also important. Accounting for this sector is complicated by the fact that recycled fibre is exported and pulp is imported. Australia has five pulp and paper mills. Production data is sourced from ABARE (2009c).

A complicating factor in the assumptions on waste with the pulp and paper stream is the fact that mills vary dramatically in their recovery according to type. Kraft pulp mills typically have a low yield of fibre (at 50%) whereas thermo-mechanical mills have a high yield (at 95%). The manufacture of recycled paper also results in a lower yield of fibre. Based on weighted inputs, a yield of 70% has been adopted.

Preservative treated softwood

Both hardwood and softwood can be preservative treated, but only softwood has been allocated a separate category. This is because treated sawn softwood has some use categories which are different to untreated softwood, whereas hardwood is usually treated so that the sapwood can be protected against borer attack and its use is then the same as for untreated hardwood.

Treated softwood poles and posts have also been included with sawn softwood, but treated hardwood poles and piles have been included with sleepers and other miscellaneous hardwood products. The ABARE statistics do not list treated timber of any description. The information used in the model has been obtained from the Timber Preservers Association of Australia.

Hardboard

The hardboard industry in Australia is quite small, with only two plants in operation. One is at Ipswich (Queensland) and the other is at Raymond Terrace (New South Wales). Hardwood is used for feedstock, sourced from pulp logs and sawmill residue.

The technology is quite old, but the products are unique and have niche markets that are likely to endure the competition from other panel products. Both hardboard producers were contacted during the study for manufacturing assumptions.

Hardwood poles, sleepers and miscellaneous

The existing stock of hardwood transmission poles in Australia is reputed to number about 6,000,000 and production is estimated to be about 100,000 poles per annum, equivalent to about 75,000 m^3 of log. Railway sleepers also represent a considerable resource, and although concrete sleepers are now used for all new work, timber sleepers will continue to be used for the maintenance of secondary lines. 'Miscellaneous' includes a range of products such as mining, fencing and landscaping timbers. The log removals information for this group is conflicting and difficult to uncover. A provisional constant of 184,400 m^3 has been proposed for use in the model and further work is recommended.

Log and woodchip exports

Woodchip exports

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

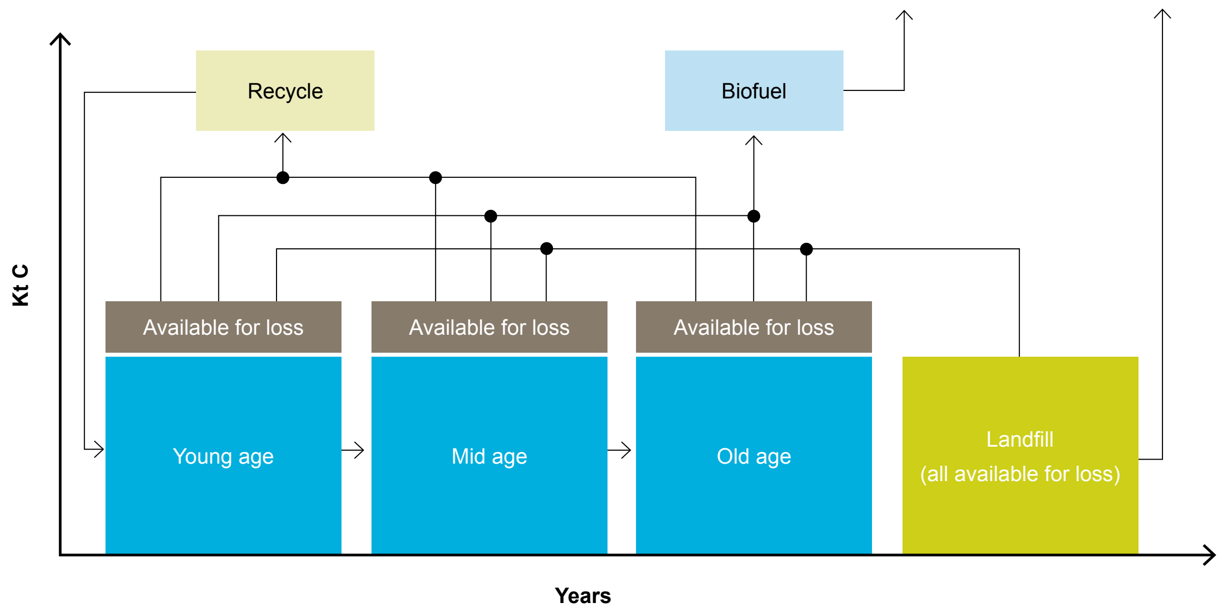
Log exports

Total exports of coniferous logs reported by ABARE (2009c) consist of both sawlog and pulp log. New South Wales exports approximately 7,000 m^3 of short length poles per year.

Life Span of Timber Products (Recycling and Landfill)

The life span of wood products must be taken into account when ascertaining the quantity of carbon stored in timber products. Considerable attention has been given to subdividing the various timber products pools into different classes based on product and decay rates. The decay rates used assume that losses of material from service life will increase with product age. Therefore the entry and exit of material from production to loss from each product pool is tracked and aged according to three age classes; young, medium and old. The proportion of material lost from each pool may vary (e.g., there may be little loss from young pools (excluding those to the medium age class)). Material is lost at a constant rate and may be placed in landfill, recycled, used for bioenergy or lost to the atmosphere (e.g., burnt with no energy capture) (Figure 7.I1).

Figure 7.I1. Structure of the Wood Products Model



For shorter-term products, the impact of the size of previous stocks is fairly slight as the recent additions to the pools have the major impact. For long-term products, an estimate of the size of the initial pool is essential, but difficult. The size of the housing pool uses housing starts data. Other pools are also only estimates. The proportion of the pool that has been derived from Australian-grown wood is required in order to implement an approach that separately deals with imported wood products. However, this component is difficult to estimate and estimates should be treated with some caution.

Life Span Pools Assumed for the Carbon Model

Very short-term products – Pool 1

- Paper and paper products.
- Age: young = 1; medium = 2; old = 3

Short-term products – Pool 2

- Hardwood – pallets and palings.
- Softwood – pallets and cases.
- Particleboard and MDF – shop fitting, DIY, miscellaneous.
- Plywood – form board.
- Hardboard – packaging.
- Age: young = 3; medium = 6; old = 10

Medium-term products – Pool 3

- Plywood – other (noise barriers).
- Particleboard and MDF – kitchen and bathroom cabinets, furniture.
- Preservative treated pine – decking and palings.
- Hardwood – sleepers and other miscellaneous hardwood products.
- Age: young = 10; medium = 20; old = 30

Long-term products – Pool 4

- Preservative treated pine – poles and roundwood.
- Softwood – furniture.
- Hardwood – poles, piles and girders.
- Age: young = 20; medium = 30; old = 50

Very long-term products – Pool 5

- Softwood – framing, dressed products (flooring, lining, mouldings).
- Cypress – green framing, dressed products (flooring, lining).
- Hardwood – green framing, dried framing, flooring and boards, furniture timber.
- Plywood – structural, LVL, flooring, bracing, lining.
- Particleboard and MDF – flooring and lining.
- Hardboard – weathertex, lining, bracing, underlay.
- Preservative treated pine – sawn structural timber.
- Age: young = 30; medium = 50; old =90

A specified proportion of material may be lost annually (an exponential loss) from each age class of each product pool. The amount lost from each age class for each product pool can be capped and different proportions can be lost according to age. This feature of the model provides for 'steps' in product loss rather than functioning on either a simple linear or exponential loss applied to a whole product pool, irrespective of the average age of the pool. If inputs vary over time the average age of products will vary, and this is represented by the amounts of material in each age class of each product pool.

Initial Stock Assumptions

Input data is available for the model since 1944 and this has the benefit of allowing the model to establish new equilibrium pools as the input material may be 'turned-over' several times prior to an equilibrium stock being reached for recent years. Initial stock estimation (for 1944) is more important for Pool 5 as this material may remain in use.

Model Calibration

Once the data on production inputs, processing flows and initial stocks is determined other model calibration requirements include:

- the age at which material moves from young to medium and medium to old pools;
- the amount of each age class for each product pool exposed to loss;
- the rate of loss from each age class in each product pool; and,
- the fraction of losses from each age class in each product pool to each of landfill, recycling, bioenergy and the atmosphere.

The model estimates used are presented in Tables 7.I2 and 8.5 (in Chapter 8).

Table 7.I2. Decomposition rates and maximum possible loss

Pool	YOUNG		MEDIUM		OLD	
	Loss Yr^{-1}	Max. Possible Loss (%)	Loss Yr^{-1}	Max. Possible Loss (%)	Loss Yr^{-1}	Max. Possible Loss (%)
1	1.0	0.60	0.500	0.65	0.333	0.90
2	0.333	0.30	0.167	0.50	0.100	0.90
3	0.10	0.15	0.050	0.65	0.033	0.45
4	0.05	0.25	0.033	0.65	0.020	0.80
5	0.033	0.20	0.020	0.55	0.011	0.95

To understand the impact of uncertainties, *Monte Carlo* analyses using the Palisade @Risk software (Palisade 1997) was applied. This approach is also able to identify model sensitivities. Through this, it is possible to identify where uncertainty in parameter estimation may be most significant in terms of a probability distribution of expected outcomes, and to focus future data collection on areas that will have greatest impact on reducing uncertainties.

Model Results

By integrating the carbon pools and life cycles of wood products, the model enables the total carbon pools and emissions to be estimated. In broad terms, the components of the models as described for each sector are similar, using:

- an estimate of raw materials input, whether of sawlogs, woodchips ex-sawmill, or pulp logs;
- an estimate of the products of processing, e.g., "x"% sawdust, shavings or sander dust for on-site energy generation or compost, "y"% 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;
- a final figure for total Australian consumption by end use categories, converted to wood fibre content (oven dry weight) and to tonnes of carbon; and
- import and export data obtained from the ABARE (2009c) by end use categories.

Table 7.I3 shows the annual additions and losses and carbon pool sizes.

Table 7.I3. Carbon stock and emissions outcomes (kt C)

Year	Domestic Production of Wood Products[(a)]	Imports of Wood Products	Exports of Wood Products[(b)]	Increase Due to Wood Products	Carbon Pool (excl. landfill)
	kt C	kt C	kt C	kt C	kt C
1990	3,307	730	80	3,957	76,756
2000	3,791	920	313	4,398	89,396
2005	4,249	1005	479	4,775	96,186
2006	4,232	960	493	4,699	97,587
2007	4,135	985	500	4,620	98,906
2008	4,179	1056	468	4,767	100,827

(a) Includes wood waste generation. (b) Excludes exports of woodchips

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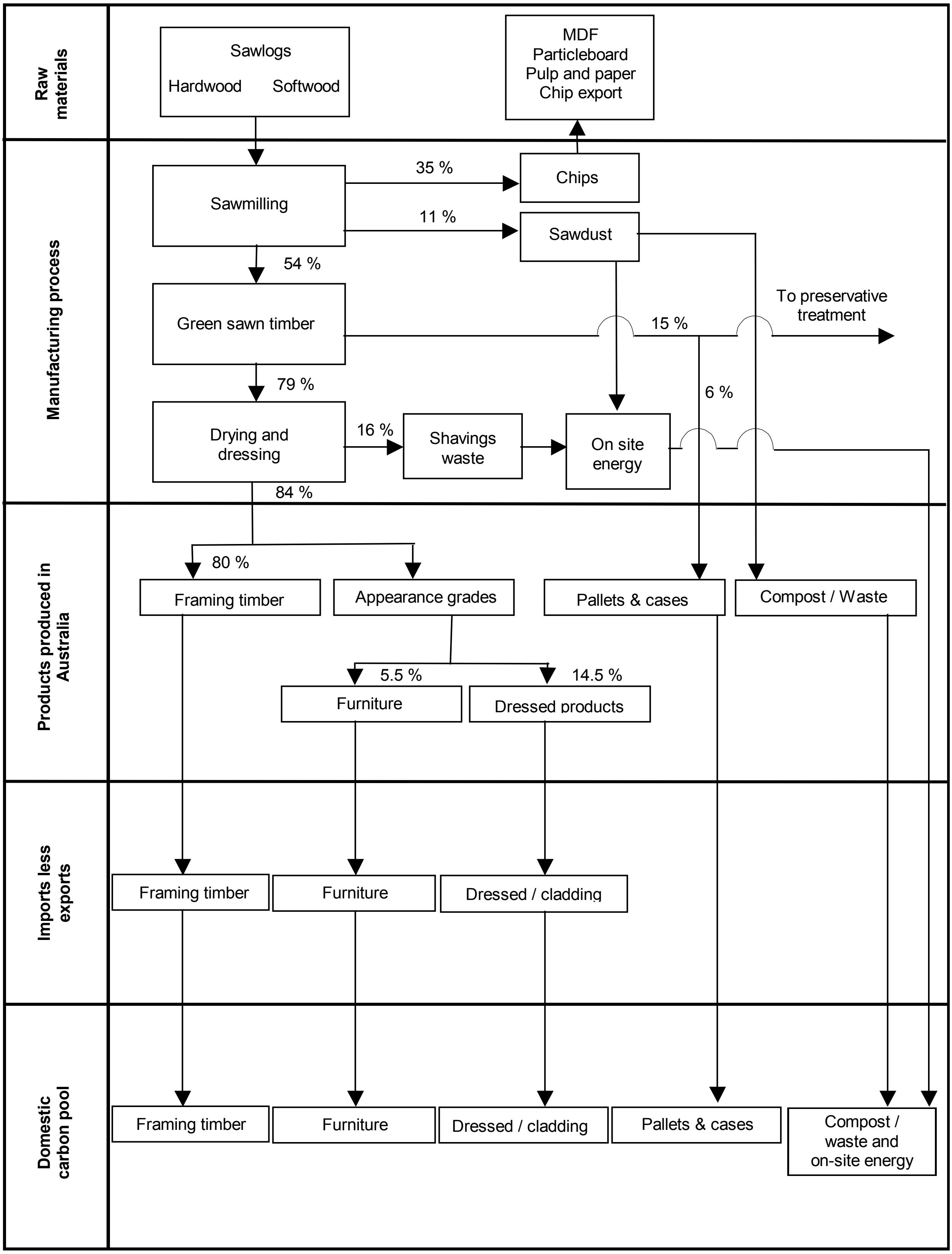
Attachment 7.I1: Wood Flows by Sector

Figure 7.I2: National Carbon Accounting Model for Wood Products – Sawmilling wood flows*



* Percentages shown for softwood sawmilling, refer to model for hardwood and cypress pine

Figure 7.I3: National Carbon Accounting Model for Wood Products – Wood flows in preservative treated products

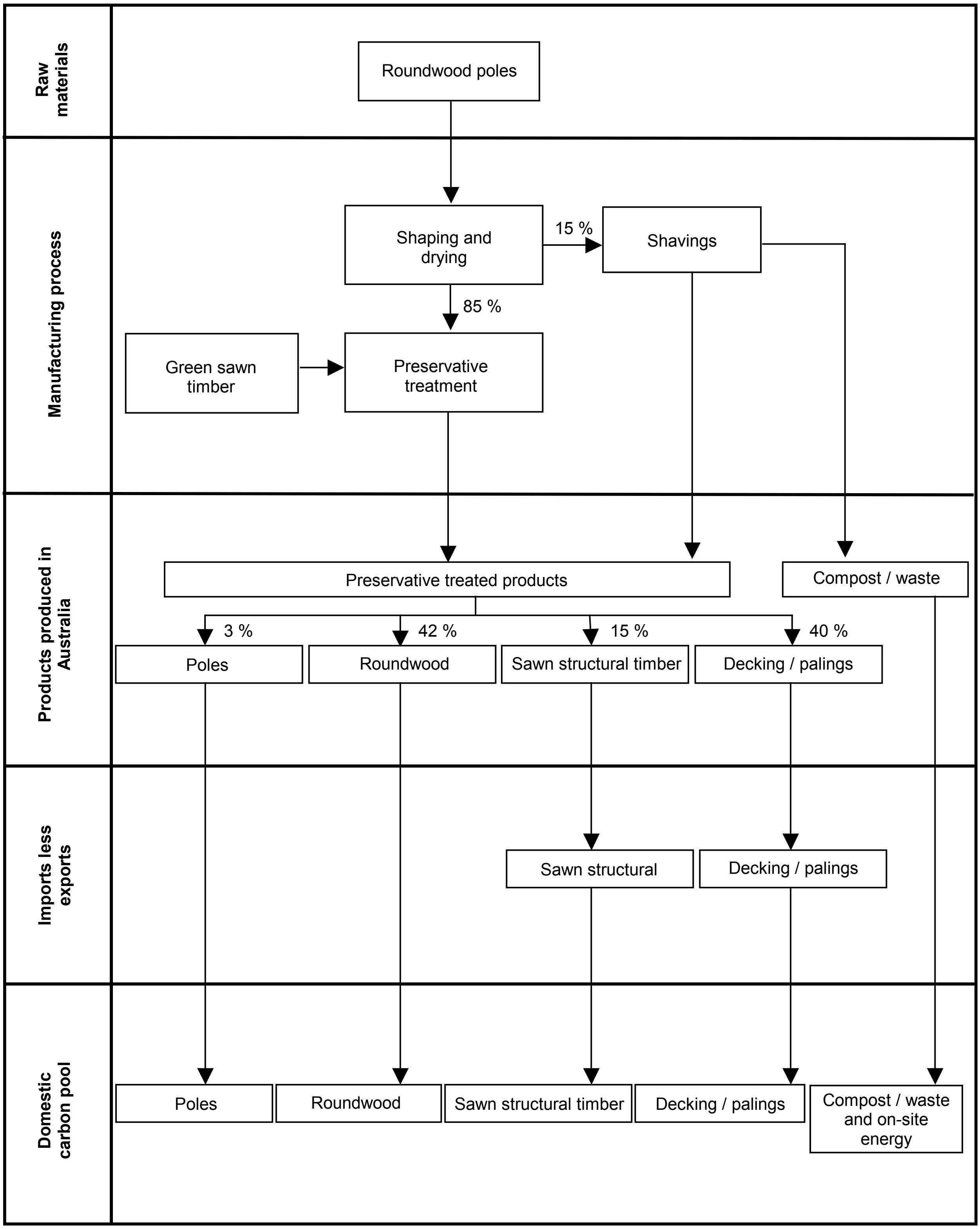


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Figure 7.I4: National Carbon Accounting Model for Wood Products – Wood flows in plywood production

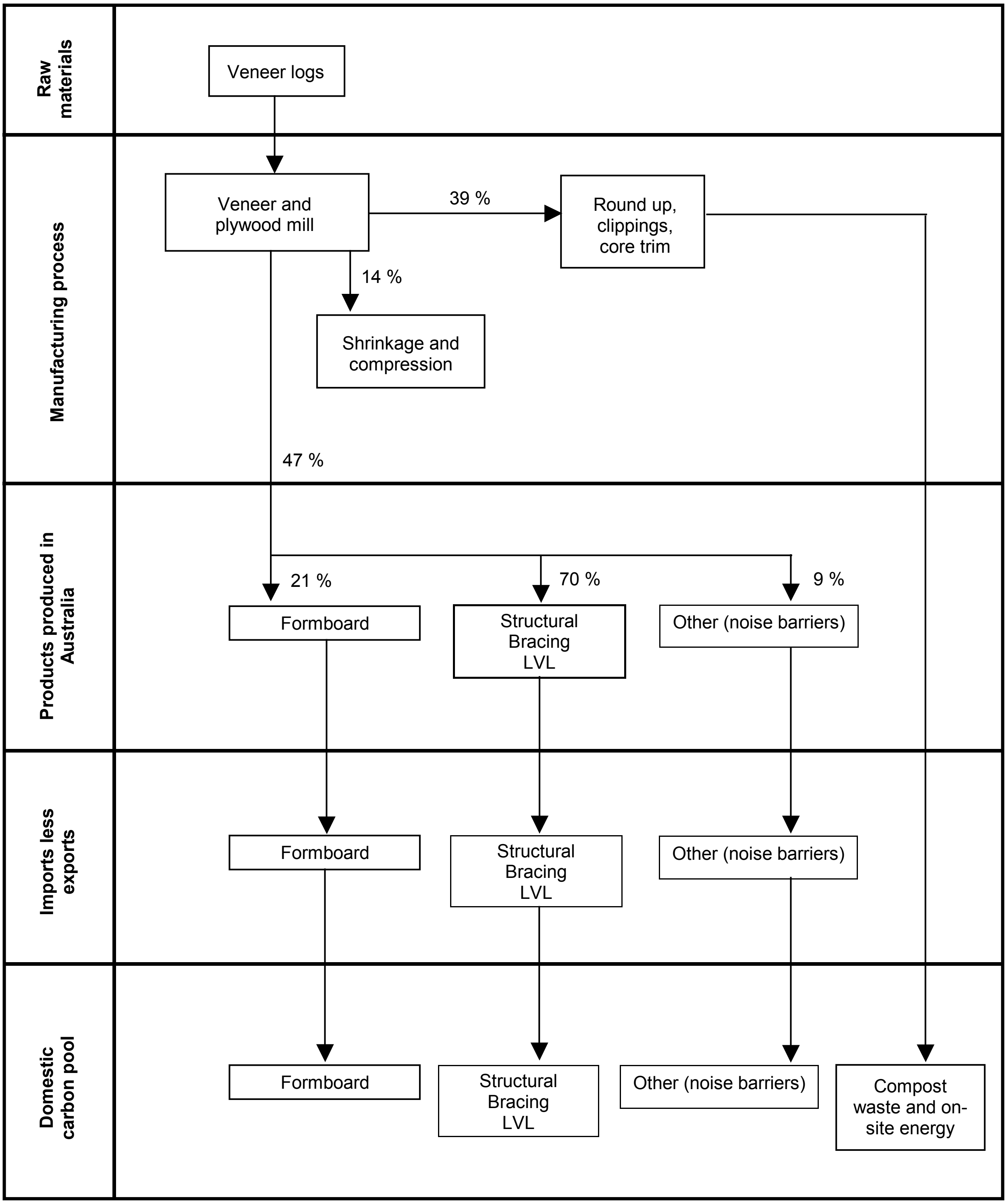

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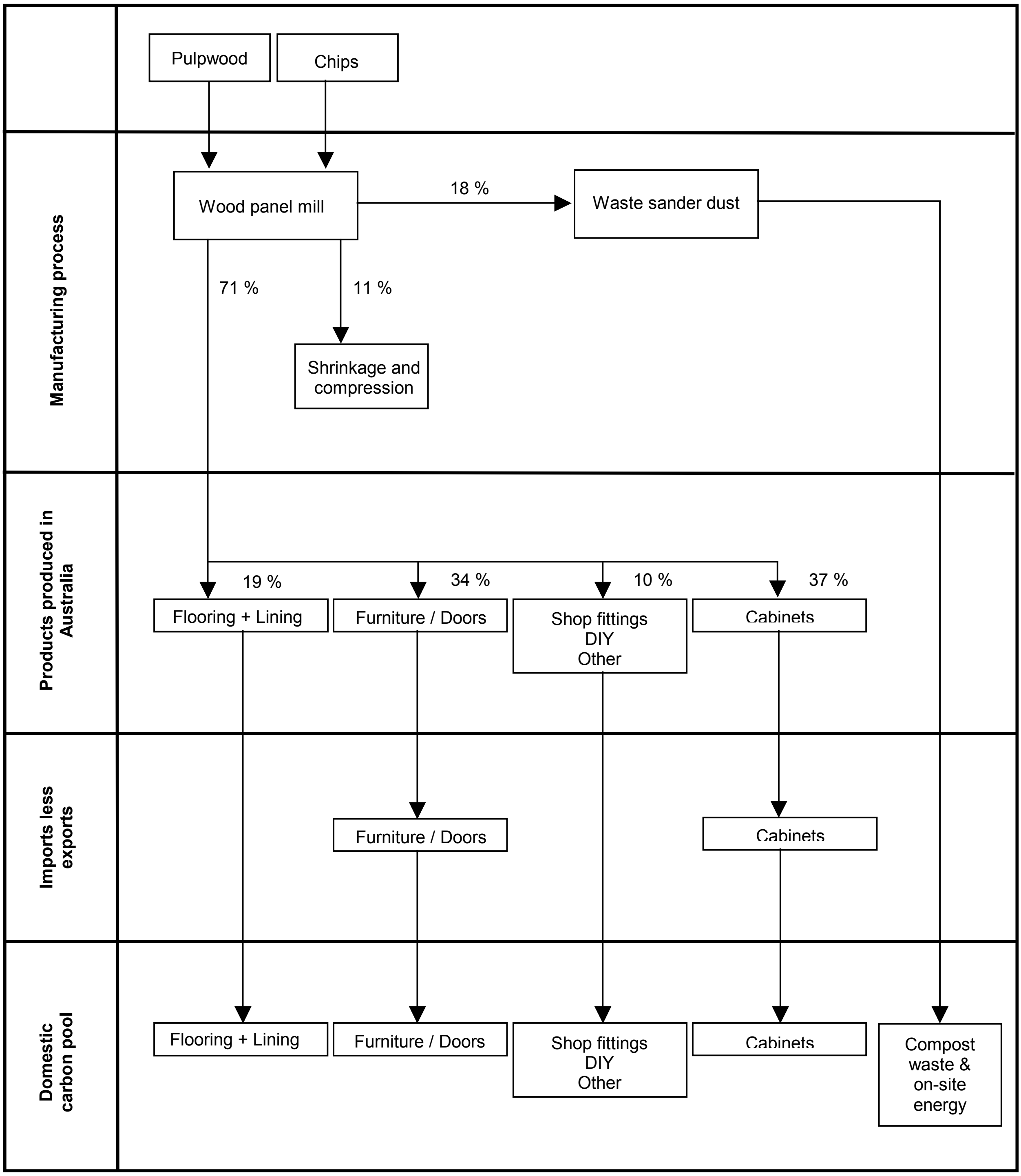
Figure 7.I5: National Carbon Accounting Model for Wood Products – Wood flows in MDF and particleboard manufacture*



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

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Figure 7.I6: National Carbon Accounting Model for Wood Products – Wood flows in pulp and paper manufacture

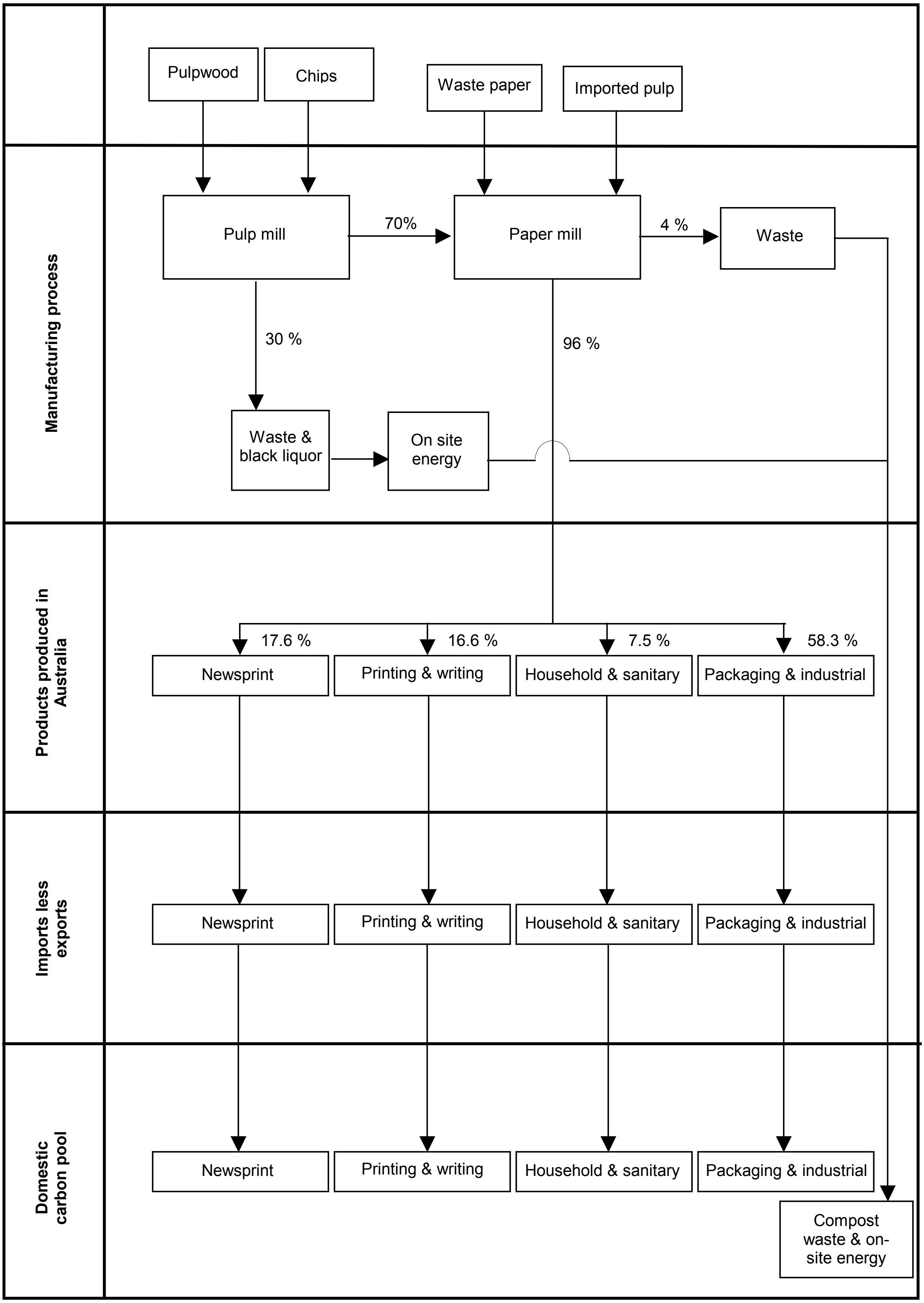

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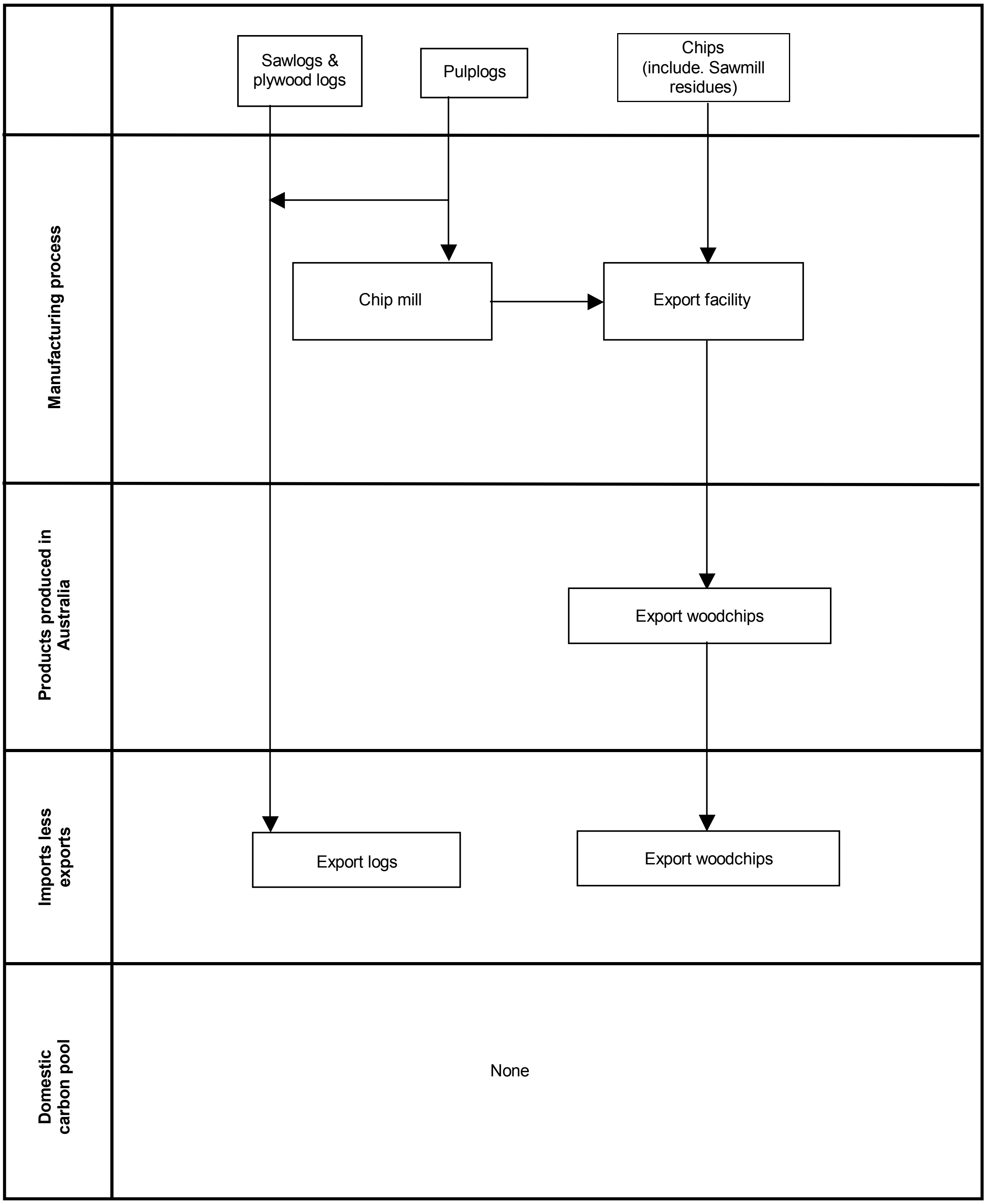
Figure 7.I7: National Carbon Accounting Model for Wood Products – Wood flows in export woodchips and logs



Appendix 7.J: Quality Assurance & Quality Control (QA/QC)

7.J.1 Introduction

Australia's National Carbon Accounting System (NCAS) uses Tier 3 (ecosystem model) methods to estimate emissions and an Approach 3 (full spatial enumeration) method to represent most land categories (IPCC, 2003). Unlike Tier 1 and Tier 2 inventory methods, which use emissions factors and annual activity data to estimate emissions, Tier 3 inventory methods use either repeat measurements or models. Australia's NCAS uses integrated ecosystem modelling and time series of remotely sensed land cover change data to estimate emissions. As climate variables are used in the NCAS model, estimates reflect both the temporal and spatial variability in emissions.

Tier 3 and Approach 3 methods were judged necessary for estimating Australia's land sector emissions for several reasons. Land use conversion in Australia involves only a small fraction of the highly diverse and dynamic land area and is unlikely to be representative of the carbon stocks and emissions factors averaged for a broader geographic region. Also, Australia's highly variable climate will cause large differences in the biological drivers of emissions on a year-by-year-basis. A simple generalised emissions factor approach cannot produce an unbiased estimate of emissions for land conversion that consists of rare occurrences in a landscape in a way that is subject to very high spatial and temporal variability.

The use of an integrated ecosystem model and a remotely sensed time series of land cover change have different sources of potential error to those encountered in lower Tier methods of emissions estimation. Tier 3 methods of emissions estimation are data intensive and require more attention to quality assurance, quality control, sensitivity analysis, uncertainty analysis, verification, transparency and peer review than is normally applied to Tier 1 and Tier 2 methods.

This chapter describes the Quality Assurance (QA), Quality Control (QC), calibration, validation and verification (including sensitivity and uncertainty testing) procedures applied to the calculation of Australia's greenhouse gas emissions from *Land-Use*, *Land-Use Change and Forestry* (LULUCF) activities using the NCAS. The QA, QC, calibration, validation and verification procedures are described in the following sections:

Section 7.J.2 – Responsibilities

Section 7.J.3 – Input data and model development

Section 7.J.4 – Managing model versions and data archiving

Section 7.J.5 – Emissions estimates

Section 7.J.6 – Transparency and Review

7.J.1.1 Scope and definition of QA, QC, validation and verification activities in the NCAS

Quality Assurance and Quality Control

Quality Assurance (QA) activities within the NCAS include independent reviews of data inputs and model outputs that are conducted by personnel not directly involved in compiling the inventory of greenhouse gas emissions from the land sector. Such activities assess how different steps in the emissions estimation process comply with detailed specifications, protocols, testing and verification procedures documented in the NCAS technical report series. Periodic external review of the NCAS as an overall program for estimating emissions from the land sector is also conducted to ensure that the NCAS meets current best practice in method and application.

Quality Control (QC) activities have been applied to ensure the integrity, correctness and completeness of model inputs and outputs, at all stages of the modelling process. Such QC activities include:

- checking for errors in the derived input data;
- checking the integrity of data sets on entry to model databases (prior to their use in models);
- testing to ensure the integrity of the model code between versions (version control); and,
- testing the sensitivity of model outputs and emissions estimates to changes in input data and model parameters.

Verification

Verification activities focus on detailed checking of land cover change areas and modelled emissions estimates. Verification of the reliability of NCAS inputs and outputs is typically against independent field/ground truth data that are unaffected by model or measurement error or high uncertainty, and which were not used to develop the model. Verification by direct measurement provides the benefit that independent data can be used to assess model and land use attribution performance in detail (e.g., by carbon pool per pixel) and in general (e.g., by region, soil type and vegetation type). Having independently derived data allows for continuous improvement of the NCAS models whereby the verification data can subsequently be used to enhance model calibration, which is then tested again in subsequent verification using further independently collected data. This ensures a growing base of data for model calibration while also ensuring that calibration and verification data remain independent. The process applied in this way provides for a combined continuous improvement and verification program.

The use of independent and directly measured data to verify and calibrate the ecosystem model provides a rigour that cannot be derived from other verification approaches such as model inter-comparison that rely on convergence and agreement of results for model validation.

Validation

The purpose of validation activities within the NCAS is to ensure that the inventory has been compiled correctly. Validation activities in the NCAS apply to preparation of data inputs, modelling and emissions estimates. Data for validation are drawn from both literature and from collection of new data.

Sensitivity and uncertainty testing

The methods of uncertainty testing described by the 2003 IPCC *Good Practice Guidance* are typically designed for Tier 1 and Tier 2 emissions factor based approaches. The fundamental approach of using *Monte Carlo* analysis for sensitivity and uncertainty testing in Tier 1 and Tier 2 remains relevant in Tier 3. However, methods for dealing with potential error propagation and inter-correlation of parameter uncertainties need to be applied to the models used in a Tier 3 inventory.

Monte Carlo analysis can be used to test the sensitivity and uncertainty of emissions estimates made using the NCAS. The *Monte Carlo* analysis determines:

- that the best estimate of emissions (most likely outcome) is not subject to bias;
- parameter sensitivity to aid understanding of the drivers of uncertainty and guide improvement programs and verification priorities; and,
- the probability distribution of possible outcomes.

To enable these tests a *Monte Carlo* analysis capability has been integrated into the NCAS modelling framework and is routinely applied. Uncertainty tests using *Monte Carlo* analysis are also supplemented by the determination of accuracies of spatial data through verification programs. Verification can also be used to identify if there is any potential bias in the spatial inputs to the emissions modelling.

Transparency and peer review

As with the methods for sensitivity and uncertainty testing, those for transparency and peer review for a Tier 3 inventory approach are not the same as for Tier 1 or Tier 2 inventory approaches. For Tier 1 and Tier 2 the focus is on the estimation of activity areas and the selection of appropriate emissions factors. For the models and datasets used in Tier 3 model-based systems, different approaches to transparency and peer review are required. The basis of transparency and peer review for the NCAS are founded on:

- periodic review;
- published specifications, protocols and methods;
- published verification results;
- public release of models, tools and data; and,
- publications in peer reviewed journals and other literature.

7.J.2 Roles and Responsibilities

7.J.2.1 Participating Organisations

Many organisations participate in the development and maintenance of the NCAS. The organisations and their roles and responsibilities are listed in Table 7.J1.

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Table 7.J1 Roles and responsibilities of organisations involved with the development and maintenance of the NCAS

Category	Sub-category	Activity	Quality Task	Responsibility	Frequency	Reports
Input data	Remote sensing for land cover and land use	Satellite data acquisitions	Data (scene) selection	External (CSIRO)	Annual	Technical specifications for image selection
			QA/QC for data consistency with specifications	External (Geoscience Australia (GA), CSIRO)	Annual	Technical specifications for image selection
			Data order	DCCEE	Annual	
			Data generation and internal QA	External (GA)	Annual	
			Data delivered to DCCEE	External (GA)	Annual	Entry to image database
		Satellite data processing	Registration and calibration	External (various contractors)	Annual	Technical specifications for registration and calibration
			Registration and calibration QA	External (DCCEE, CSIRO)	Annual	Manual for registration and calibration
			QA/QC pass for registration and calibration	External (CSIRO)	Annual	Naming standards for registration and calibration products
			Cloud cover masks generated	External (various contractors)	Annual	
			QA on cloud cover masks	External (CSIRO)	Annual	
			Image mosaic analysis of new data	External (various contractors)	Annual	Technical specifications for mosaicing
			QA on mosaicing	External (CSIRO)	Annual	Manual for mosaicing
						Naming standards for mosaic products and cloud masking
			QA/QC for mosaicing	External (CSIRO)	Annual	
		Satellite data classification	Thresholding	External (various contractors)	Annual	Technical specifications for thresholding
			QA/QC for thresholding	External (CSIRO)	Annual	National standards for thresholding products
			CPN analysis	External (CSIRO)	Annual	
			Forest extent product QA	External (CSIRO)	Annual	
			Final products	External (CSIRO)	Annual	
	Climate	Data are obtained from the Australian Bureau of Meteorology	QA and QC Checks on data integrity and spatial accuracy	External (ANU)	Annual	NCAS Technical report 23
		Check of data library	QA and QC on data entries	External (ANU)	Annual	There are defined protocols and procedures NCAS Technical report 23
		Generation of initial surfaces	QA and QC on data outputs	External (ANU)	Annual	NCAS Technical report 23
		Accuracy checking of surfaces against individual station data	Validation of surfaces	External (ANU)	Annual	NCAS Technical report 23
		Checks include data integrity and that the data for each pixel in each time epoch conforms with expectations of normal data ranges		DCCEE	Annual	Data only enters NCAS system when integrity checks passed

Category	Sub-category	Activity	Quality Task	Responsibility	Frequency	Reports
Input data	Yield	Collate and validate annual crop yield data for all IBRA regions	Develop QA and QC methods of entry of yield to data base	External (CSIRO)	Received Annually	CSIRO reports and research papers ie: Unkovich *et al.*, 2009; Unkovich *et al.*, 2006
			Collection of new yield data	External (CSIRO)	Annual	Annual reports to DCCEE
		Crop yield data is checked against previous years of data	QA/QC for the new crop yield data	DCCEE	Annual	Protocols for data entry
			New crop yield data is checked against previous years	DCCEE and External (CSIRO)	Annual	QA report on data integrity
		Enter crop yield data into NCAS data base	QA/QC for data entries	DCCEE	Annual	QA/QC checks against the original data
			New yield data is entered into the NCAS database	DCCEE	Annual	Data integrity checks on updated database
		Checks include the integrity and completeness of the relational database, and that data conform with expected ranges	Validation of data inputs	DCCEE and External (CSIRO)	Annual	
Input data	Wood and Wood Products	Obtain data on forest product statistics published by the Australian Bureau of Agricultural and Resource Economics	QA/QC of forest product data	External (MBAC consulting, Jaakko Pöyry consulting, ANU, WebNet land resource services Pty Ltd)	Annual	NCAS Technical reports 8 and 24
		Enter data into model	QA/QC for data entry, check data for consistency with previous estimates	External, DCCEE and MBAC Consulting	Annual	
			Enter new data into wood products model	DCCEE	Annual	
Model validation	Tree growth	Checks include the integrity and completeness of the relational database, and that data conform with expected ranges		DCCEE and External (CSIRO)		Published papers (Waterworth *et al.*, 2007; Brack *et al.*, 2006)
	Litter		Ensure that estimates are within expected ranges	DCCEE and External		NCAS Technical report 14 and Woldendorp & Keenan, 2005
	Soils	Checks include the integrity and completeness of the relational database, and that data conform with expected ranges	Test NCAS output for soil C stocks against measured soil C values. Validation and verification of data outputs.	DCCEE and External (CSIRO)	Periodic	NCAS Technical Report 30 Verification of outputs NCAS Technical reports 34, 36, 37 and 38
Emissions estimates	Emissions categories	Grassland remaining grassland	Validation of outputs checked against previous annual runs	DCCEE	Annual	NIR
		Cropland remaining cropland	Validation of outputs checked against previous annual runs	DCCEE	Annual	NIR
		Plantation forests	Validation of outputs checked against Tier 2 models	DCCEE	Annual	NIR
		Harvested native forests	Validation of outputs checked against independent data	DCCEE	Annual	NIR

Category	Sub-category	Activity	Quality Task	Responsibility	Frequency	Reports
		Spatial outputs of NCAS	Develop QA for spatial analysis of NCAS outputs	DCCEE	Annual	NIR
		Uncertainty analysis of NCAS	Provide uncertainty analysis of NCAS for national estimates	DCCEE	Annual	NIR
			Provide national trends with uncertainty analysis for carbon stock changes	DCCEE	Annual	NIR
		Uncertainty analysis of carbon stocks	Validation of the impacts of climate parameters on carbon stocks	DCCEE	Annual	NIR; Waterworth *et al.*, 2005 and 2007; Brack and Richards, 2002
		Climate impacts on carbon stocks				

7.J.2.2 Department of Climate Change and Energy Efficiency

The Department of Climate Change and Energy Efficiency (formerly the Australian Greenhouse Office) prepares greenhouse gas emissions data to meet Australia's national and international reporting obligations. Development of the NCAS began in the late 1990s, specifically to estimate Australia's greenhouse gas emissions from land use, land use change and forestry. The development of the NCAS has been data and labour intensive, and many external public and private sector agencies contribute to the development of data inputs, building of models, writing of model software, QA/QC, model calibration, validation, verification, uncertainty and sensitivity, and publications. The diversity of agencies requires coordination and specification of activities to ensure consistent data inputs and outputs. This section describes how those activities are managed.

Co-ordination of NCAS activities

Responsibility for the development and use of the NCAS sits with the Land Management Branch within the Department of Climate Change and Energy Efficiency (DCCEE). The Land Management Branch consists of five units that coordinate the derivation of input data, the development and testing of the NCAS models, and the estimation of Australia's greenhouse gas emissions from the land sector (Figure 7.J1). The NCAS teams also coordinate QA, QC, calibration, validation and verification activities associated with each of these elements. Staff have qualifications and expertise commensurate with the activities of the NCAS (Table 7.J2).

Figure 7.J1. Organisational structure of the Land Management Branch within the Department of Climate Change and Energy Efficiency

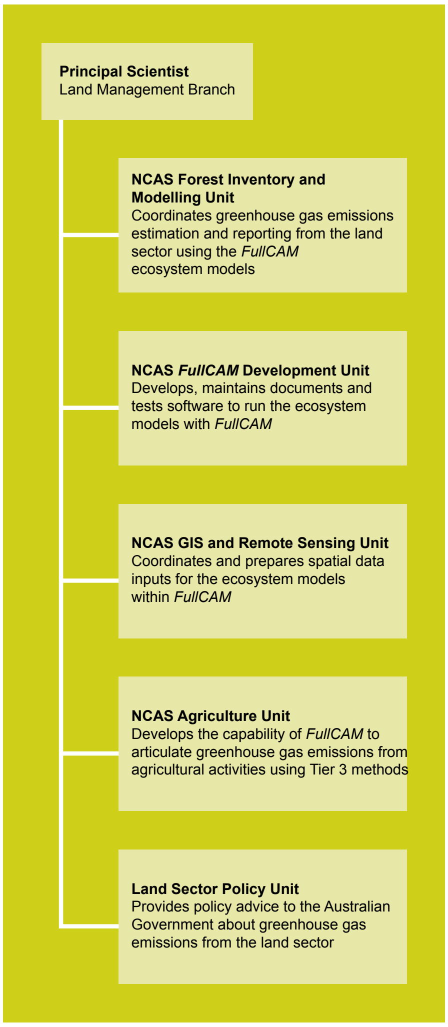


Table 7.J2. NCAS staff skills profile, as at February 2010

Name	Position	Qualification and area of expertise
Dr Robert Waterworth	Senior Research Scientist	PhD – Forest growth modelling (Australian National University). *Carbon modelling and carbon accounting, forest nutrition and ecology, systems development*
Dr Bill Slattery	Senior Research Scientist	PhD – Soil Science (University of Queensland) *Agricultural research in soil carbon, soil acidity, nutrient cycling, livestock management*
Dr Shanti Reddy	Senior Research Scientist	PhD – Remote sensing geology (Osmania University) *Remote sensing*
Ms Nikki Fitzgerald	Research Scientist	BA/BSc. Geography (Australian National University) *Remote sensing and spatial information processing and interpretation*
Mr Robert de Ligt	Research Scientist	BSc.(Hons) – Forest ecology (Australian National University) *Forest and bushfire ecology*
Dr Amanda Twomey	Research Assistant	PhD – Plant Physiology (University of Queensland) *Physiological and biochemical response of plants to environmental stresses*
Dr Melissa Parsons	Research Scientist	PhD – Ecology (University of Canberra) *Landscape ecology, environmental assessment*
Ms Rachel Burgess	Research Assistant	MSc. – Agriculture.(University of Tasmania) *Soil science, agronomy, remote sensing horticulture, geo-phyto-pathology*
Ms Fiona Wood	Research Scientist	BA/BSc. Geography (Australian National University) *Remote sensing and spatial information processing and interpretation*
Dr Zulfiquar Khwaja	Research Scientist	PhD – Remote sensing (Charles Darwin University) *GIS remote sensing, database management.*
Mr John Creasey	Research Assistant	BSc. – Geology (University of Technology Sydney) *Remote sensing, environmental mapping*
Ms Lucy McGarva	Research Assistant	BSc. – Resource and Environmental Management (Australian National University) *Remote sensing and spatial information processing and interpretation*
Ms Mary Vagg	Business Administrator	Dip. Info Tech (Canberra University) BA Business accounting (University of Technology Sydney) Dip. Legal studies (Australian National University) Certified Practising Accountant *Business analyst, data analysis and management, systems and processes*
Mr Ainslie Reddin	Business Analyst	Data and systems analysis, software development and testing, systems testing and process design.
Mr Jim Foley	Software developer	BSc. (Hons) Computer Science (Maths) (University of Queensland) *Applications development, C++, C#*
Mr Malcolm Francis	Software architect	BA Computing Studies (University of Canberra) *Applications development, C++, C#, systems design and development*
Dr Aneal Chandra	Software developer	PhD – Medical Imagery (University of Sydney) MSc. – Computer Science (Cardiff University) MSc. – Computer Science (University of Northumbria) *Applications development, C++, GUI design and development*
Mr Richard Almond	Software developer	BSc.(Hons) – Physics (University of Edinburgh) *Applications development, C++, Fortran, MFC, technical writing, geoscience*
Mr Jim Leitch	Software developer	BSc. – Computer Science (Australian National University) *Applications development, C++, systems design and development*

Input data collection and preparation

Raw input data are sourced from a range of external agencies by purchase or using publicly available databases (Table 7.J3). Input data are also analysed and prepared by both external agencies, and internally by the NCAS teams within the Land Management Branch.

Table 7.J3. Public and private sector agencies contributing to tasks associated with the collection and preparation of input data for the NCAS

Task	Contributing agencies
Calculation of land cover change from remotely sensed imagery	NCAS GIS and Remote Sensing Unit GeoScience Australia (GA) CSIRO Mathematics, Informatics and Statistics Various private sector firms
Collection and collation of current and historical land use data	CSIRO Land and Water Bureau of Rural Sciences (BRS) Australian Bureau of Agricultural and Resource Economics (ABARE) Department of the Environment, Water, Heritage and the Arts CSIRO Sustainable Ecosystems Australian National University (ANU)
Collection of climate data and derivation of modelled climate surfaces	Australian Bureau of Meteorology (BOM) Australian National University (ANU)
Derivation of an Australia-wide soil type map	State and Territory Governments CSIRO Land and Water
Collection and collation of crop yield and management data	Australian Bureau of Statistics (ABS) Bureau of Rural Sciences (BRS) CSIRO Land and Water
Collection and collation of forest growth and management data	CSIRO Sustainable Ecosystems The Australian National University (ANU) NCAS Forest Inventory and Modelling Unit Bureau of Rural Sciences (National Forest Inventory) (BRS)
Collection and collation of wood and wood products data	Australian Bureau of Agricultural and Resource Economics (ABARE)

Models

Responsibility for the development and testing of the suite of models and interfaces that operate within the NCAS sits with the NCAS *FullCAM* Development Unit within the Land Management Branch (Table 7.J4). The NCAS *FullCAM* Development Unit consists of staff specializing in business analysis, project management, programming and testing. The NCAS business analysis, project management and software testing activities are not conducted by the programmers, an important principle that maintains an effective process for defect management. The development of the conceptual and functional specifications of the ecosystem models is conducted by NCAS scientists in collaboration with external scientists from various agencies (Table 7.J4).

Table 7.J4. Public and private sector agencies contributing to tasks associated with the development, maintenance, documentation and testing of software within the NCAS, and the scientific development of NCAS functions

Task	Contributing agencies
Software development	NCAS *FullCAM* Development Unit
Defect management	NCAS *FullCAM* Development Unit
Business analysis and project management	NCAS *FullCAM* Development Unit
Scientific guidance	NCAS Forest Inventory and Modelling Unit NCAS GIS and Remote Sensing Unit NCAS Agriculture Unit NCAS Land Sector Policy Unit CSIRO Sustainable Ecosystems The Australian National University CSIRO Land and Water CSIRO Livestock Industries NSW Department of Agriculture and Fisheries Victorian Department of Primary Industries Queensland Department of Environment and Natural Resources and Water University of Western Australia

Emissions estimates for the land sector

Consolidation of Australia's greenhouse gas emissions estimates is conducted within the Department of Climate Change and Energy Efficiency (DCCEE). Within the Department, the two Branches (circled on Figure 7.J2) that contribute to the compilation of greenhouse gas emissions estimates from the land sector are the Land Management Branch (under which sits the NCAS) and the Renewables and Reporting Branch (Table 7.J5).

Figure 7.J2 Department of Climate Change and Energy Efficiency organisational chart, February 2010, showing the two divisions responsible for consolidation of Australia's greenhouse gas emissions estimates

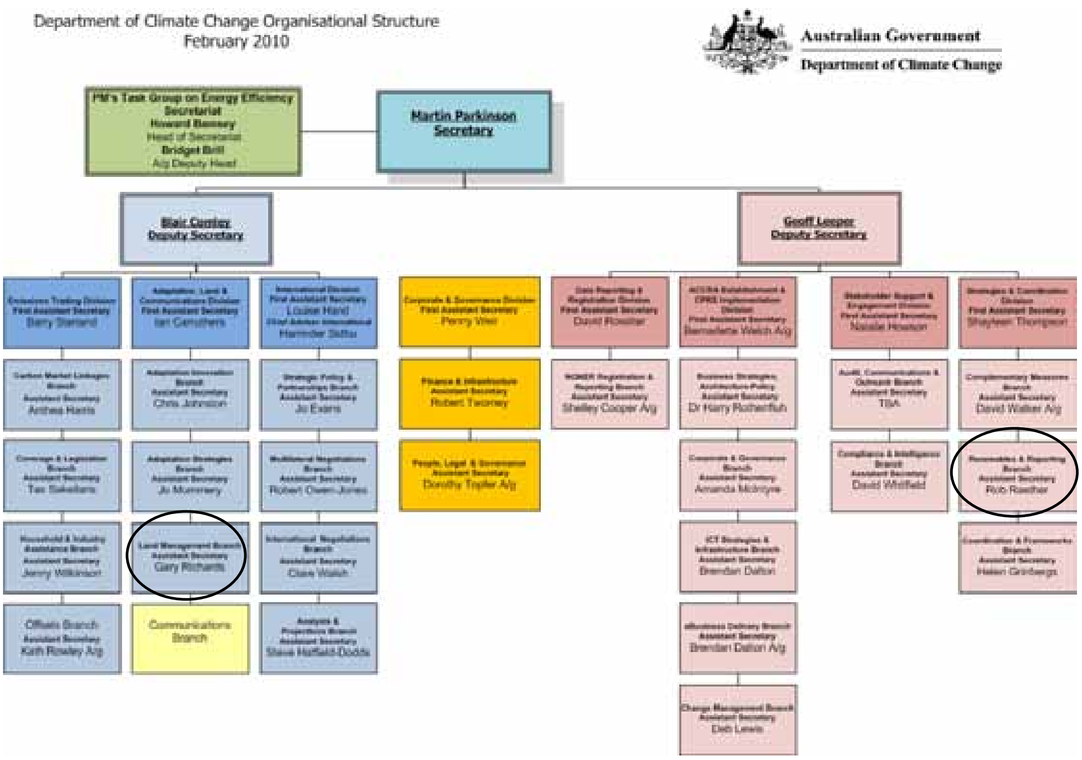


Table 7.J5 Department of Climate Change and Energy Efficiency contributions to the estimation of greenhouse gas emissions from the land sector

Task	Contributing agencies
Emissions estimates for land cover change categories	NCAS FullCAM Development Unit NCAS Forest Inventory and Modelling Unit
Integration into Australia's National Greenhouse Gas Inventory	NCAS Forest Inventory and Modelling Unit DCCEE Emissions Inventory Unit (within the Renewables and Reporting Branch)
Archiving and data management	NCAS Forest Inventory and Modelling Unit

7.J.2.3 Management of responsibilities

Contributions to the estimation of Australia's greenhouse gas emissions from LULUCF are managed by the Land Management Branch. There are many linkages between the contributors involved in estimating Australia's emissions estimates. External contributors are generally engaged on a fee for service basis. The Land Management Branch manages these contributors using various contracts and financial administration procedures. The processes undertaken to check the accuracy of data and information supplied by external contributors are detailed in later sections.

7.J.3 Input Data and Model Development

7.J.3.1 Land cover change

Rigorous and consistently applied QA/QC procedures are vital in supporting the Approach 3 methods of determining land cover change applied by the NCAS. The objective land cover determination methods used in the NCAS minimise direct and potentially subjective operator interpretation and intervention in data processing, and are more repeatable than approaches reliant on operator interpretation alone. This ensures both national and time series consistency. QA, QC and verification procedures are applied to confirm that the outputs from the land cover methods are accurate and complete.

The first year of the NCAS emissions reporting is the baseline year, 1990, with annual updates for subsequent inventory years. To make these estimates, the NCAS requires data about land cover in 1990, land cover in subsequent inventory years, and the loss of soil carbon and decay of vegetation that has occurred as a result of clearing in the previous years. The amount of regrowth vegetation is also critical for determining net emissions (i.e., sum of emissions and removals). Thus, data on forest cover change must be available for a period of approximately 20 years (from the early 1970s) prior to the first year of emissions reporting.

Adequate land cover change is available from satellite remote sensing (Furby, 2002) because Australia has available an extensive archive of Landsat ETM+, TM and MSS satellite data collected since the first Landsat sensor delivered data in 1972. A review of the data archive in 1998 showed that there was sufficient continental coverage to derive a time-series of land cover change commencing in 1972, with satellite imagery now collected annually over the entire continent. 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) such as can occur because of mis-registration, where the same areas on both images are not comparable because one or both are geographically mis-positioned (Furby and Campbell, 2001). Mis-calibration can also occur where images are processed to different spectral qualities (e.g., brightness from sunlight and greenness from seasonal conditions) which lead to false detection of spectral change.

To ensure consistency of methods, and the provision of spatially accurate land cover change data through time, a detailed protocol of remote sensing specifications for land cover change was developed by Furby (2002) through extensive pilot testing (Furby and Woodgate, 2002). These specifications determine the exact way that images are acquired, processed and classified. The three primary QA/QC items associated with the use of satellite imagery to calculate land cover change are:

1. Acquiring and selecting satellite imagery;
2. Satellite data processing, including registration, calibration and mosaicing; and,
3. Satellite data classification, to identify forest cover.

The QA/QC and data validation procedures for each of these items in the NCAS land cover change methods are summarised below and in Figure 7.J3, and are described in full in Furby (2002).

QA/QC

Acquiring and selecting satellite imagery

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

- the images purchased overlap to prevent gaps in the coverages;
- 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.

Year 2000 Australian Mosaic

A Year 2000 Australia mosaic serves as the rectification (geographical registration) and calibration (spectral consistency) base for the images from other years. The mosaic is formed from 369 Landsat 7 ETM+ scenes taken from July 1999 to September 2000. There were three steps in the process of creating the base image:

- 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 Natural Resources (QDNR) and raster versions of the AUSLIG 1:100,000 map series.

- 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.

- Mosaicing into 1:1,000,000 map sheet tiles to a seamless base

  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.

Land cover grid (pixel) resolution

To deal with the change in pixel size of the various Landsat sensors over time, and the need for spatially and temporally consistent integration with other spatial data used in the model, the 'natural' pixel size of the 1972 to 1988 Landsat MSS (57 m x 79 m) is re-sampled to a 50 x 50 m pixel. The 30 x 30 m native resolution of the Landsat TM and ETM+ data available after 1988 is produced as 25 x 25 m pixels.

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

All Landsat derived data are utilised 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 MSS 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.

Registration and Calibration

Registered and calibrated images (the multi-temporal sequence of Landsat ETM+, TM and MSS images to the Year 2000 Australia Mosaic rectification base) are returned to NCAS after both processes are complete. The assessment of each registered and calibrated image is performed in three stages:

1. the information and data provided to the NCAS is checked for completeness and the registration assessed, based on the summary information provided to the NCAS;

2. if the registration accuracy appeared to be doubtful, unacceptable or could not be determined from the information provided, it is further investigated so that the exact nature of any problem can be described to the contractor for correction; and,

3. a Registration/Calibration Quality Assurance form is completed, the processing status of the image updated in the NCAS Image Catalogue, and the image returned to the contractor for reprocessing if required.

Mosaicing

All mosaiced images (quadrants and time slices) for a particular map sheet tile are assessed at the same time. The assessment of each image is performed in two stages:

1. the information and data provided by the contractor is checked for completeness and the consistency of the mosaiced image assessed; and,
2. the processing status of the mosaic image is updated in the NCAS 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).

Thresholding

Two review processes are applied to the thresholding products. A quality assurance process is applied during and at the end of the thresholding stage of the processing. The aim of this quality assurance process is to ensure that the methodology has been correctly applied and that the intermediate and final products are consistent with the supplied ground data and with each other across stratification zone and map sheet boundaries. The assessment of the thresholding products is performed in several stages:

1. The information and data provided by the contractor after the single-date probability images are created (Step 8; see Furby, 2002) is checked for completeness. The adequacy and consistency of the analyses and the accuracy of the probability images is also assessed (CSIRO).
2. If the analyses or probability images appear doubtful or inconsistent, further investigations are carried out so that the exact nature of any problem can be reported to the contractor.
3. An Initial Assessment report is completed and the contractor advised of the results of the assessment and the actions required (either review of the analyses or continuation of the processing sequence).
4. The plausibility of the change images produced by the contractor is checked (CSIRO).
5. If the accuracy appears doubtful, images are further investigated so that the exact nature of any problem can be reported to the contractor.
6. A Change Image Assessment report is completed (CSIRO) and the contractor advised of the results of the assessment and the actions required (either review of the analyses or continuation of the processing sequence).
7. The final products supplied by the contractor are checked for completeness and the remainder of the processing by the contractor is assessed.
8. A Final Assessment report is completed and the contractor advised of the results of the assessment and the actions required (either review of the analyses or continuation of the processing sequence).

The first three steps are performed during the thresholding processing (step 8 of Furby, 2002), based on preliminary information provided by the contractor. The next three steps are performed during the thresholding processing (step 11 of Furby, 2002). The final two steps are performed after the final products had been delivered to the NCAS.

Time series consistency

From the remote sensing pilot testing, the need for time-series consistency in image data pre-processing, analysis, and subsequent formation of time-series forest presence/absence labels became clear. To this end, the operational standards (Furby, 2002) give explicit emphasis through documented rules 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 cover presence/absence labels. This process produces far superior forest extent and change results than 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 presence/absence and 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.

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 included green flushing in images due to climate, terrain illumination variability, irrigation, water bodies and fire scars. Contractors use visual image backdrops in time-series for this discrimination. Results of this discrimination are then quality assured by DCCEE. This process provides for an additional independent process of checking the land cover results.

Continuous improvement and verification

The verification of the remotely sensed land cover mapping is conducted within an overall continuous improvement and verification program. An independent program of checking the Landsat results is conducted by external parties, 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 woody and non-woody points across the continent and over the period of 1972–2000 indicated that 94–98% of forest and 85–96% of non-forest woody vegetation was correctly classified (Jones *et al.*, 2004). Accuracy in the data used for estimated rates of change (afforestation/regrowth or deforestation) was higher than the above, because the process of manual attribution, described previously, was used to confirm or reject changes in cover in the final dataset.

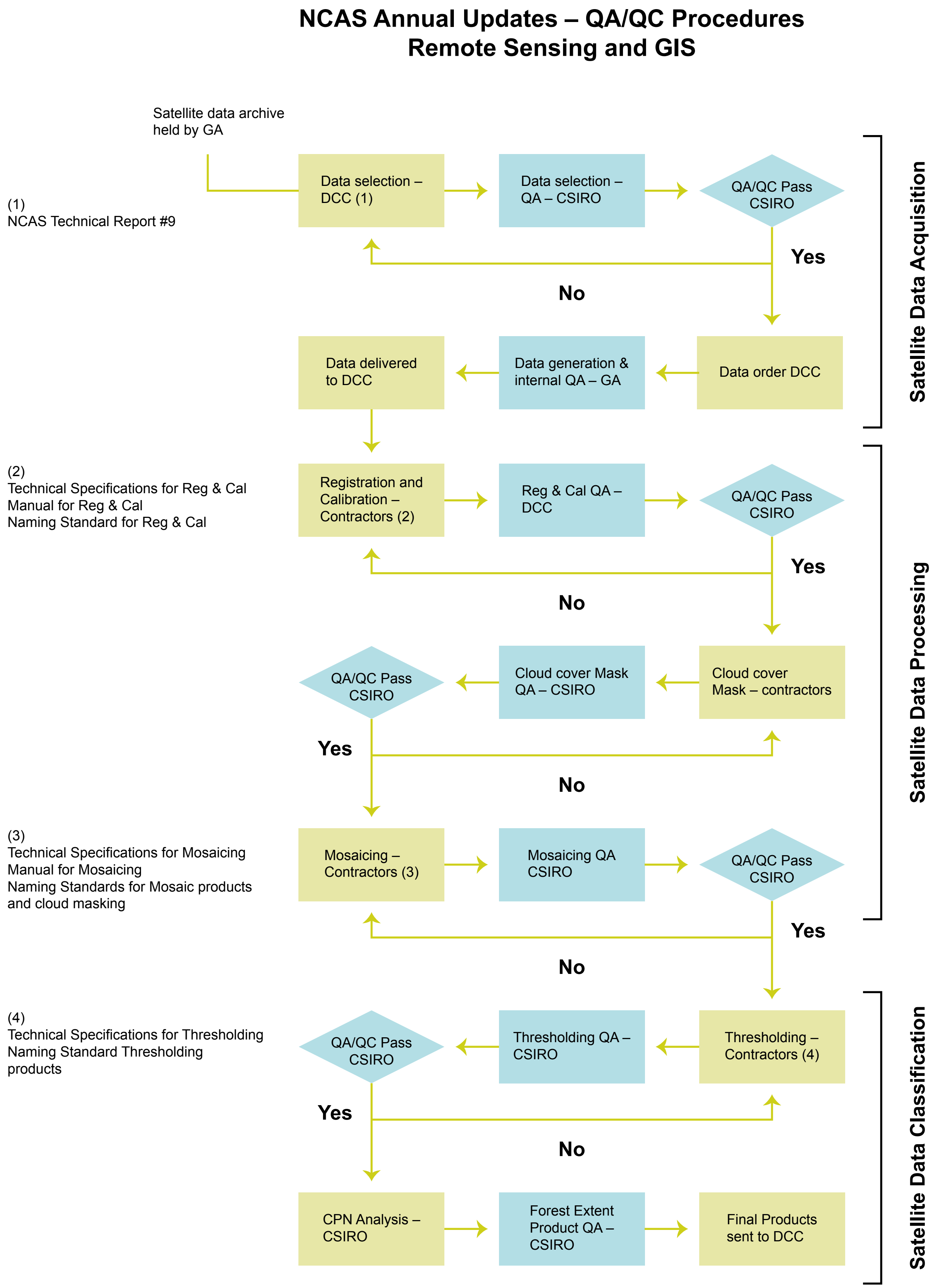
Incremental method development beyond that described in Caccetta *et al.*, (2003), and applied throughout the current time-series, includes the implementation of terrain illumination correction (Wu *et al.*, 2004), and the use of 'texture'-based analysis to map sparse vegetation extent and change (Caccetta and Furby 2004). Mapping of tree crown cover density is ongoing.

Plantations

Validation of plantation type mapping accuracy was carried out against specifically collected field data showing plantation species, stocking, condition, age and extent. This validation data was collected during a national program of site visits. The recently completed plantation mapping achieved an accuracy of 91% in terms of both species and spatial referencing for plantations identified as post-1990 plantations (MBAC Consulting, *in prep.*). Incorrect forest typing (e.g., labelling hardwood as softwood and vice versa) contributed 5% of the error, with only 4% being incorrect for both location and type. These results provide considerable confidence in the methodology applied and allow for a spatio-temporal analysis of Australia's plantation estate (see Appendix 7.D).

Methods to separate conifer plantations from native forest using the Landsat MSS data from 1972–88 (Landsat MSS data) are being developed and will be used in future inventories.

Figure 7.J3 Overview of QA/QC procedures associated with Land Cover Change calculations



7.J.3.2 Land use and land management

Land use and land management information is used by the NCAS to determine lagged emissions following land use change as well as the emissions from *cropland remaining cropland* and *grassland remaining grassland* and the effects of silviculture on emissions in the pre- and post-1990 *plantations*.

Land use mapping

Areas of *grassland remaining grassland* and *cropland remaining cropland* are obtained from the National Land Use 2001/2002 (Version 3) Summary Statistics provided by the Bureau of Rural Sciences (BRS) (http://nlwra.gov.au/). This mapping combines remotely sensed data with regionally specific information on land use collected by the Australian Bureau of Statistics (ABS). As such the QA/QC procedures are implemented by BRS and ABS. Prior to use in the NCAS modelling system, the data is checked to ensure that it is consistent with previous years' mapping. The data is also checked against areas of land use change as identified via the NCAS remote sensing programme to ensure that no double counting of land areas occurs.

Land management

Regionally specific information on land management practices over time were collated from a large range of sources and are available in NCAS technical reports 13 (for agriculture) and 32 (for forestry).

The land management data represent a composite of the best available and most comprehensive national information. A high degree of confidence can be placed in the data given the varied sources of information and direct regional knowledge of sub-contractors involved in collating the data.
This confidence is furthered by the concurrence given during State-based workshops used for reviewing the data, thus providing a measure of quality assurance through expert review. Publication of the results has also provided transparency and the opportunity for ongoing review. No concerns about the veracity of the information were identified as a result of either peer review or publication.

7.J.3.3 Climate data

Sensitivity testing during NCAS model development 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. Long-term (temporal) and regionally (spatial) averaged climate data were tested and shown to be inadequate to robustly support emissions estimates from land cover changes occurring in varying locations and under different climate conditions.

To provide robust climate data over the modelled period, mean monthly rainfall, vapour pressure deficit, pan evaporation, average temperature, minimum temperature, maximum temperature and frost days are obtained or directly derived from the Australian Bureau of Meteorology (BOM). A Digital Elevation Model (DEM) is also required for the production of climate surfaces. Monthly climate surfaces (maps) for each attribute are then derived using the ANUCLIM (McMahon *et al.*, 1995) climate modelling software (Kesteven *et al.*, 2004). Thus, the primary QA/QC issue associated with the derivation of monthly climate surfaces is to minimize errors arising from data used in the spline functions that produce the output climate surfaces by using the best available, highest quality input data. This is achieved by validating the input data used to generate monthly climate surfaces produced in ANUCLIM, and validating the output climate surfaces.

QA/QC

Three quality control aspects are associated with the production of climate surfaces. The first is examination of the completeness and quality of input monthly average climate data obtained from the BOM. Daily BOM data are accompanied by a quality control flag indicating whether or not the data have been quality controlled by the BOM. The minimum requirement for the calculation of monthly statistics is a 20-day record of quality controlled data for the average, maximum and minimum temperature variables, and a 25-day record of quality controlled data for the rainfall and number of frost day variables. Further, only those years with a full 12 months of data are used to calculate the climate surfaces.

The second quality control aspect is to obtain a DEM with sensible drainage properties, stream lines, contour lines and cliff lines. Version 2 of the 9 second (approximately 250 m) national digital elevation model (AUSLIG 2001) is used to provide terrain (elevation and aspect) mapping to support the spline functions used in the ANUCLIM software. Version 2 is based on the ANUDEM 5.0 elevation gridding program developed by the Fenner School of Environment and Society, Australian National University. The source elevation data used to produce this DEM are taken from 1:100 000 scale topographic mapping. Errors in the DEM are closely related to terrain complexity. Theoretical estimates and tests of the DEM against trigonometric data distributed evenly across the continent indicate that the standard elevation error of the DEM varies between about 7.5 m and 20 m for most of the continent. Standard errors are larger in upland areas with steep and complex terrain where the largest errors can exceed 200 metres (Hutchinson *et al.*, 2001; Kesteven *et al.*, 2004).

The third quality control aspect associated with climate data is to examine spatial location of weather stations, and the influence that errors in these data have on fitting the climate surfaces. For example, an error of 200 m altitude in a station location can equate to several degrees of temperature in a mountainous region. To fit multivariate climate surfaces the values of independent variables need to be known at the data point, and meteorological stations should be accurately located in position and elevation. However, the BOM have used various methods to geo-locate weather stations, with older locations being the least accurate. The BOM provided a base station dictionary (23 May 2001) with the supplied monthly climate data (Kesteven *et al.*, 2004). The station dictionary provided site number, latitude and longitude, elevation, location description and the start and finish year of operation (Kesteven *et al.*, 2004). This version of the BOM station dictionary was compared with a 1998 dictionary held by the Fenner School of Environment and Society at the Australian National University. Any station with a difference greater than 0.1° in position or 50 m in elevation was checked by visually locating the station using any available satellite imagery, topographic maps or aerial photographs. The correct geo-location of the station is then used in the model. The effect of the geo-location of weather stations on modelled climate surfaces is examined using variance statistics. The climate surface modelling output includes variance statistics of model residuals (RMSE) that are used to assess the extent of difference between the modelled result and actual weather station data. These residuals indicate how well the predicted climate measurement matches the actual climate measurement for a month and location. The highest 100 residuals are extracted and examined further. If these residuals indicate a geo-location error, then the location of that weather station is corrected and the model re-run. If there is no geo-location error associated with the climate surface then the station is included in the model. The climate surfaces, including all model results, have been submitted to the Australian National University's Fenner School of Environment and Society for independent QA/QC. Detailed checking of procedures and output statistics led to the conclusion that the development of the models represented application of best practice and yielded robust results.

7.J.3.4 Soils

The NCAS requires maps of soil type and pre-change ('natural' condition) soil carbon to calculate soil carbon stock changes due to land use change, ongoing management and climatic conditions. These maps provide: i) pre-clearing soil carbon stocks at a 250 m spatial resolution; and, ii) soil type description that are used to derive water holding capacity and soil clay content that determines the rate of decomposition of plant residues and the allocation of carbon to the different soil pools (Richards, 2001; Webb, 2002).

Soil type

Spatial soil coverage for all Australian states and territories are identified through the Atlas of Australian Soils and broad scale land system mapping together with regionally specific data to produce high resolution (>1:50,000) coverage that could be overlayed on to Interim Biogeographic Regionalisation of Australia (IBRA, Version 4, Thackway & Cresswell, 1995) regions (Webb, 2002). Where possible the use of land-based soil surveys and geomorphic maps were used to validate the broader scale soil type maps within an IBRA region. In addition, regional expertise was obtained at the state and territory level for the major soil types within each of the IBRA regions. This provided an estimate of the major soil types within an IBRA region and the extent of different land uses for each of these soil types. The process of developing the maps is described in Webb (2002), which was supported by the development of soil sampling protocols and standardised laboratory methods (McKenzie *et al.*, 2000).

Soil carbon

The distribution and extent of soil carbon is not uniform in the Australian landscape, and is influenced by factors such as soil type, soil moisture, climate, land cover and land use. Spatially explicit information about the underlying soil carbon potential in the top 30 cm of soil is required to accurately model soil carbon flux using NCAS (Skjemstad and Spouncer, 2003, Skjemstad *et al.*, 2000). In particular, a key input is the level of soil carbon prior to land use change, that is, soil carbon under pre-cleared conditions.

A search for existing soil carbon data revealed that parameters measured, soil analysis methods and depth of soil samples differed widely (Webb, 2002). The spatial distribution of samples was also limited (Webb, 2002). It was not feasible to undertake extensive and standardized field-based soil carbon surveys to fill these gaps. Thus, the primary QA/QC issue associated with estimation of soil carbon was how small-scale soil carbon data collected in the field using a range of methods could be associated with soil types and properties to produce an Australia-wide map of soil carbon distribution and abundance.

QA/QC

Data for the development of soil type maps was extracted from the best available resource inventory information held by state and territory governments and was subject to expert review prior to being incorporated. Initially, a comprehensive data search was conducted to determine the extent of existing chemical and physical information for uncleared sites. Organic carbon contents were determined for soil profiles then averaged for each of the Soil Orders, Principal Profile Forms or Groups within each IBRA region. Where site data were scarce or non-existent, data from similar soils in the same or neighbouring IBRA region were used (Webb, 2002). Soil clay content was also taken from these inventories and supplemented with available research data. Soil carbon content was corrected to methodological standards where the initial method of measurement was known; otherwise the data were considered unusable and were not included in the final product.

In deriving the soil carbon map the comparability among existing soil carbon measurements arising from the use of different analytical methods needed to be resolved. Soil organic carbon measurements are normally derived from combustion in a LECO furnace. However, the method historically used to derive soil carbon values for many sites is the Walkley and Black (1934) wet oxidation method.
This method has evolved over time in the major laboratories, such as by including a heating step during oxidation (Heanes, 1984) and, thus, has produced results that have varied over time. In a separate study implemented as part of the NCAS soil carbon validation program, the relationships between the Walkley and Black method and the LECO method was examined through time across the major laboratories in each state and territory. These relationships provide adjustment factors that are applied to the reported soil carbon values (Wang *et al.*, 1996; Skjemstad *et al.*, 2000; Griffin *et al.*, 2003).

The application of standardised field and laboratory protocols (McKenzie *et al.* 2000) ensures that robust and consistent data are obtained from all validation sampling undertaken for the NCAS. Extensive field calibration and independent site validation is used to develop and confirm model performance. Use of paired sites and long-term trial data over a wide range of systems ensures that spatial applications are interpolated within well understood and field-verified ranges.

Agricultural soil model calibration and validation

An independent calibration and validation of the soil carbon model used to predict changes in soil carbon caused by shifts in agricultural practice, was performed (Skjemstad and Spouncer 2003). The results were sensitive to the partitioning of carbon between the various 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 the NCAS model, provided that the decomposition rate constant (*kRPM*) of the POC pool was reduced from 0.3 to 0.15. From the calibration sites and using this single rate modification, the model performed equally well in subtropical and Mediterranean climates and for crops and pastures (Sjkemstad and Spouncer, 2003). A full description of the model calibration and validation results for agriculture can be found in Skjemstad and Spouncer (2003) and for forestry in Paul *et al.*, (2002b) and Paul *et al.*, (2003b).

For long-term rotation trials and other sites sampled from the same location on a temporal basis, validation of the model was generally very good. For new paired sites, validation of the model was more variable. In many cases, apparent poor performance of the model could be attributed to spatial heterogeneity and inadequate pairing of the sampling sites. Overestimation of modelled plant inputs at the paired sites was also identified as a possible issue. For Tier 3 methods that model soil carbon changes over time due to land use change, the associated errors in sampling are minimised, but remain an issue for the development of the spatial soil data inputs to the model. In general terms the coefficient of variation for modelled outputs of soil carbon is around 5% (Janik *et al.*, 2002), whereas the coefficient of variation for measured soil carbon is 15–40% (McKenzie *et al.*, 2000; Janik *et al.*, 2002). Further details are provided in NCAS technical reports and peer reviewed literature (Murphy *et al.*, 2003; Griffin *et al.*, 2003; Harms and Dalal, 2003).

Soil model verification

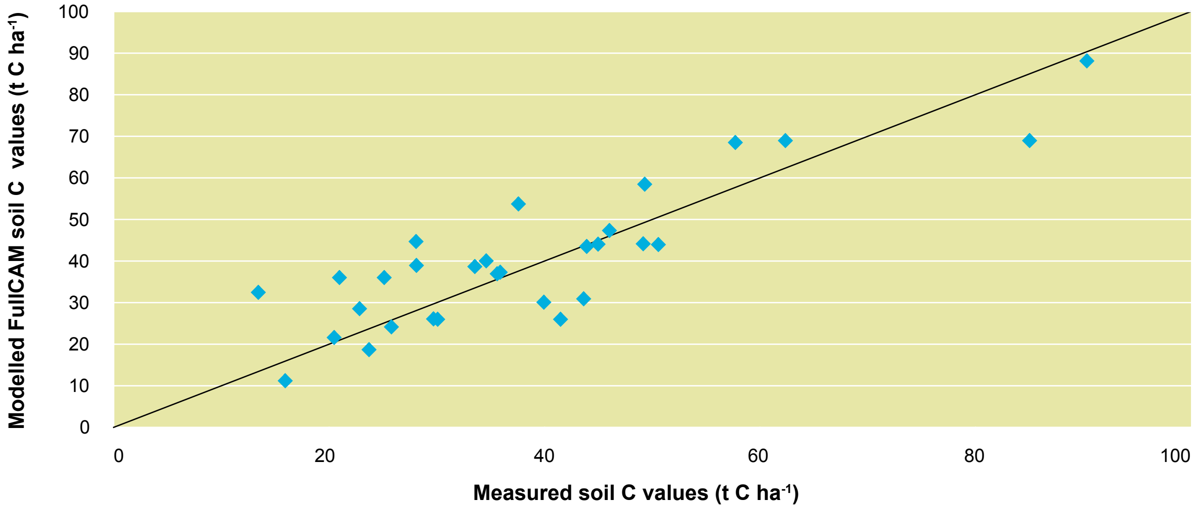
The spatial pre-cleared soil carbon map used by the NCAS was verified against measured soil carbon values at 53 sites in New South Wales (Murphy *et al.*, 2003), Western Australia (Griffin *et al.*, 2003), and Queensland (Harms and Dalal, 2003). These measured values consist of paired sites containing both a native vegetation site and another site on the same soil type that had been subject to land use change.

To validate the soil carbon model, the initial soil carbon measurements from 32 of the 53 paired sites (average of 29.5 t C ha^{-1}) were compared to the pre-clearing soil carbon values used by the NCAS (average of 29.6 t C ha^{-1}). In addition to the 53 paired sites, another 22 soil pairs (an undisturbed native vegetation site paired with a cleared site) were sampled to provide a range of verification targets for model testing. Sites were established in collaboration with state agencies in New South Wales and Western Australia, in the areas of major forest conversion activity. Sites were selected to cover a variety of crop types, soil types and times since change (i.e., time since clearing) in areas subject to most intensive activity. Sampling of sites was completed according to the standardised soil sample protocol developed for the NCAS (McKenzie *et al.*, 2000).

The verification program needed to measure fewer parameters than the model calibration/validation program (e.g., total soil carbon change rather than change in fractions) which could therefore be applied to more sites. Calibration data were drawn from a series of both forestry and agricultural research sites, which although sparse, are ideally suited to model calibration having comprehensive data records and time-series consistent measurements of key soil and management parameters.

An independent assessment of measured soil carbon values from 29 paired sites, representing a subset of all the paired sites, were compared with NCAS model outputs using site history as a means of modelling the soil carbon change after land clearing. A regression (Figure 7.J4) found a significant correlation ($r^2 = 0.73$) between the measured soil carbon values of the 29 sites and the NCAS modelled soil carbon values for the same time at which the soil was sampled for analysis. These data showed a higher level of variance between measured and modelled values (25%) compared to the validation analysis performed by Sjkemstad and Spouncer (2003), but a lower level of variance than would be expected from a field measurement due to sampling error alone (up to 40% CV; McKenzie *et al.* 2000).

Figure 7.J4. Correlation (1:1) of measured versus modelled soil carbon data collated from 29 sites across a range of soil types in northern and southern Australia



The regression analysis of measured and NCAS modelled data (Figure 7.J4) demonstrates that the logic used to establish a pre-clearing soil carbon layer for Australian soils under different management practices can be used with a high degree of confidence to estimate current soil carbon values. Therefore, for national inventory reporting requirements the NCAS model provides data of equal or better accuracy than would a measurement program, especially considering the errors associated with sampling and temporal variability.

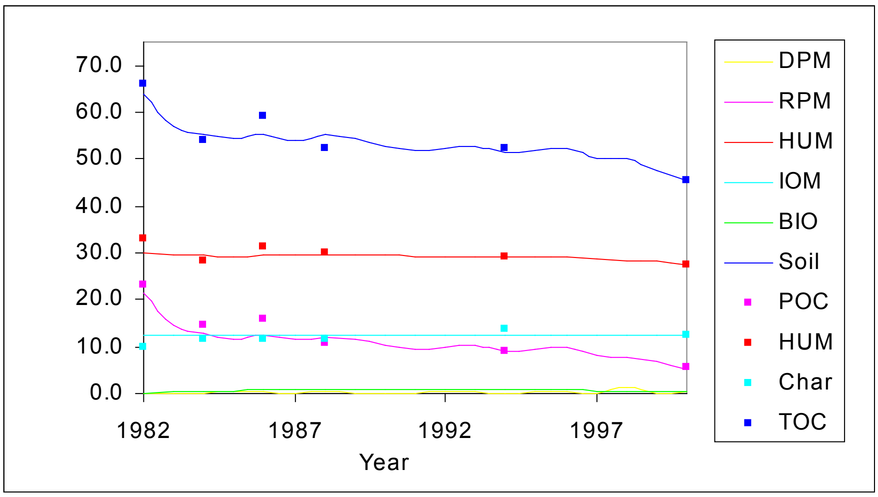
Soil carbon under cropland

The extensive verification data collected during the model development also provides guidance on the general results to be expected under different cropping systems. In most southern Australian continuous cropping systems there is a loss of soil carbon which stabilises within 10 to 30 years (see Figure 7.J5). Conversely, the crop-pasture rotational systems typically yield an increase in soil carbon (Figure 7.J6). In the north of Australia some continuous cropping systems frequently show increases in soil carbon with the introduction of irrigated crops particularly in areas of low rainfall (and low initial soil carbon stock) using management techniques such as green trash (mulch) blankets to retain soil moisture and build soil carbon.

Figure 7.J5 (a)–(f) Changes in soil carbon (■ measured and – modelled) under continuous cropping

(Key: DPM – decomposable plant material; RPM - resistant plant material; HUM – humic matter; IOM inert organic matter; BIO- biological matter; Soil – total soil carbon; POC – plant organic carbon; HUM – humic matter; Char – char; TOC – total organic carbon)

(a) Brigalow cropping (soil 64)



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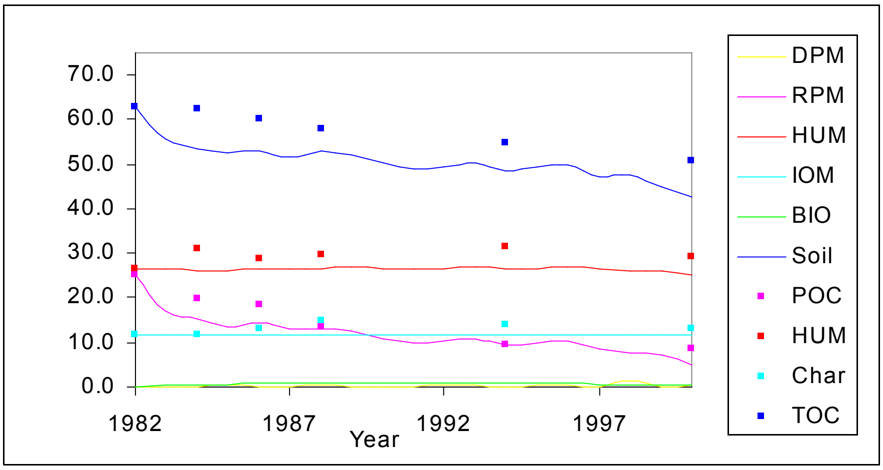
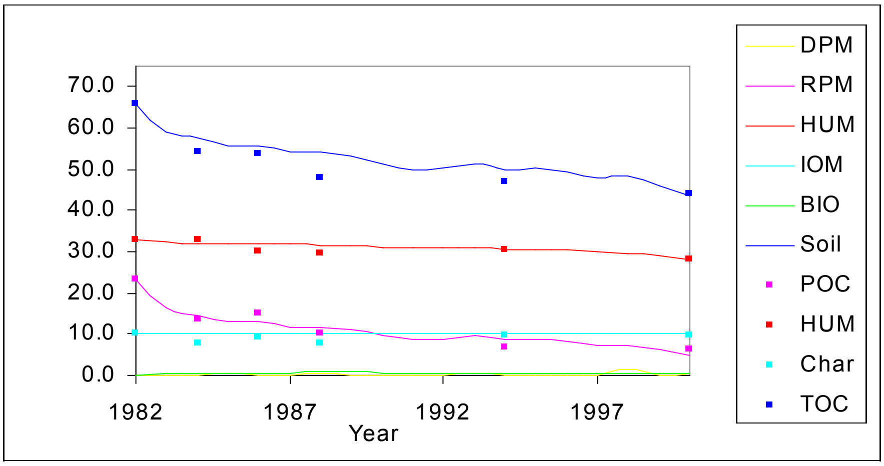
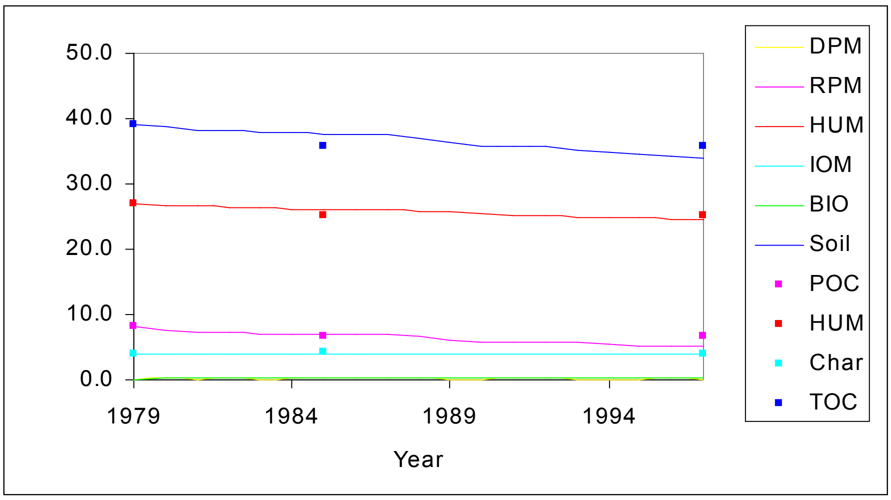
(b) Brigalow cropping (soil 65)



(c) Brigalow cropping (soil 66)



(d) Tarlee continuous wheat



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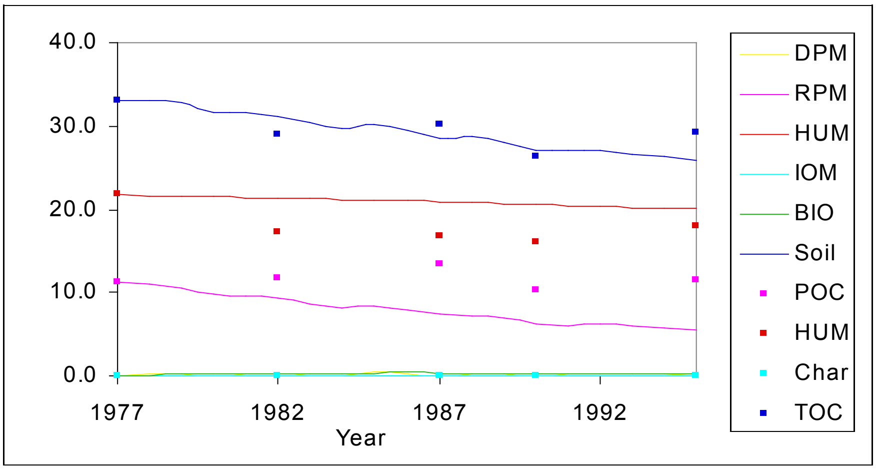
(e) Gibson continuous wheat



(f) Salmon Gums continuous wheat

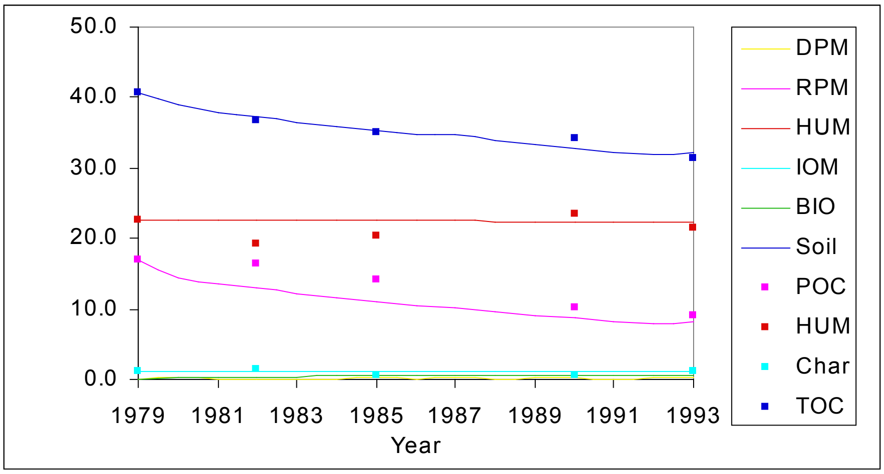
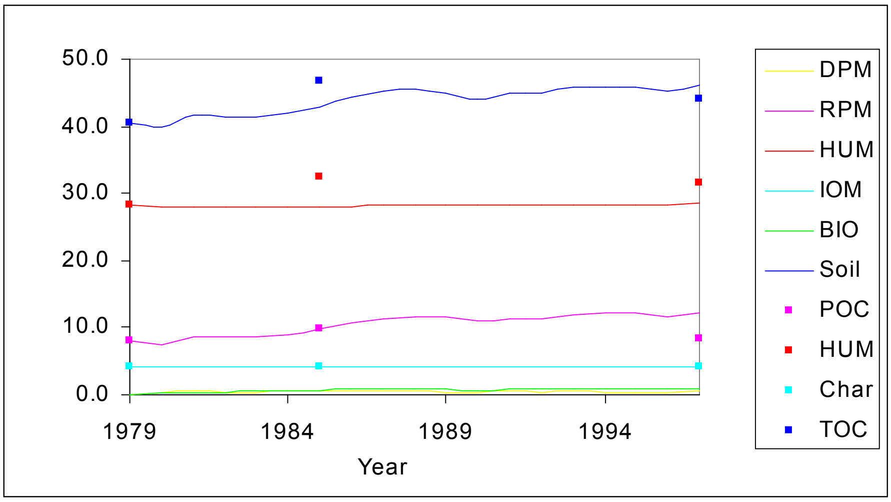


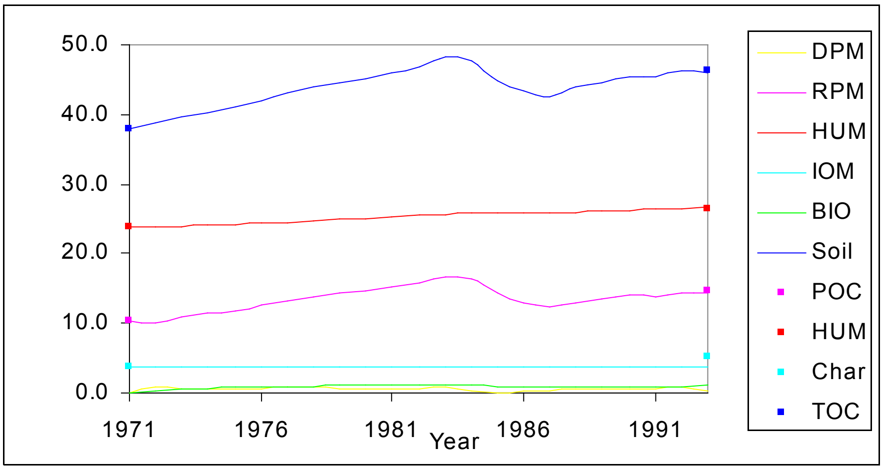
Figure 7.J6 shows changes in soil carbon under crop and pasture rotation systems. Unlike the continuous cropping systems shown in Figure 7.J5, the crop-pasture systems typically show an increase in soil carbon. The amount of increase will depend on the pattern of the rotations and the crop types used. In almost all systems there is an initial loss from land use change, but this loss moderates over time and is often replaced by a net uptake. Once the losses due to land use change have begun to stabilise, the predominant changes come from changed management, and from annual variability in crop production. Changes in crop production affect both living biomass, and subsequently, the flow-on to dead organic matter and soil carbon.

Figure 7.J6(a)–(i) Changes in soil carbon (■ measured and – modelled) under crop – pasture rotations (Key: DPM – decomposable plant material; RPM - resistant plant material; HUM – humic matter; IOM inert organic matter; BIO- biological matter; Soil – total soil carbon; POC – plant organic carbon; HUM – humic matter; Char – char; TOC – total organic matter)

(a) Tarlee wheat / pasture



(b) Glenorchy wheat / pasture



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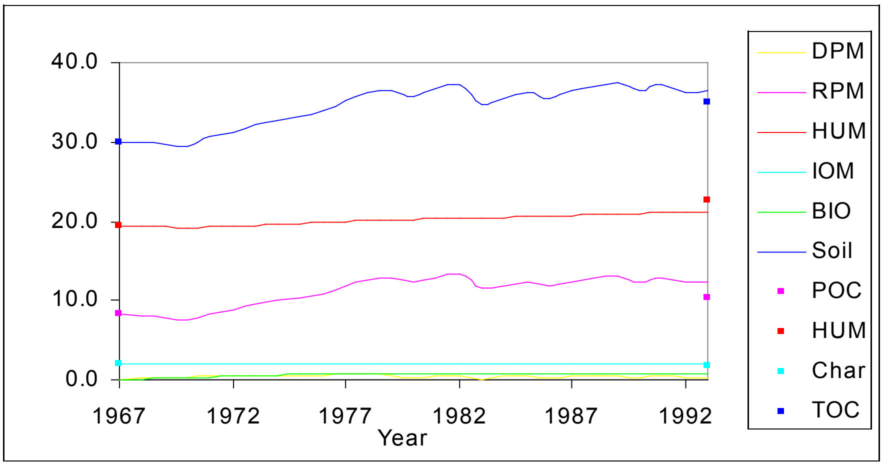
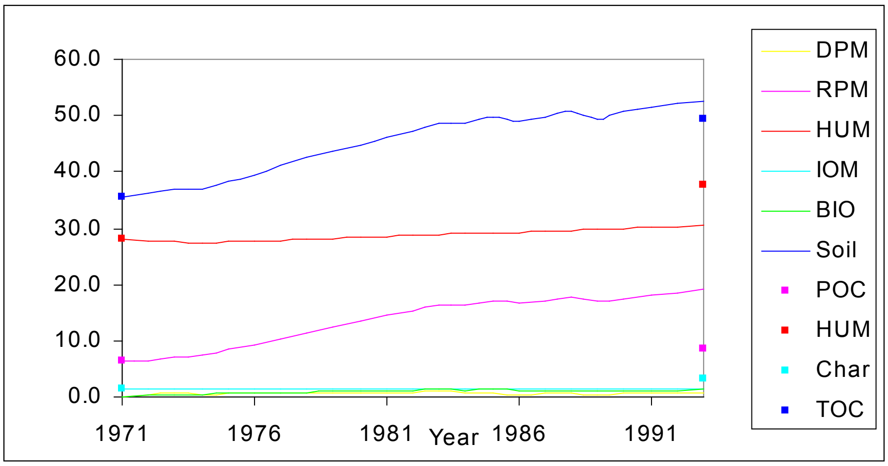
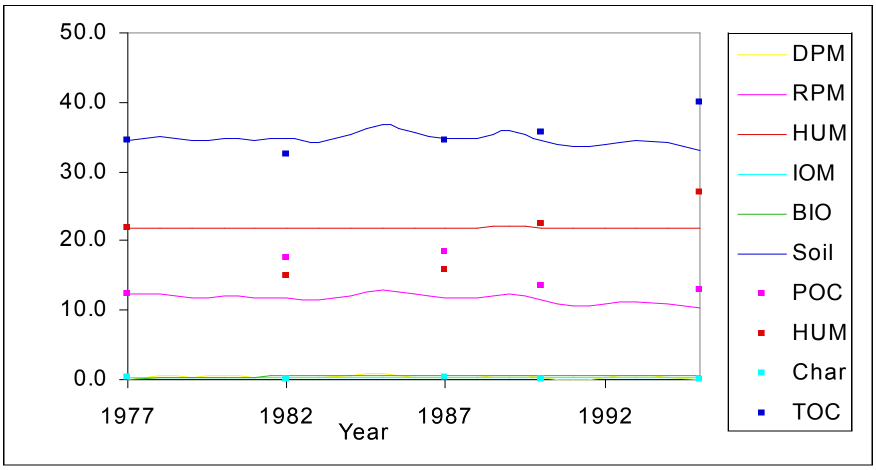
(c) Freeling barley / pasture



(d) Padthaway wheat / pasture



(e) Gibson pasture / wheat / lupins plot 16



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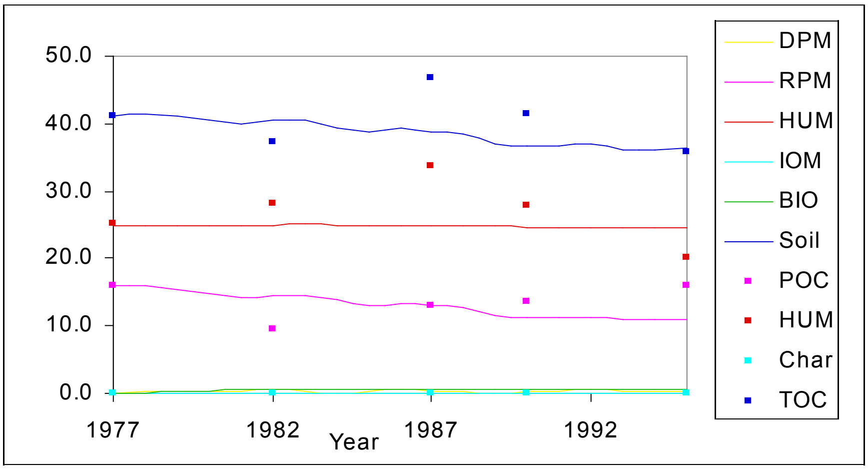
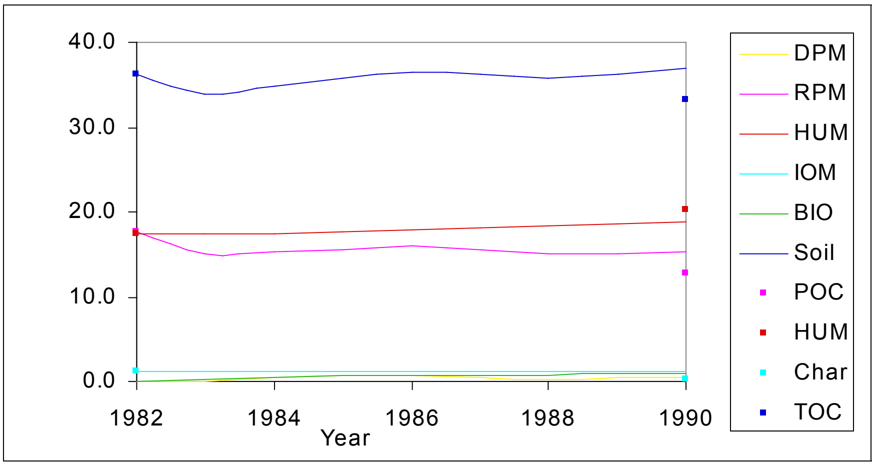
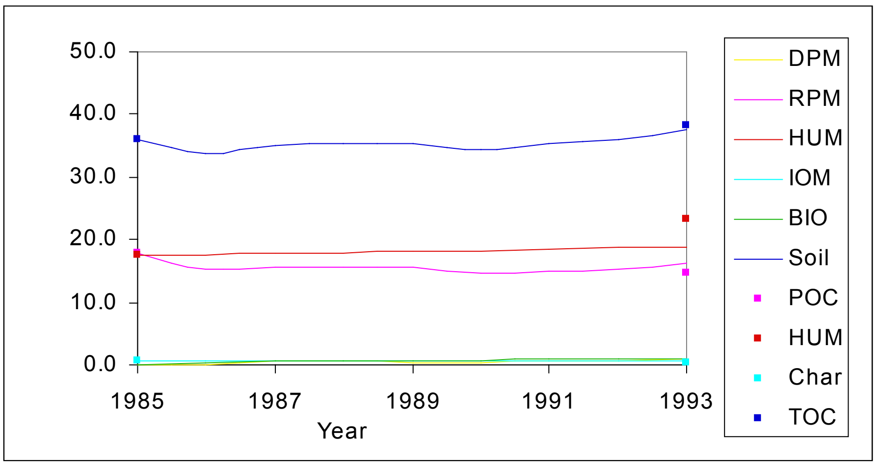
(f) Gibson pasture / wheat / lupins plot 27



(g) Salmon Gums wheat / 3 pasture



(h) Salmon Gums wheat / 3 pasture



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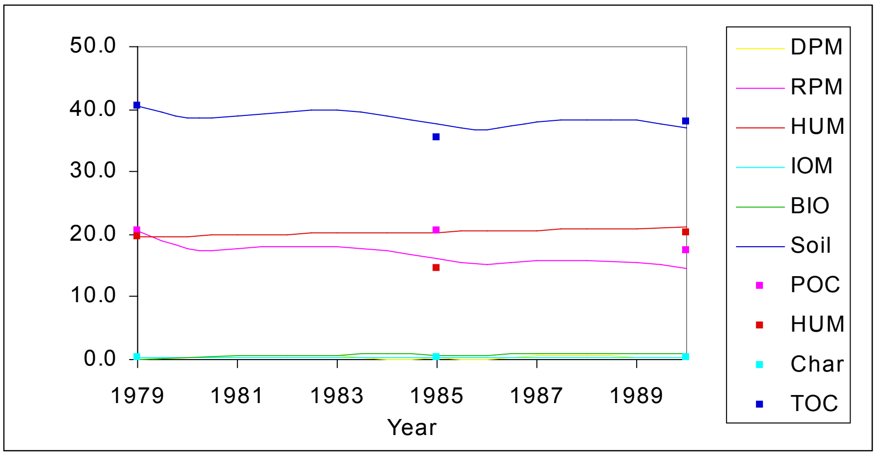
(i) Salmon Gums 3 wheat / 3 pasture

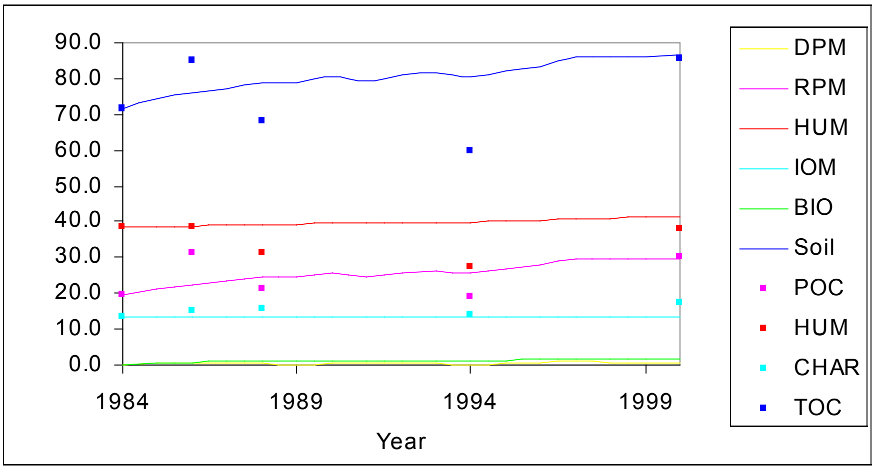


Soil carbon under grassland

The grassland category covers a much wider range of climates and soil types than cropland. Figure 7.J7 is a selection of the model calibration and validation sites reported by Skjemstad and Spouncer (2003) and Skjemstad *et al.*, (2004). These sites covered a broad representation of climates, soils, pasture types and management systems. The model testing applied initial measured estimates. Models were then run to test the ability to predict subsequent measured results.

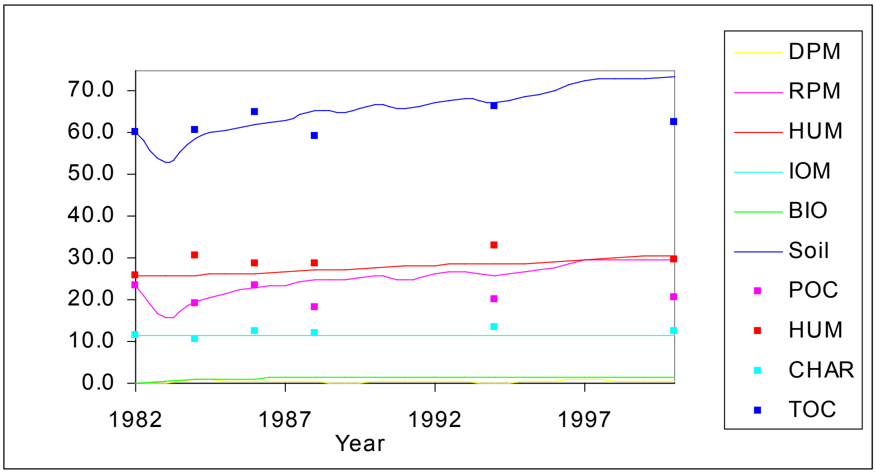
Figure 7.J7 (a)–(o) Changes in soil carbon (■ measured and – modelled) under continuous pasture (Key: DPM – decomposable plant material; RPM - resistant plant material; HUM – humic matter; IOM inert oganic matter; BIO- biological matter; Soil – total soil carbon; POC – plant organic carbon; HUM – humic matter; Char – char; TOC – total organic matter)

(a) Brigalow pasture (soil 67)

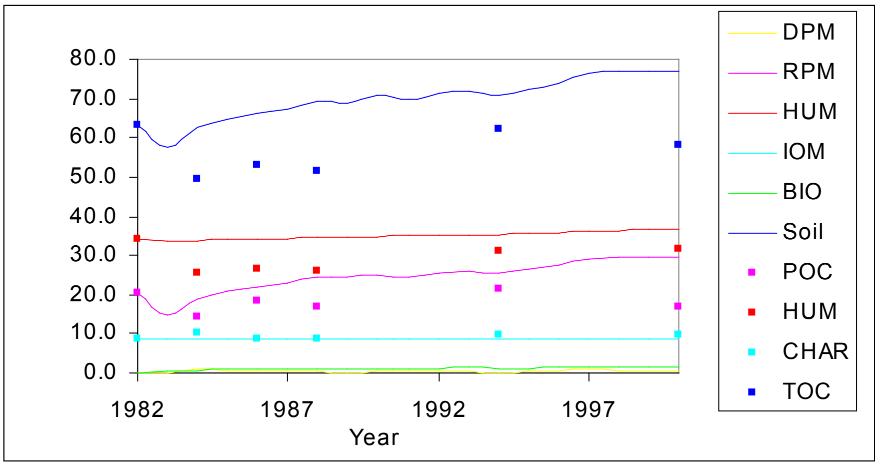


APPENDICES

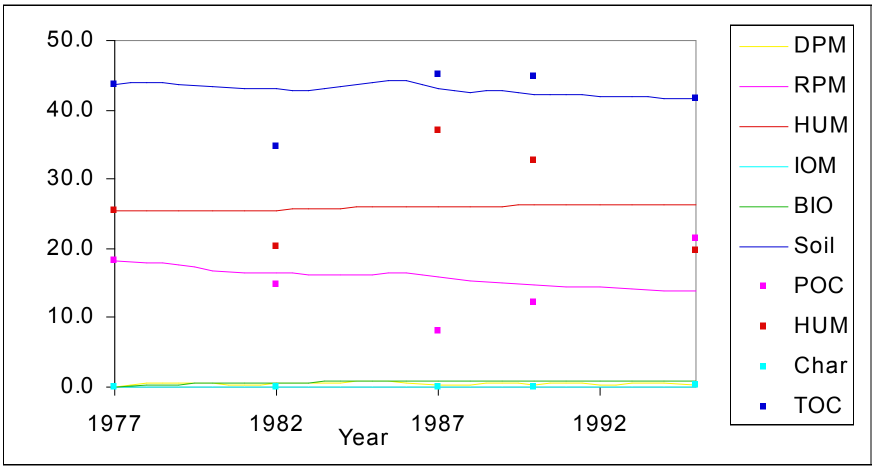
(b) Brigalow pasture (soil 68)



(c) Brigalow pasture (soil 69)



(d) Gibson continuous pasture



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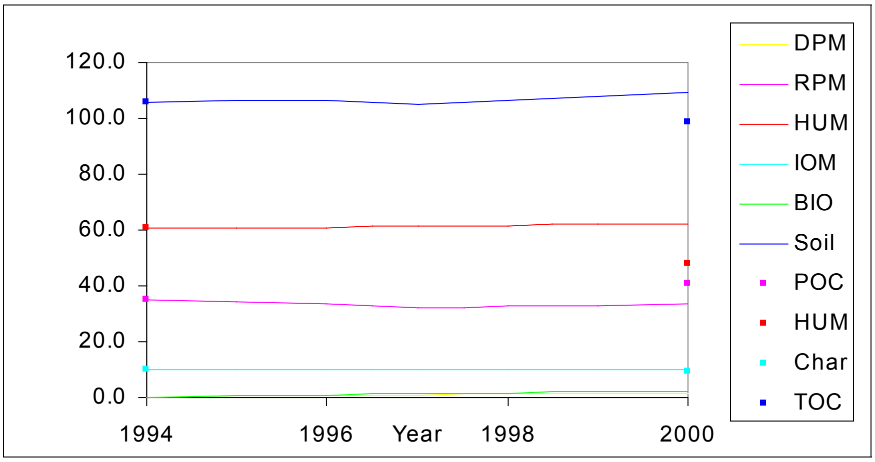
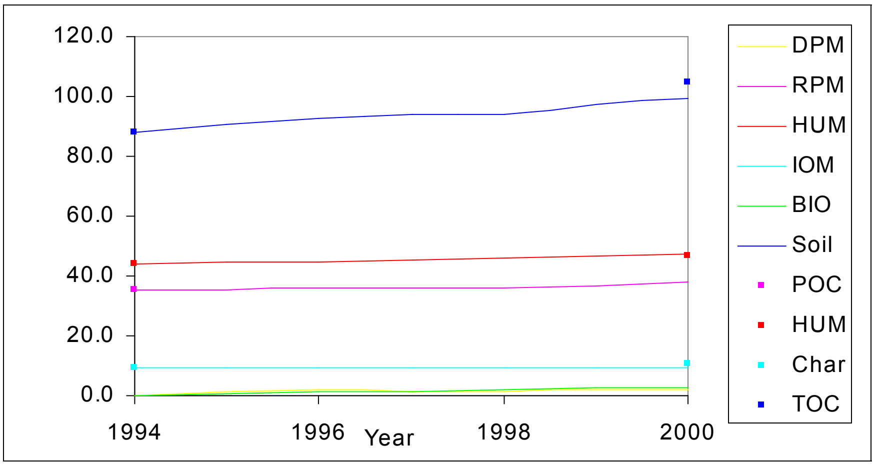
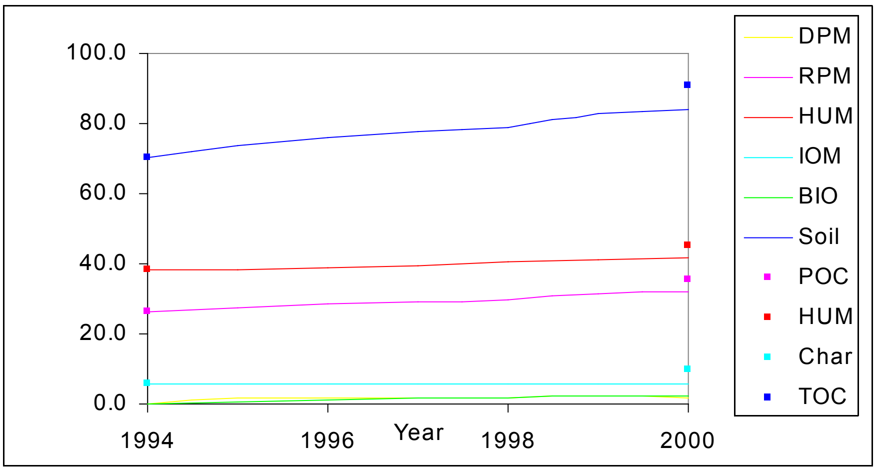
(e) Hamilton permanent pasture, Plot 10



(f) Hamilton permanent pasture, Plot 11



(g) Hamilton permanent pasture, Plot 12



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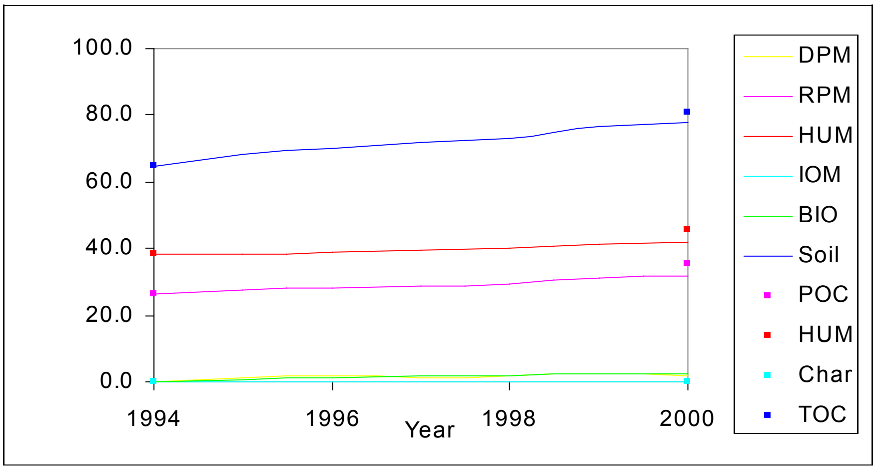
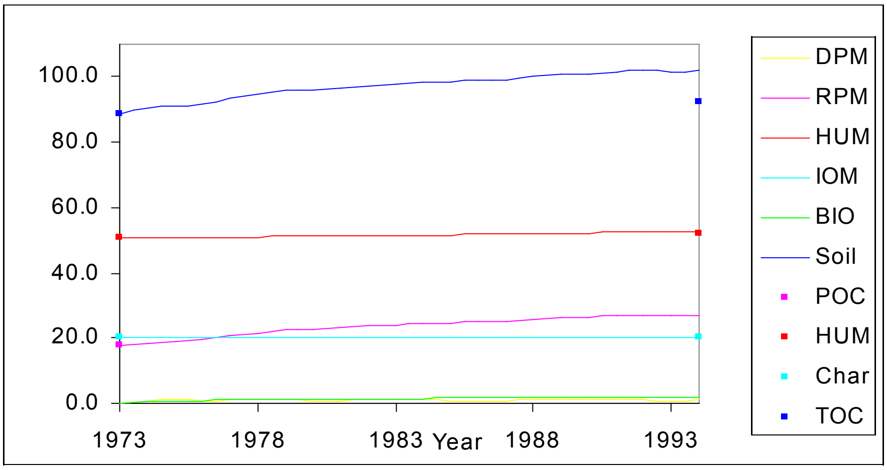
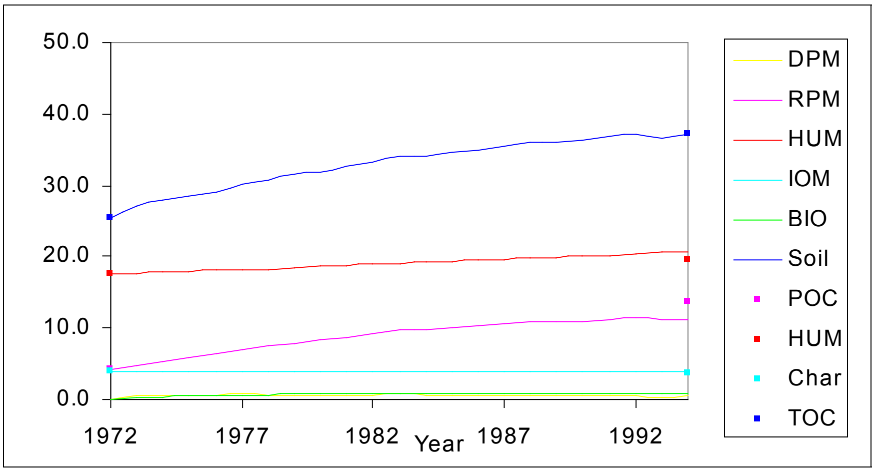
(h) Hamilton permanent pasture, Plot 12 (Char–C corrected)



(i) Glencoe permanent pasture



(j) Victor Harbour permanent pasture wheat



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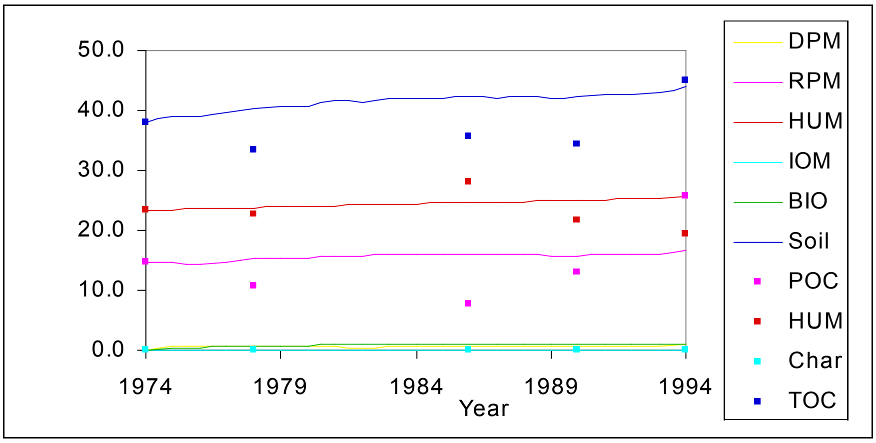
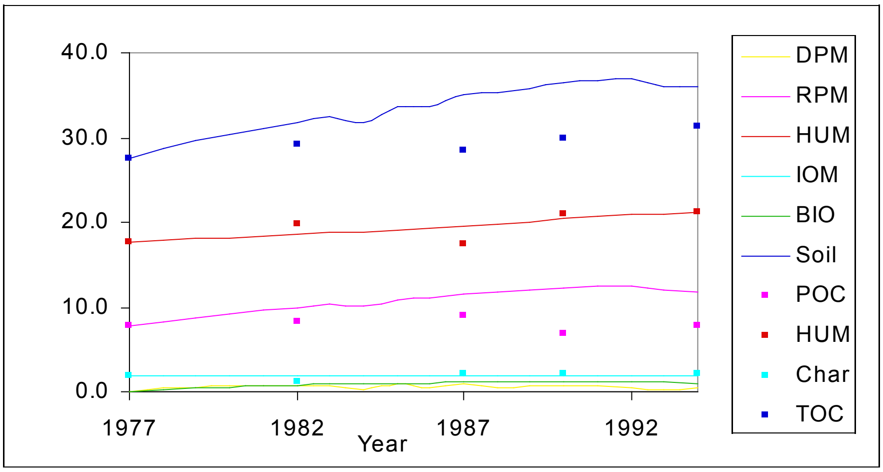
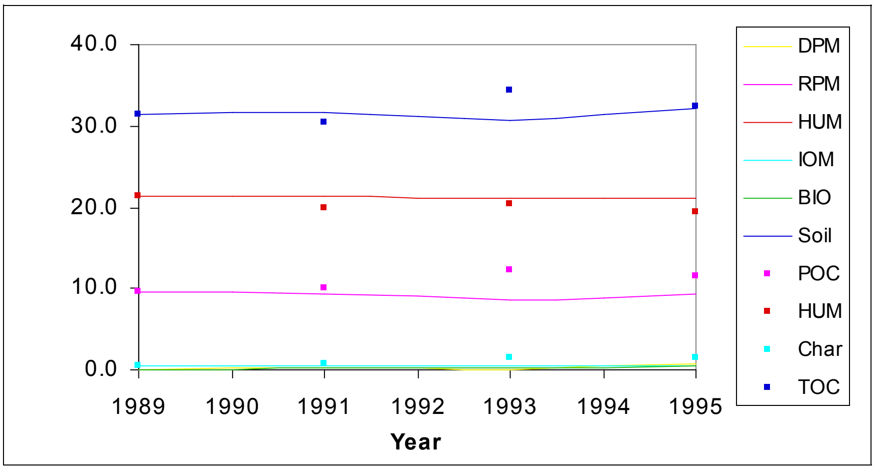
(k) Newdegate continuous pasture



(l) Merredin (heavy) continuous pasture



(m) East Beverley continuous pasture



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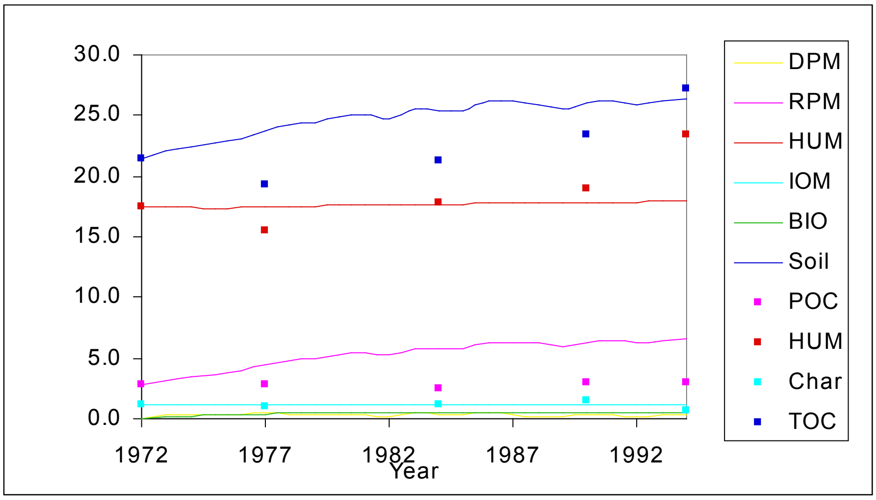
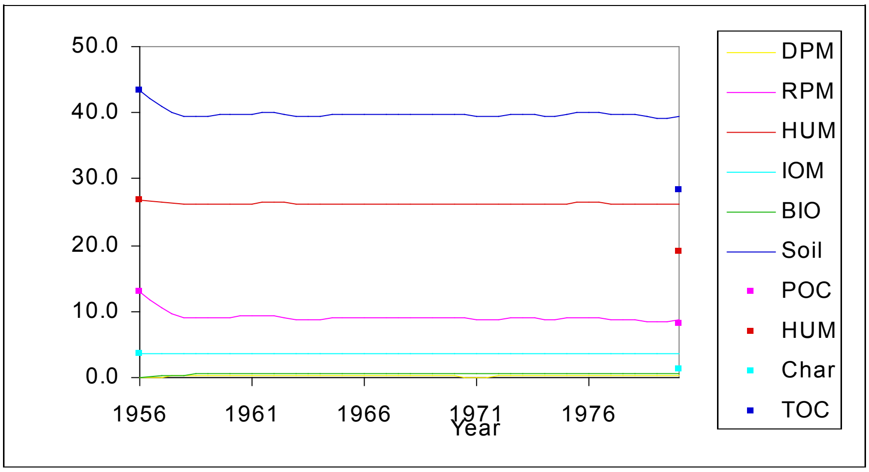
(n) Chapman continuous pasture



(o) Billa Billa pasture for 25 years



Model sensitivity

The sensitivity analysis of the soil carbon model was conducted to examine the response of individual soil carbon predictors to changes in model outputs, using both univariate and simultaneous changes in variables (Janik *et al.*, 2002). It is important to distinguish between the sensitivity of the variables and the uncertainty of their estimates. Uncertainty in a variable is less important if the model is insensitive to changes in that variable. Application of a sensitivity analysis to all model variables and input data will indicate which variables and data must be evaluated most accurately. As the sensitivity of predicted soil carbon to model variables and input data decreases, the degree of accuracy required in measuring the variables also decreases.

The NCAS soil carbon model has been optimized for Australian conditions by adjusting the decomposition rate variables for the five pools used by the model, a decomposable plant material pool (DPM); a resistant plant material pool (RPM); a microbial biomass pool (BIO), a humified organic matter pool (HUM), and an inert organic matter pool (IOM), consisting mostly of charcoal. Sensitivity analysis of the model inputs demonstrated that there was a comparative insensitivity to the BIO and DPM pool quantities and rate constants (see Table 7.J6). These pools have a rapid turnover rate and consequently have reduced impact on soil carbon content in the longer term. In contrast, the slower decomposition rates of the HUM and RPM pool leads to these pools being more important in the longer term.

Table 7.J6 Predicted carbon change (t C ha^{-1}) for a + 10% change in C pool variables over a 20–year period

Variable	Carbon	Change	(t C ha^{-1})
	1975	1980	1990
BIO rate constant	-0.03	-0.03	-0.03
DPM rate constant	-0.01	-0.01	-0.01
RPM rate constant	-0.24	0.36	-0.54
HUM rate constant	-0.07	-0.13	-0.23
RPM pool	-0.40	-0.57	0.73
IOM pool	0.04	0.07	0.13

Source: Janik *et al.*, (2002)

The standard error of the prediction of soil carbon due to uncertainties in each variable is the product of the sensitivity and the standard deviation of the estimate of that variable. The actual sensitivity for each variable is determined by fitting a polynomial to the predicted data, and then differentiating at the required values of the variable. When sensitivity data are combined with estimates of their uncertainty, the variables that will potentially cause the greatest uncertainty in the modelling process may be indicated. For example, the uncertainty analysis for plant input data (i.e., grain yield, root, and aboveground dry matter (AGDM)), demonstrated that all of the soil carbon pools showed moderate uncertainty, but small changes in the RPM pool had a significant impact upon model uncertainty (Table 7.J7).

Table 7.J7. Summary of model response to changes in rate constants and plant input data

Variable	Response	Expected Variability	Uncertainty	Contribution to uncertainty	20 year change (t C ha^{-1})
Decomposition rate of BIO pool	Very low	High	Moderate	Very small	< 0.1
Decomposition rate of DPM pool	Very low	High	Moderate	Very small	< 0.1
Decomposition rate of RPM pool	Moderate	High	Moderate	Significant	1.1
Decomposition rate of HUM pool	Moderate	High	Moderate-High	Moderate	0.4
Ratio AGDM:Grain yield	Moderate	High	Moderate	Significant	1.4
Root:AGDM	Low	High	High	Significant	0.8
OC:TDM	High	Low	Low	Small	1.2

Source: Janik *et al.*, (2002)

With regard to time scale of the simulation, those variables with rapid rate constants are likely to have less impact on the carbon simulations than those with longer time scales, but the impact will be greatest at or near clearing. The high sensitivity of soil total organic carbon (TOC) to variables associated with the RPM pool and RPM rate constant carries on throughout the 30-year simulation period (Table 7.J8). The response to the IOM pool is only moderately sensitive at the start of the simulation but becomes increasingly more sensitive at longer simulation periods.

Table 7.J8. Summary of model responses to changes in soil variables

Variable	Response	Variability	Uncertainty	Contribution to uncertainty	Range (t C ha^{-1})
Percent clay	Small	Large	Moderate	Small	< 0.1
RPM pool (t C ha^{-1})	Moderate-High	High	Moderate	Significant	1.5
IOM pool (t C ha^{-1})	Moderate	High	Low-Moderate	Moderate	0.3

Source: Janik *et al.* (2002).

The response of the model to changes in the soil variables is summarized in Table 7.J8, including the values of the soil carbon within the individual pools. The prediction of soil carbon is fairly insensitive to the amount of clay in the soil (Janik *et al.*, 2002). The final estimate is affected by less than 0.1 t C ha^{-1} when the clay content was varied between 5 and 70%, but is increasingly sensitive with very low clay content.

Model responses to the crop variables are summarised in Table 7.J9. Model response is expected to depend on the effect of the particular crop variable in modifying the amount of plant material entering the system. Of these variables, the time of sowing (crop start) and the number of months cropped (months cropped) are expected to have only a small contribution to the model uncertainty. There is moderate sensitivity to crop grain yield, but records are available for this value in most situations, or yield can be modelled. Variability in yield will, therefore, have only a moderate contribution to the overall uncertainty. The fraction of stubble retained has a low to moderate sensitivity and uncertainty. It is, therefore, rated as having only a relatively low contribution to the overall model uncertainty.

Table 7.J9. Summary of model response to changes in crop variables

Variable	Response	Variability	Uncertainty	Contribution to uncertainty	Range (t C ha^{-1})
Crop start month	Small-Moderate	Moderate	Low	Small	0.3
Months cropped	Small-Moderate	Moderate	Low	Small	0.6
Crop grain yield	Moderate	High	Moderate	Moderate	1.5
Fraction stubble retained	Small-Moderate	High	Low- Moderate	Small	0.4
DPM/RPM	Small	Small	Moderate	Small	0.4

Forest soil model

After investigation of sites that met the requirements for model calibration, two agricultural and seven forestry sites were selected. One agricultural site was located on a monsoonal subtropical environment with heavy clay soil and the other was located in a temperate Mediterranean climate with a light textured soil. At each agricultural site, archival soil samples (0-30 cm depth) from the beginning and end of the trial as well as some in between were fractionated into particulate organic carbon (POC), charcoal (char–C) and humic (HUM) pools (Skjemstad and Spouncer, 2003). These pools were then used to initialize 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. Other pools were set to zero but were generated by the model. 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. Calibration of the forestry sites was completed subsequent to the agriculture calibration in seven locations:

- *Eucalyptus globulus* in the low rainfall region, south-west of Western Australia;
- *E. globulus* in the high rainfall region, south-west of Western Australia;
- *Pinus radiata* in the Green Triangle region of South Australia and Victoria;
- *E. grandis* in south-eastern Queensland and north-eastern New South Wales;
- *P. radiata* in the south-eastern highlands New South Wales;

- *E. globulus* in south-eastern Gippsland, Victoria; and
- *E. nitens* in the Tasmanian highlands.

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

7.J.3.5 Crop yield and management

The NCAS model uses crop yield data to calculate emissions and removals in all agricultural (*cropland remaining cropland* and *grassland remaining grassland*) and conversion (*forest land converted to cropland* and *forest land converted to grassland*) sub-categories. The crop yield data is used in the Tier 3 model to calculate inputs to debris and soil carbon from turnover and post-harvest residues. The key QA/QC issue associated with crop yield is to obtain a consistent Australia-wide time series of the best available crop yield data.

QA/QC

The CSIRO is contracted by the DCCEE to supply a comprehensive annual crop and pasture yield database for the NCAS, using the Australian Bureau of Statistics (ABS) data along with research papers and reports, and farming systems annual reports (e.g., Birchip Cropping Group, Mingenew and Minnepa Farming Group, Central West Farming Services) for the major crops and pastures in Australia (Unkovich *et al.*, 2009). The annual crop and pasture yield data, which for the majority of the available data, are collected by the Australian Bureau of Statistics (ABS) and the Bureau of Rural Sciences (BRS) through national statistical surveys at the statistical local area (SLA) level for the grains, grazing and dairy industries. These surveys also provide detailed information on farm inputs (e.g., fertiliser, irrigation, sowing rates, and crop species), production (e.g., crop yields and pasture cut for hay) and economic performance for the grains, grazing and dairy sectors, which comprise more than 70 per cent of Australian farm business units.

These data are disaggregated to the Interim Bio-geographical Regions of Australia (IBRA) scale, and also differentiate between stubble management practices, crop species, crop rotations and crop distribution according to soil type (Swift and Skjemstad, 2002). Quality control for consistency of yield against previous years, constrained by climate, is conducted at the sub-IBRA scale by comparing the current year's yield against the previous year's yield. All data are checked for consistency from the previous year and any values exceeding a variance of greater than 10% of upper and lower limits are checked against industry databases where there is available data. If data are unavailable for any given region a calculation of yield is derived using a growth function (Unkovich *et al.*, 2009) using regionally specific climate data (from NCAS climate surfaces) and again checked for a 10% variance. NCAS inputs of crop yields by region and IBRA in any single year are validated against industry yield data in following years. Yield data are aligned with crop and pasture management practices as they are identified in the database and validated against industry specific data as recorded by ABS and verified by CSIRO (Unkovich *et al.*, 2009). For example, burning of crop residues or no-tillage management, pasture improvement or native (unimproved) pastures would display different yields generally within each IBRA soil classification and be recorded accordingly.

Validated crop yield data are loaded into the NCAS modelling system. Quality control of transcriptional errors and errors of yield consistency are conducted by DCCEE before the data are accepted for modelling. Errors of yield consistency that may occur are resolved in collaboration with CSIRO.
A trend analysis of the percentage change by year and state or territory is also performed. These trends are cross-referenced with annual industry data from ABS at the state/territory and regional level.
Any inconsistencies in trend analysis require further evaluation of the yield data to validate the observed change for that SLA.

Verification

Annual crop yields are highly sensitive to changes in annual rainfall that determines the degree of soil moisture, plant growth and overall residue return to the soil for decomposition into the various soil carbon pools. Large climate variation in annual rainfall, such as droughts, lead to large annual differences in the crop yield. This variability is often regionally specific and results in large changes in total above ground biomass of agricultural crops and residue returned to the soil, that can lead to substantial increases or decreases in total soil carbon stocks. To identify if changes in crop yield between years can be explained by climate and are not simply an error, this trend analysis is particularly important because simply excluding data with large inter-annual variation does not recognise the effects of climate on crop productions. This analysis ensures that the above ground biomass allocations by region are reflective of the rainfall and soil moisture conditions for that year (Sanderman *et al.*, 2009). A review of the aboveground masses for plant biomass for the main agricultural crop species grown in Australia was also conducted (Unkovich *et al.*, 2010).

Agricultural residues

Calibration

The NCAS model uses crop yield data and proportional allocation of dry matter to different plant components to estimate annual dry matter accumulation in agricultural ecosystems. The crop allocation values are assembled from estimates by expert field agronomists and include allocation to roots (above and below-ground), GBF (grains, buds and fruit), stalks and leaves.

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 derived from an estimate of harvest index from yield data, and ii) rate constants for decomposition of decomposable and resistant debris pools of plant residues. The model is set-up to run using field measured rates of plant residues and observed climate conditions. The model is 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.

Validation

Fixed harvest indices have been used to estimate total crop biomass of croplands from statistical data on crop yields in both the USA (Prince *et al.*, 2001) and Canada (Bolinder *et al.*, 2007). Their harvest indices are given in Table 7.J10, along with the average values from the Australian database for dryland crops. With the exception of grain sorghum and sunflower, the values in the Australian dataset tend to be lower than those indicated by both Prince *et al.*, (2001) and Bolinder *et al.*, (2007). A review of the harvest index under Australian conditions indicates that a higher quantity of residues would be returned per unit of production than noted in other regions of the world. In addition, none of the abovementioned studies considered variation in harvest index or included such an exhaustive assessment of crop harvest index as the Australian study (Unkovich *et al.*, 2010).

Table7.J10 Conversion factors to estimate crop dry matter (DM), harvest indices (HI), and root:shoot ratios for crops used in the study of (Prince *et al.*, 2001) in the USA and compared with Canadian harvest index data (Bolinder *et al.*, 2007), and mean values from the Australian database

Crop	Conversion to proportion DM	Root:shoot ratio	HI in US literature	HI in present NCAS database	HI in Canadian literature
Corn grain	0.871	0.18	0.53	0.52	0.50
Soybean	0.920	0.15	0.42	0.24	0.40
Oats	0.923	0.40	0.52	0.30	0.53
Barley	0.904	0.50	0.50	0.38	0.53
Wheat	0.894	0.20	0.50	0.36	0.40
Sunflower	0.931	0.06	0.27	0.40	–
Sorghum		0.08	0.44	0.45	0.25

7.J.3.6 Tier 3 forest growth and management

The NCAS model uses a Tier 3 hybrid process-empirical model to calculate forest biomass and biomass increment for the *forest land to grassland* and *cropland* and the *grassland to forest land* sub-categories. This model utilises data from a variety of sources and accounts for the effects on climate, site, species and management on growth.

Calibration

Native forests

The calibration of the model used to estimate the assumed initial biomass applied in the NCAS required high quality measures of aboveground forest biomass from across Australia. To obtain this data CSIRO, Sustainable Ecosystems (formerly CSIRO, Forest and Forest Products), was engaged to compile a database of existing biomass measurements from published and unpublished studies. Studies were only included if they had adequately reported methods, because this information is required to establish confidence in the robustness of the data (Richards and Brack, 2004a). Quality controls of the data-set included the stipulation that measurements had undergone scientific peer review prior to publication (Raison *et al.*, 2003). Included data are representative of Australia's major forest types, ranging from savannahs to rainforests (Richards and Brack, 2004a).

The biomass data was accompanied with information on the site (location, IBRA region, climate and soil type), the vegetation (tree age, vegetation type and treatments) and the methods for deriving allometric equations (biomass measurement, variables, tree number and DBH) developed for the tree plot.
The calibration data covers the mix of age classes from regrowth to senescent (old-growth) (Figure 7.J8) and therefore the potential variation in field biomass conditions. To develop this relationship a collation of available biomass data for forests was conducted by CSIRO (Raison *et al.*, 2003). These data combine all the field studies that were available and of the required standard at the time the NCAS methodology was built.

To ensure the quality and consistency of ongoing data collection for forest biomass, the NCAS developed a set of sampling protocols (NCAS technical report 31) through a series of workshops. These protocols describe the NCAS measurement techniques and sampling procedures that need to be met to be considered of a suitable quality for calibration and validation of the model. These protocols ensure that the DCCEE was in receipt of biomass data that had been sampled in a consistent and validated manner.

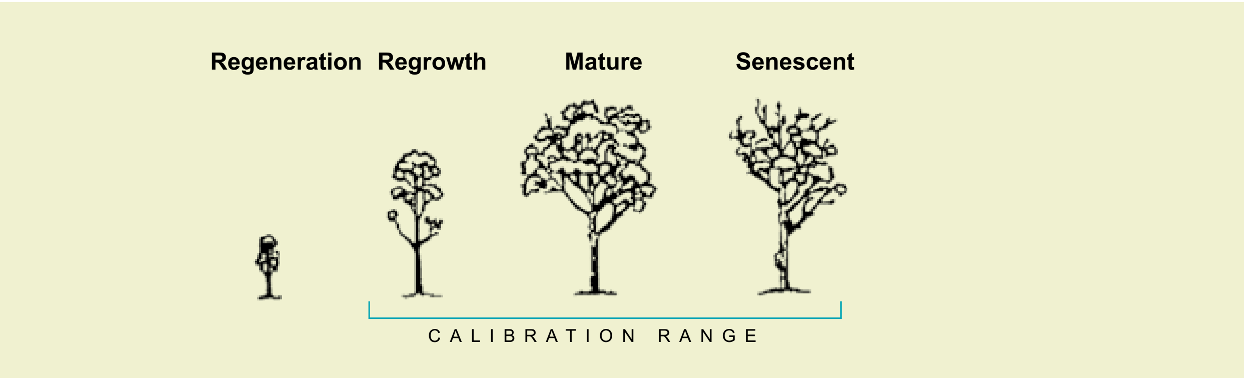
The assessment of published and unpublished literature also provided information on gaps in data. This allows for tree or stand sampling to occur in areas of data gaps to provide a more comprehensive database of forest and woodland biomass.

Model calibration and validation

Calibration

The assumed initial biomass used in the land use change modelling is applied to all first time clearing events whenever they occur. It is modelled from site productivity and field measurements reflecting a range of potential forest conditions and prior disturbance histories except those with visible evidence of recent disturbance. Mature forests were defined as having no identifiable major disturbance events since 1970 such as clearing, harvest or fire (Richards and Brack, 2004a). The lands may, however, still be experiencing ongoing low level disturbance such as grazing and low intensity fires. As the NCAS model assigns an actual value to regrowth of forest cleared after 1972, forests containing young regrowth were excluded from the assumed initial biomass calibrations to avoid an underestimate of biomass.

Figure 7.J8: 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 plots that were drawn from forest 'gaps'. Plots taken as part of fixed-grid or transect systems could potentially fall in gaps in sparse forests. As the remote sensing program at 25 m resolution is capable of separating such forest gaps from clearing events, the forest carbon mapping needs to represent the biomass of forested plots, not of that averaged over the gaps.

To determine the initial forest biomass for an individual forest site the geo-referenced calibration data set was fitted to the productivity map. This work was completed between scientists from the Australian National University and NCAS. The red line in Figure 7.J9 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 previously described (*M*) and the Long-Term Forest Productivity Index (*P*) (Equation 1). A square root transformation was required to meet assumptions of normality and homogeneity (Figure 7.J9).

$$M = (6.011 \times \sqrt{P} - 5.291)^2 \qquad (1)$$

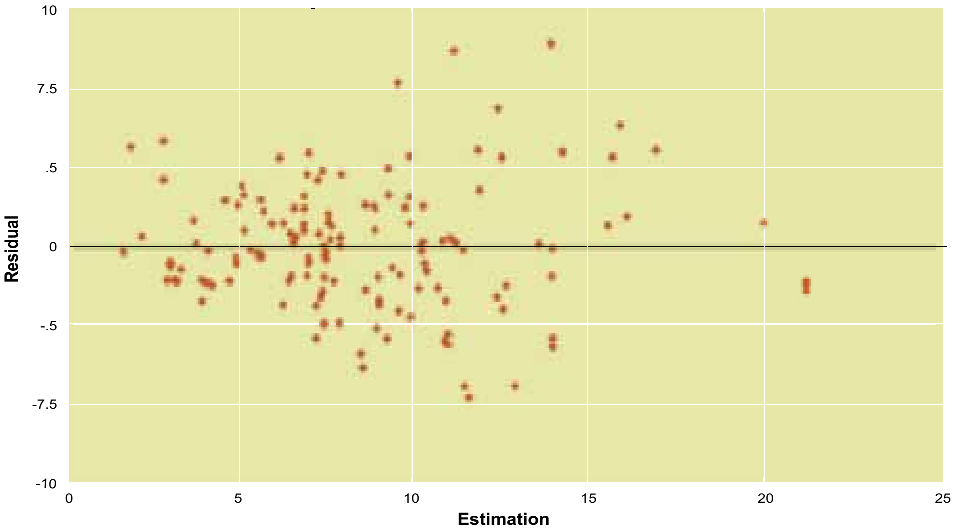
Figure 7.J9 The assumed initial biomass relationship

The goodness of fit of Equation (1) ($r^2 = 0.68$, $p < 0.01$) to the measured data confirms that a robust relationship exists between the productivity mapping and measured aboveground biomass estimates. The outer 95% confidence limits (outer pair of dotted lines) show the reliability for predicting biomass at any individual site. The inner 95% confidence intervals (inner pair of dotted lines) show the high degree of confidence in the line of best fit being able to represent the variability in the field data at the national scale. It applies throughout the continuum of productivity across the forest estate as a whole. The model shows that the assumed initial biomass is an accurate and unbiased representation of the forest estate (excluding young regrowth) as can be gauged from available data.

The initial assumed biomass at a chosen resolution for the entire continent can then be calculated by applying Equation (1) to the FPI mapping. A key benefit of the hybridisation of process modelling (through the productivity mapping) and empiricism (through known measures), is that estimates will be constrained to actual conditions (measured mass estimates) and actual growth, not that of optimal growth.

While the goodness of fit and lack of bias in error estimates (Figure 7.J10) provides confidence in the application of Equation (1) as a model to predict biomass at maturity, there is an obvious scatter in the data. This is attributable to the range of age classes and forest histories used in the model, the differing methods used in the field estimation and to an inherent variability between the 'plot' locations used to scale to one hectare mass estimates compared to the average condition reflected in the 250 m resolution productivity estimation.

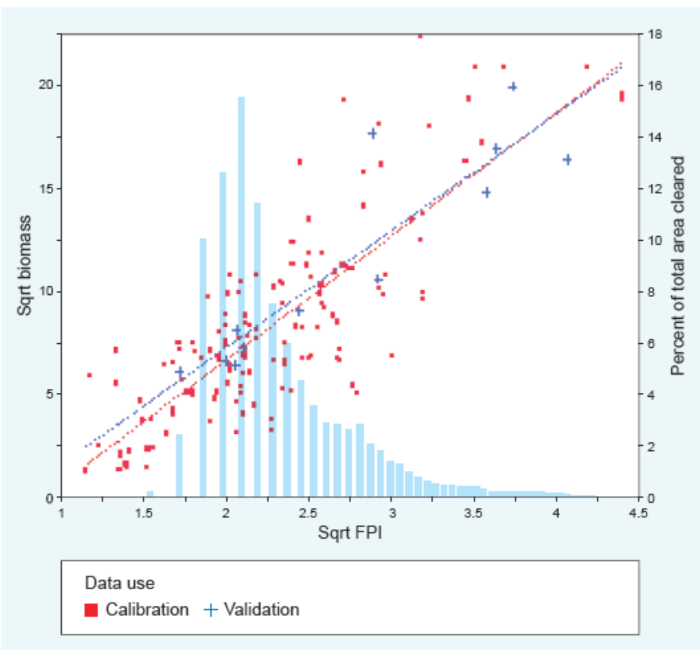
Figure 7.J10. Error distribution for equation 1



Validation

The NCAS runs a continuous improvement and validation program and is subject to wide independent review with the data and methods used in the NCAS being publically available. Calibration of the biomass model used in the NCAS has been validated by using independent research and field studies of biomass estimates, excluding forest areas with young regrowth. For example, the NCAS sponsored researchers to weigh all trees at three forest sites of varying productivity but with similar disturbance histories (Ximenes *et al.*, 2005, 2006). Other independent research studies in Australia have provided additional data that also validate the model. Since the model was first developed, data collection from 15 new field sites has since been completed that meet NCAS standards (Snowdon *et al.*, 2002) and are available for validation. These data points cover a wide range of forest types and represent forests that are near mature to mature with little evidence of recent disturbance. Validation tests show no significant difference between the validation and calibration data (Figure 7.J11). 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.J11. Calibration and validation data for the initial assumed biomass estimates



Note: The background histogram represents percentage of the area cleared by forest productivity index.

Forest litter dynamics

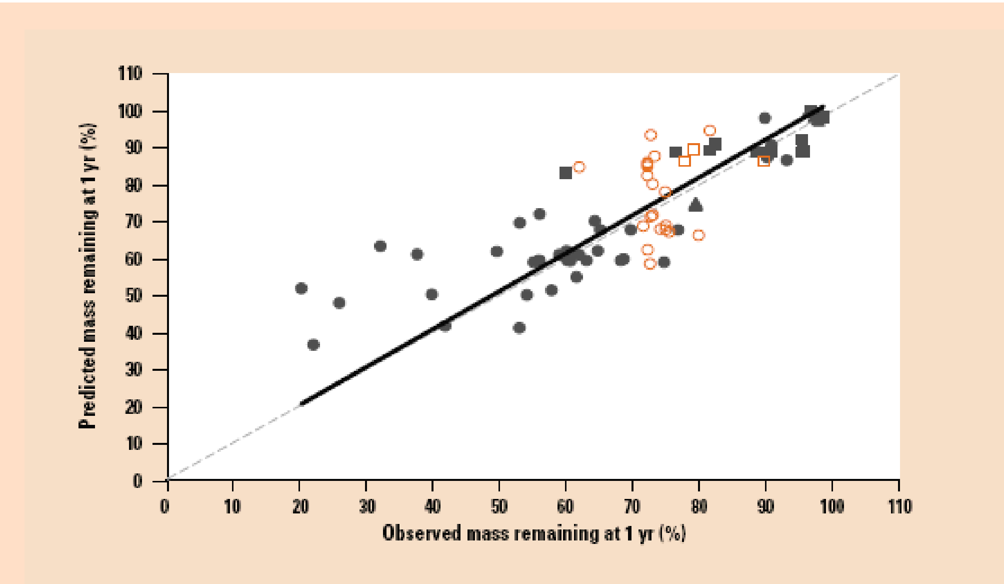
To estimate forest debris accumulation and loss, the NCAS model was calibrated and validated using litter decomposition rates taken from studies conducted around the world, representing a range of environmental settings. Half the dataset is used to calibrate algorithms and the other half is used to validate decomposition predictions (Paul *et al.*, 2004).

Two groups of parameters were calibrated: i) decomposable fraction of foliage, bark and wood and ii) rate constants for decomposition of decomposable and resistant debris pools of foliage, bark and wood (Paul *et al.*, 2004). The model was set-up to run using field measured rates of litterfall and observed climate conditions. The model was run for one year, then for the number of years corresponding to field measured published data. The mass of litter simulated to be present on the forest floor was compared to that observed in published studies. Rates of decomposition in the model were then adjusted so that simulated mass remaining best matches field measured data from a similar environmental setting.

A model efficiency index (EF) is calculated as the difference between the field-measured and model-simulated mass of litter remaining. Values of EF can be positive or negative with a maximum value of 1. 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 measured data less well than a mean of the observations. Deviations of predicted mass remaining, or predicted litter accumulation, are assessed using the mean square error (MSE). The smaller the MSE the better the model explains the data.

Once calibrated, the model predicted the observed mass remaining after one year of decomposition with an EF of 0.65 and a MSE of 117 g^2 100 g^{-2} (Paul *et al.*, 2004). The line of best fit between field measured and simulated data had a slope near unity (1.03) with an R^2 of 0.57 (Figure 7.J12).

Figure 7.J12 Relationship between observed mass remaining after one year's 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). Model EF and MSE were 0.65 and 177 g^2 100 g^{-2}, respectively.



Using the validation data, the model predicted mass remaining with an EF of 0.70 and an MSE of 80 g^2 100 g^{-2}. The line of best fit between field measured and simulated mass remaining after one year had an R^2 of 0.60 (Figure 7.J13).

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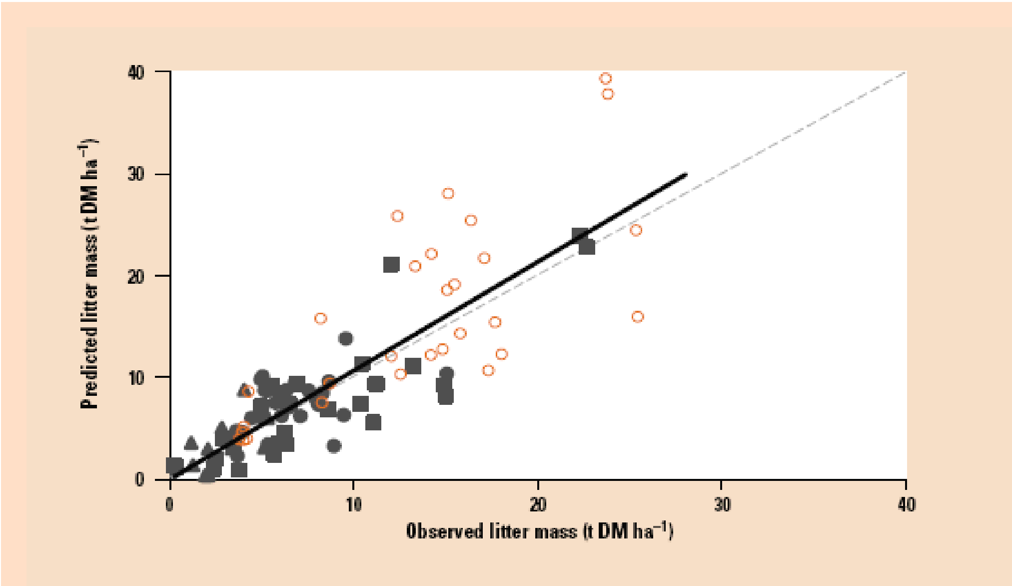
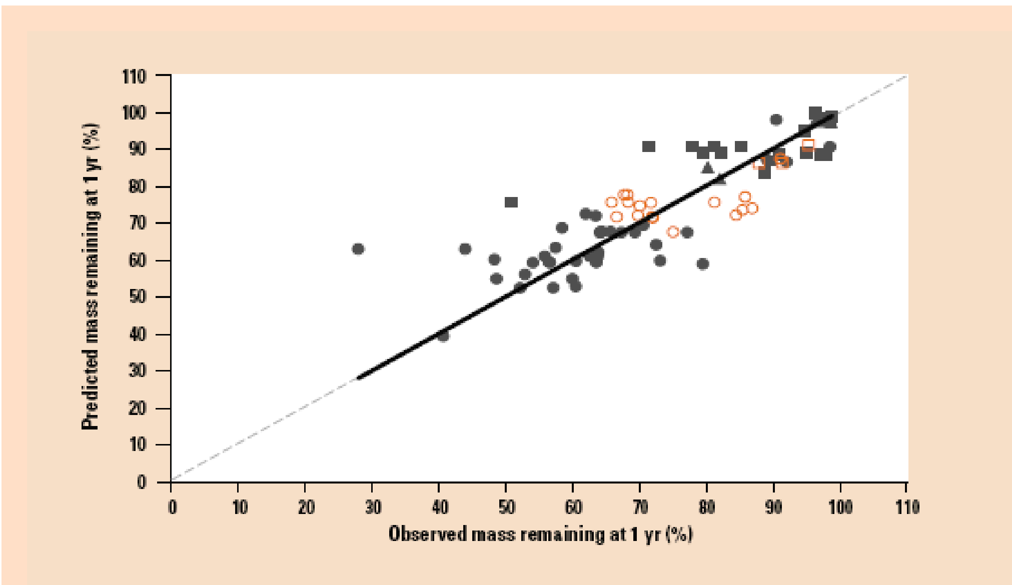
Figure 7.J13 Relationship between observed mass remaining after one year's decomposition of eucalypt leaf (●), eucalypt bark (▲), eucalypt dead wood (■), pine needles (❍) and pine dead wood (❏) from the validation dataset, and that predicted using *CAMFor*. Dashed line represents the 1:1 line. Solid line represents the linear function of best fit when forced through the origin (Slope=1.00, R^2=0.60, n=83). Model EF 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 more than 100 years with an EF of 0.65 and an MSE of 15 t^2 ha^{-2} (Paul *et al.*, 2004). The line of best fit between measured and simulated litter mass had a slope near unity (1.06) and an R^2 of 0.67 (Figure 7.J14).

Figure 7.J14 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). Model EF and MSE were 0.65 and 15 t^2 ha^{-2}, respectively.



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7.J.3.7 Interim Tier 2/3 forest growth models

The *harvested native forests* and *plantations* sub-categories of *forest land remaining forest land* currently utilise lower Tiers and Approaches than the *land converted to forest land* and *forest land converted to cropland* and *grassland* categories.

Harvested Native Forests QA/QC and Verification

Comparison with other data sources

The growth, forest area and age class data used in the model was derived from Australia's National Forest Inventory, and has been published as part of Australia's National Greenhouse Gas Inventory for several years. As such the growth and area data were publicly available, and subject to domestic and international review. The estimates of growth rates by forest type are sourced from Australia's National Forest Inventory 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) and the growth rates reported for important harvested forest types in Australia based on the data available to the Research Working Group of the Standing Committee on Fisheries and Forestry to the Australian Government (West and Mattay, 1993). Comparisons show that the growth rates used are within the range of those described by the Resource Assessment Commissions (lower estimate) and West and Mattay (higher estimate).

Data on harvest areas was obtained from a combination of annual reports of Australian State agencies, financial statements, and spatial harvest area data. As such 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 the relevant NCAS technical reports (Gifford, 2000a; Gifford, 2000b; Ilic *et al.*, 2000; 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).

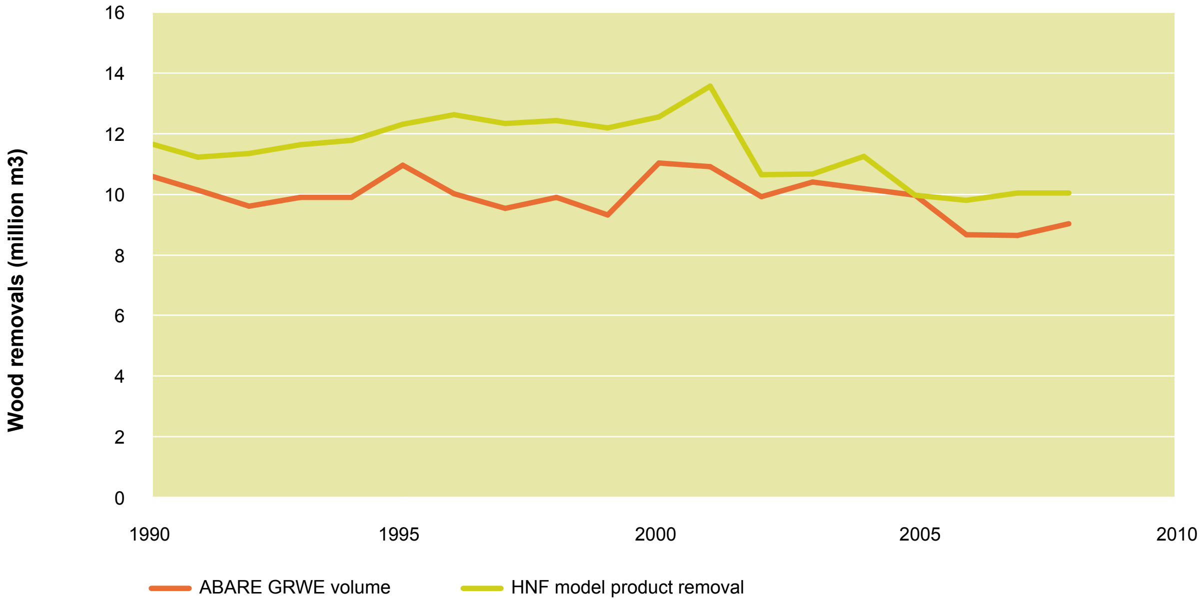
A team of highly qualified and experienced people were tasked with collecting and synthesising information on a state-by-state and topic-by-topic basis. Information was sourced from peer-reviewed published literature (a form of QA/QC), records/reports held by state and territory departments and agencies and from discussions with ex-foresters and senior staff from within state and territory departments and agencies with extensive resources and experience. Workshops were conducted with experts to scope the project.

Due in part to highly variable quality and accessibility of data, expert judgement had to be used to a very considerable degree, especially in deriving the data and completing the data tables. For example, in Victoria, 'in order to apportion the total annual harvest to the four forest types, a number of assumptions were used together with expert judgement supported by corporate knowledge and Annual Reports which often contained useful comments on forest activities across the State' (Raison & Squire, 2008). A consistent approach (Campbell, 1997) to documenting data quality standards was applied.

Verification of estimated product removals

The outputs of the *harvested native forests* model have been verified against independent data on annual roundwood removals drawn from national statistics on forest products production and consumption (ABARE, 2009c) (Figure 7.J15). The total carbon removed from the forest as forest products was converted back to stem volume assuming a stemwood carbon percentage of 52% (see Table 7.B6 in Appendix 7.B) and average wood basic density of 750 kg m^{-3}. From 2000 onwards (where the area harvested data is the most certain), the model output and roundwood data are similar. During the 1990's the *harvested native forests* model estimates slightly higher product removal. However, the estimates show similar trends and provide confidence in the model.

Figure 7.J15: National statistics on roundwood removals compared to product removal estimated from the *harvested native forests* model



Plantations

The models used to estimate emissions and removals in the pre-1990 *plantations* sub-category of *forest land remaining forest land* are based on data from several different sources. Tree growth is calculated using stem volume and yield data obtained by Australia's National Plantation Inventory which was then annualised by Turner and James (2002). The QA/QC on this data is controlled by the National Forest Inventory. Further QA/QC 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 NCAS 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).

An independent review of the models used to estimate emissions and removals in the *plantations* sub-category was undertaken by CSIRO (see Figure 7.J17).

Figure 7.J17 Letter outlining the results of the analysis undertaken by CSIRO

CSIRO

Forestry and Forest Products

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30 November 2001

Mr Ian Carruthers
Senior Executive Manager
Greenhouse Policy Group
Australian Greenhouse Office
GPO Box 621
CANBERRA ACT 2601

Dear Ian

National Article 3.3 Model

I am pleased to be able to provide the following report of the review of the National Carbon Accounting System National Article 3.3 Model performed by a team of four scientists from CSIRO Forestry and Forest Products. The CSIRO team have not been directly involved in development of the CamFor model or its calibration for this particular application. However, CSIRO are very aware of the work that has supported it.

Based on some fundamental presumptions (such as the area statements and growth and yield estimates) the CSIRO team undertook a quality control/assurance review of the modelling framework, assumptions and results. During the review, future refinements of the models were agreed with the NCAS developers.

Findings:

1. Areas and Forest Types

The modelling was based upon some prescribed inputs that were not the subject of quality assurance. These were provided by the BRS and included:

1) Area statements and plantation expansion scenarios
2) Forest types, modified from the NPI
3) Average growth and yield forecasts for each of those forest types

The assignment of areas to forest types, and the entry of growth and yield data to the model, appears to be correct.

Australian Science, Australia's Future

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2. *Model Framework*

The CAMFor/CAMForEstate models are appropriate for this task. The alternative of using a processes-based modelling approach is considered premature, due to inadequate validation at the national scale. The capability for risk analysis, which is part of the model, is an important tool for analysing uncertainty.

3. *Density, Carbon Contents and Allocations*

Data for a range of tree characteristics have been drawn from a range of published sources and transferred to the models. Wood density is drawn from the NCAS Technical Report No. 18, Carbon Contents from NCAS Technical Reports 7 and 22, and expansion factors and root:shoot ratios from NCAS Technical Reports 5a, 5b and 17. The reports summarise the extent of readily available knowledge. This information has been summarised and correctly incorporated into CAMFor.

4. *Turnover Rates*

In this model application, rates of change were specified for :

(i) Turnover of tree components, and (ii) decomposition of wood products.

The turnover rates of tree components applied in the model provide realistic results. They should be revised to ensure more consistent model performance, but this is unlikely to have a major impact on forecasts of C sequestration.

The wood product decomposition rates are those derived from the NCAS Technical Reports 8 and 24, and whilst representing the state-of-knowledge in this area, are very uncertain. Getting better estimates is very important to improving future predictions.

5. *Model Results*

Model predictions are consistent with site level changes in carbon pools for the range of forest types examined.

6. *Transparency*

The model and data underpinning its calibration have been published in a range of NCAS reports, and peer-reviewed literature. Thus the assumptions can be readily reviewed, and feedback at several levels has been used to refine the model.

7. Future Developments

While the National Article 3.3 model represents good practice there are a range of areas where additional development would be beneficial.

1) Area Statements – a desirable objective would be to derive a plantation map from the NCAS satellite data. This will provide a more robust and spatial estimation of Kyoto-compliant forests. Projected rates of plantation establishment are the greatest source of uncertainty in estimating future carbon sequestration.

2) Growth and Yield –growth and yield curves should be progressively updated based on research and industry data so as to account for change in the plantation land base and management methods.

3) Forest Litter and Soils – while forests soils tend to stabilise around small net change in carbon stock in the medium to long term, the short term changes combined with highly skewed age class distributions have the potential to impact on the national account over the first Commitment period. Continued development of the NCAS capacity to operationalise a spatial soil carbon model should be pursued.

4) Data – the information used for model calibration, such as partitioning and turnover are the best available, but requires improvement. Further collection and synthesis of such data are required.

Yours sincerely

John Raison

John Raison
Chief Research Scientist

Uncertainty analysis

Brack and Richards (2002) have provided the basis for the uncertainty analysis using the @Risk *Monte Carlo* capabilities attached to the *FullCAM* model. The analysis undertaken took advantage of the progression from treating all parameters as 'uncertain' with ranges of potential values, to describing the potential 'variance' within many parameters in terms of a probability distribution.

Dealing with quantified variance rather than constrained uncertainty within *Monte Carlo* analyses in *FullCAM* makes it possible to consider the correlation between variables and parameters and the likelihood of any single or interacting circumstance occurring. When the *Monte Carlo* analysis runs all statistical variants of possible inputs in combination, unrealistic biophysical scenarios may be induced. For example, under high rainfall, growth rate and decomposition rates will likely increase. If the *Monte Carlo* analysis is not informed that these parameters are positively correlated, then the random selection of high growth values may be incorrectly associated with decreased decomposition rates.

If correlations are not prescribed, combinations such as increased growth and decreased decomposition rates (a negative correlation) are as likely to be selected as a positive correlation, yet they are not likely in reality. This inclusion of unrealistic scenarios will considerably increase perceived uncertainty in model outcomes. The result is that a simple multiplicative array of potential (yet unrealistic) extreme results increases uncertainty ranges, as the generally ameliorating impacts of correlated inputs are not acknowledged.

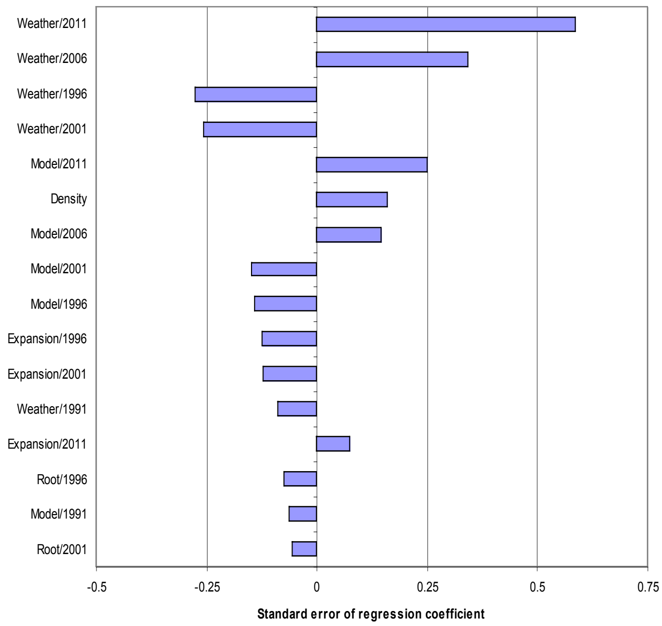
Brack and Richards (2002) modelled the performance of an individual stand using growth rates determined according to the observed growth variance around rainfall variability, error in allocating a growth index for the relevant growth model, and known variance or uncertainty in other key parameters. The key output for consideration is shown in Figure 7.J18.

The tornado graph (Figure 7.J18) shows the sources of uncertainty of model parameters and variables in order of their importance to uncertainty in the model outcome. On an individual stand basis and in this instance, predictions are more prone to climate based variation than any other influence.

Figure 7.J19 provides the mean and standard deviations for projected performance, providing the logical conclusion that stands aged around their maximum potential growth rate would be most affected (largest standard deviation) by variability largely driven by climate.

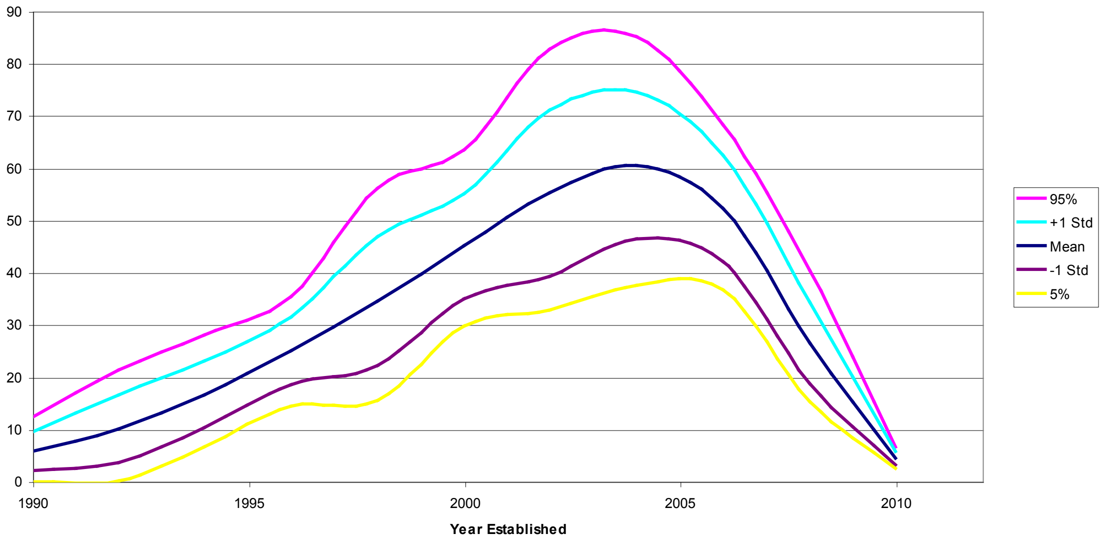
To take such individual stand-based uncertainty analyses to a national scale by simplistically extrapolating high and low outcomes would yield unrealistic results. The use of a 'low' base and the lower standard deviation is founded on the unlikely potential for below average rainfall for all plantation areas across the whole continent. Given the vast areas covered by *plantations*, it is a reasonable expectation that across the continent, 'more average' conditions will be achieved at the national level.

Figure 7.J18: Tornado diagram derived from @ Risk simulations of the correlation between uncertainty of the inputs and distribution of sequestration estimates between 2008 and 2012 for a plantation established in 1990



Weather/xxxx denotes the variation in weather during 5-year period commencing xxxx. Model/xxxx denotes the variation in the modelled site index during the 5-year period commencing xxxx. Expansion/xxxx denotes the variation in the expansion factors (caused as a result of the variation in increment of bark, branches, twigs and leaves) during the 5-year period commencing xxxx. Roots/xxxx denotes the variation in root increment and decay during the 5-year period commencing xxxx.

Figure 7.J19. Variability in stand performance by age of stand



Source: Brack and Richards 2002

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7.J.3.8 Wood products

QA/QC

A national database of domestic wood production, including import and export quantities, has been maintained in Australia since the 1930's. This consistent and detailed collection of time-series data provides a sound basis for the development of a national wood products model. Wood product data are available through the Australian Forests Products Statistics published quarterly by the Australian Bureau of Agricultural and Resource Economics (ABARE, 2008c). Data are also available through the Levies Management Unit of the Department of Agriculture, Fisheries and Forests, on behalf of the Forest and Wood Products Research and Development Corporation (FWPRDC), and are also published by the relevant State Forest Services and these provide a valuable crosscheck on ABARE data. Jaakko Pöyry Consulting were initially engaged by the NCAS to develop a national carbon accounting model for wood products based on ABARE, FWPRDC and State data. This work provided the precursor model to that adopted by NCAS.

An independent review of the models used to estimate emissions in the wood products category was undertaken by Jaakko Pöyry Consulting (see Figure 7.J20).

Figure 7.J20 Letter outlining the results of the analysis undertaken by Jaakko Pöyry Consulting

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Date October 4, 2004

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REVIEW OF WOOD PRODUCTS MODEL – UPDATE 2004

Dear Gary

As agreed Jaakko Pöyry Consulting has reviewed the 2004 update of the AGO's Wood Products Model. The update was made by MBAC Consulting in June 2004.

The focus of Jaakko Pöyry Consulting's work was to check that the updated data were consistent with our understanding of the wood products' industry production, import and export statistics and to consider if any recent changes in the industry necessitated adjustments to assumptions or the structure of the model. However, the underlying integrity of the model's calculations has not been checked.

Pulp and paper worksheet

We have no significant concerns about the updated statistics added to the pulp and paper worksheet. The base data entered since 1998 is consistent with the data collected and published by APIC and changes in the industry over the last six years do not require any changes in the assumptions.

In particular, it was considered that the start-up of the new Visy pulp and paper mill at Tumut may have changed the destination fraction of Raw Material for the industry (rows 38 – 40). However, a check of this indicated the destination fraction of wood to pulp had only changed from 71% to 69% with the start-up of the Visy mill, so that the estimate in the model of 70% remains valid.

Some minor points to note are as follows:

- The industry body which is the reference source for the pulp and paper data, has now changed its name from APIC to A3P, so this could be noted to assist in locating data for any subsequent update.
- Similarly, it is noted that the data listed under a particular calendar year in the model, is actually the data for the financial year commencing 1st July in that year. This is unlikely to have any significant impact on the outputs of the model, but again could be noted to assist in any subsequent update.
- Notes by MBAC refer to correcting some of the units from 1000m^3 to tonnes. In fact the units for wood volumes entered in rows 25 – 30 which are sourced

from APIC still need to be shown as kilotonnes rather than $1000m^3$. (That is the numbers entered in the model are in fact kilotonnes.)

The model structure and calculations obviously makes a number of simplifications to the overall complex product flows that occur in the industry. This has introduced some small errors or inconsistencies in the model which are noted below. Overall, the carbon from pulp and paper is possibly overstated by 10%, but given the level of assumptions in the model, this is probably not that significant.

- Some of the data in the model is in dry tonnes and some is in air dried or "as produced" tonnes. Typical moisture content of paper is 4-8%, which could be allowed for in the model.

- Some paper, particularly, printing and writing grades has a significant content of filler or pigment, up to 20%, which is not allowed for. Averaged over all grades, filler content is probably about 3%.

- Waste paper is treated like pulp in that losses to waste stream are only 4%, (row 43). In fact average losses in converting waste paper to recovered fibre for use on the paper machine are 12%.

- While the model requires inputs for each specific grade of paper (newsprint, tissue, printing and writing, packaging) in fact all of these grades are considered to have the same input of raw materials, so that the model actually treats them all the same.

- The model does not make any allowance for consumption growth in the future. A typical figure for paper grades is approximately 2%.

<u>Solid wood worksheets</u>

The inputs and percentages of product recovery, residues, domestic market, imports and exports all seem to be in the right order of magnitude and appear to be based on reasonably reliable data sources.

Though it has been noted that there are no inputs recorded for hardboard since 1999, in the covering explanation for that table it is stated that "no data reported in ABARE Statistics; assumed to be included with MDF from 1999 on". JPC is aware that there are two operating hardboard mills in Australia (Weathertex located at Raymond Terrace, NSW – production 14,000 tonnes per annum & Australian Hardboards located at Ipswich, Qld – production 42,500 tonnes per annum). Including those hardboard mills volumes in with MDF will distort the MDF statistics.

Yours sincerely

Steven W. King

Steven King
Consultant

Model calibration and validation

Once data on production inputs, processing flows and initial stocks were determined other model calibration requirements included:

- the age at which material moves from young to medium and from 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 loss from each age class, in each product pool, to each of landfill, recycling, bioenergy and the atmosphere.

The model estimates used are presented in Tables 7.J11 and 8.5 (in Chapter 8).

Table 7.J11. Decomposition rates and maximum possible loss

Pool	YOUNG		MEDIUM		OLD	
	Loss Yr^{-1}	Max. Possible Loss (%)	Loss Yr^{-1}	Max. Possible Loss (%)	Loss Yr^{-1}	Max. Possible Loss (%)
1	1.0	0.60	0.500	0.65	0.333	0.90
2	0.333	0.30	0.167	0.50	0.100	0.90
3	0.10	0.15	0.050	0.65	0.033	0.45
4	0.05	0.25	0.033	0.65	0.020	0.80
5	0.033	0.20	0.020	0.55	0.011	0.95

To understand the impact of uncertainties, *Monte Carlo* analyses using the Palisade @Risk software (Palisade 1997) was applied. This approach is also able to identify model sensitivities. Through this, it is possible to identify where uncertainty in parameter estimation may be most significant in terms of a probability distribution of expected outcomes, and to focus future data collection on areas that will have greatest impact on reducing uncertainties.

Uncertainty Analysis

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.J12, 7.J13, 7.J14 and 7.J15. Distributions of possible outcomes were stabilised over 100,000 model iterations. The Tornado Graph (Figure 7.J21) 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.J12. 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.J13. Decomposition rate uncertainty ranges used in the *Monte Carlo* Analysis

Age	Pool	Lower Bound	Expected Value	Upper Bound
Young	1	2.000	1.000	0.667
	2	1.000	0.333	0.333
	3	0.200	0.100	0.067
	4	0.067	0.050	0.040
	5	0.050	0.033	0.025
Medium	1	1.000	0.500	0.333
	2	0.333	0.167	0.111
	3	0.067	0.050	0.040
	4	0.050	0.033	0.020
	5	0.025	0.020	0.017
Old	1	0.500	0.333	0.250
	2	0.200	0.100	0.067
	3	0.050	0.033	0.025
	4	0.025	0.020	0.017
	5	0.013	0.011	0.010

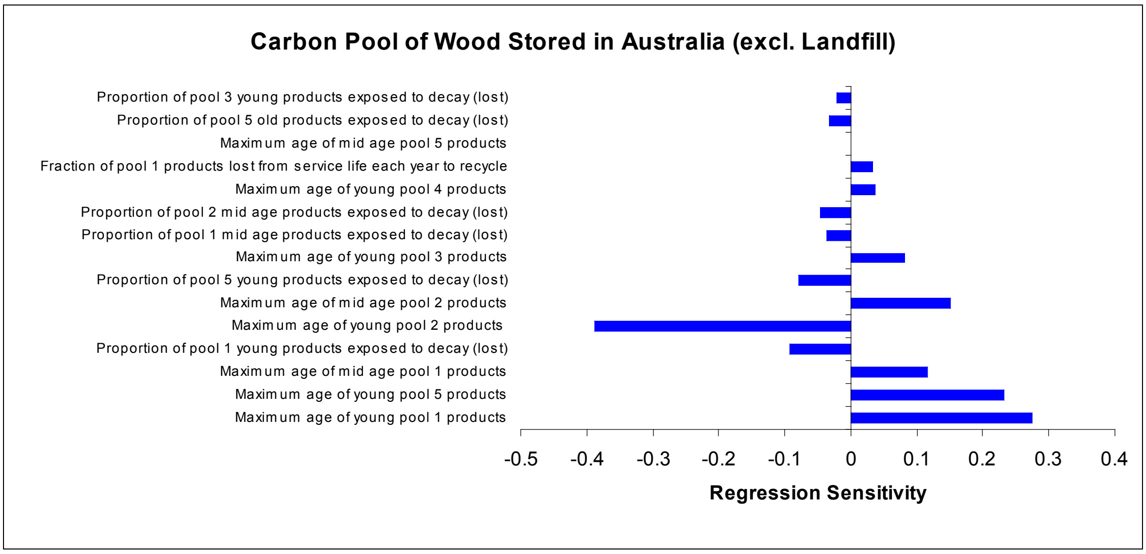
Table 7.J14. Pool fractions exposed to decomposition uncertainty ranges used in the *Monte Carlo* Analysis

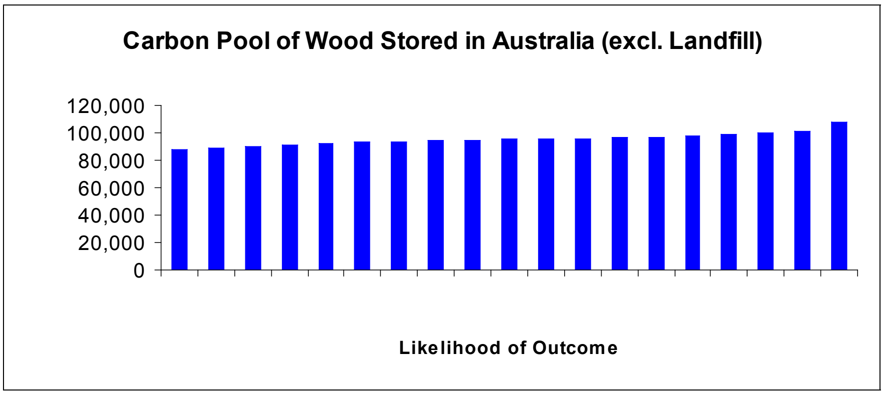
Age	Pool	Lower Bound	Expected Value	Upper Bound
Young	1	0.500	0.600	0.700
	2	0.250	0.300	0.350
	3	0.120	0.150	0.180
	4	0.225	0.250	0.275
	5	0.175	0.200	0.225
Medium	1	0.550	0.650	0.750
	2	0.400	0.500	0.600
	3	0.550	0.650	0.750
	4	0.550	0.650	0.750
	5	0.450	0.550	0.650
Old	1	0.800	0.900	1.100
	2	0.800	0.900	1.100
	3	0.400	0.450	0.500
	4	0.700	0.800	0.900
	5	0.800	0.950	1.150

Table 7.J15. Destination fraction uncertainty ranges used in the *Monte Carlo* Analysis

Age	Pool	Landfill			Recycle			Biofuel		
		Lower Bound	Expected Value	Upper Bound	Lower Bound	Expected Value	Upper Bound	Lower Bound	Expected Value	Upper Bound
Young	1	0.380	0.440	0.500	0.450	0.490	0.530	0.630	0.040	0.050
	2	0.600	0.750	0.900	0.180	0.200	0.220	0.040	0.050	0.060
	3	0.800	0.950	1.100	0.400	0.050	0.060	–	0	–
	4	0.700	0.850	1.000	0.130	0.150	0.170	–	0	–
	5	0.700	0.850	1.000	0.090	0.100	0.110	0.040	0.050	0.060

Figure 7.J21. Results of the @Risk sensitivity analyses





APPENDICES

7.J.4 Managing Model Versions and Data Archiving

7.J.4.1 Testing of model outputs

The model software development life cycle involves stages of requirements, analysis, design, implementation, verification and maintenance. Testing activities associated with *FullCAM* fall across the design, implementation, verification and maintenance domains of the software development life cycle, because the development of *FullCAM* follows an agile, or iterative, development philosophy. An iterative development philosophy was suited to the NCAS because requirements and solutions evolved through collaboration between *FullCAM* end users, scientists, *FullCAM* software developers and the Australian Government. Thus, frequent adaptations and subsequent testing were required to guide the complex *FullCAM* model through various iterations of development. This section outlines the way that the outputs of the *FullCAM* models were tracked and managed through these various software development iterations.

Errors or inconsistencies in model code are managed using Fogbugz, a web-based project management application. Fogbugz is used to record bugs, errors and feature requests identified during *FullCAM* development or by *FullCAM* end-users. Cases are recorded in Fogbugz as either bugs or features, then assessed, prioritized and allocated to application developers for necessary action. Resolved cases are passed to the NCAS systems analyst for testing. Once successfully tested, cases are closed and added to the current build cycle. Release notes are created for each build accordingly. User registration is required to access Fogbugz, and access is maintained by the NCAS system analyst. Fogbugz also records details of *FullCAM* inquiries from the public email address. Such inquiries are actioned by the NCAS system analyst.

Version control is managed using Sourcegear Vault, an application development source code version control system. Sourcegear Vault is used by the NCAS *FullCAM* development team to manage the source code for the *FullCAM* application. Local code updates by *FullCAM* developers are checked in, with any resulting errors being fixed prior to the next build. User registration is required to access Sourcegear Vault. User registration is managed by the NCAS *FullCAM* development team. Unit testing is a software development procedure that tests whether individual units of source code are fit for use. Regression testing is used to ensure that corrections to source code in one unit have been implemented correctly, and do not introduce errors in other units.

7.J.4.2 Data management

Data storage

Each year, the NCAS generates large amounts of data during the preparation of the national inventory of greenhouse gas emissions from the land sector. All data, including input data, models and output data are stored on a Sun-Microsystems server (the NCAS server) with 77 terabytes of storage space. Associated with this server is a high-performance cluster with 26 compute nodes. This storage and computing capacity is required to run *FullCAM* for the million-plus individual pixels of Australia's land-cover change in each reporting category.

Backup and data recovery plan

The NCAS has a data back-up strategy and recovery plan to avoid the loss of all input, processing, output and development data. Given the extensive amount of spatial input data used in the NCAS, the back-up of these data is outsourced to the data-providers, as these organisations have existing back-up and recovery plans in place, as well as comprehensive data management and storage systems. The back-up of NCAS input data is outsourced in the following way:

- GeoScience Australia – Provides a back-up of all satellite imagery data, including raw and processed satellite imagery.

- CSIRO Mathematics, Informatics and Statistics – Provides a back-up of all satellite imagery used in NCAS processing as well as imagery provided at various stages of processing by contractors. Thus, all processing data needed for the creation of the final land cover change data used as input to *FullCAM* are backed up.
- ANU Fenner School of Environment and Society – This organization provides all climate data used in the NCAS and has a comprehensive back-up and recovery strategy.

Within the DCCEE, all data are routinely (weekly-fortnightly) backed-up offline, and as a periodic copy from the server to external hard drives and CD/DVDs. A tape-system back-up of the NCAS server will also be implemented in 2010. These activities ensure a complete back-up of input data, the current version of *FullCAM*, *FullCAM* model outputs and emissions calculations.

Reported errors in, and updates to, *FullCAM* model code are backed up nightly to a secure off-site data repository. This repository is also backed up. In addition, *FullCAM* developers each have a copy of the current version of code on their workstations. These measures provide the capacity to retrieve all versions of model code in the event of an IT infrastructure failure.

System security

A suite of factors act to ensure security of the NCAS data. The NCAS IT infrastructure is located within the access controlled DCCEE offices. Electronic and physical access to the server is password and swipe-card controlled, respectively. The NCAS server is separate to the DCCEE internal network and is not directly connected to the internet. Workstations can access the internet, but not through the NCAS server. The server and workstations use virus and malware detection tools. These factors protect the NCAS server, which holds the input data, models and code used to calculate Australia's emissions inventory for the land sector.

7.J.5 Emissions Estimates

Australia reports on *forest land remaining forest land*, *forest land converted to grassland*, *forest land converted to cropland*, *grassland converted to forest land*, *grassland remaining grassland* and *cropland remaining cropland*. This section describes the QA/QC activities associated with the emissions estimates for Australia's lands.

The combination of being able to view and analyse spatial outputs and generate long-term, point-based models across the country allows for verification of results over both space and time. Carbon outputs can be evaluated alongside relevant data on land cover change, climate, vegetation, management and soil type for verification in both contexts. The point-based models can also be used to ensure that the correct spatial data have been used in the model. The ability to perform spatial overlays (e.g., carbon change over time against land cover change over time) provides strong visual validation of the carbon outputs. This can be enhanced by the creation of animations that show progress of change in carbon and land cover over time.

For the *forest land converted to cropland* and *grassland* and *grassland converted to forest land* categories, the results of the Tier 3 Approach 3 method have also been compared to those obtained using a Tier 2, Approach 2 method.

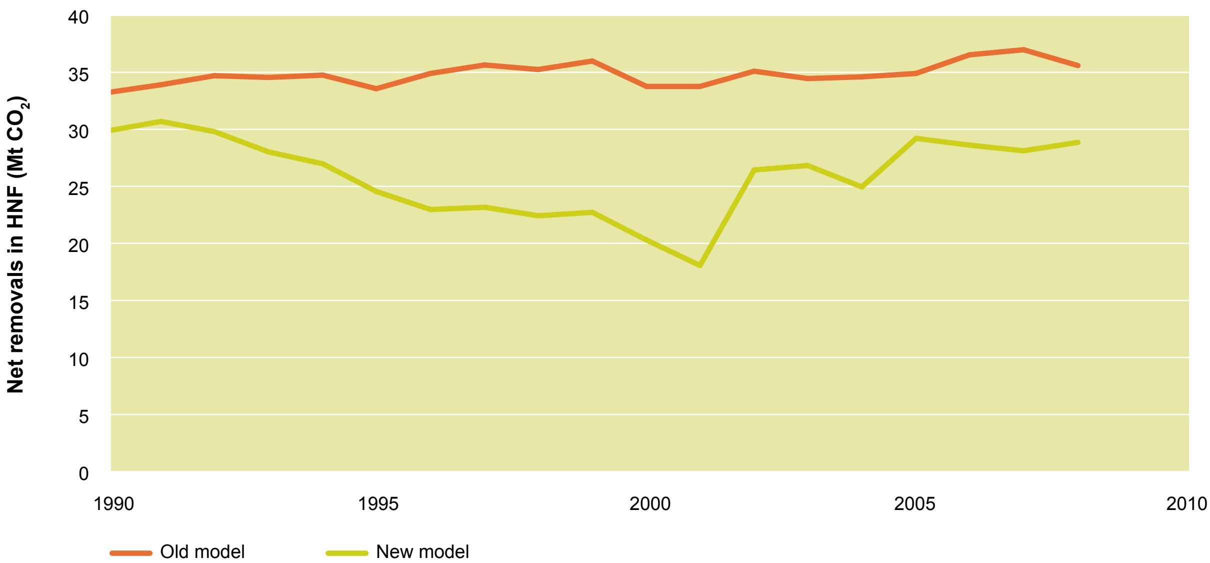
The validation processes of the NCAS focus on the detailed checking of land areas and modelled emissions estimates. Testing of the NCAS results is typically against actual field/ground truth measures that have a known outcome. Extensive application of this approach provides benefits that cannot be derived from other indirect approaches such as model inter-comparison. This is made possible by the vast resources available for NCAS development. The benefits of validation by direct measurement are, first, the detailed data derived can be used to determine the model and land area estimation performances in general (e.g., by region, soil type, vegetation type) and in detail, for example, by carbon pool (e.g., litter, fast turnover soil organic matter). Second, having actual measurements allows for continuous improvement whereby the validation data can subsequently be used to enhance model calibration, which is then tested again in subsequent validation using further independent data. This ensures a growing base of data for model calibration while also ensuring that calibration and validation data remain independent.

7.J.5.1 Harvested Native Forests

Comparison with Tier 2 model

The *harvested native forests* model was also verified by comparing the emissions estimated for the current inventory (using the *FullCAM* model) with those estimated using the former model (Figure 7.J16). The current estimates produce lower net removals than previously estimated, and display greater variability by including the effects of age-based forest growth, debris accumulation and the effects of management. The impact of using the area harvested to estimate emissions and removals is clearly observed with peak harvest areas during the mid 1990's with a spike in 2001, before a significant decrease in the annual area harvested through the 2000's. The reduction in the harvested area has been driven by a reduction in the maximum allowable harvest volume in many of the harvested native forests in Australia (Montreal Process Implementation Group for Australia 2008). This has been driven by improved resource information particularly forest yield, as well as reductions in the areas of forests where harvesting is permitted (Montreal Process Implementation Group for Australia 2008).

Figure 7.J22: Estimated net removals in *harvested native forests*, new Tier 2 model compared to the former model used in previous inventories



7.J.5.2 Forest land converted to cropland and grassland

Tier 2 and Tier 3 model comparisons

The results of the Tier 3 Approach 3 model used for *forest land converted to cropland and grassland* have been compared to the results of 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 NCAS methods. As such the model concept and implementation was previously peer-reviewed and subject to QA/QC. The annual area added to the *forest land to cropland and grassland* was obtained from the NCAS remote sensing programme as described in Appendix 7.A. The Tier 2 model stratifies the areas cleared into three broad classes: closed (tropical forest), open (predominantly eucalypt forest) or woodland forest. The area cleared within each forest class was calculated based on the proportion of area that each forest category inhabits within each State and Territory. The proportion of area cleared in each forest class was obtained by overlaying the areas cleared from the remote sensing analysis on a map of closed, open and woodland forest derived from the National Vegetation Information System (NVIS; see Appendix 7.A).

The aboveground biomass of each forest class was estimated using the summary data provided in Snowdon *et al.*, (2002) and Raison *et al.* (2003) (Table 7.J16). National emissions and removals were estimated by aggregating the estimations of each State and Territory.

Net emissions from forest clearing were calculated as the difference between emissions and removals. Both CO_2 and non-CO_2 emissions from land clearing were incorporated.

The CO_2 emissions include:

- Emissions from onsite burning,
- Emissions from off-site burning,
- Emissions from release of carbon from the soil,
- Emissions from onsite burning of debris, and
- Emissions from forest decay.

The non-CO_2 emissions include:

- Emissions from onsite burning, and
- Emissions from onsite burning of debris.

Non-CO_2 (CH_4 and N_2O) emissions were estimated by multiplying the CO_2 emissions from onsite burning and onsite burning of debris with a 'non-CO_2 to CO_2' coefficient. The non-CO_2 to CO_2 coefficient incorporates the ratio of mass of non-CO_2 gas to the mass of carbon it contains, the ratio of non-CO_2 gas emitted to carbon emitted, the ratio of the amount of CO_2 with equivalent greenhouse gas effect to an amount of non-CO_2 gas and the fraction of CO_2 that is carbon by weight.

Both aboveground and belowground (based on root to shoot ratios) biomass was incorporated for estimating CO_2 emissions from burning and forest decay (Table 7.J16). Forest debris was assumed to decay over a period of 10 years (IPCC, 2003). The removal of CO_2 includes regrowth of forest biomass and regrowth of agricultural (crop and grass) biomass, both above and below ground. Forests were assumed to reach maturity at 25 years. The CO_2 emission from the soil carbon pool was calculated as the difference between the ultimate loss of carbon from the soil (that is, the amount of carbon a soil could lose) and the amount of carbon remaining in the soil after a fraction has been lost during that year (Table 7.J16).

Table 7.J16 Tier 2 'default' coefficients used to estimate emissions and removals from forest clearing

Core parameters	Closed Forest	Open Forest	Woodland Forest
Initial biomass of forests#* (t dm ha^{-1})	370	250	70
Root:shoot ratio	0.25	0.25	0.40
Debris onsite mass* (t dm ha^{-1})	100	75	50
Soil carbon¥ (t C ha^{-1})	70	73	42

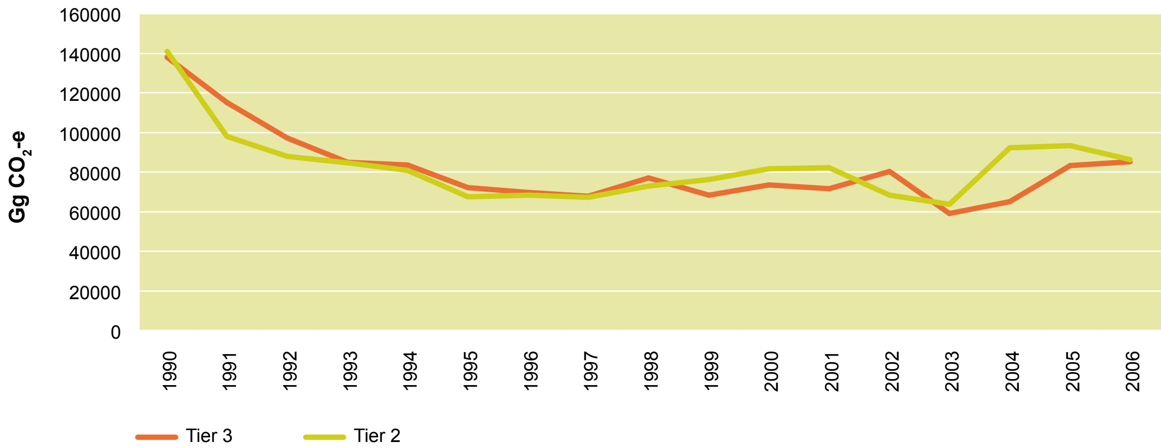
Aboveground biomass.
* Used for all States and Territories.
¥ Used to calculate ultimate loss of soil carbon.

The Tier 3, Approach 3 model for deforestation (land use change) was carried out with the *FullCAM* model. *FullCAM* integrates information drawn from the land cover change programme, productivity surfaces and other ancillary data to estimate emissions and removals from the deforestation (land use change) account (Richards, 2002). A full description of the Tier 3, Approach 3 is provided in Appendices 7.A and 7.F.

The difference in emissions output between the Tier 2 method and the Tier 3 method ranged from 0.13% in 1993 up to 42.38% in 2004 (Figure 7.J23). By and large, the emissions output does not vary substantially between the Tier 2 and Tier 3 models; however, the discrepancies between the two model approaches can be explained further.

The Tier 2 method uses country-specific 'default' coefficients to estimate emissions and removals from deforestation (land use change). It standardises the biophysical (soil, climate, etc.) environment, and hence forest productivity, across Australia. That is, the Tier 2 model does not encompass the spatial variability relating to soil types (and their characteristics) and climate variability (particularly rainfall) which would have an effect on emission levels and as such, CO_2 emissions and removals could therefore be overestimated or underestimated. The Tier 3, Approach 3 method is spatially explicit, operates at a fine scale (25 m) and incorporates the variability of the biophysical environment (climate and soil) across Australia. This therefore includes the effects of climate, better represents regrowth and reclearing cycles and varies emissions based on the site characteristics of the land subject to clearing.

Figure 7.J23 Total emissions (Gg CO_2-e) output from Tier 2 and Tier 3 methodology from 1990 to 2006.



7.J.5.3 Grassland Converted to Forest Land

To assist with the verification of the Tier 3, Approach 3 model a new series of Tier 2 models based on standard yield tables were produced. The Tier 2 models are similar to those used for the pre-1990 *plantations* sub-category but have been updated to better reflect the types of plantations that have been established since 1990 (primarily short rotation eucalypt plantations). The new Tier 2 models include improved growth estimates based on the most recent data available from Australia's National Plantation Inventory, improved age-based density estimates and expansion factors and more accurate representation of slash management techniques (primarily the use of slash incorporation via chopper rolling). A total of 28 representative Tier 2 plots were developed. The area of each type of forest in each region was determined from the NCAS remote sensing program. As the areas are derived from the same data, the model inter-comparison primarily represents a test of the Tier 3 model rather than the land representation.

The Tier 2 and Tier 3 models are largely in agreement from 1990 through to 2008. There are very slight differences in the early years, with higher stocks in the Tier 2 models is early years and slightly lower in later years.

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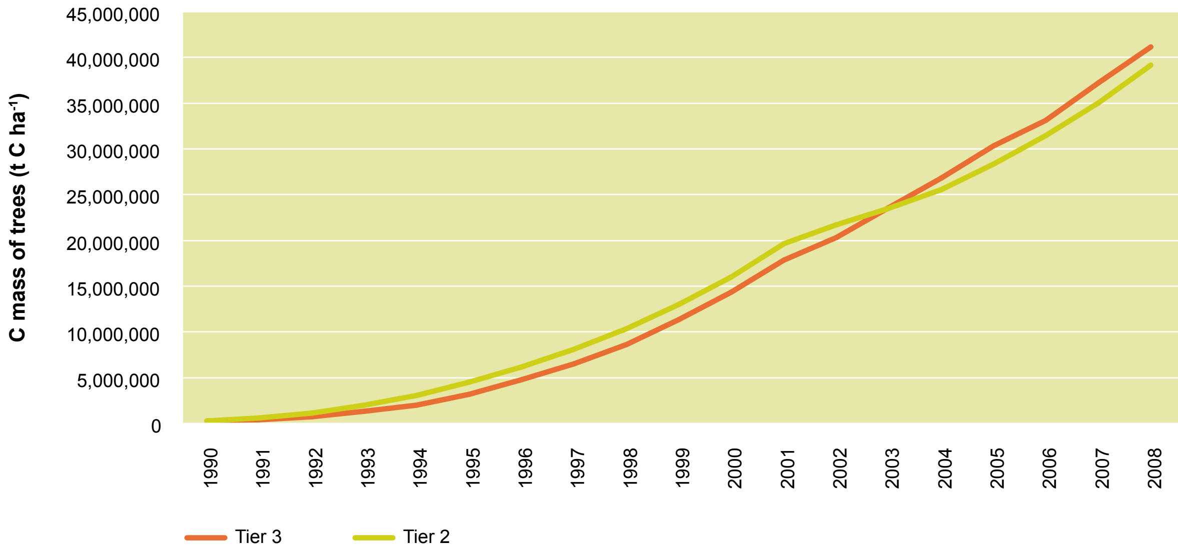
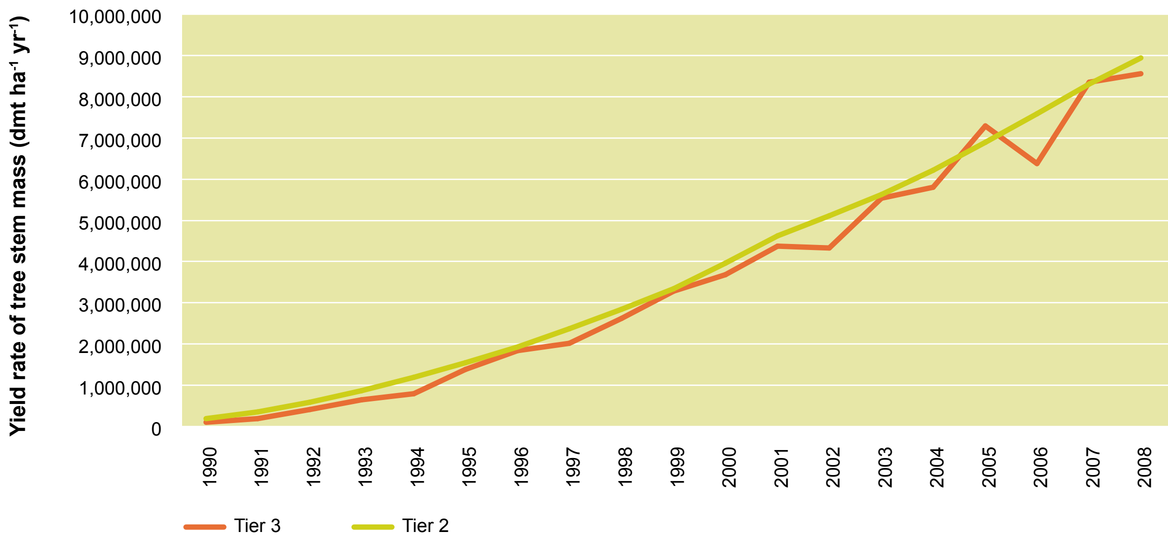
Figure 7.J24 Carbon mass of trees (t C ha^{-1}) output from Tier 2 and Tier 3 methodology from 1990 to 2008



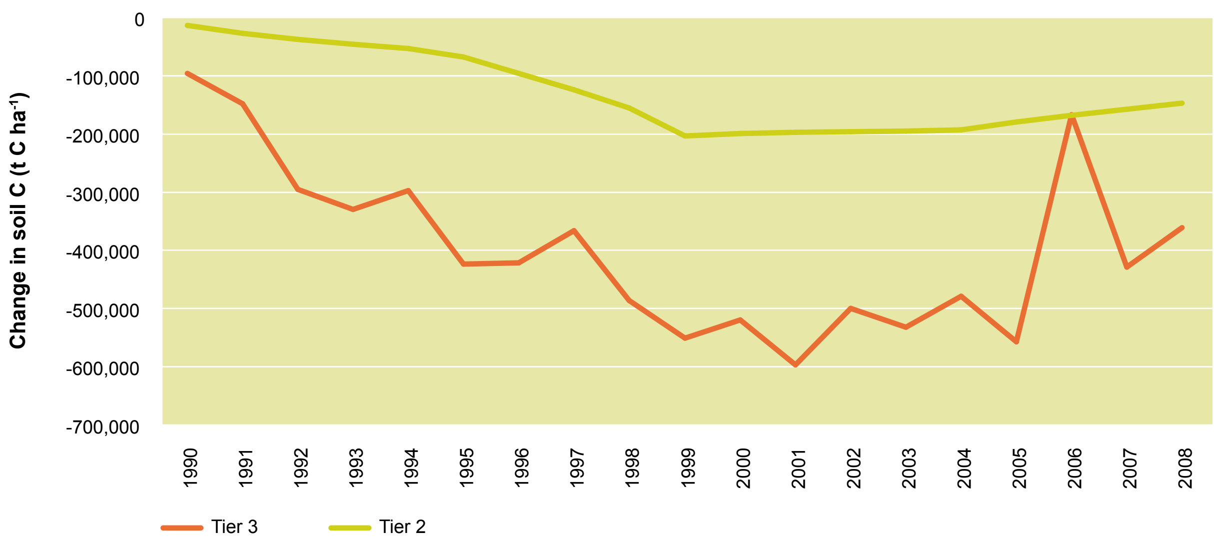
A comparison of the increment in carbon mass of trees (Figure 7.J24) and yield rate of tree stem mass (Figure 7.J25) showed very close agreement between the two models. This is not surprising given that the Tier 2 model uses estimates similar to those used to calibrate the Tier 3 model. The estimates from the Tier 3 model are more variable, reflecting the ability of the Tier 3 model to represent the effects of climate on growth.

Figure 7.J25 Yield rate of tree stem mass (dmt ha^{-1} yr^{-1}) output from Tier 2 and Tier 3 methodology from 1990 to 2008



The results of the Tier 3 soil carbon model (Figure 7.J26) were also compared to the Tier 2 approach developed by Polglase *et al.*, (2004) and described in Appendix 7.C. The comparison shows that the trend is similar but that emissions predicted under the Tier 3 model are greater and more variable due to the effects of climate and better representation of the effects of previous land use on initial soil carbon stocks.

Figure 7.J26 Soil carbon (t C) output from Tier 2 and Tier 3 methodology from 1990 to 2008



Uncertainty analysis

Uncertainty and sensitivity analyses have been an important part of the development of the NCAS programs. Method development, data compilation, remote sensing and field measurement programs have all been undertaken using sensitivity testing as an integral component. The sensitivity analysis has been targeted at providing an understanding of the key factors in carbon stock change estimation. Priorities in program development have been established around improvement in the specific inputs identified though sensitivity testing. Sensitivity analyses have mostly been undertaken using *Monte Carlo* type analyses. These analyses were carried out using the @Risk (Palisade Corporation 1997) software which was applied to both the Excel-based developmental and test models and in direct application in the *FullCAM* model. The various results of the uncertainty and sensitivity analyses are reported in Brack and Richards (2002), Brack (2001a), Paul *et al.*, (2002a), Paul *et al.*, (2003a) and Janik *et al.*, (2002).

The development of the NCAS was initiated with a clear understanding that the data available would be imperfect, but that the significance of data limitations (and, therefore, priority supplementation) could be fully assessed only in a functional integrated system. It was also recognised that no matter what quality of biophysical data were available, there will almost certainly be variability in the quality of those data. This tacit acceptance of variability allowed for a proper focus on matters of accuracy and bias, rather than on potentially unachievable precision. Following from this comes recognition that over a large sample, such as a national inventory derived from an aggregation of fine-scale events, a robust central estimate can be achieved provided that error propagation via biased or 'skewed' inputs is avoided. Over the large sample (several hundred million 25 m model applications for the *forest land converted to cropland* and *forest land converted to grassland* sub-categories), a bias away from a central estimate is a key item for attention.

The focus of the land cover change program was to identify any potential bias that may be caused by errors of omission or commission (bias toward inclusion of false change or only including change where this is absolutely certain). With the extensive QA/QC, verification and continuous improvement programs built into the overall programs, the potential for such bias is insignificant. Ongoing accuracy assessment is built into continuous improvement programs and will provide for ongoing refinement and incremental identification of potential improvements. The biomass estimation program sensitivity analyses were applied in a variety of ways including tests of variability in growth (Brack and Richards 2002; Brack 2001b) and of mass at maturity (Richards and Brack 2004a).

Variability in growth over time and wood density were shown to be the most sensitive factors in biomass estimation. Inter-annual variability in growth has been included via the multi-temporal productivity mapping which is used to adjust growth according to the prevailing climate (as is reflected in the temporal variability in the productivity mapping). The method used in the Tier 3, Approach 3 application of *FullCAM* to estimate biomass and biomass increment directly provides a measure of aboveground mass, so no measure of wood density is required to convert volume into mass. This approach is described in Richards and Brack (2004a). As shown in Snowdon *et al.*, (2000) there is limited information available on root-to-shoot ratios for tree species. The adopted ratios represent the best estimates from the available data. There is no cause, from the data available, to presume that there is any bias introduced, despite the evident lack of precision in the data. The low sensitivity of model results to the root-to-shoot ratio is largely due to the compensatory effects of regrowth. As regrowth is accounted for in the modelling, over- or under-estimates in losses due to forest conversion will be compensated for by a symmetrical over- or under-estimate in regrowth.

The mass estimation of the initial (1972) biomass has been constrained to the available known mass measures as reported in Richards and Brack (2004a). The approach provides a 'measured' or empirical constraint derived from field measurements to the process-based modelling. While the data available are variable (imprecise), the method used to develop a best fit mathematical model of the available data was reviewed for potential to derive biased error estimates. Unbiased error estimates provide reassurance that bias is not occurring in the mathematical model and should therefore not be expressed or propagated in model application.

The sensitivity of the model to changes in BI_a was tested by Richards and Brack (2004a). The sensitivity testing showed the value of BI_a=10 years produced yield curves that moderated the patterns to a similar shape to those produced if a higher value of 15 was used. To test the sensitivity of the *forest land converted to cropland* and *forest land converted to grassland* sub-categories to BI_a the model was rerun applying a value of BI_a=15 for all forests. The increase in BI_a from 10 to 15 caused little change in the results (1.0 Mt increase in CO_2–e in 1990, less than 1% of emissions). The minimal effect of this parameter on the model results is due to the balancing of reduced emissions from cyclic regrowth clearing by the slower growth rate of regrowth areas that were not cleared in 1990.

The multi-temporal productivity mapping and climate mapping were subject to independent quality assurance, providing confidence that the use of these data products does not provide a potential source of bias in the modelling. The spatial and temporal resolution provided by these products reduces the significant potential for bias in soil carbon models that has been shown to arise from spatially or temporally averaged data inputs (Janik *et al.*, 2002). Extensive sensitivity testing of the soil carbon modelling, as reported in Janik *et al.*, (2002) and Paul *et al.*, (2002a), showed that input data are required to be at a fine temporal and spatial resolution, as regionally and temporally averaged data provided uncertain, and frequently spurious, results. The use of input data at the appropriate scale, and verification against relevant field measurements, were the main forms of uncertainty reduction.

The most extensive sensitivity testing was undertaken for the soil carbon model calibration and verification program. The multi-faceted testing included reviews of model performance against measured chronosequence soil pairs and long-term trial data. The model calibration and verification as reported in Skjemstad and Spouncer (2003) gives no cause to suspect that there is any bias from model over- or under-estimation. Under the spatially and temporally disaggregated approaches taken, variance in input data for each grid (25 m) of the model run (presuming it is without skew in the variability in inputs) will, over a large sample, provide a robust and stable central estimate. In terms of uncertainty and potentially biased estimates, this is a significant advance on the default approaches which use constants (emissions factors) to define the change in stock as suggested under Tier 1 and Tier 2 accounting as described in the 2003 IPCC *Good Practice Guidelines* (IPCC, 2003).

7.J.6 Transparency and Review

As with the methods for uncertainty and sensitivity analysis, the approach to transparency and peer review will differ for a Tier 3 (spatially explicit) approach from those used in a Tier 1 or Tier 2 (area by emissions factor) approach. For Tier 1 and Tier 2 the focus is on the determination of area estimates and the selection of appropriate emissions factors. For the complex Tier 3 methods, which incorporate models and large datasets, different approaches to transparency and peer review are required. Transparency and review of the NCAS is founded on:

- published specifications, protocols and methods;
- published verification results;
- public release of models, tools and data ; and,
- publication in peer reviewed journals or other literature.

This chapter lists the publications arising from the development, testing, and implementation of the NCAS under four categories: 1) published specifications, protocols and methods, 2) published verification results, 3) public release of models, tools and data, and 4) publication of NCAS related material in peer reviewed journals or other literature.

7.J.6.1 Published specifications, protocols and methods

NCAS Technical Report Series 1

Australian Greenhouse Office. 1999. Setting the Frame: Part 1 – System Framework & Part 2 – Project Specification for 1990 Baseline Estimation, Land Use Change and Forestry Sector. National Carbon Accounting System Technical Report No. 1. Australian Greenhouse Office: Canberra, Australia.

Webbnet Land Resource Services Pty. Ltd. 1999. Estimation of Changes in Soil Carbon Due to Changed Land Use. National Carbon Accounting System Technical Report No. 2. Australian Greenhouse Office: Canberra, Australia.

Turner, B., Wells, K., Bauhus, J., Carey, G., Brack, C. And Kanowski, P. 1999. Woody Biomass: Methods for Estimating Change. National Carbon Accounting System Technical Report No. 3. Australian Greenhouse Office: Canberra, Australia,

Australian Greenhouse Office. 2000. Land Clearing: A Social History. National Carbon Accounting System Technical Report No. 4. Australian Greenhouse Office: Canberra, Australia.

Eamus, D., McGuinness, K. and Burrows, W. 2000. Review of Allometric Relationships for Estimating Woody Biomass for Queensland, the Northern Territory and Western Australia. National Carbon Accounting System Technical Report No. 5A. Australian Greenhouse Office: Canberra, Australia.

Keith, H., Barrett, D. And Keenan, R. 2000. Review of Allometric Relationships for Estimating Woody Biomass for New South Wales, the Australian Capital Territory, Victoria, Tasmania and South Australia. National Carbon Accounting System Technical Report No. 5B. Australian Greenhouse Office: Canberra, Australia.

Mackensen, J. and Bauhus J. 1999. The Decay of Coarse Woody Debris. National Carbon Accounting System Technical Report No. 6. Australian Greenhouse Office: Canberra, Australia.Gifford, R.M. 2000. Carbon Content of Woody Roots: Revised Analysis and a Comparison with Woody Shoot Components. National Carbon Accounting System Technical Report No. 7. Australian Greenhouse Office: Canberra, Australia.

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Jaakko Pöyry Consulting (Asia-Pacific) Pty Ltd. 1999. Usage and Life Cycle of Wood Products. National Carbon Accounting System Technical Report No. 8. Australian Greenhouse Office: Canberra, Australia.

Furby, S. 2002. Land Cover Change: Specification for Remote Sensing Analysis. National Carbon Accounting System Technical Report No. 9. Australian Greenhouse Office: Canberra, Australia.

Australian Greenhouse Office. 1999. Phase 1 Implementation Plan for the 1990 Baseline. National Carbon Accounting System Technical Report No. 10. Australian Greenhouse Office: Canberra, Australia.

Australian Greenhouse Office. 1999. International Review of the Implementation Plan for the 1990 Baseline. National Carbon Accounting System Technical Report No. 11. Australian Greenhouse Office: Canberra, Australia.

NCAS Technical Report Series 2

Webb, A. (Editor). 2002. Pre-Clearing Soil Carbon Levels in Australia. National Carbon Accounting System Technical Report No. 12. Australian Greenhouse Office: Canberra, Australia.

Swift, R. and Skjemstad, J. 2002. Agricultural Land Use and Management Information. National Carbon Accounting System Technical Report No. 13. Australian Greenhouse Office: Canberra, Australia.

McKenzie, N., Ryan, P., Fogarty, P. and Wood, J. 2000. Sampling, Measurement and Analytical Protocols for Carbon Estimation in Soil, Litter and Coarse Woody Debris. National Carbon Accounting System Technical Report No. 14. Australian Greenhouse Office: Canberra, Australia.

Skjemstad, J., Spouncer, L.R. and Beech, A. 2000. Carbon Conversion Factors for Historical Soil Carbon Data. National Carbon Accounting System Technical Report No. 15. Australian Greenhouse Office: Canberra, Australia.

Furby, S. and Woodgate, P. (Editors). 2002. Remote Sensing Analysis of Land Cover Change – Pilot Testing of Techniques. National Carbon Accounting System Technical Report No. 16. Australian Greenhouse Office: Canberra, Australia.

Snowdon, P., Eamus, D., Gibbons, P., Khanna, H., Raison, J. and Kirschbaum, M. 2000. Synthesis of Allometrics, Review of Root Biomass and Design of Future Woody Biomass Sampling Strategies. National Carbon Accounting System Technical Report No. 17. Australian Greenhouse Office: Canberra, Australia.

Ilic, J., Boland, D., McDonald, G., Downes, G. and Blakemore, P. 2000. Wood Density Phase 1: State of Knowledge. National Carbon Accounting System Technical Report No. 18. Australian Greenhouse Office: Canberra, Australia.

Polglase, P.J., Paul, K.I., Khanna, P.K., Nyakuengama, J.G., O'Connell, A.M., Grove, T.S. and Battaglia, M. 2000. National Carbon Accounting System Technical Report No. 20. Australian Greenhouse Office: Canberra, Australia.

Australian Greenhouse Office. 2000. NCAS System Design. National Carbon Accounting System Technical Report No. 21. Australian Greenhouse Office: Canberra, Australia.

Gifford, R.M. 2000. Carbon Contents of Above-Ground Tissues of Forest and Woodland Trees. National Carbon Accounting System Technical Report No. 22. Australian Greenhouse Office: Canberra, Australia.

Kesteven, J., Landsberg, J. and URS Australia. 2004. Developing a National Forest Productivity Model. National Carbon Accounting System Technical Report No. 23. Australian Greenhouse Office: Canberra, Australia.

Jaakko Pöyry Consulting (Asia-Pacific) Pty Ltd. 2000. Analysis of Wood Product Accounting Options for the National Carbon Accounting System. National Carbon Accounting System Technical Report No. 24. Australian Greenhouse Office: Canberra, Australia.

Grierson, P., Williams, K. and Adams, M. 2000. Review of Unpublished Biomass-Related Information: Western Australia, South Australia, New South Wales and Queensland. National Carbon Accounting System Technical Report No. 25. Australian Greenhouse Office: Canberra, Australia.

Richards, G. and Evans, D. 2000. Carbon Accounting Model for Forests (CAMFor) User Manual Version 3.35. National Carbon Accounting System Technical Report No. 26. Australian Greenhouse Office: Canberra, Australia.

NCAS Technical Report Series 3

Richards, G.P. (Editor). 2002. Biomass Estimation: Approaches for Assessment of Stocks and Stock Change. National Carbon Accounting System Technical Report No. 27. Australian Greenhouse Office: Canberra, Australia.

Richards, G.P. 2001. The FullCAM Carbon Accounting Model: Development, Calibration and Implementation for the National Carbon Accounting System. National Carbon Accounting System Technical Report No. 28. Australian Greenhouse Office: Canberra, Australia.

Paul, K., Polglase, P., Coops, N., O'Connell, T., Grove, D., Mendham, C., Carlyle, B., May, P., Smethurst, P. and Baillie, C. 2002. Modelling Change in Soil Carbon Following Afforestation or Reforestation: Preliminary Simulations Using GRC3 and Sensitivity Analysis.National Carbon Accounting System Technical Report No. 29. Australian Greenhouse Office: Canberra, Australia.

Janik, L., Spouncer, L., Correll, R. and Skjemstad, J. 2002. Sensitivity Analysis of the Roth-C Soil Carbon Model (Ver. 26.3 Excel©). National Carbon Accounting System Technical Report No. 30. Australian Greenhouse Office: Canberra, Australia.

Snowdon, P., Raison, J., Keith, H., Ritson, P., Grierson, P., Adams, M., Montagu, K., Bi, H., Burrows, W. and Eamus, D. 2002. Protocol for Sampling Tree and Stand Biomass. National Carbon Accounting System Technical Report No. 31. Australian Greenhouse Office: Canberra, Australia.

Burrows, W.H., Hoffman, M.B., Compton, J.F. and Back, P.V. 2001. Allometric Relationships and Community Biomass Stocks in White Cypress Pine (Callitris glaucophylla) and Associated Eucalypts of the Carnarvon Area – South Central Queensland (with additional data for Scrub Leopardwood – Flindersia dissosperma). National Carbon Accounting System Technical Report No. 33. Australian Greenhouse Office: Canberra, Australia.

NCAS Technical Report Series 4

Murphy, B., Rawson, A., Ravenscroft, L., Rankin, M. and Millard, R. 2003. Paired-Site Sampling for Soil Carbon Estimation – New South Wales. National Carbon Accounting System Technical Report No. 34. Australian Greenhouse Office: Canberra, Australia.

Dalal, R., Wang, W., Robertson, G.P., Parton, W.J., Meyer, C.M. and Raison, R.J. 2003. Emission Sources of Nitrous Oxide from Australian Agricultural and Forest Lands and Mitigation Options. National Carbon Accounting System Technical Report No. 35. Australian Greenhouse Office: Canberra, Australia.

Skjemstad, J. and Spouncer, L. 2003. Integrated Soils Modelling for the National Carbon Accounting System. National Carbon Accounting System Technical Report No. 36. Australian Greenhouse Office: Canberra, Australia.

Harms, B. and Dalal, R. 2003. Paired-Site Sampling for Soil Carbon (and Nitrogen) Estimation – Queensland: Part A & Part B. National Carbon Accounting System Technical Report No. 37. Australian Greenhouse Office: Canberra, Australia.

Griffin, E.A., Verboom, W.H. and Allen, D. 2003. Paired-Site Sampling for Soil Carbon Estimation – Western Australia. National Carbon Accounting System Technical Report No. 38. Australian Greenhouse Office: Canberra, Australia.

NCAS Technical Report Series 5

Lowell, K., Woodgate, P., Jones, S. and Richards, G. 2003. Continuous Improvement of the National Carbon Accounting System Land Cover Change Mapping. National Carbon Accounting System Technical Report No. 39. Australian Greenhouse Office: Canberra, Australia.

Paul, K., Polglase, P., Bauhaus, J., Raison, J. and Khanna, P. 2004. Modelling Change in Litter and Soil Carbon Following Afforestation or Reforestation. National Carbon Accounting System Technical Report No. 40. Australian Greenhouse Office: Canberra, Australia.

Polglase, P., Snowdon, T., Theiveyanathan, K., Paul, K., Raison, J., Grove, T. and Rance, S. 2004. Calibration of the FullCAM Model to Eucalyptus globulus and Pinus radiata and Uncertainty Analysis. National Carbon Accounting System Technical Report No. 41. Australian Greenhouse Office: Canberra, Australia.

Australian Greenhouse Office and the NSW Department of Infrastructure, Planning and Natural Resources. 2002. Outcomes from the Workshop: Deriving Vegetation Canopy Cover Estimates. National Carbon Accounting System Technical Report No. 42. Australian Greenhouse Office: Canberra, Australia.

Valzano, F., Murphy, B. and Koen, T. 2005. The Impact of Tillage on Changes in Soil Carbon with Special Emphasis on Australian Conditions. National Carbon Accounting System Technical Report No. 43. Australian Greenhouse Office: Canberra, Australia.

Raison, J., Keith, H., Barrett, D., Burrows, B. and Grierson, P. 2003. Spatial Estimates of Biomass in 'Mature' Native Vegetation. National Carbon Accounting System Technical Report No. 44. Australian Greenhouse Office: Canberra, Australia.

Snowdon, P., Ryan, P. and Raison, J. 2005. Review of C:N Ratios in Vegetation, Litter and Soil under Australian Native Forests and Plantations. National Carbon Accounting System Technical Report No. 45. Australian Greenhouse Office: Canberra, Australia.

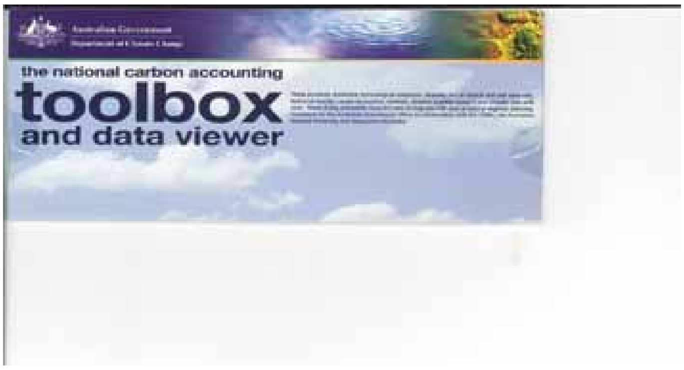
NCAS Technical Report Series 6

Jones, S., Lowell, P., Woodgate, L., Buxton, L., Mager, A. and Liebchen, S. 2004. Update on the National Carbon Accounting System Continuous Improvement and Verification Methodology. National Carbon Accounting System Technical Report No. 46. Australian Greenhouse Office: Canberra, Australia.

7.J.6.2 Public release of models, tools and data

The National Carbon Accounting Toolbox (NCAT) was released in 2005 (Figure 7.J22). This publically available CD included a copy of *FullCAM* version 3.0. Accompanying the NCAT was a Data Viewer, available on DVD or via the internet that enabled access to a visual record of landscape and vegetation change in Australia since 1972, and a 30-year record of regional climate statistics, including average temperature and rainfall. Over 10 000 copies of the NCAT have been distributed nationally and internationally since 2005.

Figure 7.J22 The publicaly available National Carbon Accounting Toolbox pack, released in 2005.



7.J.6.3 Publications in peer reviewed journals or other literature

Brack, C.L. and Richards, G.P. 2002. Carbon accounting model for forests in Australia. *Environmental Pollution* **116**: 187–194.

Brack, C., Richards, G.P. and Waterworth, R.M. 2006. Integrated and comprehensive estimation of greenhouse gas emissions from land systems. *Sustainability Science* **1**: 91–106.

Dalal, R., Wang, W., Robertson, P. and Parton, W.J. 2002. Nitrous oxide emissions from agricultural lands and mitigation options: a review. *Australian Journal of Soil Research* **41**: 165–195.

Harms, B., Dalal, R.C. and Cramp, A.P. 2005. Changes in soil carbon and soil nitrogen after tree clearing in the semi-arid rangelands of Queensland. *Australian Journal of Botany* **53**: 639–650.

Kaur, R., Kumar, S. and Gurung, H. P. 2002. A pedo-transfer function (PTF) for estimating soil bulk density from basic soil data and its comparison with existing PTFs. *Australian Journal of Soil Research* **40**: 847–858.

Kiiveri, H., Caccetta, P.A., and Evans, F. 2001. Use of conditional probability networks for environmental monitoring. *International Journal of Remote Sensing* **22**: 1173–1190.

Kiiveri, H. Caccetta, P. Campbell, N. Evans, F., Furby, S. and Wallace, J. 2003. *Environmental monitoring using a time series of satellite images and other spatial data sets*. In: D.D. Denison, M. H. Hansen, C. Holmes, B. Mallick, B. Yu (Eds), 'Nonlinear Estimation and Classification, Lecture Notes In Statistics'. New York: Springer Verlag. Pages 49–62.

Lowell, K. E., Richards, G.P., Woodgate, P., Jones, S. and Buxton, L. 2005. Fuzzy Reliability Assessment of Multi-Period Land-cover Change Maps. *Photogrammetric Engineering and Remote Sensing* **71**: 939–945.

APPENDICES

Paul, K.I., Booth, T.H., Elliot, A., Kirschbaum, M.U.F., Jovanovic, T. and Polglase, P.J. 2006. Net carbon dioxide emissions from alternative firewood-production systems in Australia. Biomass and Bioenergy 30: 638–647.

Paul K.I. and Polglase P.J. 2004. Calibration of the Roth–C model to turnover of soil carbon under eucalypts and pines. *Australian Journal of Soil Research* **42**: 883–95.

Paul, K.I. and Polglase, P.J. 2004. Prediction of decomposition of litter under eucalypts and pines using the *FullCAM* model. *Forest Ecology and Management* **191**: 73–92.

Paul K.I., Polglase, P.J., Nyakuengama, J.G. and Khanna, P.K. 2002. Change in soil carbon following afforestation. *Forest Ecology and Management* **168**: 241–257.

Paul, K.I., Polglase, P.J. and Richards G.P. 2003. Predicting Change in Soil Carbon following Afforestation or Reforestation, and analysis of controlling factors by linking a C accounting model (CAMFor) to models of forest growth (3–PG), litter decomposition (GENDEC) and soil C turnover (Roth–C). *Forest Ecology and Management* **177**: 485–501.

Paul, K., Polglase, P.J. and Richards, G.P. 2003. Sensitivity analysis of predicted change in soil carbon following afforestation. *Ecological Modelling* **164**: 137–152.

Paul, K.I., Polglase, P.J., Snowdon, P., Theiveyanathan, T., Raison, J., Grove, T. and Rance, S. 2006. Calibration and uncertainty analysis of a carbon accounting model to stem wood density and partitioning of biomass for *Eucalyptus globulus and Pinus radiata. New Forests* **31**: 513–533.

Paul, K.I., Booth, T.H., Jovanovic, T., Sands, P.J. and Morris, J.D. 2007. Calibration of the forest growth model 3-PG to eucalypt plantations growing in low rainfall regions of Australia. *Forest Ecology and Management* **243**: 237–247.

Paul, K.I. Jacobsen, K., Koul, V., Leppert P. and Smith, J. 2008. Predicting growth and sequestration of carbon by plantations growing in regions of low-rainfall in southern Australia. *Forest Ecology and Management* **254**: 205–216.

Richards, G.P. and Brack, C. 2004. A continental biomass stock and stock change estimation approach for Australia. *Australian Forestry* –: 284–288.

Richards, G.P. and Brack, C. 2004. A modelled carbon account for Australia's post-1990 plantation estate. *Australian Forestry* **67**: 289–300.

Richards, G.P. and Evans, D. 2004. Development of a carbon accounting model (*FullCAM* Vers. 1.0) for the Australian continent. *Australian Forestry* **67**: 277–283.

Richards, G.P., Borough, C., Evans, D., Reddin, A., Ximenes, F. and Gardner, D. 2007. Developing a carbon stocks and flows model for Australian wood products. *Australian Forestry* **70**: 108–119.

Skjemstad, J.O., Spouncer, L.R., Cowie, B. and Swift, R.S. 2004. Calibration of the Rothamsted organic carbon turnover model (RothC ver. 26.3), using measurable soil organic carbon pools. *Australian Journal of Soil Research* **42**: 79–88.

Unkovich, M., Baldock, J. and Forbes, M. 2010. Variability in harvest index of grain crops and potential significance for carbon accounting: examples from Australian agriculture. *Advances in Agronomy* **105**: 173–219.

Unkovich, M., Baldock, J., and Marvanek, S. 2009. Which broadacre crops and pastures should be included in a carbon accounting system for Australia's cropping zone? *Crop and Pasture Science* **60**: 617–626.

Waterworth, R.M., Brookhouse, M.T. and Kesteven, J. 2005. Use of tree ring data to test a broad-scale model of forest productivity in Australia. In: Innes, J.L., Edwards, I.K. and Wilford, D.J. (Eds.). IUFRO 2005. The International Forestry Review, Brisbane, Australia, p. 76.

Waterworth, R.M. and Richards, G.P. 2008. Implementing Australian forest management practices into a full carbon accounting model. *Forest Ecology and Management* **255**: 2434–2443.

Waterworth, R.M., Richards, G.P., Brack, C.L. and Evans, D.M.W. 2007. A generalised hybrid process-empirical model for predicting plantation forest growth. *Forest Ecology and Management* **238**: 231–243.

Ximenes, F., Gardner, D. and Richards, G.P. 2006. Total above-ground biomass and biomass in commercial logs following the harvest of Spotted Gum (*Corymbia maculata*) forests of SE NSW. *Australian Forestry* **69**: 213–222.

APPENDICES