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April 2011

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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 53.97 Mt CO₂-e in 2009 (Table 7.1).

Table 7.1: Land use, land use change and forestry net CO₂-e emissions, 2009

| Greenhouse gas source and sink categories | CO ₂ -e emission (Gg) | | | |
|---|----------------------------------|-----------------|------------------|---------|
| | CO ₂ ^(a) | CH ₄ | N ₂ O | Total |
| 5 LAND USE, LAND USE CHANGE AND FORESTRY | 49,533 | 3,101 | 1,337 | 53,971 |
| A. Forest land | -57,270 | 1,660 | 453 | -55,156 |
| A.1 Forest land remaining forest land | -42,258 | 1,660 | 453 | -40,145 |
| A.2 Land converted to forest land | -15,012 | 1 | 0 | -15,011 |
| B. Cropland | -25,993 | 526 | 203 | -25,265 |
| B.1 Cropland remaining cropland | -25,777 | IE | IE | -25,777 |
| B.2 Land converted to cropland | -216 | 526 | 203 | 512 |
| C. Grassland | 135,993 | 914 | 250 | 137,157 |
| C.1 Grassland remaining grassland | 92,586 | IE | IE | 92,586 |
| C.2 Land converted to grassland | 43,407 | 914 | 250 | 44,571 |
| D. Wetlands | NE | NE | NE | NE |
| E. Settlements | NE | NE | NE | NE |
| F. Other land | NO,NA | NO,NA | NO,NA | NO,NA |
| G. Other ^(b) | -3,197 | NA | 431 | -2,766 |

(a) A negative sign denotes a sink. (b) Includes Harvested Wood Products, Agricultural lime application and N₂O from disturbance associated with land-use conversion to Grassland. N₂O from disturbance associated with land-use conversion to Cropland is reported under Cropland.

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

Forest land (5A) comprises emissions and removals from *plantations, harvested native forests and other native forests*. Emissions from *fuelwood consumption* and biomass burning in forests (*slash burning, prescribed burning and wildfire*) are also included as are the removals associated with post fire recovery. The forest land category is estimated to have constituted a net sink of 55.2 Mt CO₂-e in 2009.

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 25.3 Mt CO₂-e in 2009.

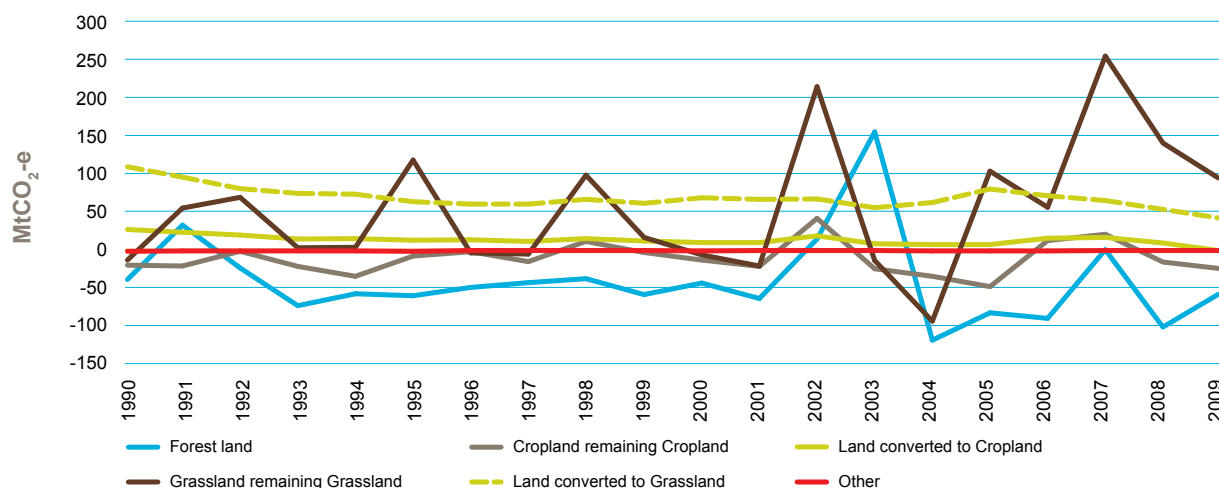
Grassland (5C) comprises emissions and removals from *grassland remaining grassland* and *forest land converted to grassland*. The *grassland* subsector is estimated to have constituted a net source of 137.2 Mt CO₂-e in 2009.

Forest land converted to cropland and *grassland* was a net source of 45.1 Mt CO₂-e in 2009 while the associated emissions of N₂O from soil disturbance were 0.06 Mt CO₂-e.

Harvested wood products are not reported in the *forest land* category and carbon stocks are transferred to 5G *Other – harvested wood products*. As the reporting tables do not account for transfers of carbon stocks between forests and harvested wood products, this leads to an apparent, but not real, emission from *forest land* and a 4.3 Mt ‘sink’ in *harvested wood products*.

Agricultural lime application is estimated to have contributed emissions of 1.1 Mt CO₂-e in 2009.

Figure 7.1: Net CO₂-e emissions from Land use, land use change and forestry, by sub-sector, 1990–2009



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 2009, the net *land use, land use change and forestry* emissions increased from 43.15 Mt CO₂-e in 1990 to 53.97 Mt CO₂-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-sectors.

The 2009 estimate of total emissions from *forest land converted to cropland* and *forest land converted to grassland* was 65.8% (86.6 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 *N₂O from soil disturbance* associated with conversion of *forest land* to *cropland* and *grassland* has declined by 17.6% (0.01 Mt) between 1990 and 2009.

Within *forest land* (5A), *forest land remaining forest land* changed from a net sink of 42.1 Mt in 1990 to a net sink of 40.1 Mt CO₂-e in 2009, while the removals from *lands converted to forest land* increased from 0.2 to 15.0 Mt CO₂-e. The combined effect of these changes is an increase in the *forest land* net sink of 30.4% (12.9 Mt CO₂-e) between 1990 and 2009.

Emissions from *agricultural lime application* have increased from 0.2 Mt in 1990 to 1.1 Mt in 2009. The trend in agricultural lime application will tend to follow climate cycles with decreased lime application during drought.

Table 7.2: Annual area of forest change (ha)

| Year | Forest land converted to | |
|------|--------------------------|----------------|
| | Cropland (ha) | Grassland (ha) |
| 1990 | 117624 | 458697 |
| 1991 | 88080 | 343236 |
| 1992 | 67602 | 314843 |
| 1993 | 67177 | 343637 |
| 1994 | 75712 | 292408 |
| 1995 | 58427 | 249772 |
| 1996 | 69071 | 270066 |
| 1997 | 64487 | 245439 |
| 1998 | 62352 | 271581 |
| 1999 | 63472 | 281127 |
| 2000 | 61075 | 297109 |
| 2001 | 59350 | 316195 |
| 2002 | 58358 | 250931 |
| 2003 | 59509 | 250547 |
| 2004 | 74467 | 340796 |
| 2005 | 75491 | 334622 |
| 2006 | 83663 | 322813 |
| 2007 | 65973 | 236071 |
| 2008 | 61524 | 180255 |
| 2009 | 53212 | 133171 |

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 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 was caused by one of the worst droughts in Australia's history (Figure 7.3) which led to a large reduction in crop yield and subsequent reduction in biomass residue carbon returning to the soil (Figure 7.4). In other years the relationship between total emissions and climate may not be as strong due to the wide variance in climate that can exist from one side of the country to the other. For example drought conditions in Western Australia may lead to an increase in emissions, but could be balanced by good rain in the eastern States with subsequent reduction in emissions.

Figure 7.2: Emissions (Mt CO₂) from *Cropland remaining Cropland*

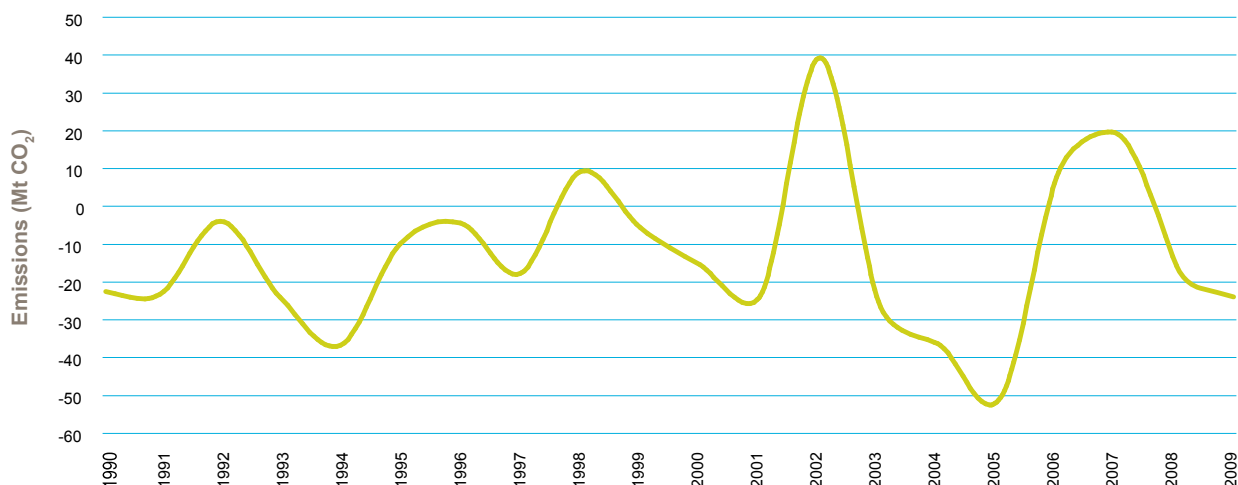


Figure 7.3: Relative rainfall and Vapour Pressure Deficit (VPD) across Australia

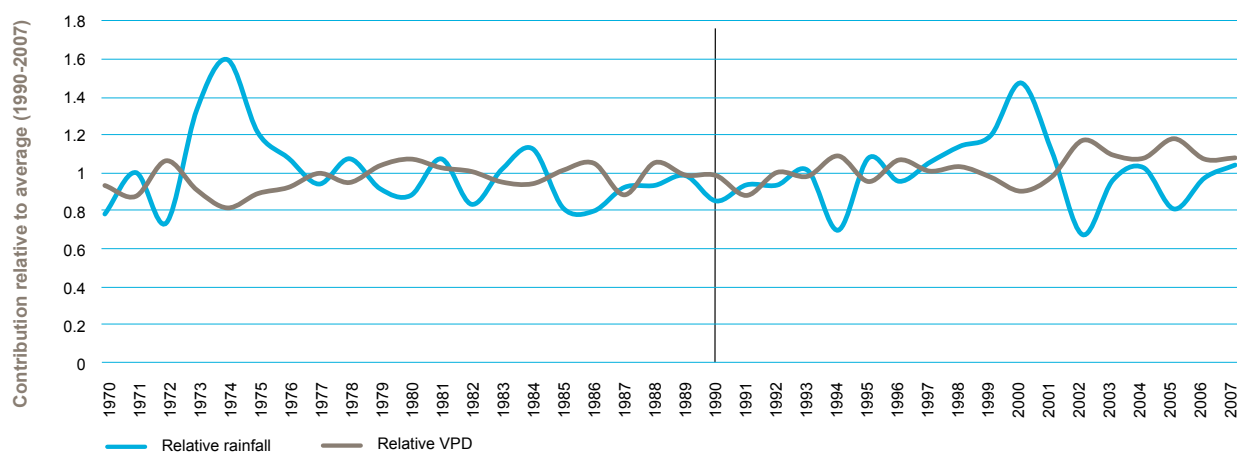


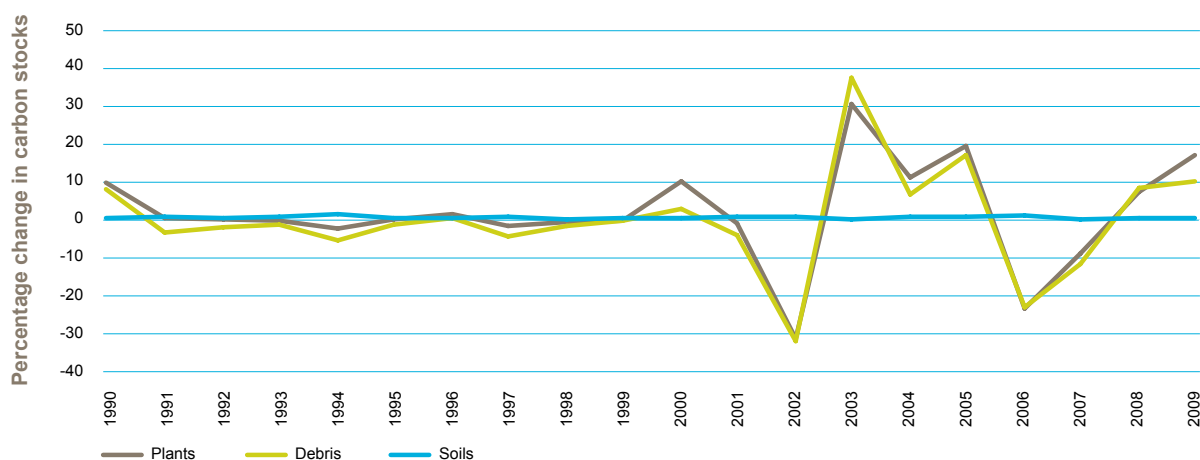
Figure 7.4: Average yield of crops across Australia (not weighted by area planted to each crop type), used in FullCAM from 1990 to 2009 for *Cropland remaining Cropland*



The effect of the drought on emissions in the *cropland* categories is clearly observable when represented as the percentage change in carbon stocks by pool (Figure 7.5). In Australia, crops are generally grown in the winter months with maximum plant biomass obtained towards the end of the calendar year. This means that any change in crop yield will directly affect the emissions estimates because change in

the standing biomass of crops is included in the estimates. This leads to high variability in emissions estimates because the amount of standing crop biomass at the end of the calendar year varies considerably due to climate. For example, 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. This large change in the carbon stock of plants and debris compared to the previous year 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. Although 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 slight reduction in the soil carbon stocks.

Figure 7.5: Percent (%) annual 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 reporting for the LULUCF sector is the estimation of emissions and removals of carbon dioxide (CO₂) from these activities. CO₂ 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 (N₂O) 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 (CH₄), 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 ₂ O | | NO _x , CO and NMVOC | |
|---|-----------------|-------|-----------------|----|------------------|----|--------------------------------|----|
| | Method applied | EF | Method applied | EF | Method applied | EF | Method applied | EF |
| 5. LAND USE, LAND USE CHANGE AND FORESTRY | | | | | | | | |
| A. Forest Land | | | | | | | | |
| 1. Forest land remaining Forest land | | | | | | | | |
| Harvested Native Forests | T2 | M | | | | | | |
| Other Native Forests | T2 | CS | | | | | | |
| Pre-1990 Plantations | T3 | M | | | | | | |
| Fuelwood consumed | T1 | CS | | | | | | |
| 5(V) Biomass Burning – 5.A.1. | | | CS | CS | CS | CS | CS | CS |
| 2. Land converted to Forest land | T3 | M | | | | | | |
| B. Cropland | | | | | | | | |
| 1. Cropland remaining Cropland | T3 | M | | | | | | |
| 2. Land converted to Cropland | T3 | M | | | | | | |
| 5(III) Disturbance associated with land conversion | | | | | T2 | CS | | |
| 5(V) Biomass Burning – 5.B.2 | | | CS | CS | CS | CS | CS | CS |
| C. Grassland | | | | | | | | |
| 1. Grassland remaining Grassland | T3, T2 | M, CS | | | | | | |
| 2. Land converted to Grassland | T3 | M | | | | | | |
| 5 (V) Biomass Burning: 5.C.2 | | | CS | CS | CS | CS | CS | CS |
| D. Wetlands | | | | | | | | |
| 1. Wetlands remaining Wetlands | NE | NE | | | | | | |
| 2. Land converted to Wetlands | IE | IE | | | | | | |
| E. Settlements | | | | | | | | |
| 1. Settlements remaining Settlements | NE | NE | | | | | | |
| 2. Land converted to Settlements | IE | IE | | | | | | |
| F. Other Lands | | | | | | | | |
| 1. Other Lands remaining Other Lands | NA | NA | | | | | | |
| 2. Land converted to Other Lands | NO | NO | | | | | | |
| G. Other | | | | | | | | |
| Harvested Wood Products | T3 | M | | | | | | |
| 5(I) N fertilisation | | | | | IE | IE | | |
| 5(II) Drainage of Soils | | | | | NE | NE | | |
| 5(III) Disturbance associated with land conversion to grassland | | | | | T2 | CS | | |
| 5(IV) Agricultural lime application | T1 | CS | | | | | | |

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

7.2.1 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 developed progressively 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 an empirically constrained 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 nineteen 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 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* 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 provides 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 dominated by *Eucalyptus* species) which are used for wood production, recreation and conservation, and plantations of native (primarily *Eucalyptus* species) and exotic species (primarily *Pinus* species).

7.3.1.2 Climate

Australia is a dry continent where rainfall is highly variable 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 2009

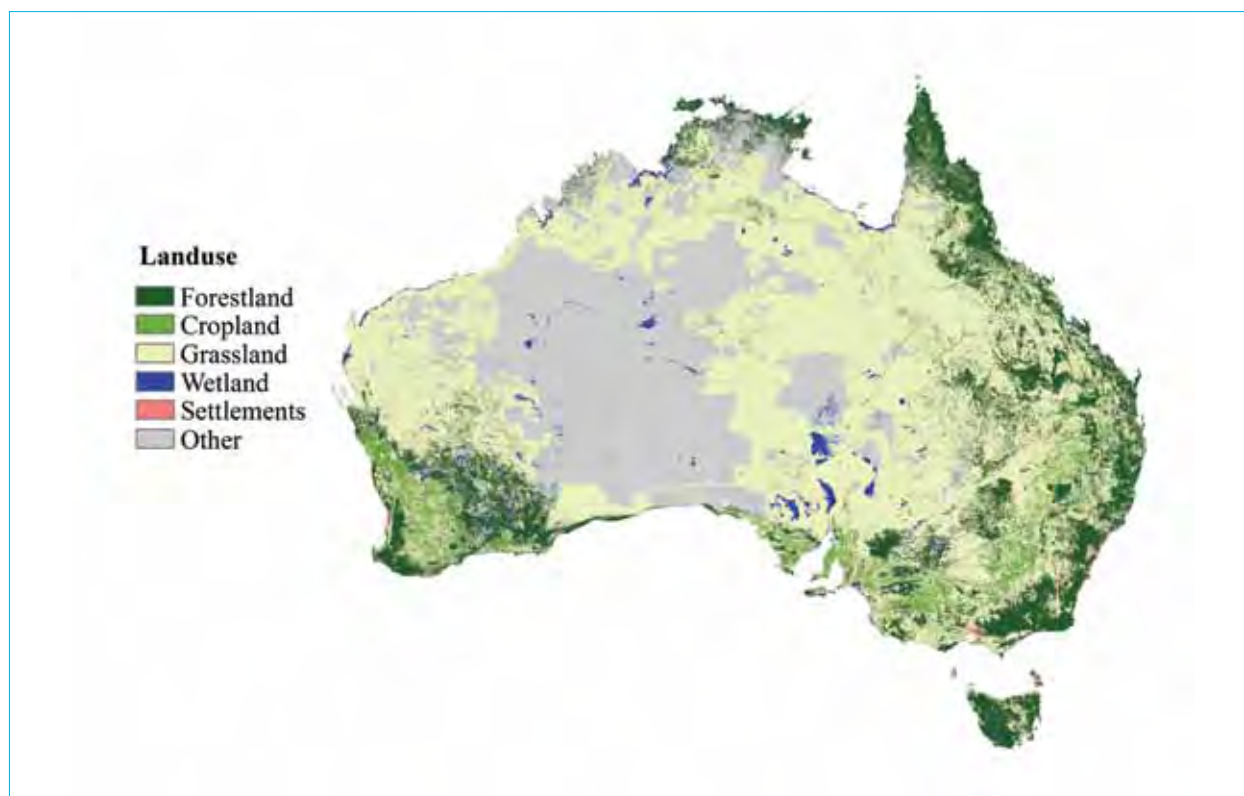


Figure 7.7: Average annual rainfall 1970 to 2008

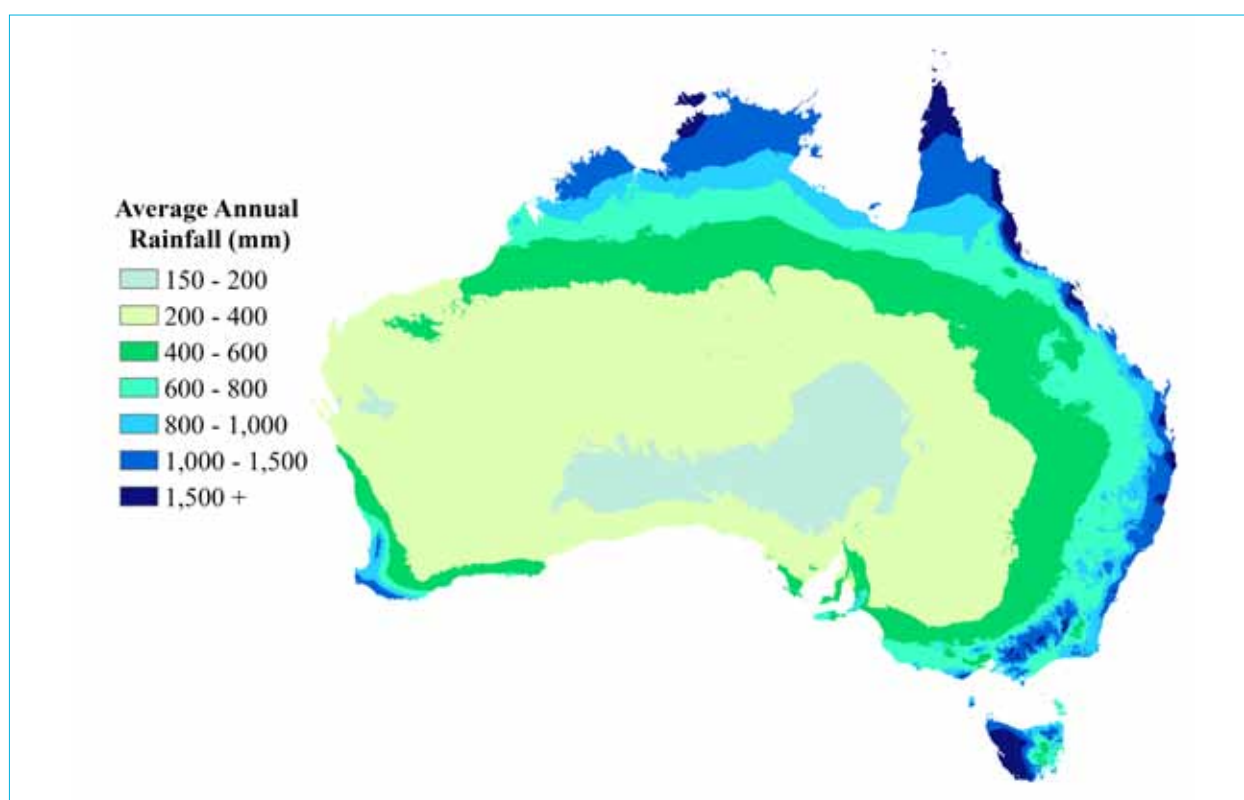
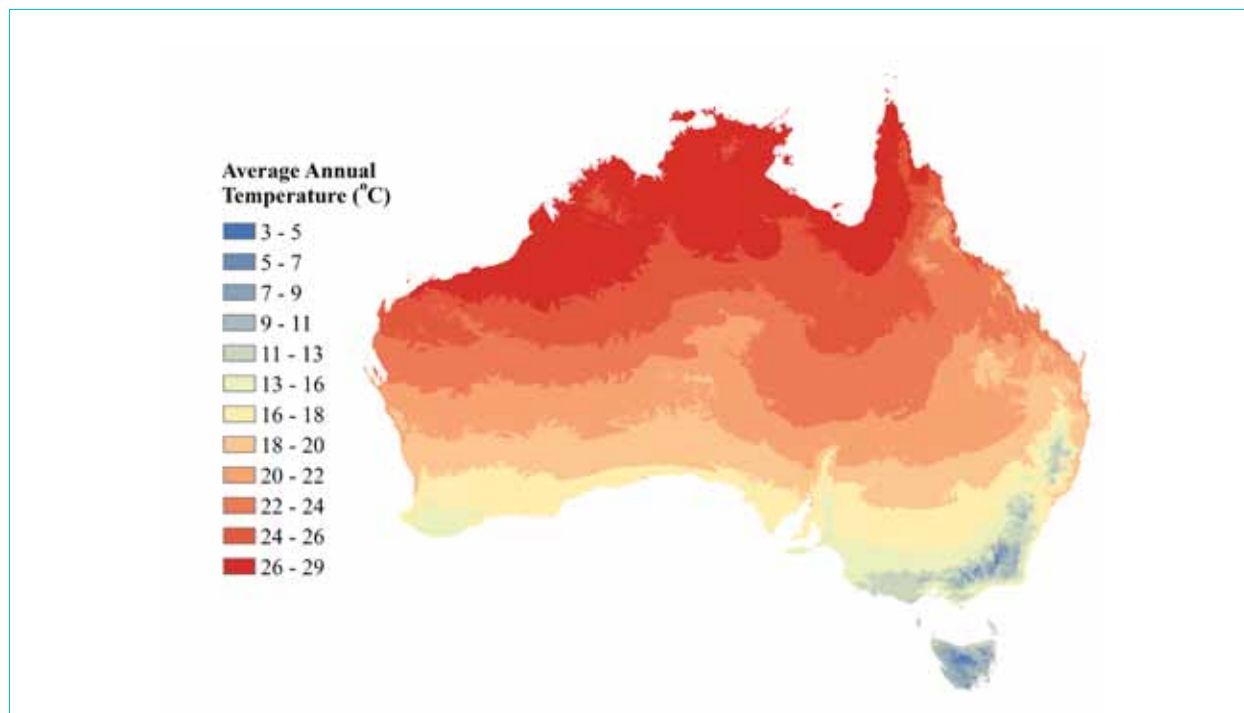


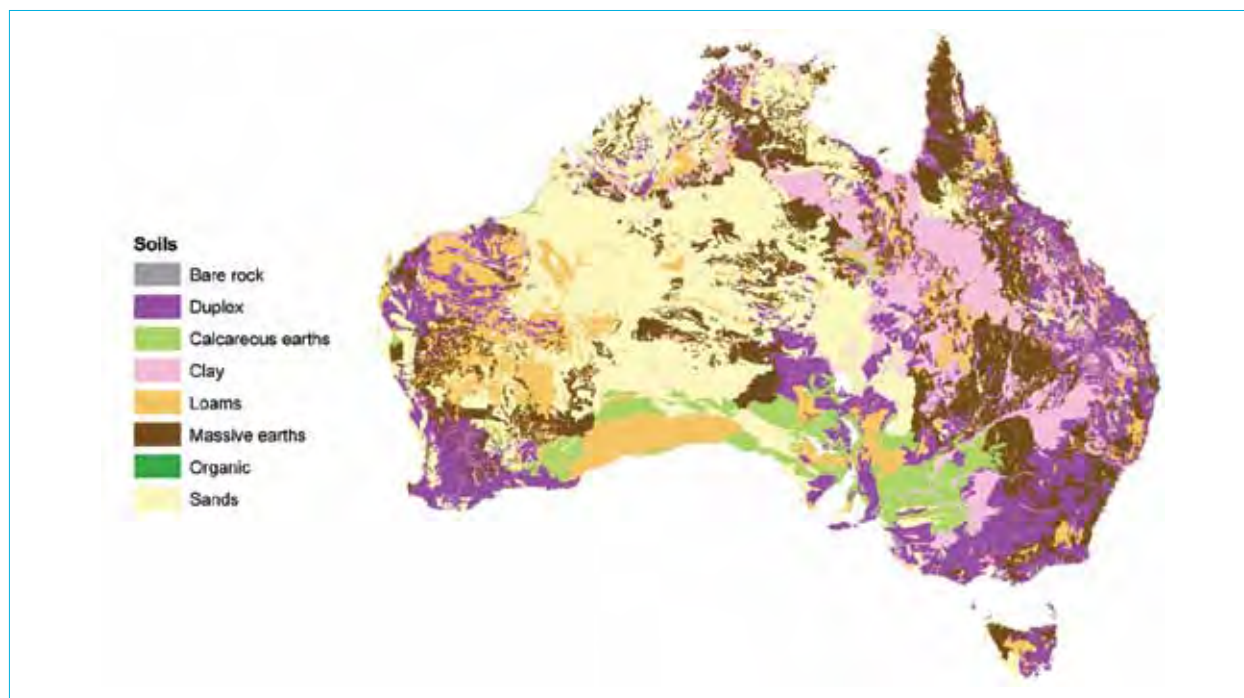
Figure 7.8: Average annual temperature 1970 to 2008



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 nitrogen, phosphorus and other nutrients. Soils under well managed agricultural land use 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 (Source: Bureau of Rural Sciences)



7.3.2 Land Category Definitions

7.3.2.1 Forest Land

Forest land includes all lands with a tree height of at least 2 metres and crown canopy cover of 20% or more (Figure 7.10). 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.

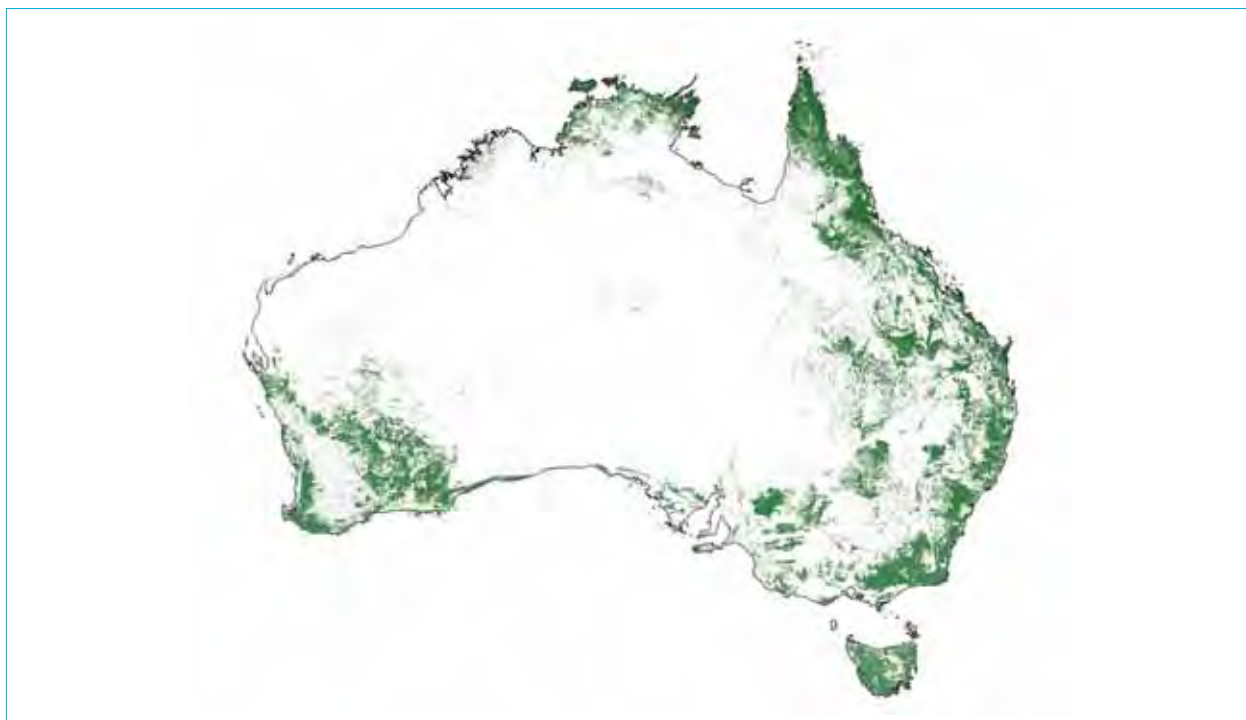
In choosing a forest definition Australia took several factors into account, including:

- 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, reforestation and forest management activities, 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 (ha). Consistent with the definition used since 1992 for Australia's National Forest Inventory, 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 sector.

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

Figure 7.10: Forest extent in Australia 2009



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. For this reason, whenever land is cropped it is considered *cropland* and reported under a *cropland* category although the emission estimates take into account that management systems may have transferred intermittently between cropping and pasture. 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, crown canopy cover and minimum forest area criteria for *forest land*.

7.3.2.4 Settlement

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

7.3.2.5 Wetland

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

7.3.2.6 Other land

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

7.3.2.7 Managed and unmanaged lands

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

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

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

7.4 REPRESENTATION OF LAND AREAS

The principal method of representing land is through a time-series national remote sensing program. This consistent representation of land is a 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 performed on a land unit by land unit basis to ensure that there are no gaps or overlaps which would lead to omission or double counting of areas of land. To support estimation of emissions and removals in the *forest land* category, Australia uses some non-spatial data drawn from Australia's National Forest Inventory. This is used exclusively within a reporting category consistent with Approach 3. Land areas in the *cropland remaining cropland*, *grassland remaining grassland*, *wetlands*, and *settlements* categories are drawn from the Land Use Mapping programme of Australia's Bureau of Rural Sciences. Areas of *forest land* and *forest land converted to grassland and cropland* (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 (start of 1990 to end of 2009)

| Land use | 1990 ^(a) (Mha) | 2009 (Mha) | Net Change (Mha) |
|--------------------------------------|------------------------------|---------------|---------------------|
| Forestlands total | 111.9 | 106.5 | -5.4 |
| Forestland remaining Forestland | 111.9 | 105.4 | -6.5 |
| Harvested Native Forests | 14.9 | 14.9 | 0.0 |
| Plantations | 0.8 | 0.8 | 0.0 |
| Other Native Forest | 96.2 | 89.7 | -6.5 |
| Grassland converted to Forest Land | 0.0 | 1.1 | 1.1 |
| Grasslands total | 444.4 | 448.3 | 3.9 |
| Grassland remaining Grassland | 437.2 | 435.4 | -1.8 |
| Forest Land converted to Grassland | 7.2 | 12.9 | 5.7 |
| Cropland total | 24.7 | 26.1 | 1.4 |
| Cropland remaining Cropland | 21.7 | 21.7 | 0.0 |
| Forest Land converted to Cropland | 3.0 | 4.4 | 1.4 |
| 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 |

Note: (a) The land areas for 1990 in this table are the land areas at the start of 1990. The net change is therefore the change in land area including change that occurred in 1990 through to 2009 inclusive.

Table 7.5: Annual land area matrices from 1990 to 2009 (The area reported in the final area column is the land area by category at the end of the year)

| 1990 | Forest land | Grassland | Cropland | Wetlands | Settlements | Other land | Final Area |
|--------------|-------------|-----------|----------|----------|-------------|------------|------------|
| Forestland | 111.30 | 0.69 | | | | | 111.99 |
| Grassland | 0.46 | 443.71 | | | | | 444.17 |
| Cropland | 0.12 | | 24.74 | | | | 24.85 |
| Wetlands | | | | 13.49 | | | 13.49 |
| Settlements | | | | | 1.60 | | 1.60 |
| Other land | | | | | | 172.90 | 172.90 |
| Initial Area | 111.87 | 444.40 | 24.74 | 13.49 | 1.60 | 172.90 | 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 |
|---------------------|-------------|-----------|----------|----------|-------------|------------|------------|
| <i>Forestland</i> | 111.56 | 0.55 | | | | | 112.10 |
| <i>Grassland</i> | 0.34 | 443.62 | | | | | 443.97 |
| <i>Cropland</i> | 0.09 | | 24.85 | | | | 24.94 |
| <i>Wetlands</i> | | | | 13.49 | | | 13.49 |
| <i>Settlements</i> | | | | | 1.60 | | 1.60 |
| <i>Other land</i> | | | | | | 172.90 | 172.90 |
| <i>Initial Area</i> | 111.99 | 444.17 | 24.85 | 13.49 | 1.60 | 172.90 | 769.00 |
| <i>Net change</i> | 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 |
|---------------------|-------------|-----------|----------|----------|-------------|------------|------------|
| <i>Forestland</i> | 111.72 | 0.66 | | | | | 112.39 |
| <i>Grassland</i> | 0.31 | 443.30 | | | | | 443.62 |
| <i>Cropland</i> | 0.07 | | 24.94 | | | | 25.01 |
| <i>Wetlands</i> | | | | 13.49 | | | 13.49 |
| <i>Settlements</i> | | | | | 1.60 | | 1.60 |
| <i>Other land</i> | | | | | | 172.90 | 172.90 |
| <i>Initial Area</i> | 112.10 | 443.97 | 24.94 | 13.49 | 1.60 | 172.90 | 769.00 |
| <i>Net change</i> | 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 |
|---------------------|-------------|-----------|----------|----------|-------------|------------|------------|
| <i>Forestland</i> | 111.98 | 0.43 | | | | | 112.40 |
| <i>Grassland</i> | 0.34 | 443.19 | | | | | 443.54 |
| <i>Cropland</i> | 0.07 | | 25.01 | | | | 25.08 |
| <i>Wetlands</i> | | | | 13.49 | | | 13.49 |
| <i>Settlements</i> | | | | | 1.60 | | 1.60 |
| <i>Other land</i> | | | | | | 172.90 | 172.90 |
| <i>Initial Area</i> | 112.39 | 443.62 | 25.01 | 13.49 | 1.60 | 172.90 | 769.00 |
| <i>Net change</i> | 0.02 | -0.08 | 0.07 | 0.00 | 0.00 | 0.00 | 0.00 |

1994

| | Forest land | Grassland | Cropland | Wetlands | Settlements | Other land | Final Area |
|---------------------|-------------|-----------|----------|----------|-------------|------------|------------|
| <i>Forestland</i> | 112.03 | 0.38 | | | | | 112.42 |
| <i>Grassland</i> | 0.29 | 443.15 | | | | | 443.44 |
| <i>Cropland</i> | 0.08 | | 25.08 | | | | 25.15 |
| <i>Wetlands</i> | | | | 13.49 | | | 13.49 |
| <i>Settlements</i> | | | | | 1.60 | | 1.60 |
| <i>Other land</i> | | | | | | 172.90 | 172.90 |
| <i>Initial Area</i> | 112.40 | 443.54 | 25.08 | 13.49 | 1.60 | 172.90 | 769.00 |
| <i>Net change</i> | 0.02 | -0.09 | 0.08 | 0.00 | 0.00 | 0.00 | 0.00 |

1995

| | Forest land | Grassland | Cropland | Wetlands | Settlements | Other land | Final Area |
|---------------------|-------------|-----------|----------|----------|-------------|------------|------------|
| <i>Forestland</i> | 112.11 | 0.32 | | | | | 112.43 |
| <i>Grassland</i> | 0.25 | 443.12 | | | | | 443.37 |
| <i>Cropland</i> | 0.06 | | 25.15 | | | | 25.21 |
| <i>Wetlands</i> | | | | 13.49 | | | 13.49 |
| <i>Settlements</i> | | | | | 1.60 | | 1.60 |
| <i>Other land</i> | | | | | | 172.90 | 172.90 |
| <i>Initial Area</i> | 112.42 | 443.44 | 25.15 | 13.49 | 1.60 | 172.90 | 769.00 |
| <i>Net change</i> | 0.02 | -0.07 | 0.06 | 0.00 | 0.00 | 0.00 | 0.00 |

1996

| | Forest land | Grassland | Cropland | Wetlands | Settlements | Other land | Final Area |
|---------------------|-------------|-----------|----------|----------|-------------|------------|------------|
| <i>Forestland</i> | 112.09 | 0.26 | | | | | 112.36 |
| <i>Grassland</i> | 0.27 | 443.11 | | | | | 443.38 |
| <i>Cropland</i> | 0.07 | | 25.21 | | | | 25.28 |
| <i>Wetlands</i> | | | | 13.49 | | | 13.49 |
| <i>Settlements</i> | | | | | 1.60 | | 1.60 |
| <i>Other land</i> | | | | | | 172.90 | 172.90 |
| <i>Initial Area</i> | 112.43 | 443.37 | 25.21 | 13.49 | 1.60 | 172.90 | 769.00 |
| <i>Net change</i> | -0.08 | 0.01 | 0.07 | 0.00 | 0.00 | 0.00 | 0.00 |

1997

| | Forest land | Grassland | Cropland | Wetlands | Settlements | Other land | Final Area |
|---------------------|-------------|-----------|----------|----------|-------------|------------|------------|
| <i>Forestland</i> | 112.05 | 0.23 | | | | | 112.28 |
| <i>Grassland</i> | 0.25 | 443.14 | | | | | 443.39 |
| <i>Cropland</i> | 0.06 | | 25.28 | | | | 25.34 |
| <i>Wetlands</i> | | | | 13.49 | | | 13.49 |
| <i>Settlements</i> | | | | | 1.60 | | 1.60 |
| <i>Other land</i> | | | | | | 172.90 | 172.90 |
| <i>Initial Area</i> | 112.36 | 443.38 | 25.28 | 13.49 | 1.60 | 172.90 | 769.00 |
| <i>Net change</i> | -0.08 | 0.01 | 0.06 | 0.00 | 0.00 | 0.00 | 0.00 |

1998

| | Forest land | Grassland | Cropland | Wetlands | Settlements | Other land | Final Area |
|---------------------|-------------|-----------|----------|----------|-------------|------------|------------|
| <i>Forestland</i> | 111.95 | 0.26 | | | | | 112.21 |
| <i>Grassland</i> | 0.27 | 443.13 | | | | | 443.40 |
| <i>Cropland</i> | 0.06 | | 25.34 | | | | 25.41 |
| <i>Wetlands</i> | | | | 13.49 | | | 13.49 |
| <i>Settlements</i> | | | | | 1.60 | | 1.60 |
| <i>Other land</i> | | | | | | 172.90 | 172.90 |
| <i>Initial Area</i> | 112.28 | 443.39 | 25.34 | 13.49 | 1.60 | 172.90 | 769.00 |
| <i>Net change</i> | -0.08 | 0.01 | 0.06 | 0.00 | 0.00 | 0.00 | 0.00 |

1999

| | Forest land | Grassland | Cropland | Wetlands | Settlements | Other land | Final Area |
|---------------------|-------------|-----------|----------|----------|-------------|------------|------------|
| <i>Forestland</i> | 111.86 | 0.52 | | | | | 112.38 |
| <i>Grassland</i> | 0.28 | 442.88 | | | | | 443.17 |
| <i>Cropland</i> | 0.06 | | 25.41 | | | | 25.47 |
| <i>Wetlands</i> | | | | 13.49 | | | 13.49 |
| <i>Settlements</i> | | | | | 1.60 | | 1.60 |
| <i>Other land</i> | | | | | | 172.90 | 172.90 |
| <i>Initial Area</i> | 112.21 | 443.40 | 25.41 | 13.49 | 1.60 | 172.90 | 769.00 |
| <i>Net change</i> | 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 |
|---------------------|-------------|-----------|----------|----------|-------------|------------|------------|
| <i>Forestland</i> | 112.02 | 0.53 | | | | | 112.55 |
| <i>Grassland</i> | 0.30 | 442.63 | | | | | 442.93 |
| <i>Cropland</i> | 0.06 | | 25.47 | | | | 25.53 |
| <i>Wetlands</i> | | | | 13.49 | | | 13.49 |
| <i>Settlements</i> | | | | | 1.60 | | 1.60 |
| <i>Other land</i> | | | | | | 172.90 | 172.90 |
| <i>Initial Area</i> | 112.38 | 443.17 | 25.47 | 13.49 | 1.60 | 172.90 | 769.00 |
| <i>Net change</i> | 0.17 | -0.23 | 0.06 | 0.00 | 0.00 | 0.00 | 0.00 |

2001

| | Forest land | Grassland | Cropland | Wetlands | Settlements | Other land | Final Area |
|---------------------|-------------|-----------|----------|----------|-------------|------------|------------|
| <i>Forestland</i> | 111.73 | 0.08 | | | | | 111.81 |
| <i>Grassland</i> | 0.76 | 442.85 | | | | | 443.61 |
| <i>Cropland</i> | 0.06 | | 25.53 | | | | 25.59 |
| <i>Wetlands</i> | | | | 13.49 | | | 13.49 |
| <i>Settlements</i> | | | | | 1.60 | | 1.60 |
| <i>Other land</i> | | | | | | 172.93 | 172.93 |
| <i>Initial Area</i> | 112.55 | 442.93 | 25.53 | 13.49 | 1.60 | 172.93 | 769.03 |
| <i>Net change</i> | -0.74 | 0.68 | 0.06 | 0.00 | 0.00 | 0.00 | 0.00 |

2002

| | Forest land | Grassland | Cropland | Wetlands | Settlements | Other land | Final Area |
|---------------------|-------------|-----------|----------|----------|-------------|------------|------------|
| <i>Forestland</i> | 111.00 | 0.08 | | | | | 111.07 |
| <i>Grassland</i> | 0.76 | 443.50 | | | | | 444.26 |
| <i>Cropland</i> | 0.06 | | 25.59 | | | | 25.65 |
| <i>Wetlands</i> | | | | 13.49 | | | 13.49 |
| <i>Settlements</i> | | | | | 1.60 | | 1.60 |
| <i>Other land</i> | | | | | | 172.93 | 172.93 |
| <i>Initial Area</i> | 111.81 | 443.58 | 25.59 | 13.49 | 1.60 | 172.93 | 769.00 |
| <i>Net change</i> | -0.74 | 0.68 | 0.06 | 0.00 | 0.00 | 0.00 | 0.00 |

2003

| | Forest land | Grassland | Cropland | Wetlands | Settlements | Other land | Final Area |
|--------------|-------------|-----------|----------|----------|-------------|------------|------------|
| Forestland | 110.08 | 0.08 | | | | | 110.17 |
| Grassland | 0.93 | 444.18 | | | | | 445.11 |
| Cropland | 0.06 | | 25.65 | | | | 25.71 |
| Wetlands | | | | 13.49 | | | 13.49 |
| Settlements | | | | | 1.60 | | 1.60 |
| Other land | | | | | | 172.93 | 172.93 |
| Initial Area | 111.07 | 444.26 | 25.65 | 13.49 | 1.60 | 172.93 | 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 |
|--------------|-------------|-----------|----------|----------|-------------|------------|------------|
| Forestland | 109.18 | 0.08 | | | | | 109.26 |
| Grassland | 0.91 | 445.03 | | | | | 445.94 |
| Cropland | 0.07 | | 25.71 | | | | 25.78 |
| Wetlands | | | | 13.49 | | | 13.49 |
| Settlements | | | | | 1.60 | | 1.60 |
| Other land | | | | | | 172.93 | 172.93 |
| Initial Area | 110.17 | 445.11 | 25.71 | 13.49 | 1.60 | 172.93 | 769.00 |
| Net change | -0.91 | 0.84 | 0.07 | 0.00 | 0.00 | 0.00 | 0.00 |

2005

| | Forest land | Grassland | Cropland | Wetlands | Settlements | Other land | Final Area |
|--------------|-------------|-----------|----------|----------|-------------|------------|------------|
| Forestland | 107.87 | 0.06 | | | | | 107.93 |
| Grassland | 1.31 | 445.89 | | | | | 447.20 |
| Cropland | 0.08 | | 25.78 | | | | 25.86 |
| Wetlands | | | | 13.49 | | | 13.49 |
| Settlements | | | | | 1.60 | | 1.60 |
| Other land | | | | | | 172.93 | 172.93 |
| Initial Area | 109.26 | 445.94 | 25.78 | 13.49 | 1.60 | 172.93 | 769.00 |
| Net change | -1.33 | 1.25 | 0.08 | 0.00 | 0.00 | 0.00 | 0.00 |

2006

| | Forest land | Grassland | Cropland | Wetlands | Settlements | Other land | Final Area |
|--------------|-------------|-----------|----------|----------|-------------|------------|------------|
| Forestland | 107.03 | 0.05 | | | | | 107.08 |
| Grassland | 0.81 | 447.15 | | | | | 447.96 |
| Cropland | 0.08 | | 25.86 | | | | 25.94 |
| Wetlands | | | | 13.49 | | | 13.49 |
| Settlements | | | | | 1.60 | | 1.60 |
| Other land | | | | | | 172.93 | 172.93 |
| Initial Area | 107.93 | 447.20 | 25.86 | 13.49 | 1.60 | 172.93 | 769.00 |
| Net change | -0.84 | 0.76 | 0.08 | 0.00 | 0.00 | 0.00 | 0.00 |

2007

| | Forest land | Grassland | Cropland | Wetlands | Settlements | Other land | Final Area |
|---------------------|-------------|-----------|----------|----------|-------------|------------|------------|
| <i>Forestland</i> | 106.09 | 0.06 | | | | | 106.15 |
| <i>Grassland</i> | 0.93 | 447.89 | | | | | 448.82 |
| <i>Cropland</i> | 0.07 | | 25.94 | | | | 26.01 |
| <i>Wetlands</i> | | | | 13.49 | | | 13.49 |
| <i>Settlements</i> | | | | | 1.60 | | 1.60 |
| <i>Other land</i> | | | | | | 172.93 | 172.93 |
| <i>Initial Area</i> | 107.08 | 447.96 | 25.94 | 13.49 | 1.60 | 172.93 | 769.00 |
| <i>Net change</i> | -0.93 | 0.87 | 0.07 | 0.00 | 0.00 | 0.00 | 0.00 |

2008

| | Forest land | Grassland | Cropland | Wetlands | Settlements | Other land | Final Area |
|---------------------|-------------|-----------|----------|----------|-------------|------------|------------|
| <i>Forestland</i> | 105.91 | 0.19 | | | | | 106.10 |
| <i>Grassland</i> | 0.18 | 448.64 | | | | | 448.82 |
| <i>Cropland</i> | 0.06 | | 26.01 | | | | 26.07 |
| <i>Wetlands</i> | | | | 13.49 | | | 13.49 |
| <i>Settlements</i> | | | | | 1.60 | | 1.60 |
| <i>Other land</i> | | | | | | 172.93 | 172.93 |
| <i>Initial Area</i> | 106.15 | 448.82 | 26.01 | 13.49 | 1.60 | 172.93 | 769.00 |
| <i>Net change</i> | -0.06 | -0.01 | 0.06 | 0.00 | 0.00 | 0.00 | 0.00 |

2009

| | Forest land | Grassland | Cropland | Wetlands | Settlements | Other land | Final Area |
|---------------------|-------------|-----------|----------|----------|-------------|------------|------------|
| <i>Forestland</i> | 105.91 | 0.61 | | | | | 106.52 |
| <i>Grassland</i> | 0.13 | 448.21 | | | | | 448.34 |
| <i>Cropland</i> | 0.05 | | 26.07 | | | | 26.12 |
| <i>Wetlands</i> | | | | 13.49 | | | 13.49 |
| <i>Settlements</i> | | | | | 1.60 | | 1.60 |
| <i>Other land</i> | | | | | | 172.93 | 172.93 |
| <i>Initial Area</i> | 106.10 | 448.82 | 26.07 | 13.49 | 1.60 | 172.93 | 769.00 |
| <i>Net change</i> | 0.42 | -0.47 | 0.05 | 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 the land area matrices. Australia is investigating methods to separate the reporting of lands that transfer between forest and non-forest due to natural variability that will provide greater transparency in the areas of land transferred between land categories without changing land use.

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

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

Australia has elected to move lands from the conversion sub-category to the remaining category after 50 years. This longer period of time reflects the long term impacts of conversion on carbon dynamics in some systems under low rainfall conditions. Given the long time period, additional sub-categories are used to separate recent land conversions from older land conversions. The respective periods for these sub-categories are 0 to 20 years and 21 to 50 years. After 50 years, the lands will be moved into the “land remaining” sub-categories. Following the recommendation of the 2010 Expert Review Team (ERT), Australia is working to apply this consistently across all land use categories in future submissions.

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 (8-15 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 configurations and patterns observed.

7.4.2.3 Mapping Resolution and Re-sampling

Modelling grid resolution

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

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

Land cover grid resolution

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

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

All Landsat derived data are utilised at a consistent 25 m resolution for the full time-series analysis by re-sampling the 50 m pixels (1972-1988) into four 25 m pixels. The spatial-temporal model is important at this time, as it reduces the effect of “mixed” isolated and edge pixels. The period of the transition to the true 25 m data takes place prior to the period where it would have any significant effect on the first reported year of emissions. The 50 m data resolution is effectively only used to run-in the model to establish forest age (if the forest is regrowth from non-forest land or in response to a forest removal since 1972). The ability to determine, from 1990 onwards, the effects of land use change to 0.2 ha minimum areas is robust, given that this area is greater than the pixel resolution (approximately 0.0625 ha) and the approach used removes mixed and other pixels which are temporally and spatially inconsistent. These methods ensure that the change area within the 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 ortho-rectified using a standard algorithm (PCI Orthoengine) with standard inputs (a consistent digital elevation model). For time-series classification, these standards also include the use of a joint spatial-temporal model: in this case a conditional probability network (Caccetta, 1997; Caccetta *et al.*, 2003; Kiiveri *et al.*, 2001, 2003) for determining 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 errors that are associated with pair-wise differencing methods. Pair wise differencing methods for estimating forest cover change are affected by errors due to seasonally changing land management effects (introducing large contiguous areas of false change), and 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 reduce the occurrence of unlikely events such as multiple one year conversions between forest and non-forest – for example conversion from non-forest to forest and then back to non-forest is an unlikely event over a short period, for example, three years. The rules are particularly effective when the time between observations is less than that of a forest growth and harvest cycle. This is one of the key reasons and advantages for having a relatively dense time-series of Landsat data.

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

7.5 SOURCE CATEGORY 5A FOREST LAND

7.5.1 Methodology

7.5.1.1 Forest Land Remaining Forest Land

There are four broad sub-divisions to *forest land remaining forest land*: *harvested native forests*, *other native forests*, *fuelwood consumed* and *plantations*. These are treated as independent sub-divisions and emissions estimates are modelled independently 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-divisions used in the Forest land remaining Forest land category

| Harvested Native Forests | Fuelwood | Plantations | Other Native Forests | | | |
|---|--|---|--|--|---|--|
| | | | Single change in extent | Ephemeral change in extent | Loss of foliage mass in continuous forest | Fire |
| Areas of native forest that have been harvested at some time, or may still be available 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. | Commercial plantations that were established prior to 1990. | Forest areas that have had a permanent change in their cover status, but there <u>has</u> been no identifiable human intervention and they are likely to change again. | These forest areas fluctuate above and below the forest cover thresholds, largely as a result of climate influences. | These forest areas always meet forest cover status, but without commercial forest production. | CO ₂ emissions due to wildfire and prescribed burning and subsequent removals from post-fire recovery across all forest categories. |

Harvested Native Forests

Harvested native forests are those forests comprised of endemic species arising from natural regrowth (including 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, harvest 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.D.

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

Plantations (established prior to 1990)

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

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

Emissions of CO₂ 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 CO₂ emissions.

Annual fuelwood data is obtained from the Australian Bureau of Agricultural and Resource Economics-Bureau of Rural Sciences (ABARE-BRS) to estimate CO₂ emissions. These statistics report three separate fuelwood classes: residential, industrial, and wood and paper. Fuelwood consumed in the residential sector represents over 92% of the total emissions of all fuelwood consumed. Only emissions from the burning of fuelwood for the residential and industrial sectors are reported under the *Fuelwood consumed* sub-category.

Fuelwood is extracted from dead organic matter across all forest categories and as such the CO₂ emissions associated with the consumption of *fuelwood* are reported separately rather than against any specific sub-category of *forest land*. The CO₂ emissions associated with *fuelwood* consumption are based on energy use (Petajoules, PJ) of fuelwood by industry as reported by ABARE-BRS (2010). The data used to estimate CO₂ emissions are updated annually based on the most recent ABARE-BRS statistics.

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

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

7.5.1.2 Land Converted to Forest Land

Grassland converted to Forest Land

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

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

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

7.5.2 Uncertainties and Time Series Consistency

Uncertainties for the *forest land* category are estimated to be $\pm 30\%$ for CO₂. 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 2008 Inventory

There have been minor improvements and updates made to estimates of emissions and removals in the *forest land* category for the 2009 inventory submission. This has resulted in small recalculations to the time series of some of the sub-categories.

The *harvested native forests* sub-category has been modelled using the Tier 2, non-spatial capabilities of the *FullCAM* model as implemented in the 2008 inventory submission. Annual activity data updates and data quality control processes have resulted in a small adjustment to the time-series resulting in a 328.9 Gg CO₂-e increase in the 1990 sink and a 72.8 Gg CO₂-e increase in the 2008 sink. For *other native forests* a small recalculation has occurred due to the annual update of forest extent data this has resulted in a 169.1 Gg increase in the 1990 sink and a 557.5 Gg CO₂-e increase in the 2008 sink.

The annual update of remote sensing data of forest cover change has resulted in a recalculation of the *grassland converted to forest land* sub-category. The update resulted in a small increase in the area confirmed as *grassland converted to forest land* in 2008 producing a 195.8 Gg CO₂-e decrease in the 2008 sink estimate.

For *fuelwood consumed* revised data for energy use by fuelwood were provided in ABARES Australian Energy Statistics for 2008. This resulted in a 1346.7 Gg CO₂-e increase in the 2008 emissions for *fuelwood consumed*.

The net effect of all recalculations was to increase the 1990 sink estimate by 571.8 Gg CO₂-e and to reduce the 2008 sink estimate by 1020.2 Gg CO₂-e.

Table 7.7: 5.A Forest land: recalculation of total CO₂-e emissions (Gg), 1990-2008

| | 2010 submission | 2011 submission | Change | |
|------|-------------------------|-------------------------|-------------------------|------|
| | (Gg CO ₂ -e) | (Gg CO ₂ -e) | (Gg CO ₂ -e) | (%) |
| 1990 | -41727.47 | -42299.27 | -571.79 | 1.4 |
| 2000 | -46122.00 | -48627.25 | -2505.25 | 5.4 |
| 2001 | -66460.04 | -68316.93 | -1856.89 | 2.8 |
| 2002 | 11469.81 | 10611.37 | -858.43 | -7.5 |
| 2003 | 152389.03 | 152207.91 | -181.12 | -0.1 |
| 2004 | -121261.27 | -121646.38 | -385.10 | 0.3 |
| 2005 | -85131.85 | -85220.70 | -88.85 | 0.1 |
| 2006 | -92483.57 | -92819.29 | -335.72 | 0.4 |
| 2007 | -2528.18 | -3256.88 | -728.69 | 28.8 |
| 2008 | -104224.53 | -103204.37 | 1020.16 | -1.0 |

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

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://adl.brs.gov.au>). *Cropland remaining cropland* covers an area of over 20 million hectares (Figure 7.11) with the area planted varying in any one year depending upon climate forecasts 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*.

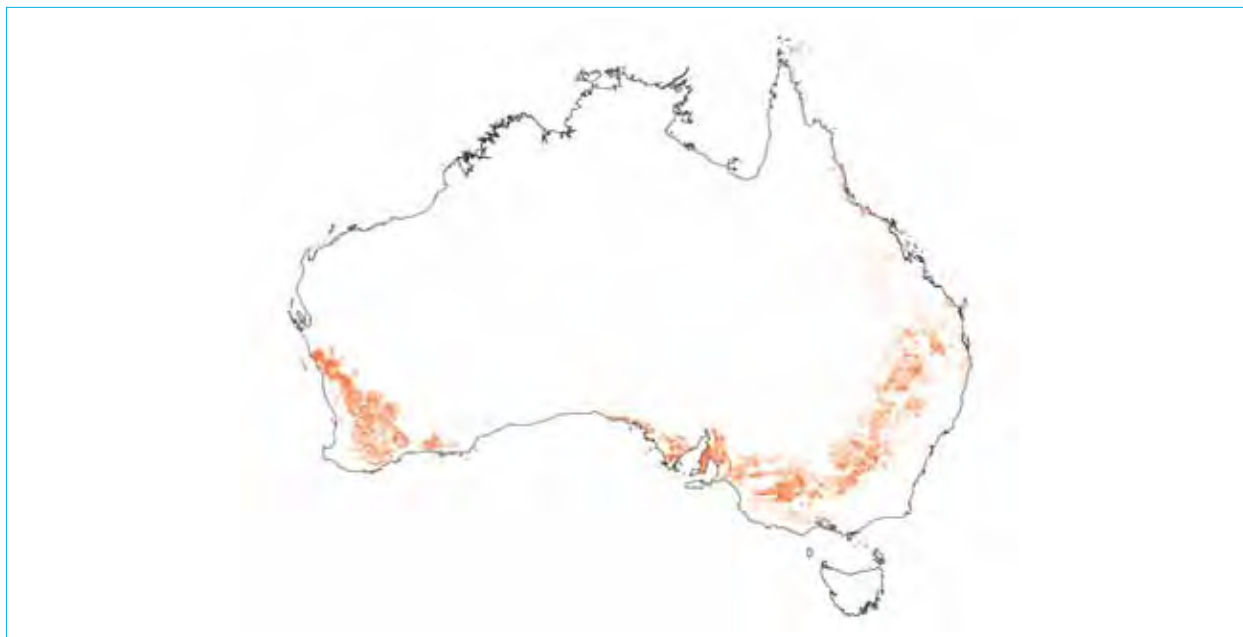
In this reporting structure, *cropland remaining cropland* includes only those lands that were used for cropping prior to 1972, and remain as *cropland*. Where land has been identified as cropland in 1972, it is assumed that these croplands were transitioned from *forest land* at any time between the period of 1940 and 1971. It is not possible to determine when the conversion from forest to crop occurred for any area of land prior to 1972. Therefore, to provide a model 'run-in', it is assumed that conversion from forest to crop occurred at a time during the 30 year period prior to 1972 leading to a land use transition period of between 18 and 30 years rather than a constant 20 years. This approach provides a realistic reflection of the extended period over which these lands have been cropland and their current condition.

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 approximately 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. Table 7.8 shows the various crop types that are in this land use category.

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, ecosystem model *FullCAM*, as described in Appendix 7.A. The data used in the modelling are provided in Appendix 7.G.

Non-CO₂ 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

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

Source: Bureau of Rural Sciences

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

7.6.1.2 Land Converted to Cropland

Forest land converted to Cropland

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

The 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 $\pm 10\%$ 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 2008 Inventory

Australia has continued to implement annual updates of remote sensing data to identify the area of *forest land converted to cropland* and *grassland*. Australia's quality control processes have led to improved management data for the 2009 submission. There were no methodological changes implemented for the 2009 inventory submission for the *cropland* category.

Quality control processes for review of data, resulted in improved management data for the relative frequency of cropland and grassland management in northern NSW. This improvement increased the proportion of forest land conversion attributed to grasslands compared to croplands since 2001. Additionally, improved attribution of forest cover change where fire had also occurred resulted in an increase in the area identified as *forest land converted to cropland and grassland*. The combination of these improvements resulted in a decrease in the emissions from *forest land converted to cropland* throughout the time-series. This includes a decrease in emissions of 1133.3 Gg CO_2 -e in 1990 and 1985.0 Gg CO_2 -e in 2008. This decrease was balanced by a slightly greater increase in the emissions from *forest land converted to grassland* that resulted from the increased proportion of forest conversion to grassland.

The recalculations to the *forest land converted to cropland* sub-category, together with minor recalculations to the *cropland remaining cropland* sub-category resulted in overall recalculations for the *cropland* category of a decrease of 1094.9 Gg CO_2 -e for the 1990 emissions estimate and an increase of 1995.2 Gg CO_2 -e for the 2008 estimate.

Table 7.9: 5.B Croplands: recalculation of total CO₂-e emissions, 1990-2008

| | 2010 submission | 2011 submission | Change | |
|------|-------------------------|-------------------------|-------------------------|-------|
| | (Gg CO ₂ -e) | (Gg CO ₂ -e) | (Gg CO ₂ -e) | (%) |
| 1990 | 1316.21 | 221.36 | -1094.85 | -83.2 |
| 2000 | -9254.54 | -10688.70 | -1434.16 | 15.5 |
| 2001 | -17081.15 | -17845.93 | -764.77 | 4.5 |
| 2002 | 54234.63 | 52599.05 | -1635.58 | -3.0 |
| 2003 | -21766.08 | -22418.45 | -652.37 | 3.0 |
| 2004 | -32680.75 | -33460.91 | -780.16 | 2.4 |
| 2005 | -46863.29 | -47902.94 | -1039.65 | 2.2 |
| 2006 | 22065.25 | 20802.42 | -1262.83 | -5.7 |
| 2007 | 31635.92 | 29915.81 | -1720.11 | -5.4 |
| 2008 | -12127.67 | -14122.91 | -1995.23 | 16.5 |

7.6.5 Source Specific Planned Improvements

Annual crop yields are currently obtained from Australia Bureau of Statistics (ABS) data and validated using industry data. In areas where there is poor quality data an estimate of crop yield is modelled from rainfall availability during the crop growth period. A new crop growth model is being developed for integration with the existing inventory methods. The new crop growth model will be implemented when calibration, verification and quality assurance has been finalised.

The model is also being further developed to include a non-CO₂ capacity. This will be achieved by enhancing the model to include nitrogen cycling. To date, the model code has been implemented and initial calibrations tested. This module still requires further testing and validation and will only be introduced following quality assurance, testing and review.

7.7 SOURCE CATEGORY 5C GRASSLAND

7.7.1 Methodology

7.7.1.1 Grassland Remaining Grassland

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

The distribution of land areas in the *grassland remaining grassland* sub-category are estimated using the National Land Use 2001/2002 (Version 3) Summary Statistics provided by the Bureau of Rural Sciences (<http://adl.brs.gov.au>). In 2009 *grassland remaining grassland* covered an area of 435 million hectares (of the 448 million hectares of grassland reported in Table 7.4) which is evenly distributed around Australia (Figure 7.12). The remaining area of grassland is reported under the *forest land converted to grassland* sub-category.

There are three components of the *grassland remaining grassland* emission estimates – the grassland component, the shrubland transitions component and the CO₂ emissions and post fire removals associated with savanna burning. Shrublands are areas of woody vegetation that are not, by definition, ‘forest’. Shrublands are typically sparse tree and shrub formations and are not separable into areas made up of uniquely tree or shrub plant types. Emissions from the *grassland remaining grassland* category are estimated using interim methods. The Tier 3 *FullCAM* model is used to estimate emissions and removals of all pools (living biomass, dead organic matter and soil) for the grass only areas of the *grassland remaining grassland* category. A Tier 2 method is used to estimate emissions and removals for the shrubland (sub-forest) areas for live biomass and dead organic matter. Shrubland emissions are estimated for transitions of land between shrubs and grasses for the *grassland remaining grassland* sub-category.

These methods are described in Appendix 7.H. The methods for estimating CO₂ emissions and removals associated with fires are described in section 7.12.1.2.

Non-CO₂ 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* categories would lead to a false increase in emissions from the *forest land converted to grassland* category. Lands which are managed under a crop-pasture rotation are reported under *forest land converted to cropland*.

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

N₂O 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-CO₂ emissions from on-site burning associated with land conversion are estimated as described in section 7.12.1.3. Other non-CO₂ 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 $\pm 10\%$ for CO₂. 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 2008 Inventory

Australia has continued to implement annual updates of remote sensing data to identify the area of *forest land converted to cropland and grassland*. Australia's quality control processes have led to improved management data for the 2009 submission. There were no methodological changes implemented for the 2009 inventory submission for the cropland category.

Quality control processes for review of data, resulted in improved management data for the relative frequency of cropland and grassland management in northern NSW. This improvement increased the proportion of forest land conversion attributed to grasslands compared to croplands since 2001. This has resulted in a decrease in emissions from *forest land converted to cropland* and is balanced by an increase in emissions from *forest land converted to grassland*. Additionally, improved attribution of forest cover change where fire had also occurred resulted in an increase in the area identified as *forest land converted to cropland and grassland*. The combination of these changes resulted in an increase in the emissions estimate of 1989.6 Gg CO₂-e in 1990 and 4595.1 Gg CO₂-e in 2008 for *forest land converted to grassland*.

The estimates of emissions and removals from *grassland remaining grassland* have been subject to a small recalculation for the 2009 inventory submission. This recalculation is due to three data updates for 2009, including: the annual update of forest and shrub vegetation extent data which is used to spatially exclude areas that are considered to be woody vegetation; updated yield data for the 2009 submission; and, improved mapping of yields to a small area where yields were previously not estimated. These updates resulted in an increase of 3335.6 Gg CO₂-e to the 1990 sink and an decrease of 2647.9 Gg CO₂-e to the 2008 emissions.

The overall recalculation for *grasslands* is a decrease of 1346.1 Gg CO₂-e in the 1990 emissions estimate and an increase of 1947.2 Gg CO₂-e to the 2008 emissions estimate.

Table 7.10: 5.C Grasslands: recalculation of total CO₂-e emissions, 1990-2008

| | 2010 submission | 2011 submission | Change | |
|------|-------------------------|-------------------------|-------------------------|--------|
| | (Gg CO ₂ -e) | (Gg CO ₂ -e) | (Gg CO ₂ -e) | (%) |
| 1990 | 90860.52 | 89514.45 | -1346.07 | -1.48 |
| 2000 | 56635.42 | 49557.49 | -7077.93 | -12.50 |
| 2001 | 39993.21 | 46910.07 | 6916.86 | 17.30 |
| 2002 | 276180.27 | 273101.27 | -3079.00 | -1.11 |
| 2003 | 36397.74 | 40897.96 | 4500.22 | 12.36 |
| 2004 | -36605.36 | -36244.97 | 360.39 | -0.98 |
| 2005 | 178101.20 | 181899.10 | 3797.90 | 2.13 |
| 2006 | 121496.04 | 124011.75 | 2515.71 | 2.07 |
| 2007 | 313778.88 | 319144.56 | 5365.69 | 1.71 |
| 2008 | 188407.48 | 190354.68 | 1947.20 | 1.03 |

7.7.5 Source Specific Planned Improvements

A new grass growth model is being developed for integration with the existing inventory methods. The new crop growth model will be implemented when calibration, verification and quality assurance has been finalised. The model is also being further developed to include a non-CO₂ 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 in 2011 for Australia to undertake further method development using the data for application in future inventory submissions (see Appendix 7.H for details).

7.8 SOURCE CATEGORY 5D WETLAND

7.8.1 Methodology

7.8.1.1 Wetland Remaining Wetland

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

7.8.1.2 Land Converted to Wetland

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

7.9 SOURCE CATEGORY 5E SETTLEMENTS

7.9.1 Methodology

7.9.1.1 Settlements Remaining Settlements

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

7.9.1.2 Land Converted to Settlements

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

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

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

7.10 SOURCE CATEGORY 5F OTHER LANDS

7.10.1 Methodology

7.10.1.1 Other Lands Remaining Other Lands

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

7.10.1.2 Land Converted to Other Land

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

7.11 SOURCE CATEGORY 5G OTHER

7.11.1 Methodology

7.11.1.1 Harvested Wood Products

Australia reports the carbon stock changes and associated emissions and removals of CO₂ 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 N₂O Emissions from N Fertilisation 5(I)

Nitrous oxide emissions associated with nitrogen fertilisers are reported under the *agriculture* sector (4D). N₂O released from the application of N fertiliser on forests is reported as IE (agriculture). The amount of N applied to lands in Australia is obtained from national statistics of the amount of N purchased. It is not possible to split the use of N fertiliser between agriculture and forests.

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

7.11.1.3 N₂O Emissions from Drainage of Soils 5(II)

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

7.11.1.4 N₂O Emissions from Disturbance Associated with Land-Conversion to Cropland and Grassland 5(III)

An increase in N₂O 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 N₂O emissions from the process of nitrification and denitrification.

The IPCC (2003) methods are used to calculate N₂O 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 CO₂ Emissions from Agricultural Lime Application 5(IV)

Limestone and dolomite are used in Australia to ameliorate soil acidity, improve soil structure, and improve plant growth in *cropland* and *grassland* and to a very limited degree in *forest land*. Adding carbonates to soils in the form of lime (eg. calcic limestone (CaCO₃) or dolomite (CaMg(CO₃)₂) leads to CO₂ emissions as the carbonate reacts with acids in the soil to produce bicarbonate and eventually leading to the production of CO₂ and water.

For agricultural lime application, the annual emissions of CO₂ are calculated as:

$$E_{ijk} = ((M_{jk} \times \text{FracLime}_{jk} \times P_{k=1} \times EF_{k=1}) + (M_{jk} \times (1 - \text{FracLime}_{jk}) \times P_{k=2} \times EF_{k=2})) \times C_1 / 1000 \dots (5IV_1)$$

Where: E_{ijk} = annual emission of CO₂ 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_1 = 44/12 factor to convert elemental mass of CO₂ 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 2008 Inventory

As the emissions estimates for *forest land converted to cropland* and *grassland* have been recalculated, the estimate of N₂O emissions from disturbance associated with land-use conversion has also been subject to a small recalculation. The recalculation for *land converted to grassland* results in a minor decrease in the 1990 emissions estimate of 32.9 Gg CO₂-e and a 19.6Gg CO₂-e increase to the 2008emissions estimate.

There were minor revisions of the national Australian Forest and Wood Products Survey Statistics by the Australian Bureau of Agriculture and Resource Economics and Sciences. This produced a small decrease of 3.7 Gg CO₂-e to the 1990 sink estimate and a 22.5 Gg CO₂-e increase to the 2008 sink estimate.

Table 7.11: 5.G Other: recalculation of total CO₂-e emissions, 1990-2008

| | 2010 submission | 2011 submission | Change | |
|------|-------------------------|-------------------------|-------------------------|-------|
| | (Gg CO ₂ -e) | (Gg CO ₂ -e) | (Gg CO ₂ -e) | (%) |
| 1990 | -4324.94 | -4288.37 | 36.57 | -0.85 |
| 2000 | -3764.58 | -3746.53 | 18.05 | -0.48 |
| 2001 | -3285.50 | -3274.01 | 11.49 | -0.35 |
| 2002 | -3343.89 | -3330.51 | 13.37 | -0.40 |
| 2003 | -3650.52 | -3634.71 | 15.81 | -0.43 |
| 2004 | -3997.60 | -3979.70 | 17.90 | -0.45 |
| 2005 | -3955.50 | -3939.07 | 16.44 | -0.42 |
| 2006 | -3792.85 | -3783.11 | 9.74 | -0.26 |
| 2007 | -3348.84 | -3336.47 | 12.37 | -0.37 |
| 2008 | -3537.13 | -3540.06 | -2.93 | 0.08 |

7.11.6 Source Specific Planned Improvements

All data and methodologies are kept under review and development. Appendix 7.A specifies the detailed development plans for the National 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 as a result of both anthropogenic and wildfires. Anthropogenic burning is carried out for a variety of reasons including fuel reduction for the prevention of uncontrollable wildfires, and traditional Aboriginal burning. These anthropogenic fires influence natural fire regimes and may ameliorate the frequency and intensity of wildfires that would occur naturally otherwise, albeit with differing frequency and at other times of the year. Climatic variability contributes large year-to-year variations in biomass burning in Australia.

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

$$M_{jk} = A_{jk} \times FL_{jk} \times Z_{jk} \times 10^{-3} \dots\dots\dots (5V_1)$$

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

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

FL_{jk} = fuel loading (dry weight) (Mg ha⁻¹) (Table 7.12 and Table 7.13),

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

then for CH₄, CO and NMVOCs the total annual emissions are calculated as:

$$E_{ijk} = M_{jk} \times CC_{jk} \times EF_{ijk} \times C_i \dots\dots\dots (5V_2)$$

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 7.15),

EF_{ijk} = emission factor for gas i from vegetation (Table 7.16),

C_i = factor to convert from elemental mass of gas species i to molecular mass (Table 7.17),

and total annual emissions for NO_x and N_2O are:

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

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 7.15)
 NC_{jk} = nitrogen to carbon ratio in biomass (Table 7.15)
 E_{ij} = emission factor for gas i from vegetation (Table 7.16)
 C_i = factor to convert from elemental mass of gas species i to molecular mass (Table 7.17)

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

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

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

Table 7.13: Fuel load for Wildfires in Australia (Mg dry matter ha^{-1})

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

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

Table 7.14: Burning efficiencies for Prescribed Burning and Wildfires in Australia

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

Tolhurst (1994)

Table 7.15: 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 7.16: Mean emissions factors for carbon and nitrogen trace gases from forest biomass burning

| Gas species <i>i</i> | | Emission factor E_{ijk} (Gg element in species/Gg element in fuel burnt) |
|----------------------|------------------|---|
| 1. | CH ₄ | 0.0054 |
| 2. | N ₂ O | 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 7.17: Elemental to molecular mass conversion factor (C_i)

| CH ₄ | N ₂ O | NO _x | CO | NMVOC |
|-----------------|------------------|-----------------|------|-------|
| 1.33 | 1.57 | 3.29 | 2.33 | 1.17 |

Slash Burning

The CO₂ emissions associated with slash burning in *harvested native forests* are estimated by the NCAS and as such CO₂ 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-CO₂ gas emissions associated with slash burning.

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

The algorithms for total annual emissions of CH₄, CO and NMVOCs are:

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

and for total annual emissions for NO_x and N₂O are:

$$E_{ijk} = FC_{jk} * NC_{jk} * EF_{ijk} * C_i \dots\dots\dots (5V_7)$$

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 7.16),
 NC_{jk} = nitrogen to carbon ratio in biomass (Table 7.15)
 C_i = factor to convert from elemental mass of gas species *i* to molecular mass (Table 7.17).

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

The CO₂ emissions and removals associated with the burning and subsequent regrowth of savannas and temperate grasslands are reported under 5.C.1 *grassland remaining grassland* and thus are not reported under 5(V) *biomass burning* to ensure no double counting occurs. The description of the method used to estimate these emissions and removals is provided in Appendix 7.H.

Non-CO₂ emissions are reported under 4.E *prescribed burning of savannas* in the *agriculture* sector.

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

Carbon dioxide emissions from on-site burning associated with land conversion are 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-CO₂ 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 CH₄, CO and NMVOCs are:

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

and for total annual emissions for NO_x and N₂O are:

$$E_{ijk} = FC_{jk} * NC_{jk} * EF_{ijk} * C_i \dots\dots\dots (5V_9)$$

Where: FC_{jk} = annual fuel carbon burnt in land conversion (Gg),
 EF_{ijk} = emission factor for gas *i* from vegetation (Table 7.16),
 NC_{jk} = nitrogen to carbon ratio in biomass (Table 7.15)
 C_i = factor to convert from elemental mass of gas species *i* to molecular mass (Table 7.17).

7.12.2 Uncertainties and Time Series Consistency

Uncertainties for biomass burning emissions of CH₄ and N₂O were estimated to be in the order of -45 to +93% for forest land, and ±20% for forest conversion categories. The narrower uncertainty range for forest conversion categories is due to the more accurate fuel load estimates 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 CH₄ 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 CH₄ emissions between vegetation types it was considered that the Australian measurement data would provide the most accurate estimate of CH₄ emissions.

The IPCC defaults for CH₄ 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 2008 Inventory

As with the 2008 inventory submission Australia has adopted the advice of the UNFCCC Expert Review Team and continues to report biomass burning as annual emissions.

Small recalculations to the *forest land remaining forest land* biomass burning emissions have resulted in a small decrease of 72.6 Gg CO₂-e to the 1990 emissions estimate and 37.7 Gg CO₂-e decrease in the 2009 emissions 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 increase of 47.6 Gg CO₂-e to the 1990 emissions estimate and a 133.3 Gg CO₂-e increase to the 2008 emissions estimate.

Table 7.18: 5V Biomass Burning: recalculation of total CO₂-e emissions, 1990-2008

| | 2010 submission | 2011 submission | Change | |
|------|-------------------------|-------------------------|-------------------------|-------|
| | (Gg CO ₂ -e) | (Gg CO ₂ -e) | (Gg CO ₂ -e) | (%) |
| 1990 | 6206.86 | 6181.89 | -24.97 | -0.40 |
| 2000 | 3810.04 | 3641.52 | -168.52 | -4.42 |
| 2001 | 5091.15 | 5165.97 | 74.82 | 1.47 |
| 2002 | 6335.70 | 6251.67 | -84.03 | -1.33 |
| 2003 | 14158.67 | 14178.74 | 20.07 | 0.14 |
| 2004 | 4061.34 | 4078.38 | 17.04 | 0.42 |
| 2005 | 5254.27 | 5327.80 | 73.53 | 1.40 |
| 2006 | 4711.30 | 4812.36 | 101.06 | 2.14 |
| 2007 | 8071.80 | 8164.75 | 92.96 | 1.15 |
| 2008 | 4249.18 | 4344.93 | 95.75 | 2.25 |

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 CH₄ 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 (CO₂, CH₄ and N₂O), 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 estimation 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

empirically constrained 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 based 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 development of 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 nineteen time epochs from 1972 to 2010 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 change¹ 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:

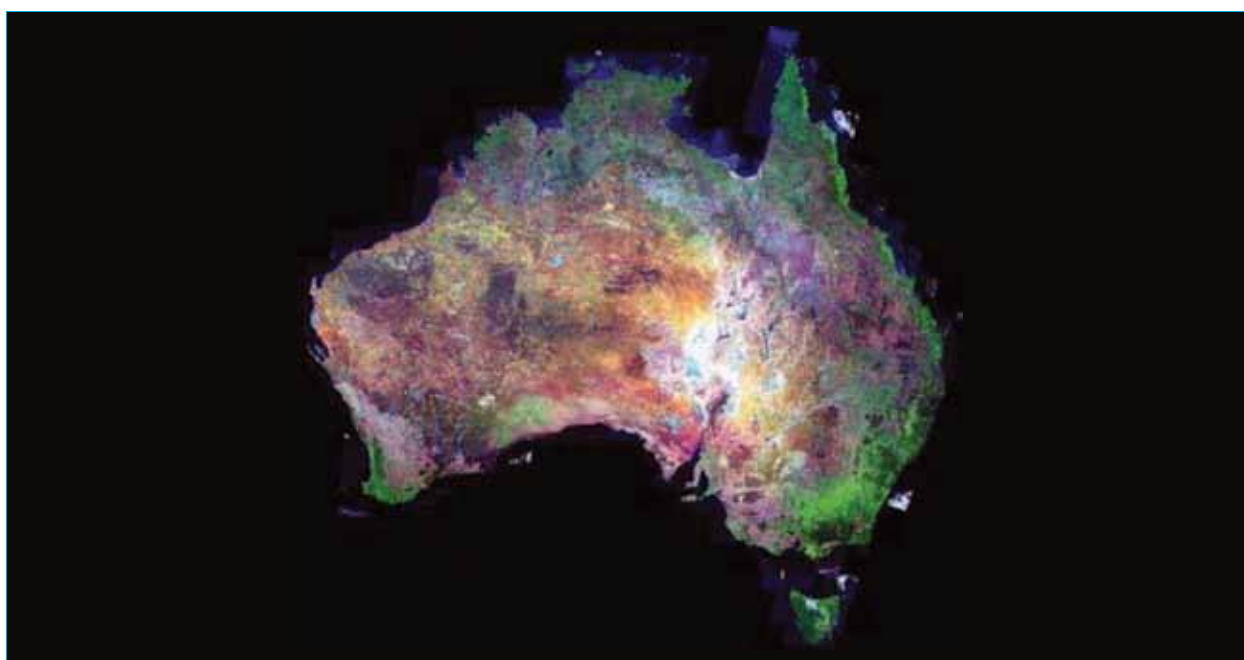
- Air photographs: The air photograph archive is not uniformly adequate and available across Australia. Also, the use of air photographs presented an excessively intensive analytic task due to the largely manual interpretation required. However, the archive of available air photographs provides a high-resolution 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).

¹ Land Cover Change refers to a change from forest to non-forest (or vice-versa) vegetation cover.

The use of Landsat data to analyse land cover change through time at a fine pixel resolution required a consistent geographically registered² and spectrally calibrated³ reference base (Figure 7.A1). Also, standard specifications for processing and interpretation (including attribution⁴) 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 introducing false land cover change 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



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;
- mosaicing⁵ of registered and calibrated images to the single map tiles for each time sequence (Figure 7.A3);
- sun-angle (terrain illumination) correction;
- thresholding⁶ through all time sequences; and,
- attribution of change to direct human-induced change.

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.

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.

Figure 7.A2: Land Cover Change Program conceptual framework

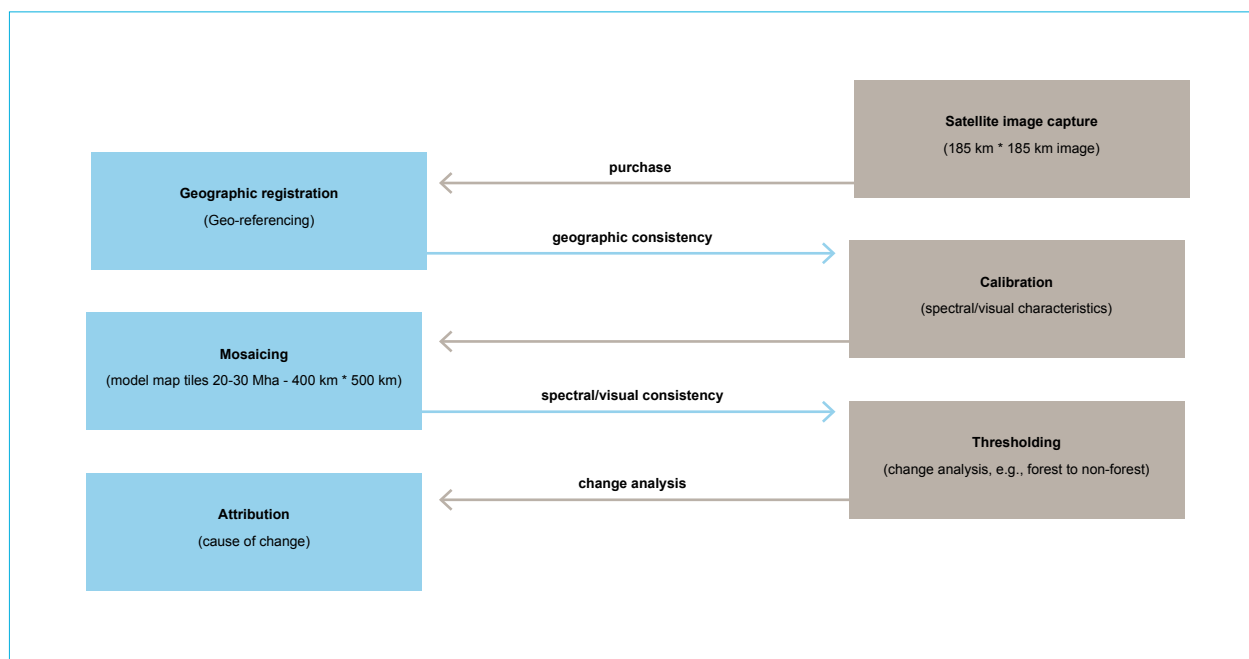
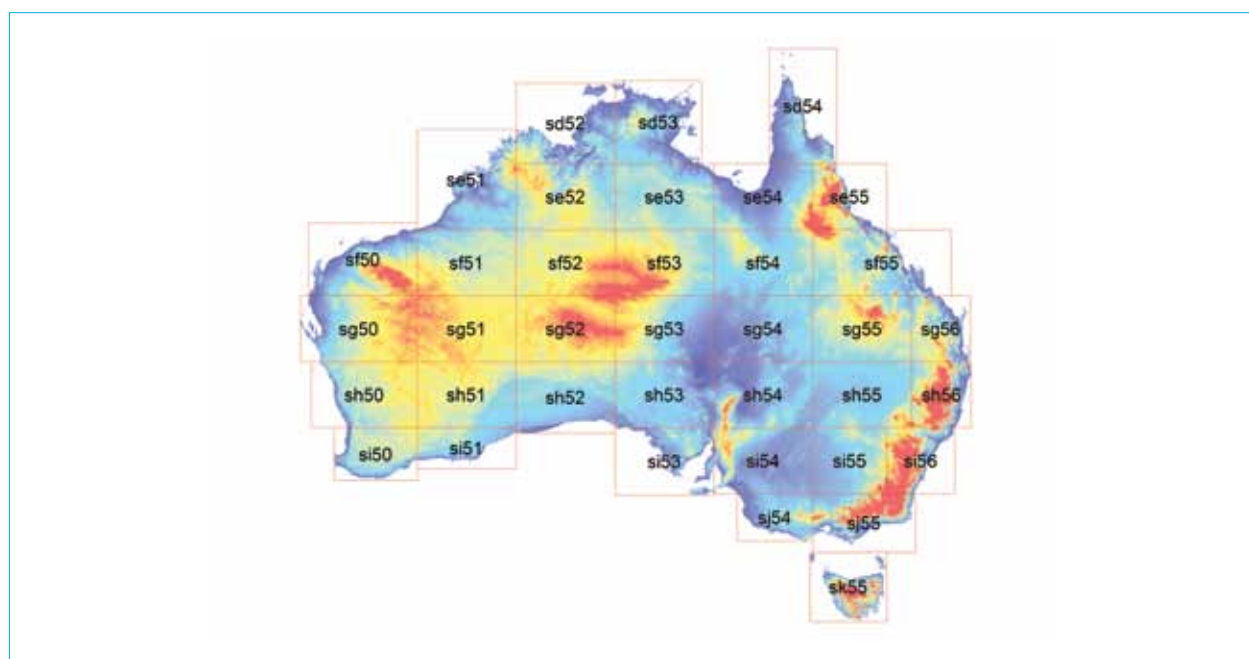


Figure 7.A3: The 37 1:1 million scale map tiles used in the NCAS program



7.A.2.3 Program implementation

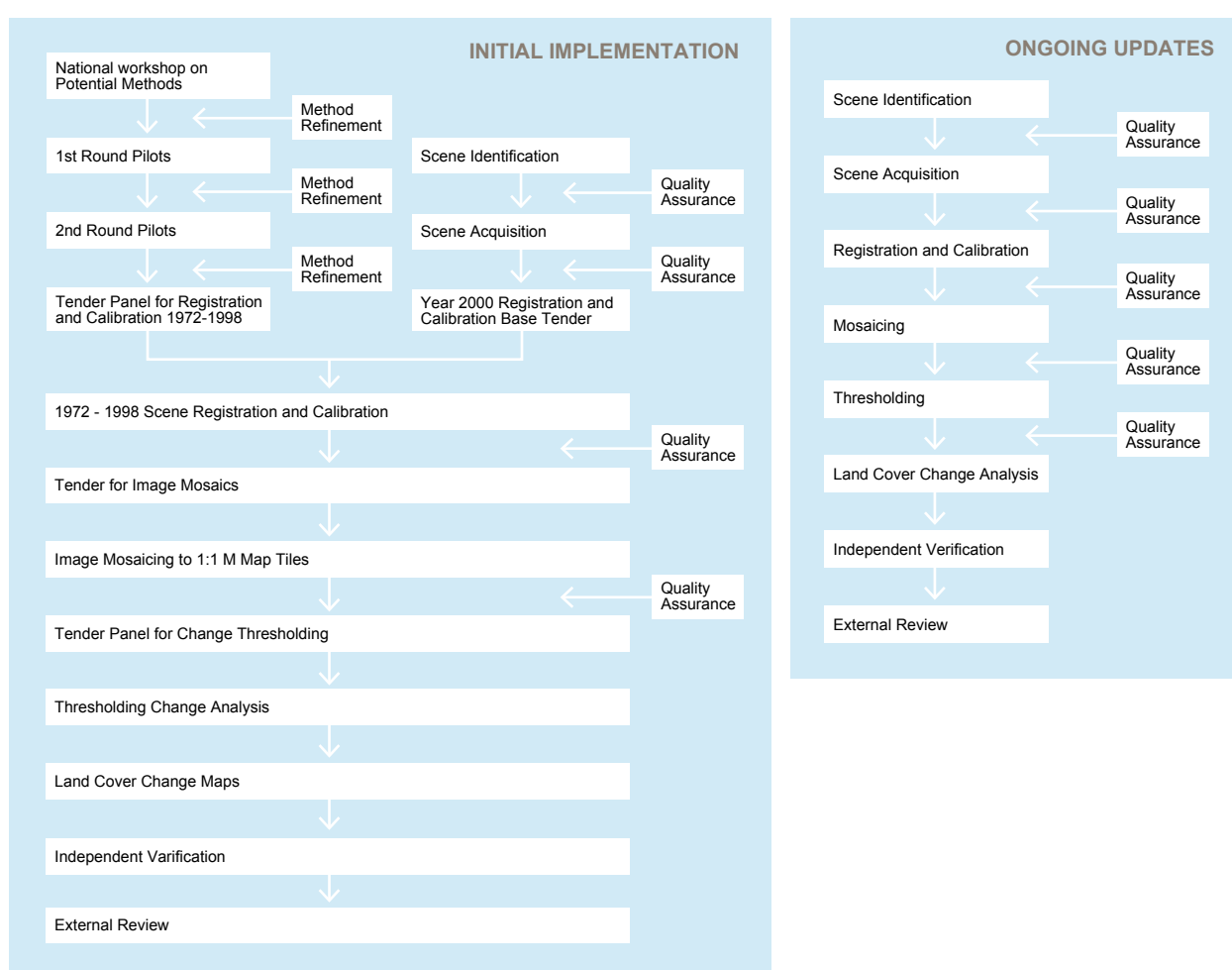
Pilot tests were used to train and develop industry capacity, refine methods and software and to develop logistical systems to maximise both output and opportunity for progressive quality assurance and quality control (QA/QC). The results of the pilot studies are published in Furby and Woodgate (2002).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

The approach to program administration provides for centralised progress monitoring and QA/QC at each stage in the processing of the Landsat data. Figure 7.A4 outlines the program stages and their sequence. Each processing stage is a regionally defined package of work based on 37 1:1,000,000 (1:1 M) map tiles of Australia (Figure 7.A3). The finalised program approach maximised quality assurance opportunities,

expanded the use of competitive service acquisition and enhanced information flow. A set of 19 national coverages of Landsat data have been compiled at intervals between 1972 and 2010. The sequence of images shown in Table 7.A1 was designed to give maximum temporal resolution immediately before and after 1990, so as to achieve the best possible accuracy of emissions in 1990. The return to annual acquisition of data from 2004 onwards allows for the best possible accuracy for every year in the first Kyoto commitment period (2008-2012).

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 x 185 km Landsat images processed for this project are summarised in Table 7.A1. The image selection criteria (Furby, 2002) require the images to be within three months of the nominated target date. The target dates vary between the north (winter or dry season) and south (summer) of the country and aim to provide the best possible forest discrimination. The precise date allocated to each land cover change (clearing and regrowth) pixel is randomly generated by 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 |
| 2010 | 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’ (CPN⁷) 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.

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.

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.

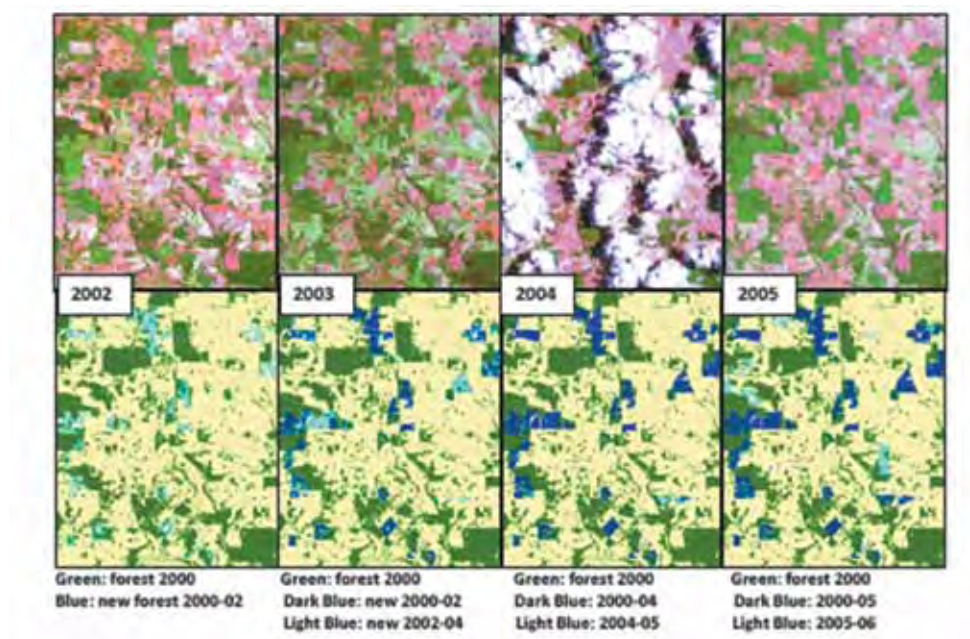
Conditional Probability Network

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).

Figure 7.A5: Images of forest extent and change from NCAS CPN 2002-2004: area – 16 x 20 km



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

Forest extent and change analysis

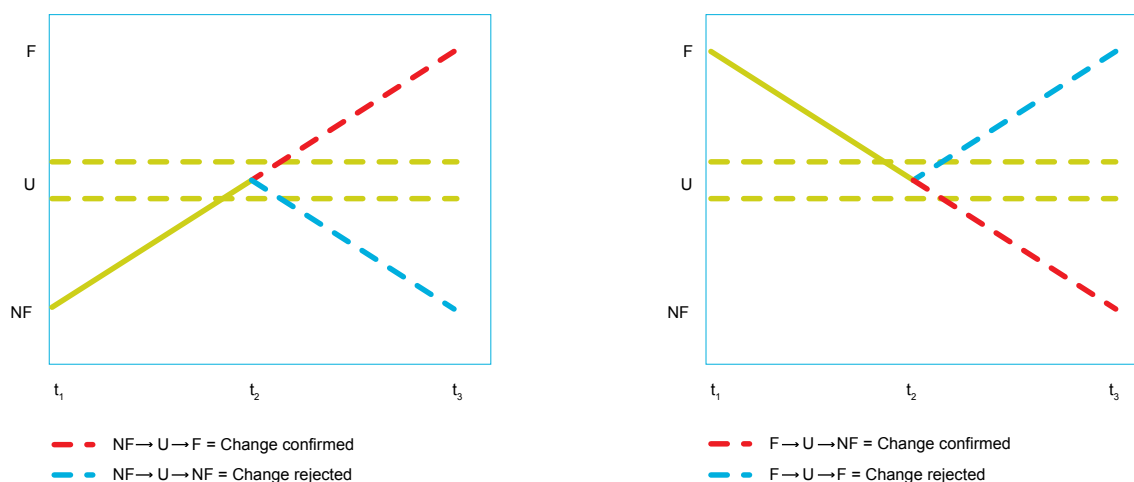
Once the change in forest cover status has been determined for each pixel for a point in time, the spatial relationship of each change pixel to other surrounding or nearby change pixels is assessed to identify isolated pixels with forest cover that do not form part of a forest system. This allows for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

The area of land cover change is determined as the sum of the changed pixels through time (See for example Figure 7.A7). 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 in the certainty of identifying forest cover change is provided by the use of a three class determination of forest cover: non-forest, forest and uncertain forest. Pixels identified as uncertain forest have a lower probability of being forest, and unless confirmed as forest after the CPN application, are determined as non-forest. The same applies to non-forest determination. This will typically yield lower (more certain and conservative) cover change statistics than more common analytic methods using

only a two-class (forest, non-forest) analytic procedure. Therefore, the last step 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.

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



7.A.2.4 Attribution of Change

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

Loss of forest cover due to factors other than a change in land use are initially identified through the application of both the fire masks developed during the image processing, and tenure masks to define areas of public forest management. Subsequently, land cover change due to 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;
- salinity;
- drought and growth flushes; and,
- terrain illumination.

7.A.2.5 Plantation typing

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

7.A.2.6 Quality Assurance and Quality Control

Full documentation of the quality assurance and quality control processes, calibration, verification and sensitivity analysis for the development and implementation of Australia's National 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.A7) (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).

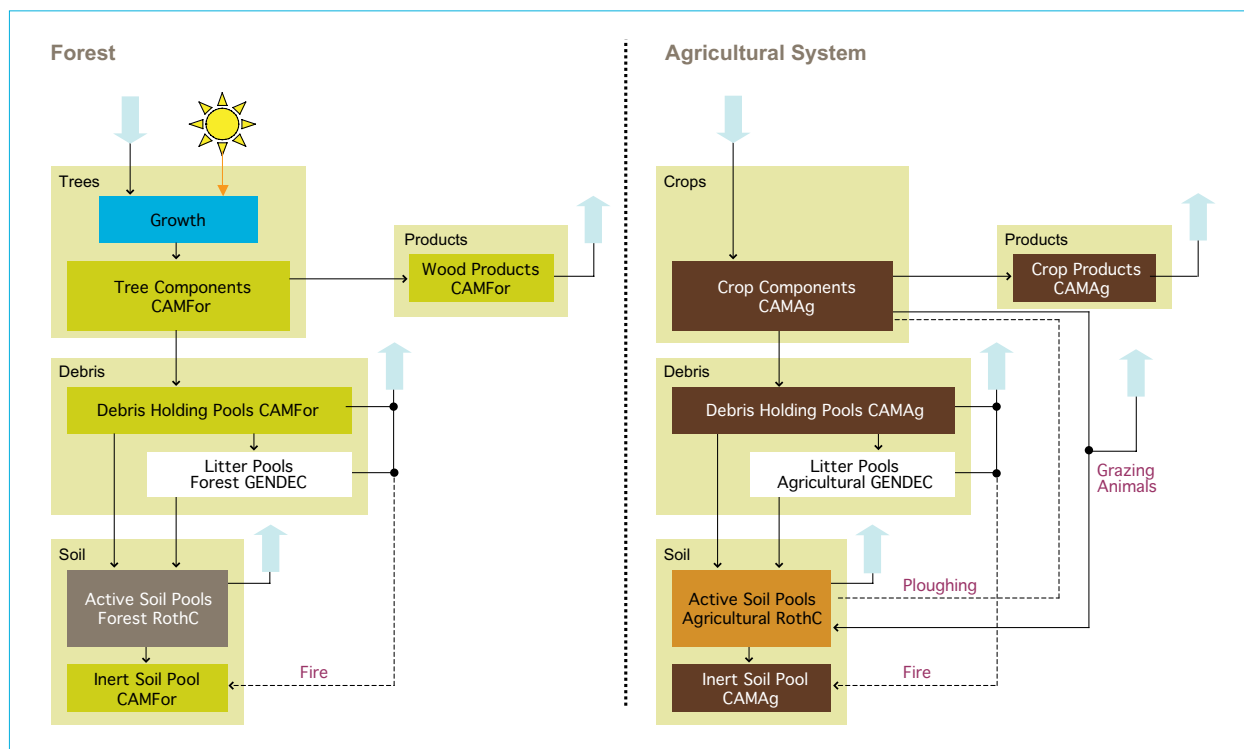
These models have been independently developed for the various purposes of predicting:

- 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.A7: 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.

Forest Productivity Index

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

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

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

CAMFor

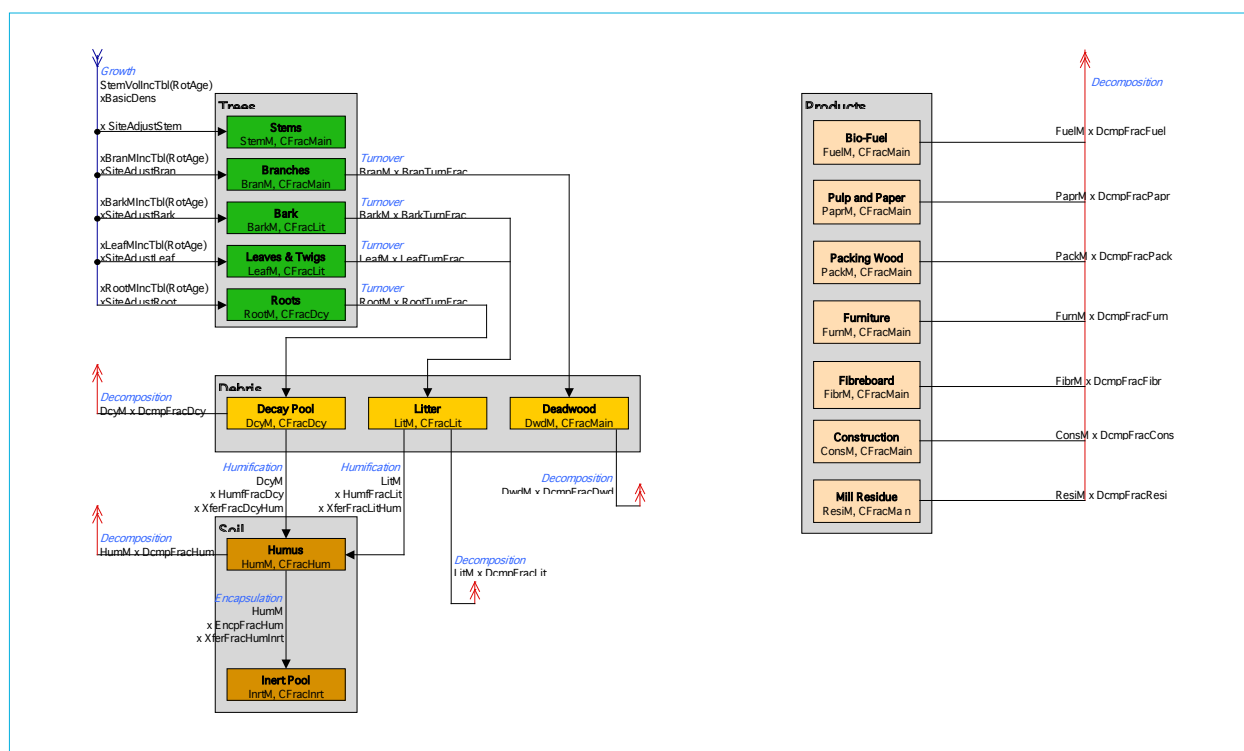
CAMFor (Carbon Accounting Model for Forests) (Richards and Evans, 2000a) was developed within the NCAS to provide capacity for both project and continental scale accounting (Figure 7.A8). *CAMFor* primarily focused on carbon sequestration in forests using basic species information and standard forestry yield tables entered by the user, with limited debris and soil carbon modelling capabilities. *CAMFor* has its origins in the 1990 CO₂ 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 adsorption 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:

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

Figure 7.A8: The CAMFor model pool structure



CAMAg

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

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

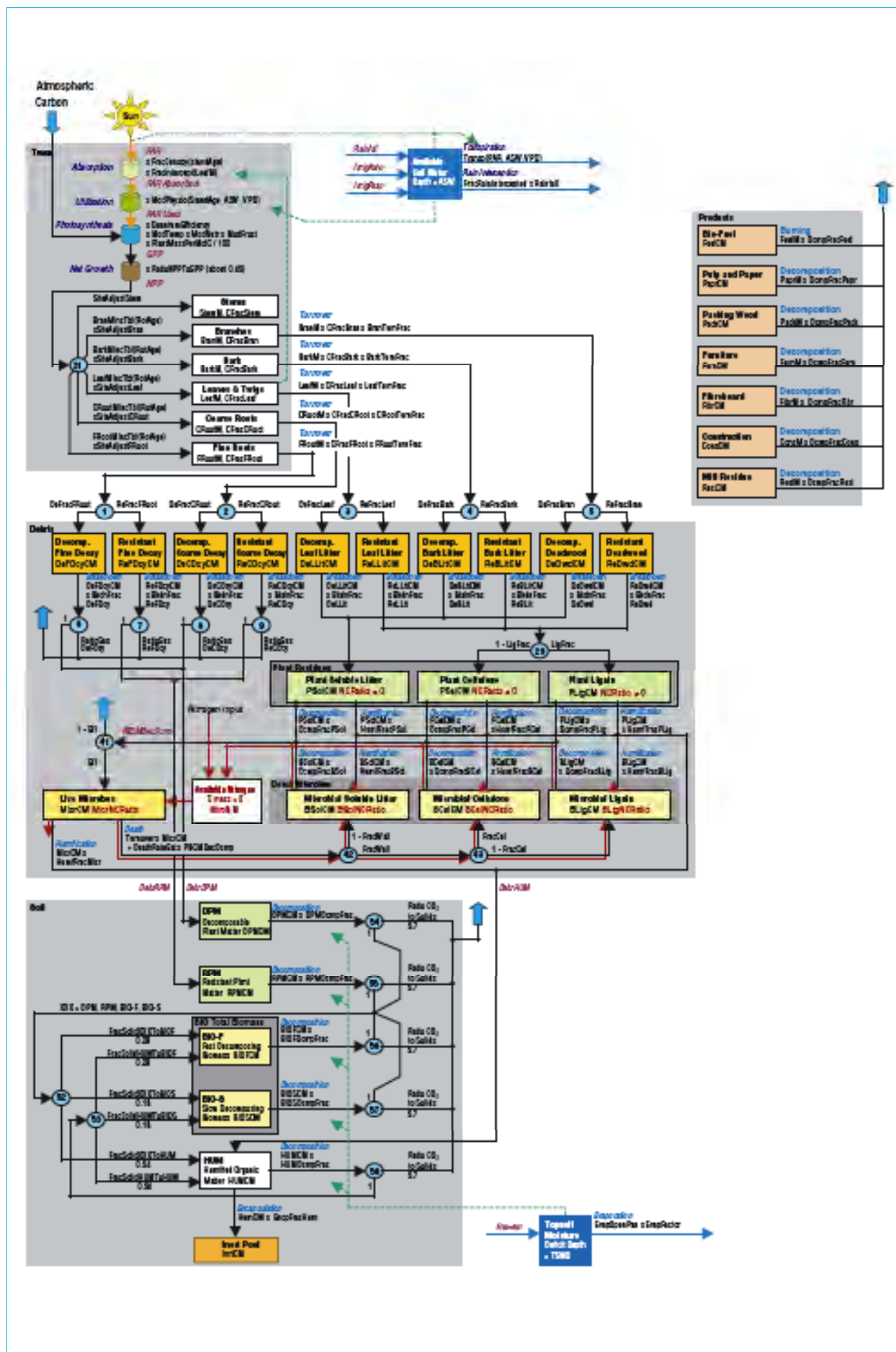
The integration into a single compendium model was initially undertaken in Excel as a test version. The prototype forest model derived, *GRC3* (Richards and Evans, 2000c) (Figure 7.A9), was subsequently tested by CSIRO (Paul *et al.*, 2002a). Several independent studies to test and calibrate the model 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. *FullCAM* 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 was in the order of \$9M AUS, including the cost of data collection and developing process understanding for model calibration to prepare and complete the model for initial national application. 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 are reported in Appendix 7.J.

Figure 7.A9: The forest ‘side’ of the *FullCAM* model



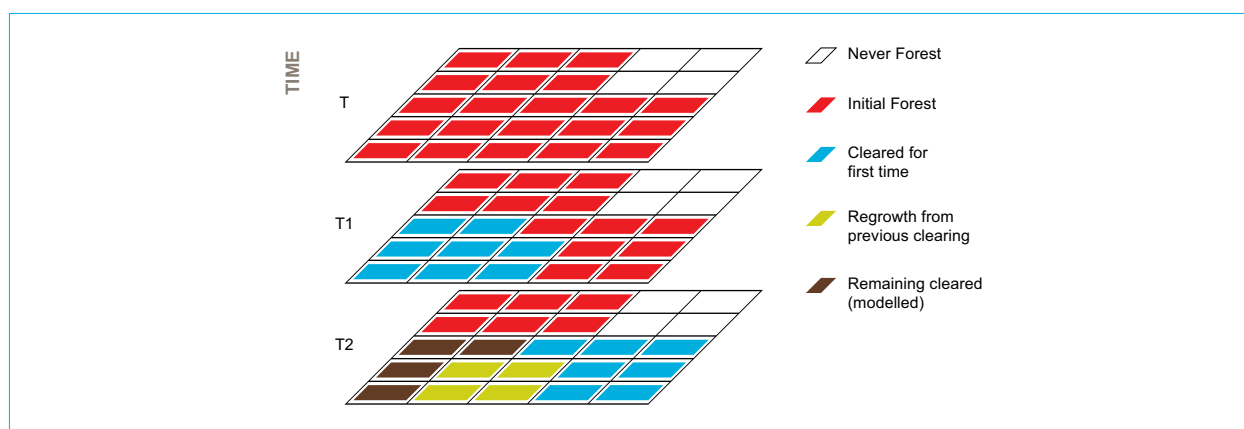
7.A.3.4 Spatial application of *FullCAM*

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

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 256 million pixels that are each individually modelled in *FullCAM* as part of the *Forest Land converted to Cropland* and *Forest Land converted to Grassland* categories. The Approach 3, spatially explicit modelling method applied by the NCAS is shown in Figure 7.A10. 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 as shown in Figure 7.A10.

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.A10: 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.

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

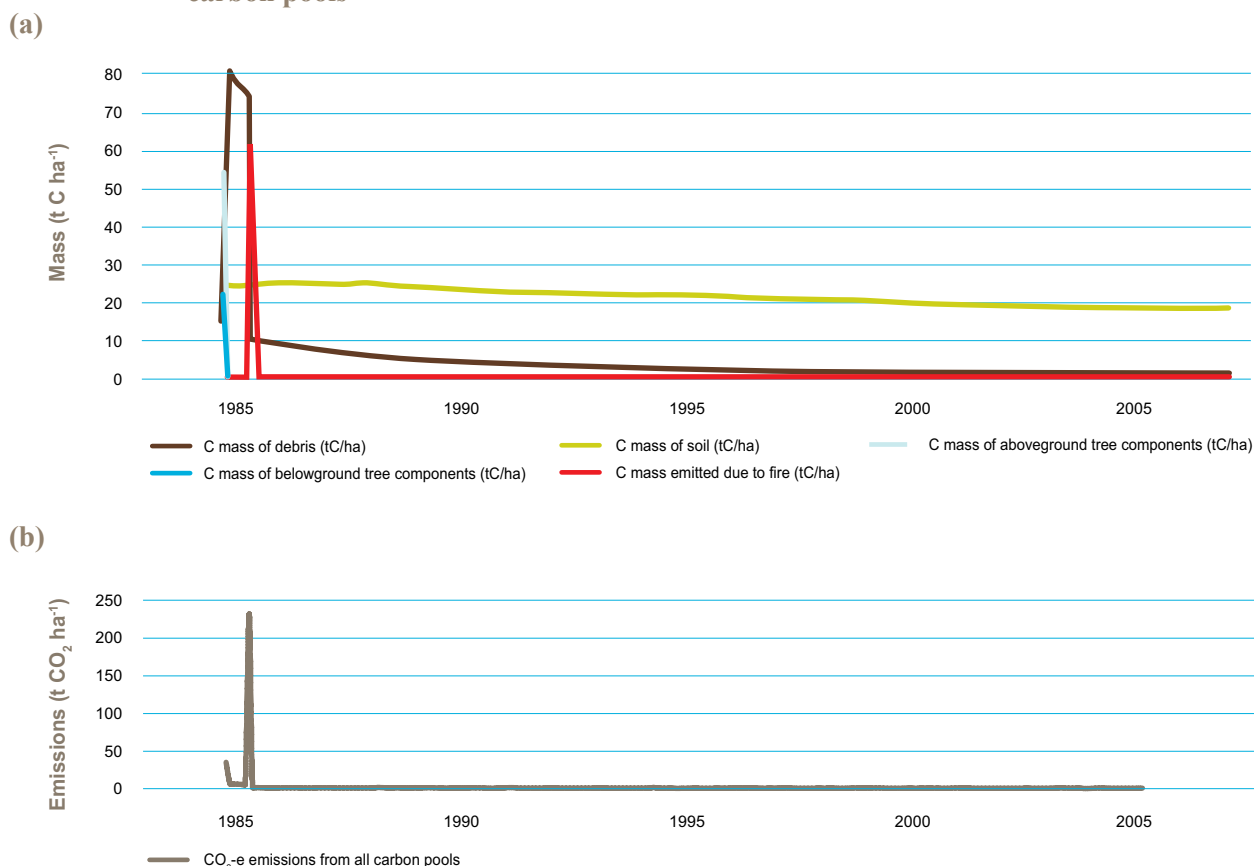
Accounting for lagged emissions

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

As 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.A11 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.A11: *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 CO₂-e ha⁻¹) from all carbon pools

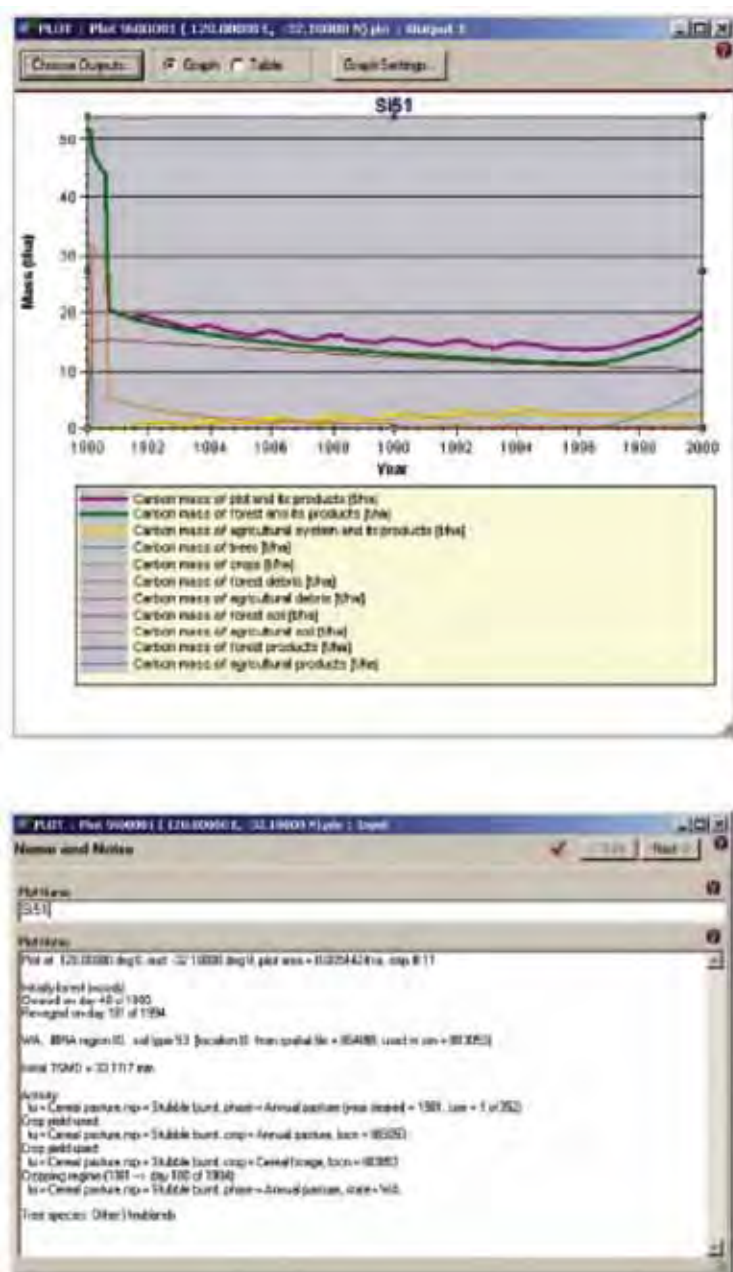


7.A.3.5 Model Outputs

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.

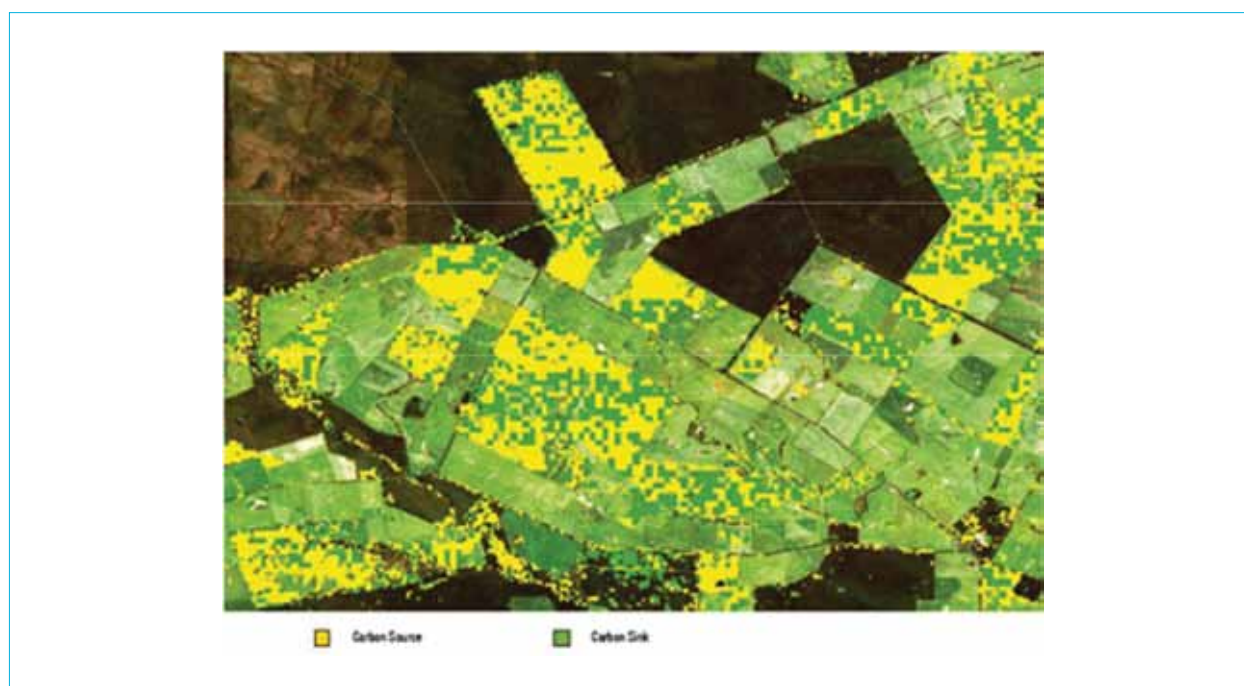
There are three general types of outputs from *FullCAM*: point-based, tabular (from spatial analyses) and spatial (grids). As well as being able to operate independently as a point-based model, *FullCAM* can be applied spatially (Figure 7.A12) to generate point-based models (Figure 7.A14) from the spatial surfaces to produce files at a user specified frequency. These are used for verification of the spatial model implementation.

Figure 7.A12: 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.

Figure 7.A13: Spatial carbon stock change output (100 m grids)



Note: Each 100 m grid has a unique carbon stock change value. The spatial array of source and sink values generally represents the 'proportions' of agricultural practices applied by random allocation and the history of land use and land use change for the pixel.

Tabular results from *FullCAM* include:

- summaries of input data across the spatial surface, e.g., the areas of land cover change (clearing, regrowth, re-clearing⁸) each year;
- carbon outputs including 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, including 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 compiled from the results of each 25 m pixel being modelled. This produces a 'map' of the output of interest for a point in time (Figure 7.A13). 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.

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.

7.A.3.6 Model coherence and validation

As previously noted, the fundamental analytic unit of the NCAS model is the pixel, (25 m x 25 m) of which there are approximately 256 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 land converted sub-categories (*forest land converted to cropland and grassland* and (the implied emissions factor or; IEF) will not reflect any individual, or cluster of individual pixels. As the number of pixels active in land converted sub-categories accumulates over time, the IEFs for each of the accounts for each year will reflect a mix of area change and change in pixel output. The change in pixel output is also strongly affected by the amount of time since the land was cleared and climate variability. As there are multiple variable factors, the implied emissions factors from the overall inventory cannot be used to test the model's coherence as the model processes can no longer be observed in anything like their original analytic unit.

Testing for coherence in a Tier 3 (Approach 3) model-based pixel by pixel inventory method requires very different techniques to those applied to checks on trends and emissions factors in Tier 1 and Tier 2 models. Tests of model coherence and validation can only be meaningfully undertaken at the pixel level. This is the approach taken and is consistent with the good practice recommendations of the *2006 IPCC Guidelines*. As the robustness of the national account simply flows from the correct summing of the outputs of the individual pixels, testing the results at the individual pixel scale will validate the national results. Therefore, programs to test model cohesion operate in two realms. The first is coherence testing by time series to validate model calibrations and verify the results at the pixel level. The second is quality control to ensure robust summation of the pixels to an aggregate national account.

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

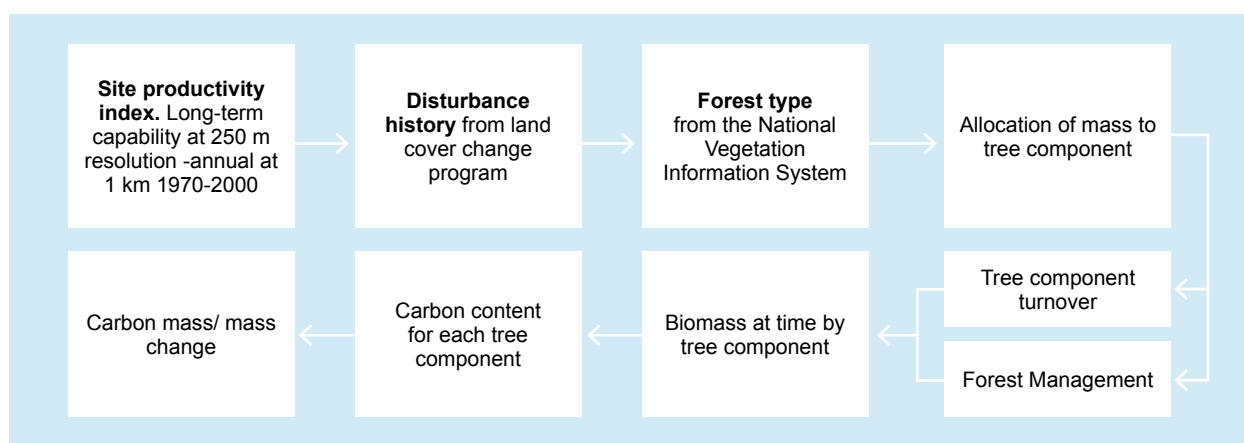
One key part of the NCAS is the ability to estimate the carbon stocks of mature forests and the rates of carbon accumulation in any forest regrowth, inclusive of both spatial and temporal variability. At the start of the NCAS program there was no comprehensive growth data or growth modelling capability (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 and parameters constrains the model within known ranges (Figure 7.A14). It is the empirical data that constrains the model to reflect extensive field data (both existing and specifically collected).

To derive the spatial and temporal patterns of forest growth the simplified form of the 3-PG model (Landsberg and Waring, 1997; Coops *et al.*, 1998; Coops *et al.*, 2001) was used to provide relative indices of growth potential (productivity indices⁹) at a 1 km grid scale on a monthly basis since 1970. The site-based, multi-temporal productivity indices are used to support a generalised empirical growth model. All modelling is done on the basis of aboveground biomass with subsequent factors to account for belowground (fine and coarse root) material.

Figure 7.A14: 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. This provides a site index of plant productivity that is independent of the type of forest present. The essence of the model is the calculation of the amount of photosynthetically active radiation absorbed by plant canopies (APAR). APAR is calculated (Equation 1) as half the amount of short-wave (global) incoming radiation (SWRadn) absorbed by plant canopies.

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

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 $(NDVI \times 1.0611) + 0.3431$. APAR is multiplied by a factor that converts it to biomass.

This, in effect, amalgamates two steps, the conversion of absorbed CO₂ 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).

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

There is substantial variation in ϵ values, but no clear pattern in relation to plant type, so a value of $1.25 \text{ gm Biomass MJ}^{-1}$ 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 limitation). Modifiers used in this way are discussed by Landsberg (1986), McMurtrie *et al.*, (1992) and Landsberg and Waring (1997).

The modifying factors are:

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

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

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

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):

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

$$\text{Transpiration} = \text{EqEvapn}_j \times \text{SWmod}_{j-1} \dots\dots\dots (4)$$

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

$$\text{SoilWaterContent}_j = \text{SoilWaterContent}_{j-1} + \text{WaterBal}_j \dots\dots\dots (6)$$

Initial Soil Water Content was taken as $0.75 \times \text{SWcapacity}$. Soil Water Content carries over from one time step to the next. The soil moisture calculation sequence was run for 3 years, after which Soil Water Content had essentially equilibrated to stable monthly values. Soil Water Content values in year 3 were therefore used in the analysis. The soil water modifier (*Swmod*, Equation 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).

$$\text{MoistRatio} = \text{SoilWaterContent} / \text{SWcapacity} \dots\dots\dots (7)$$

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

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 $VPD_{mod} < SW_{mod}$) then soil water is not a limiting factor, even if soil water content is relatively low. The converse applies, that is, if $SW_{mod} < VPD_{mod}$, soil water is the limiting factor.

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

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

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

Equation (9) gives a hyperbolic response curve, with $T_{mod} = 0$ when $T_{av} = T_{min}$ or T_{max} . T_{min} is set to $\frac{1}{2}$ 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 $\frac{1}{2}$ the minimum temperature of the coldest month if the minimum temperature of the coldest month is less than 0°C). T_{max} is set to 5°C above the maximum temperature of the hottest month of the year and T_{opt} as equal to the average of T_{min} and T_{max} . Consequently, T_{mod} generally had relatively small effects on the calculation of NPP.

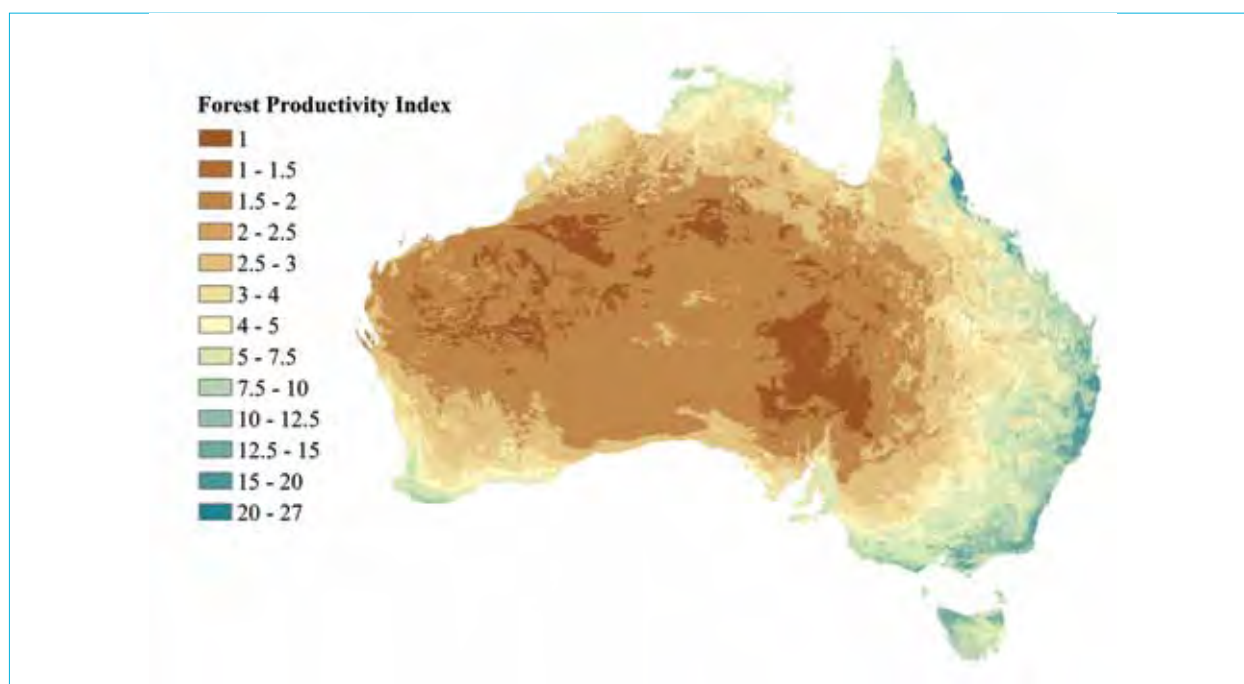
A frost modifier is included, using the simple assumption that frost temporarily inactivates the photosynthetic mechanism in foliage, so there is no growth on a frost day. The modifier is, therefore, simply the ratio of number of frost days/month to the number of days in the month.

Calculation of the Forest Productivity Index

The Forest Productivity Index (FPI) is calculated both temporally and spatially using the monthly (since 1968) 1km grid climate and site information described in section 7.A.6. A further 250 m long-term average FPI is also calculated, using a slope and aspect corrected APAR calculation (Figure 7.A15).

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

Figure 7.A15: 250 m slope and aspect corrected productivity index map



7.A.4.2 Initial assumed biomass

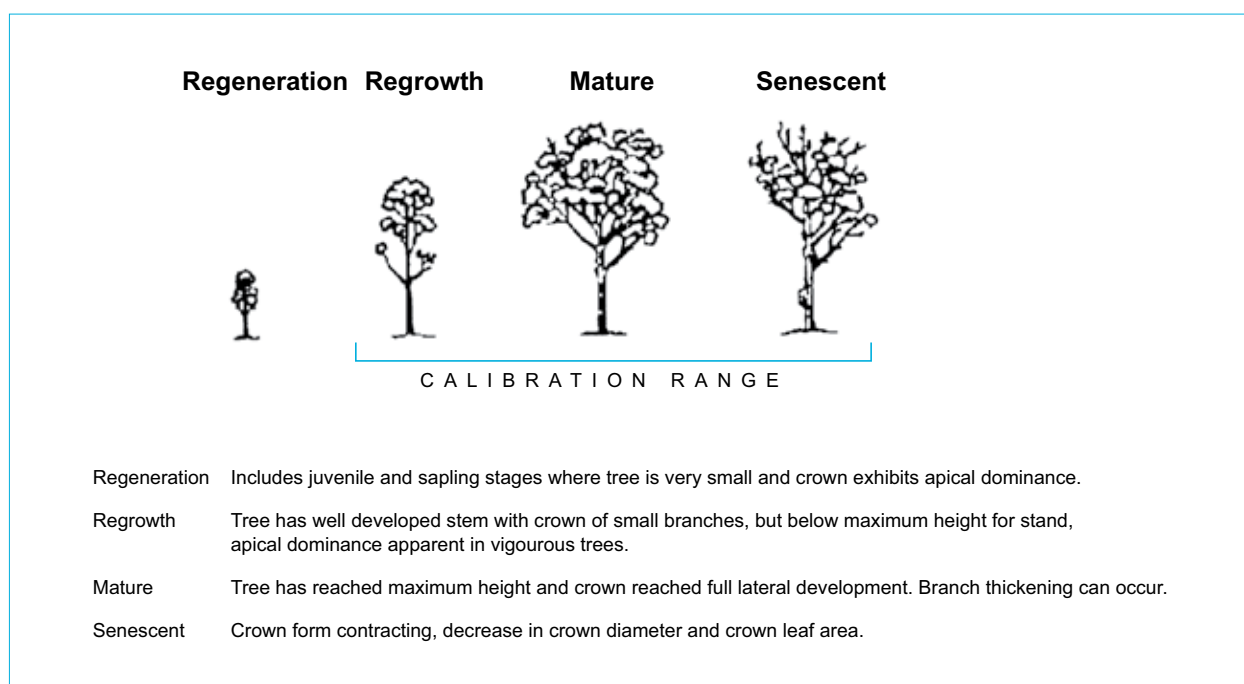
Calibration

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.A16) 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.A16: Diagram showing the range of data used in the calibration of the model.



Source: Base image and text from Florence (1996)

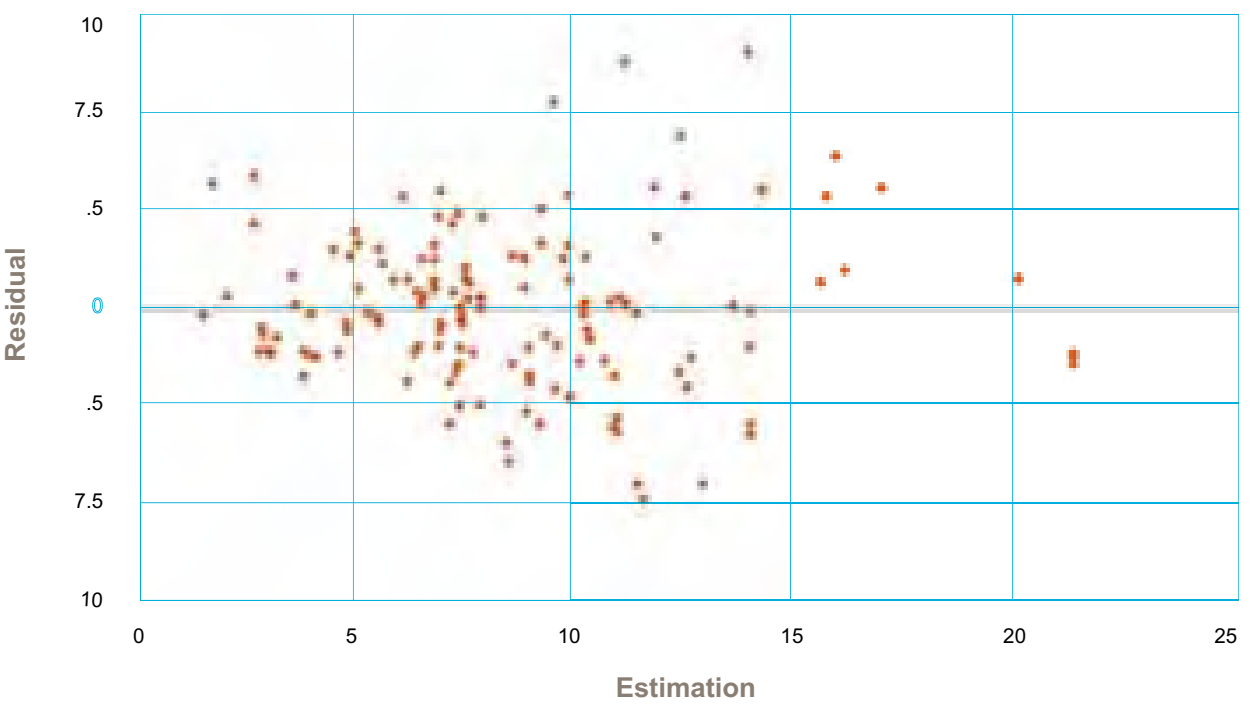
In the collection of the calibration plot data, caution was exercised to exclude forest ‘gaps’ contained in some field measurements. Plots taken as part of fixed-grid or transect systems could potentially fall in gaps in sparse forests. As the remote sensing program at 25 m resolution is capable of separating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

To determine the initial forest biomass for an individual forest site the geo-referenced calibration data set was fitted to the productivity map. The red line in Figure 7.A17 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.A17).

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

Figure 7.A17: The assumed initial biomass relationship

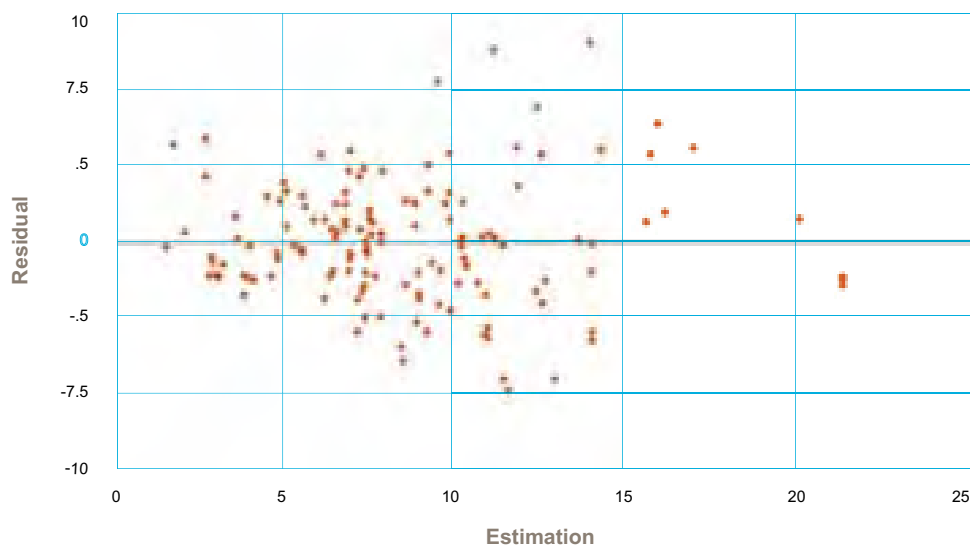


The goodness of fit of Equation (10) ($r^2 = 0.68$, $p < 0.01$) to the measured data confirms that a robust relationship exists between the productivity mapping and measured aboveground biomass estimates. The outer 95% confidence limits (outer pair of dotted lines) show the reliability for predicting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

The initial assumed biomass at a chosen resolution for the entire continent can then be calculated by applying Equation (10) to the FPI mapping. 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.A18) 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.A18: 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 regrow

Key Terms used in the biomass model

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

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

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

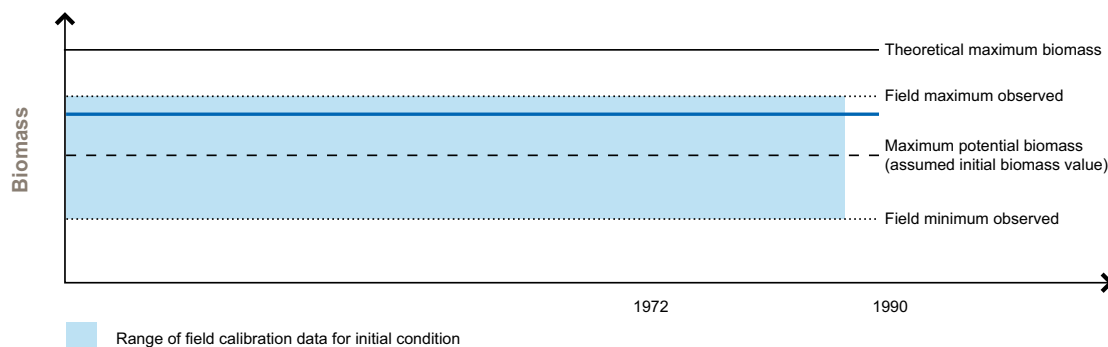
Validation data – data that are independent from the calibration data, and is used to test models built on the calibration data.

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

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

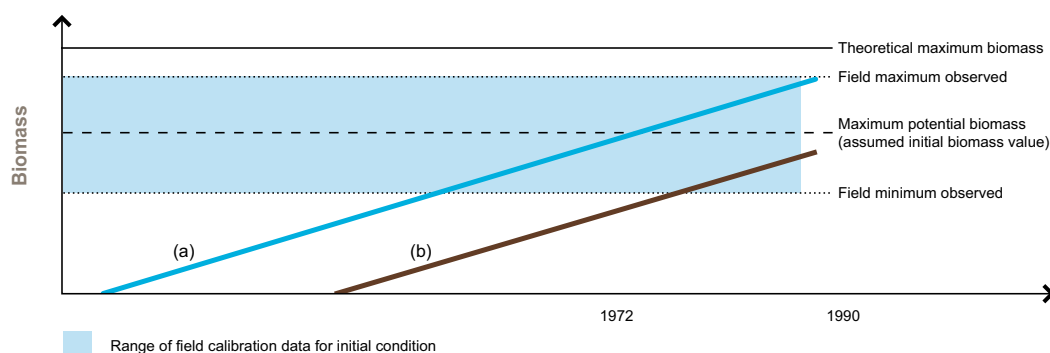
Figures 7.A19 (a) to (c) (below) show the relationship between the model's assumed initial biomass and the likely biomass in each of the three historical disturbance cases. In Case 1 (Figure 7.A19 (a)) the forest site was undisturbed prior to 1972, (as represented by the continuous blue line) and remains 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.A19: (a) Biomass of forest undisturbed prior to 1972



In Case 2 (Figure 7.A19 (b)), the forest area was cleared at some time prior to 1972, but was not cleared between 1972 and 2008 and at the time of clearing the forest was still growing. For the majority of forests in this case, the biomass in 1990 will have recovered to be within the range of observed values used in the model calibration but may not have reached the assumed initial biomass value.

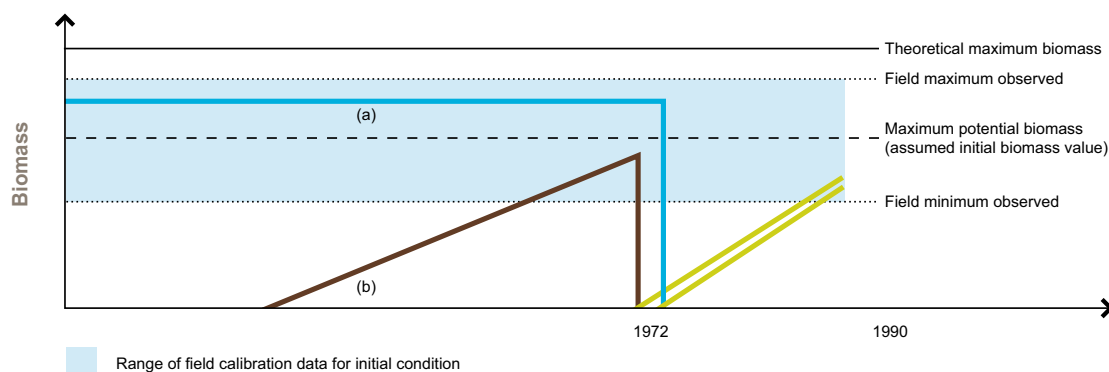
Figure 7.A.19: (b) Biomass of forest cleared prior to 1972



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

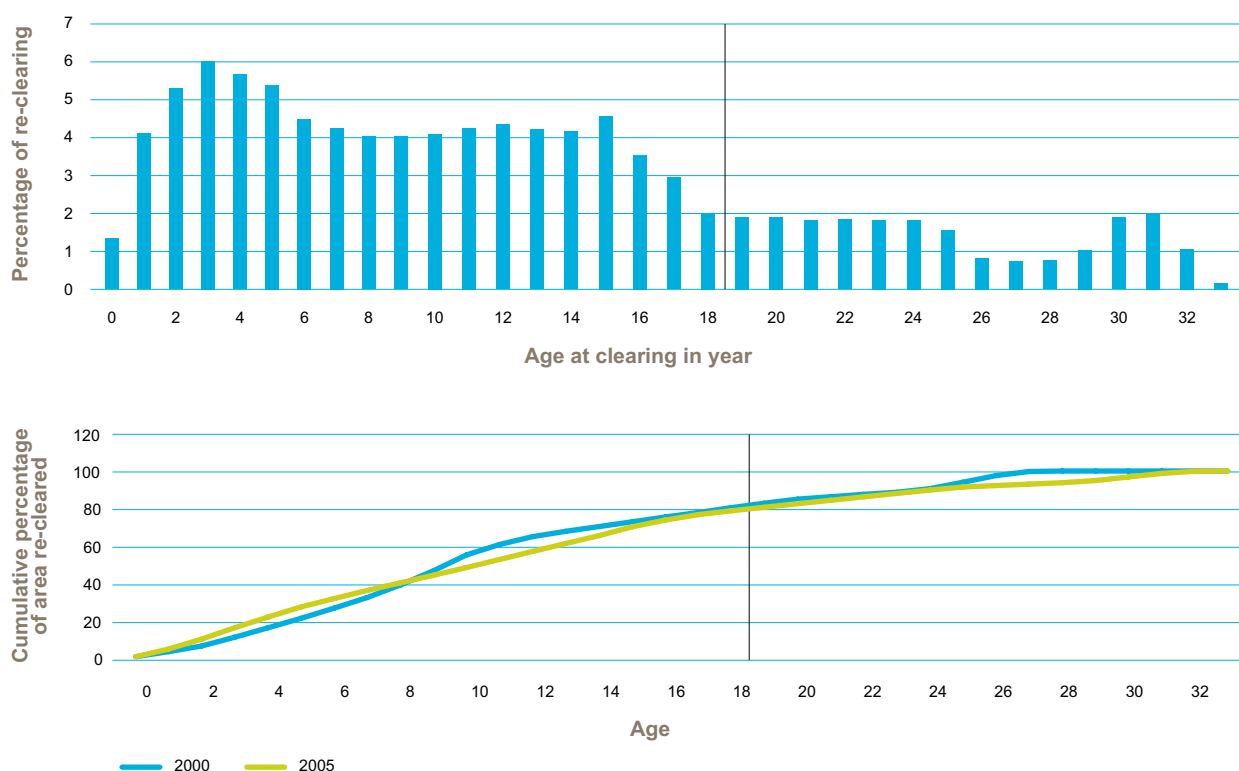
Both Cases 2 (a) and 2 (b) are relatively rare occurrences. This is because the average re-clearing cycle is 8 to 11 years, with 80% of re-clearing happening within 18 years of the last regrowth event (Figure 7.A20). This means that of the forests possibly in Case 2 (a) and 2 (b) (that is previously cleared and regrowing at an unknown time before 1972) around 80% would likely have a re-clearing event before 1990 and would actually be in Case 3(b) below. For those forests that are not re-cleared and are actually in Case 2, the assumed initial biomass may be overestimated or underestimated, depending on when the initial (unobserved) clearing took place. There is no basis for presuming that any individual pixel is more likely to be either 2 (a) or 2 (b).

Figure 7.A.19: (c) Biomass of forest cleared post-1972



In Case 3 (Figure 7.A19 (c)) the forest is interpreted from the post-1972 remote sensing data to have been 'cleared for the first time' after 1972 (Case 3 (a)) and has subsequently regrown. In this case the age of the forest is known and the biomass is modelled directly using the age of the forest and site productivity (see Biomass Growth Increments section 7.A.4.4). The green lines in both (a) and (b) represent biomass that can be calculated by the model because the age of regrowth can be observed. The assumed initial biomass is not used for any subsequent re-clearing event as the age of regrowth forest is known at the time of re-clearing. Prior to 1972, the forest may have been undisturbed (represented in the blue line (a)) or disturbed (represented in the red line (b)). Regardless of whether the situation was (a) or (b) the initial biomass assumption at time of first clearing will not affect the biomass estimates for a re-clearing event after an initial clearing has been identified.

Figure 7.A.20: 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).

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

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 $0.5k$. 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):

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

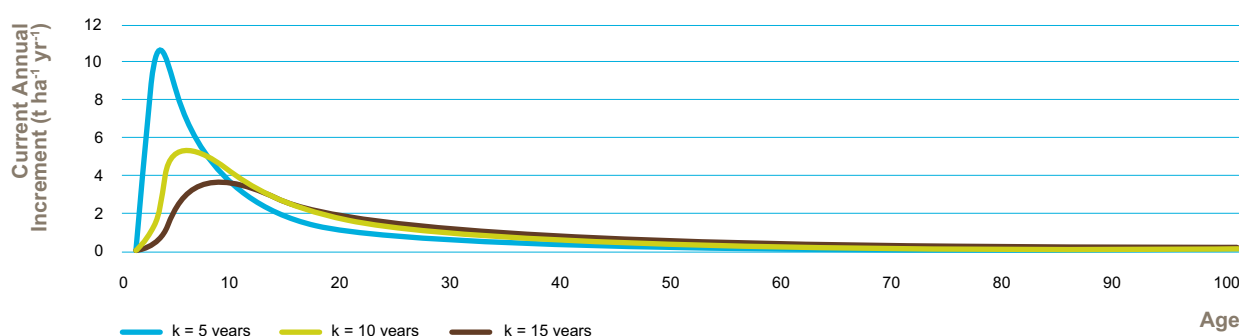
However, as productivity in any given year may vary around the average due to non-average weather or other factors, the average annual increment may be adjusted by the productivity in a given year (P_a) as a ratio with the average productivity (P):

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

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.A21 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.A21: Effects of varying age of maximum current annual increment

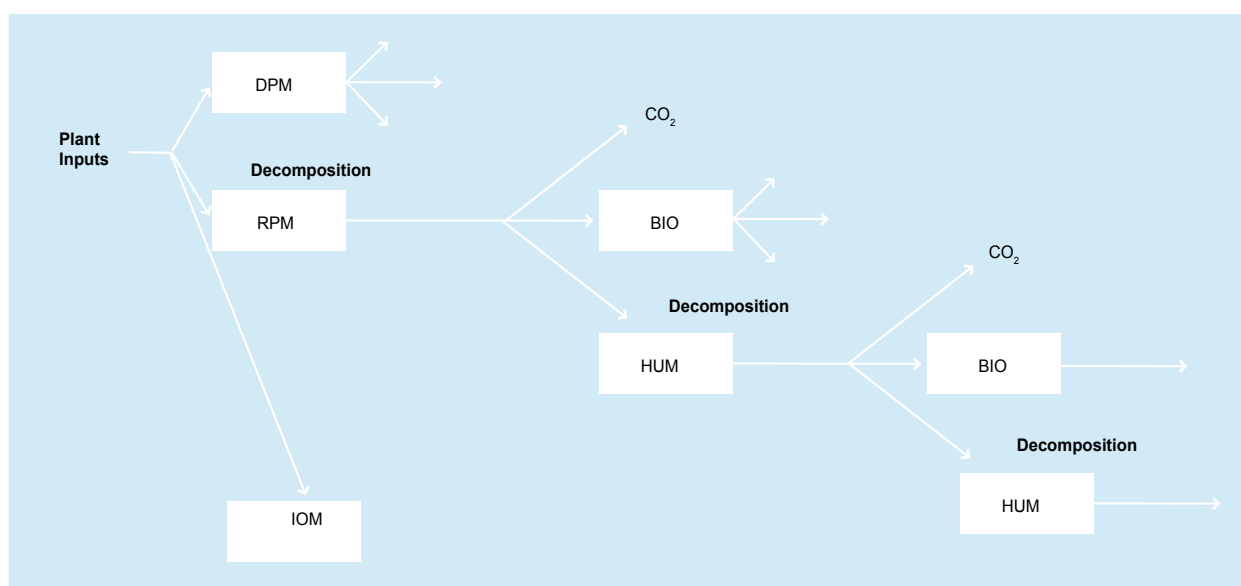


7.A.5 Estimating changes in soil carbon

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.A22.

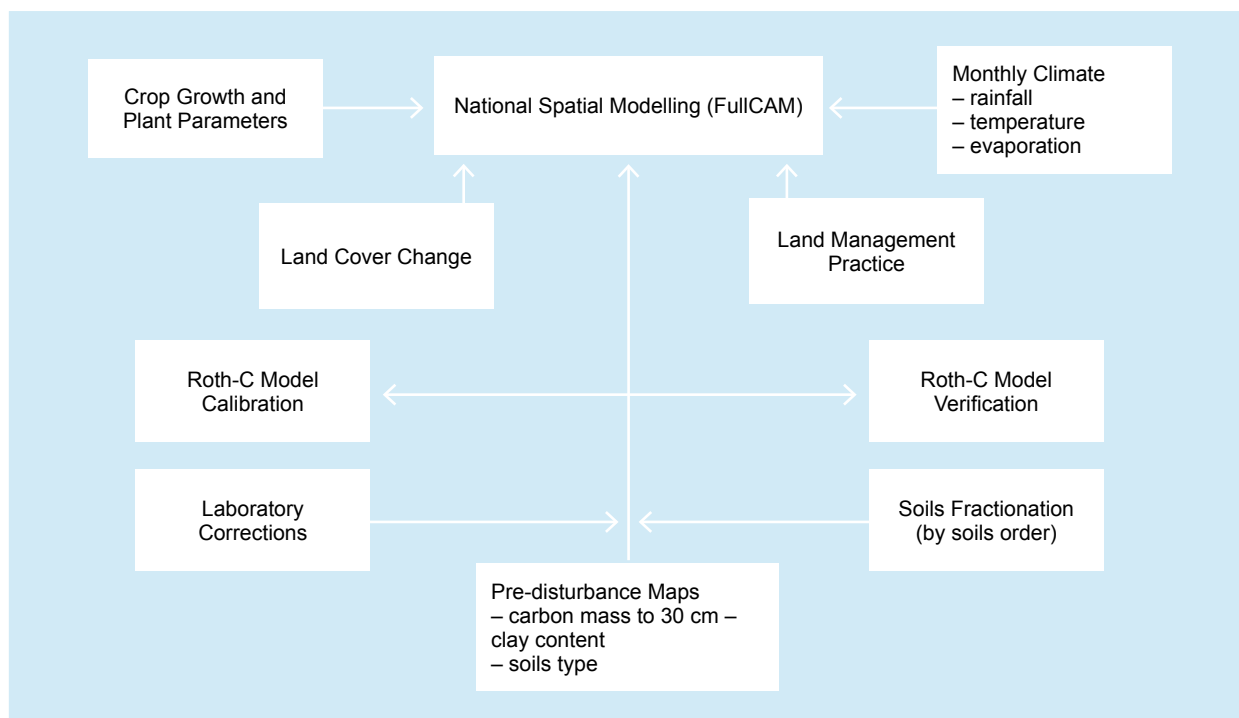
The overall soil carbon program developed both resource inventory (mapping) descriptions and model calibration and verification. The integrated soil carbon program for the NCAS is shown in Figure 7.A23. The background to the selection of methods and design of the program can be found in Webbnet Land Resource Services Pty. Ltd. (2000).

Figure 7.A22: 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.A23: 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 Webbnat Land Resource Services Pty. Ltd. (2002). Figure 7.A24 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.A25) using the same map base. The mapped soil units provide pre-disturbance carbon (organic) content, clay content and soil type. The soil types (Table 7.A2) allow for the initial soil carbon values from the mapping to be partitioned into the carbon pools used by the carbon model via a relational database. These pools are defined by their differences in turnover times (i.e., the resistant versus decomposable). The proportion of material in each soil pool (fractionation) was established by laboratory analysis of soil samples held in CSIRO and State/Territory Government archives.

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

Figure 7.A24: Pre-disturbance soil carbon map

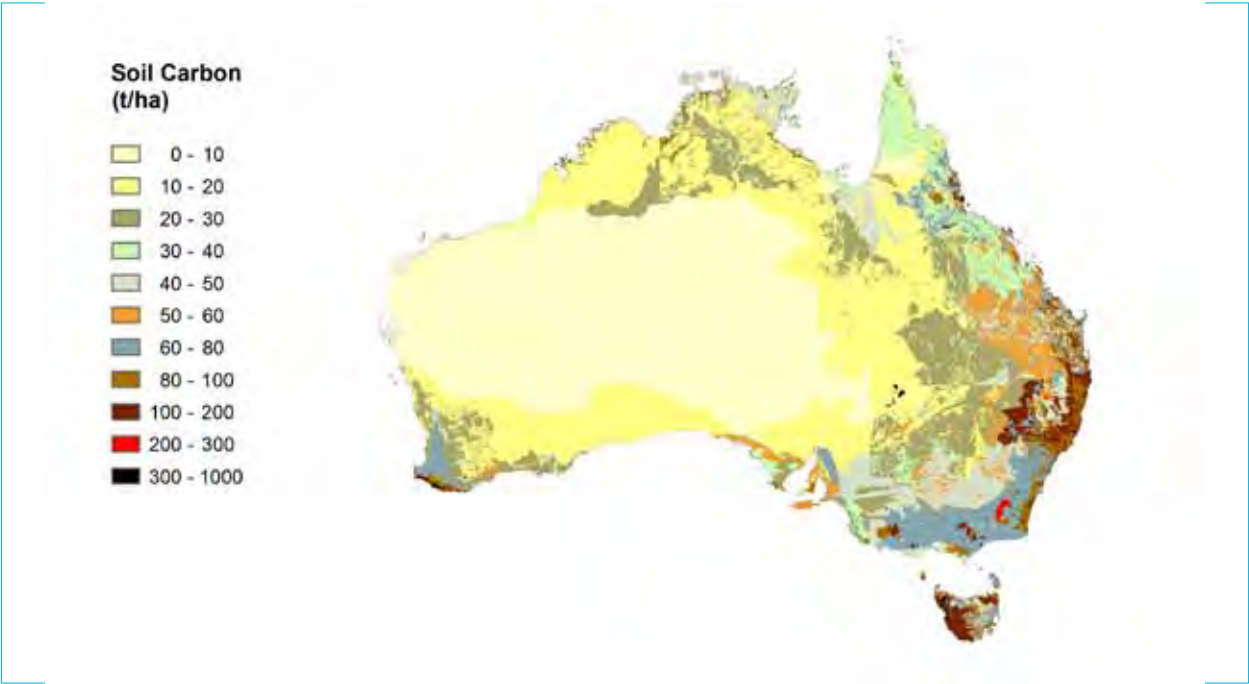


Figure 7.A25: Clay content map

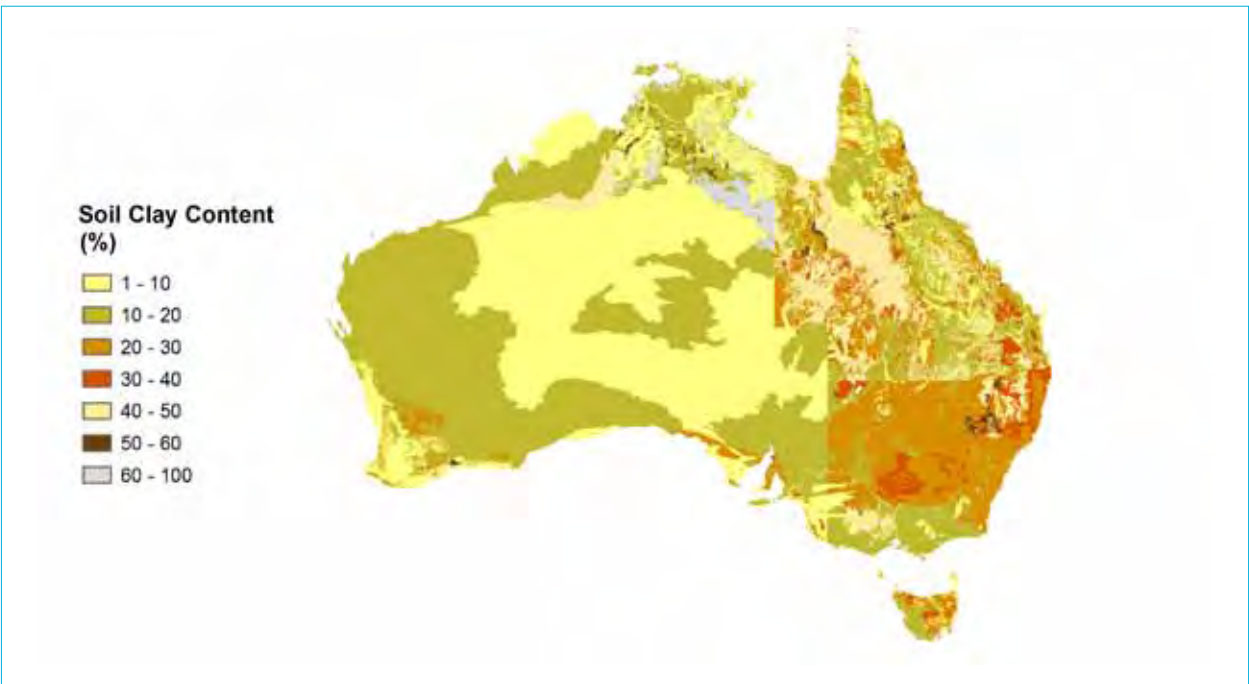


Table 7.A2: Soil classification used in the modelling

| 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

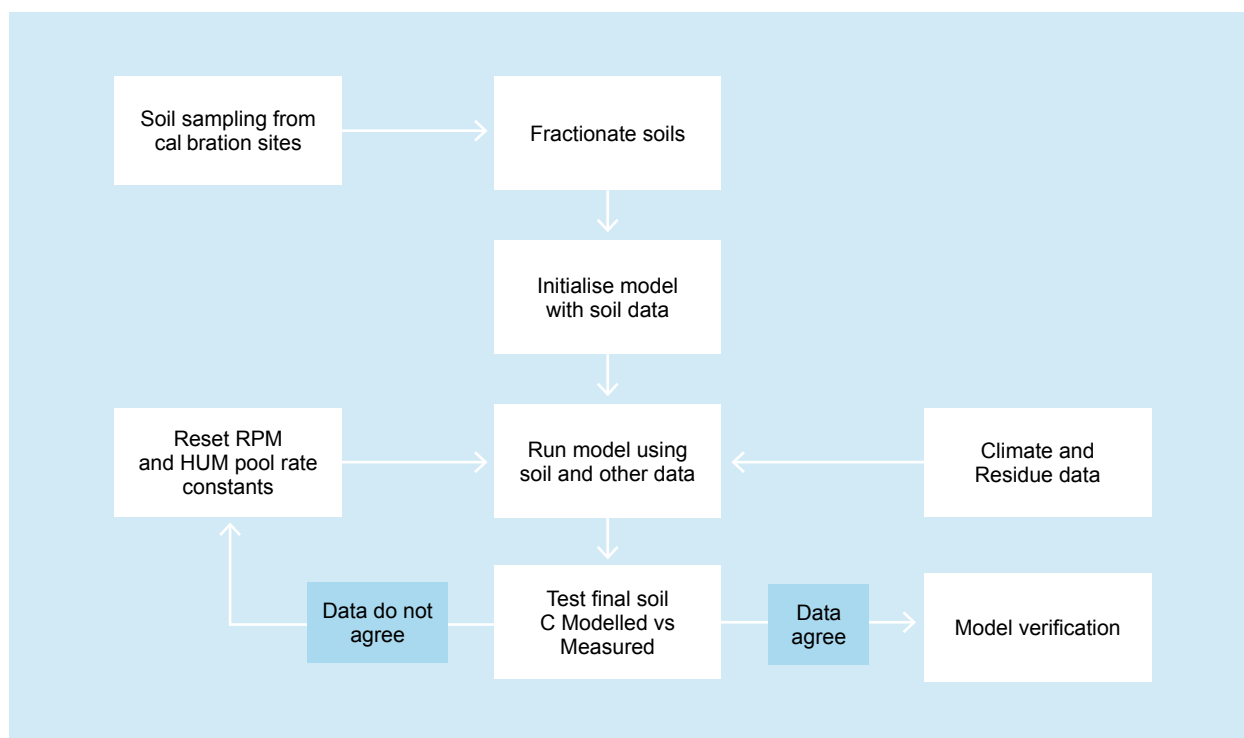
Early policy and technical analysis of the requirements for carbon accounting under the IPCC inventory guidelines, the Kyoto Protocol, and of the national data and methodological capacity available for the task, led to the development of a model-based methodology underpinned by the *Roth-C* soil carbon 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.A26.

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

Figure 7.A26: Procedure for the calibration of the Roth-C soil component of *FullCAM*



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; Webbnat Land Resource Services Pty. Ltd., 2002).

7.A.6.1 National Forest Inventory

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

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

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

Despite the continual improvement of accuracy of Australia's NFI, the data are provided by a wide range of sources and are collected for a variety of reasons and are not always of comparable quality or at a common scale. For example, Australia's NFI does not apply a minimum area requirement in its definition of a forest; therefore NCAS undertook an extensive process to select an appropriate minimum area value (0.2 ha) to define a forest. Australia's NFI does not utilise a systematic set of routinely measured national sample plots and while individual states/territories and businesses maintain various inventory systems, sample plot data is not readily available to the Commonwealth. In addition, Australia's NFI does not provide carbon stock estimates of mature or regrowth forests. Therefore the model approach of NCAS is used to estimate the carbon stocks of mature forests and the rates of carbon accumulation in forest regrowth both spatially and temporally. The NCAS model approach is also used to report carbon stocks and emissions to the FAO and UNFCCC as well as providing forest carbon stock data to Australia's NFI for incorporation into Australia's State of Forests Report (i.e., Chapter 5, Australia's State of Forests Report 2008) (Montreal Process Implementation Group for Australia, 2008).

7.A.6.2 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.A27 to 7.A30 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).

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.A27: Long-term average rainfall

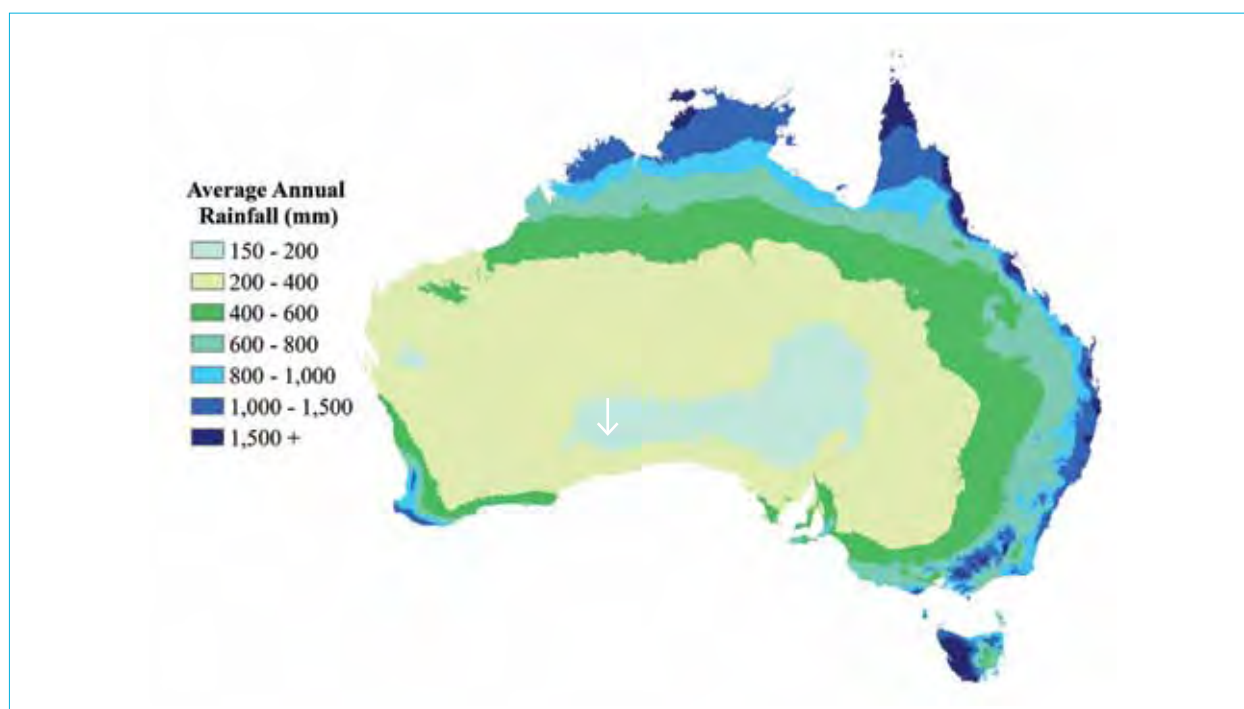


Figure 7.A28: Long-term average annual temperature

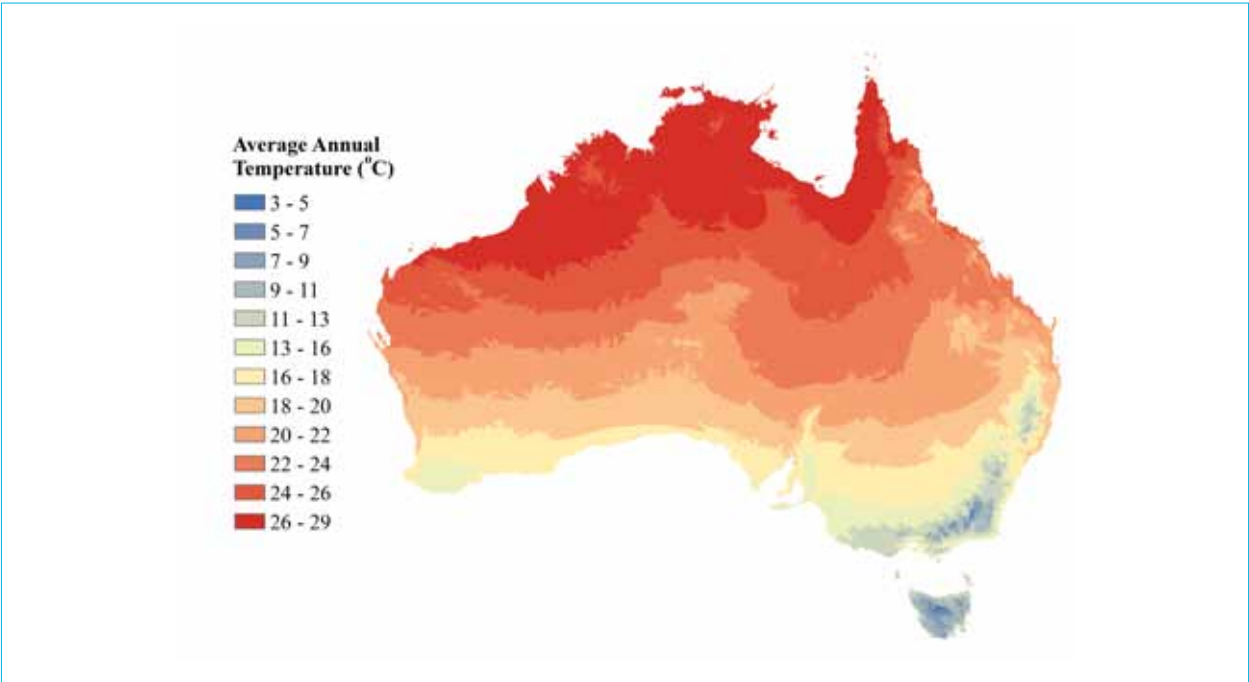


Figure 7.A29: Long-term average annual evaporation

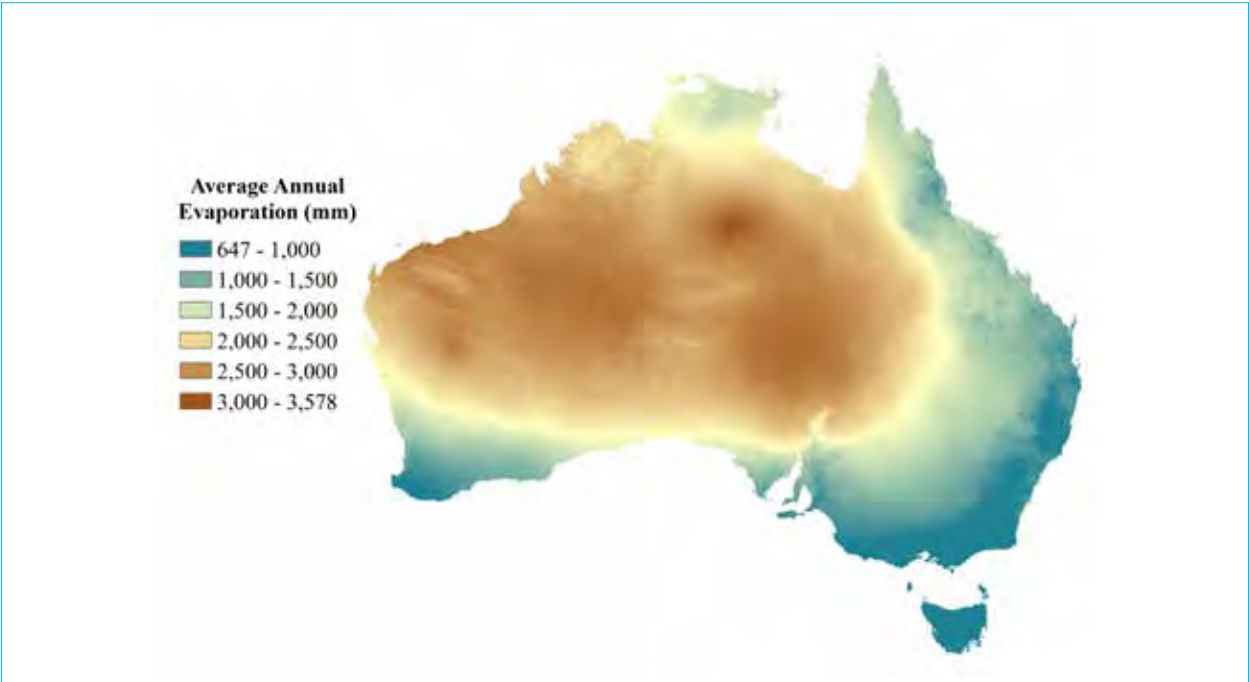
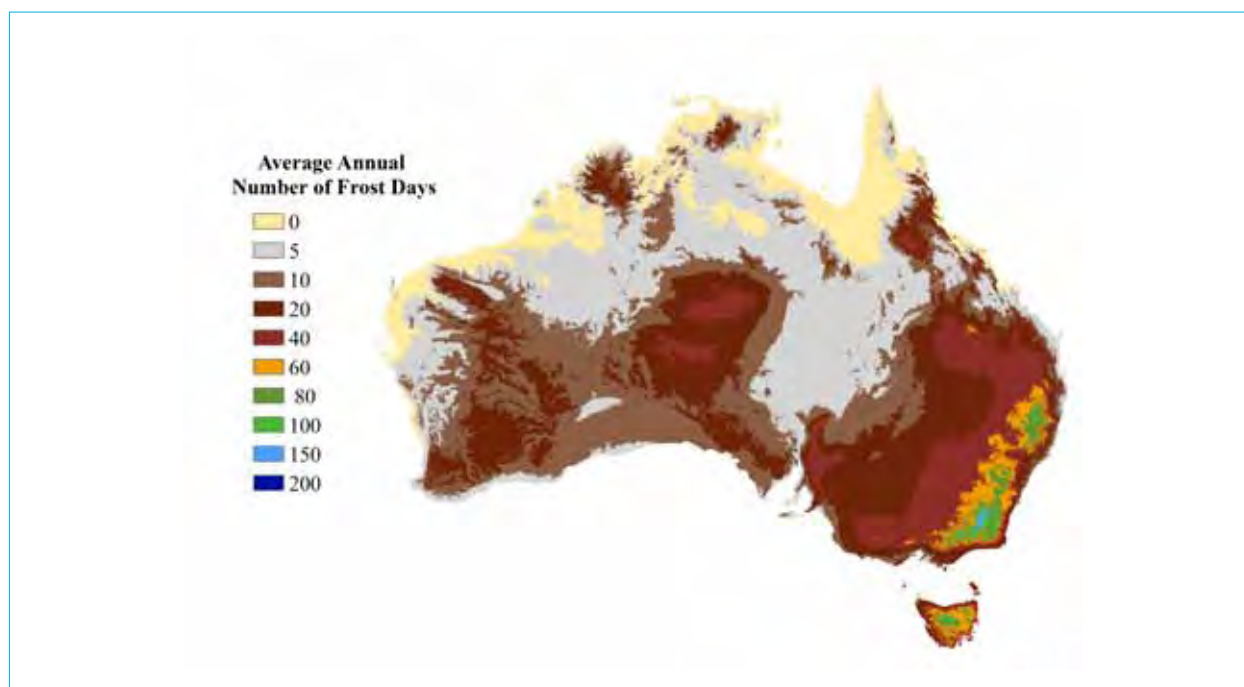


Figure 7.A30: Long-term average number of frost days per year



7.A.6.3 Soils and other spatial data

Soils

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

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

Land Tenure

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

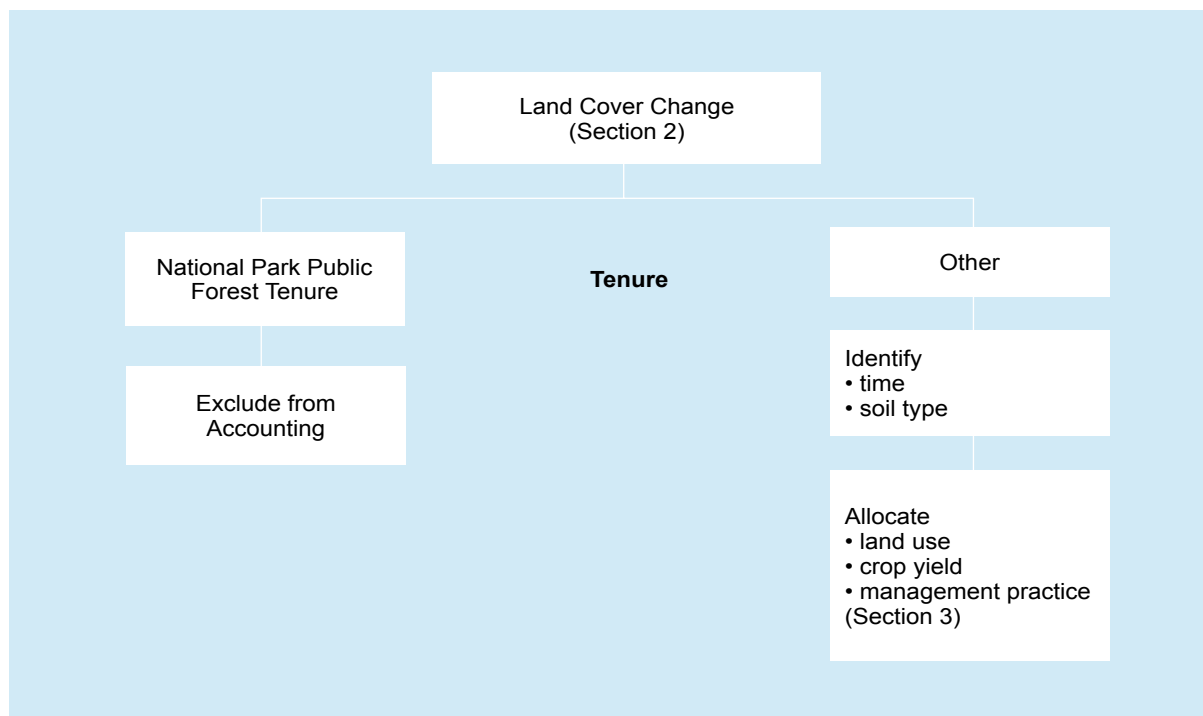
7.A.6.4 Land Use and Management Data

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

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

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.A31).

Figure 7.A31: 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.A32) 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.

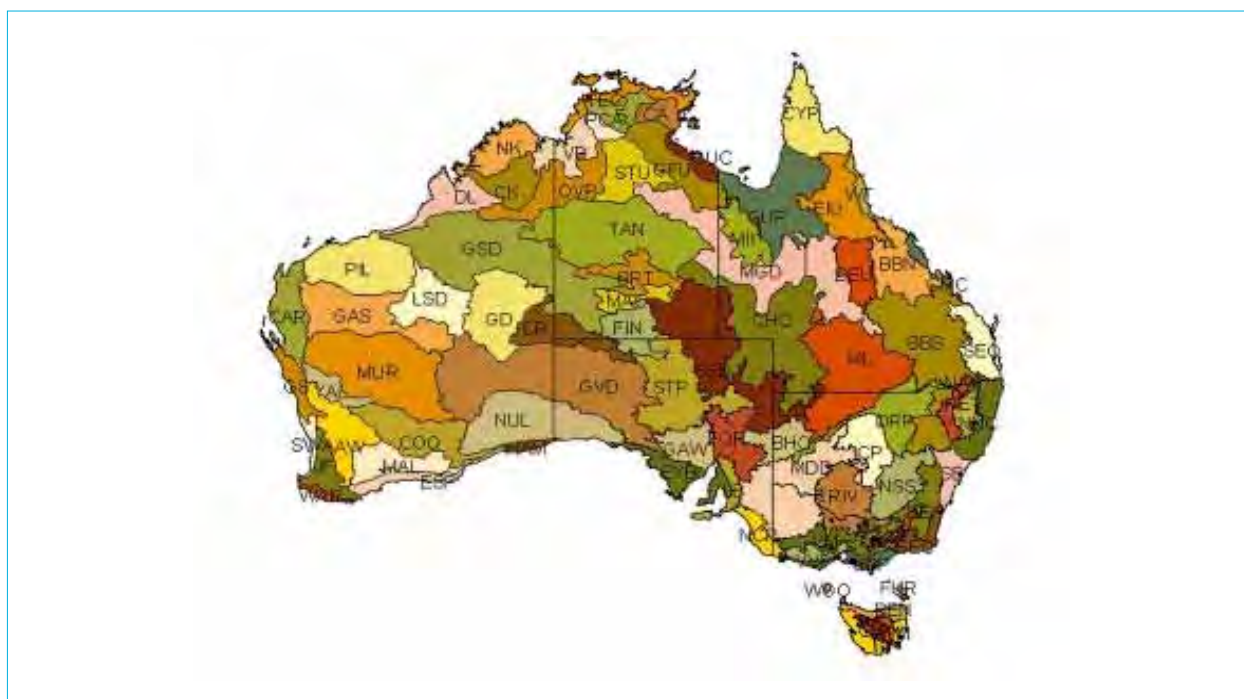
Table 7.A4: Example land use table

| Soil type | % of cell | Land use | % of soil | Management practices | | % of Land use | Phase | % of Management 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 | crop | | 0 |
| | | | | | | | cereal | | 0 |
| | | | | | | 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 | crop | | 0 |
| | | | | | | | cereal | | 0 |
| | | | | | | 0 | crop | | 0 |
| | | | | | | | cereal | | 0 |
| | | Dedicated for pasture | 17 | | | 100 | | 100 | 4 |
| Sand | 0 | | | | | | | | |

Source: Swift and Skjemstad, 2002

Note: IBRA cell: Darling Riverine Plains (17) Climate subdivision : nil Time period: 1975: 1978

Figure 7.A32: Interim Biogeographic Regionalisation of Australia (IBRA) regions



| Code | Name | Code | Name |
|------|--------------------------|------|-------------------------------|
| CH | Central Highlands | MII | Mount Isa Inlier |
| AA | Australian Alps | EYB | Eyre and Yorke Blocks |
| WT | Wet Tropics | SEQ | Southern Eastern Queensland |
| LB | Lofly 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 | Camaron |
| VB | Victoria Bonaparte | NSS | NSW South Western Slopes |
| CK | Central Kimberley | RIV | Riverina |
| DL | Dampierland | SEH | Southern Eastern Highlands |
| NK | Northern Kimberley | STU | Sturt Plateau |
| CP | Cobar Penneplain | 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 | Einiasleigh 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 | Southern 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 | Freyinet |
| NNC | NSW North Coast | FUR | Fumeaux |

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.6.5 Other non-spatial data

Plant characteristics

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

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

Coarse woody debris and litter

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

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

Given the complex and dynamic nature of this pool, it was concluded that verification could not rely on the measurement of inputs, transitions and losses due to disturbance. Instead, the mass balance cycling model approach was used to determine the quality of model calibration. If inappropriate or poorly calibrated parameters of inputs, transfer and losses 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* 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* 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 N₂O 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 category of which the emission for that year is catalogued to the year when the land entered the land converted category. For example, to report emissions for the year 2007, land may have entered the land converted category from 1972 onward. The emissions for that land converted 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 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.

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)

CO₂ = 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)

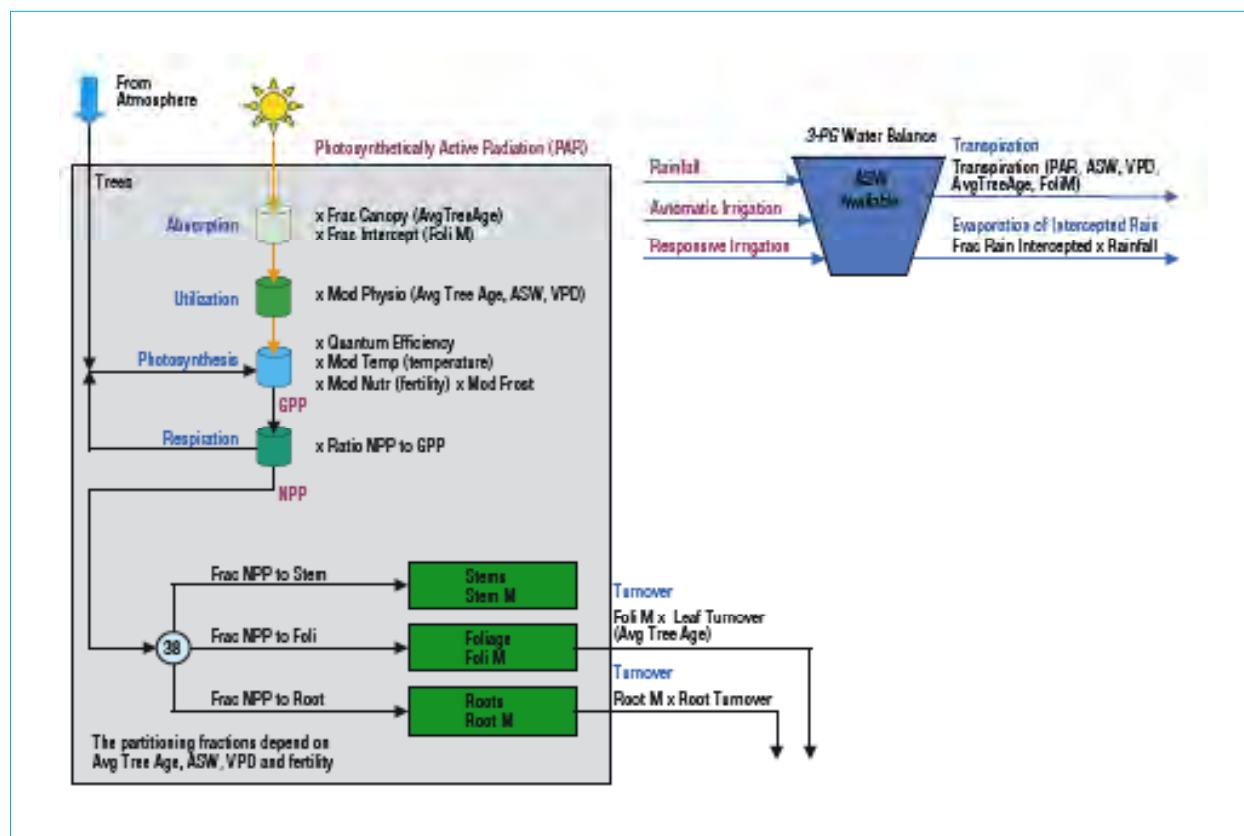
RPM = Resistant plant material (resistant to decomposition) (Roth-C only)

TSMD = Topsoil moisture deficit

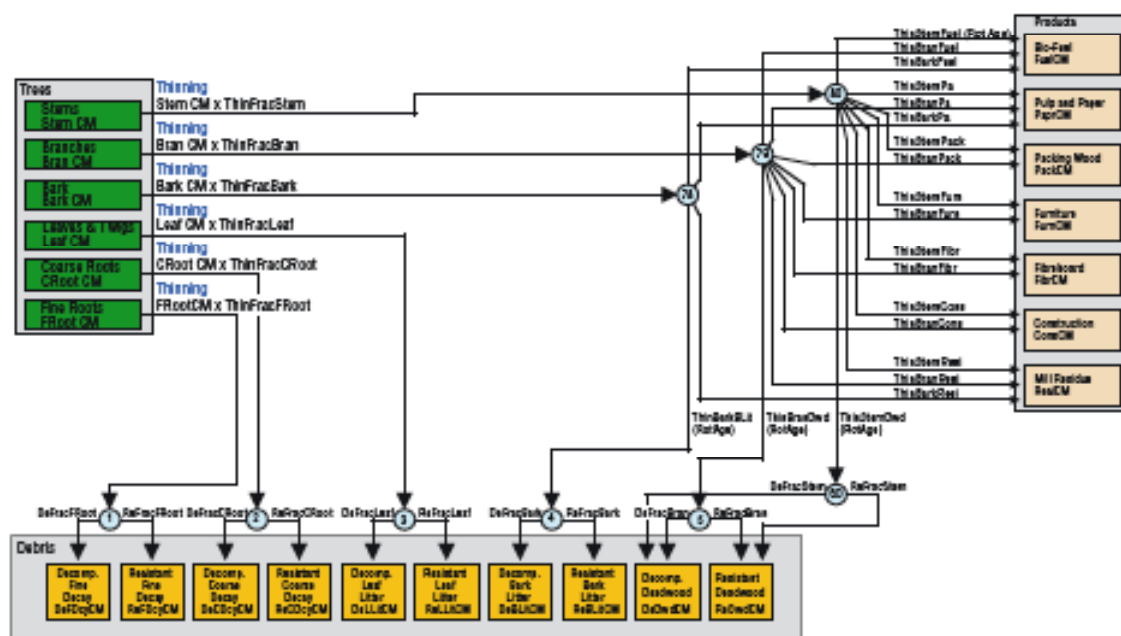
VPD = Vapor Pressure Deficit (in kPa) (3-PG only)

XXX = DPM, RPM, BIO-F or BIO-S (all active soil carbon categories except HUM)

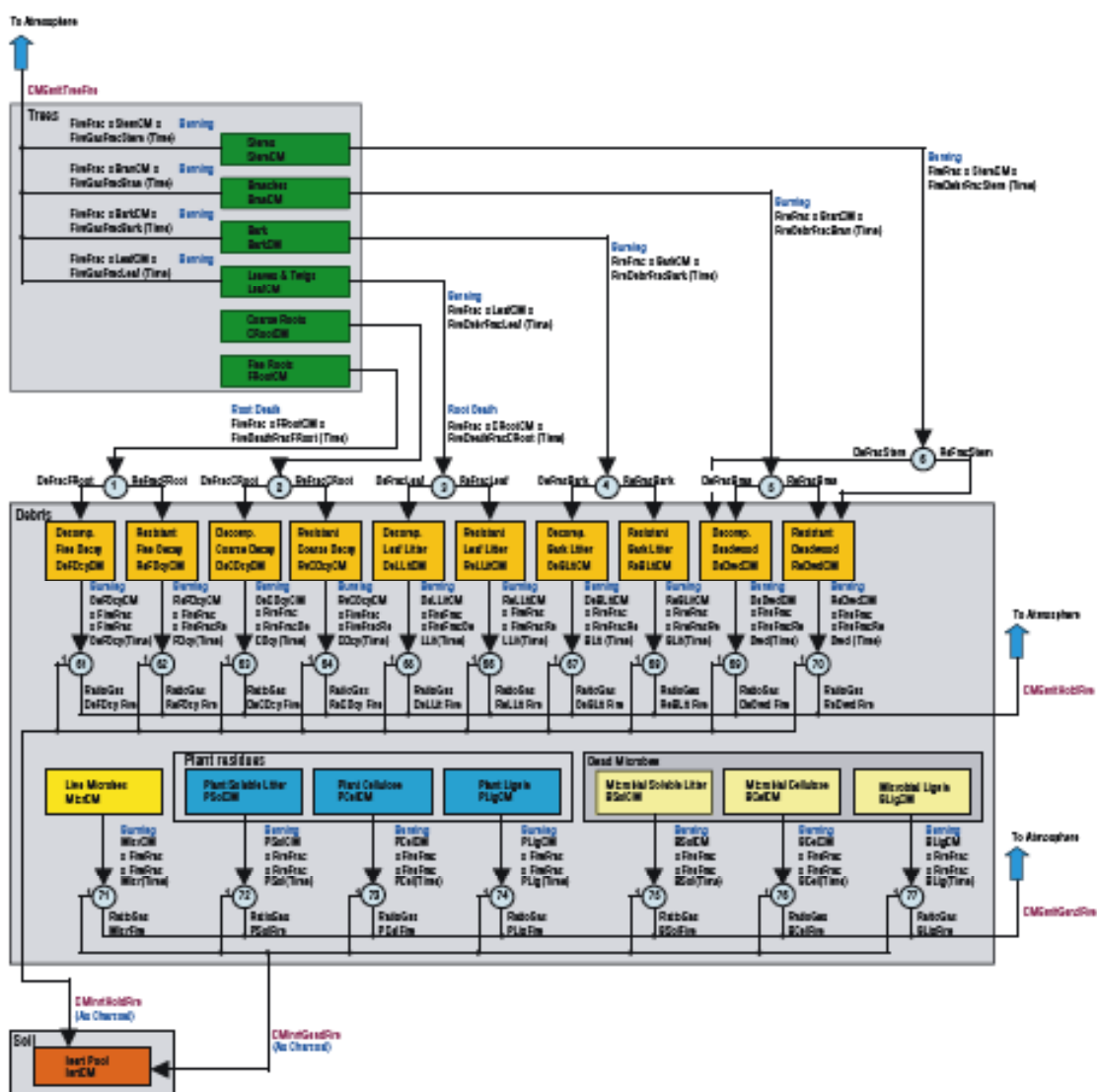
The 3-PG Model



APPENDIX 7.A

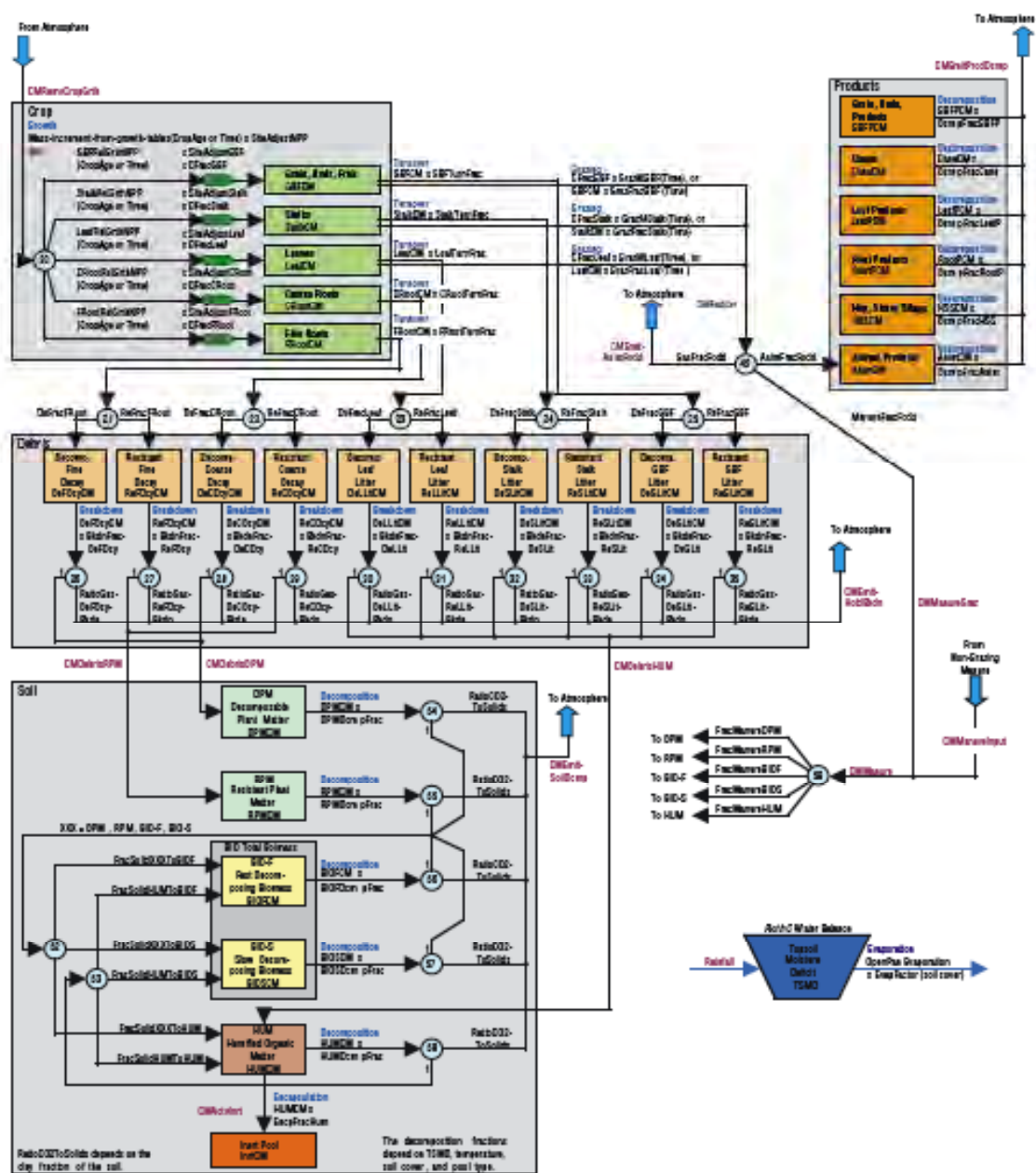


The CAMFor Model (b) Fire

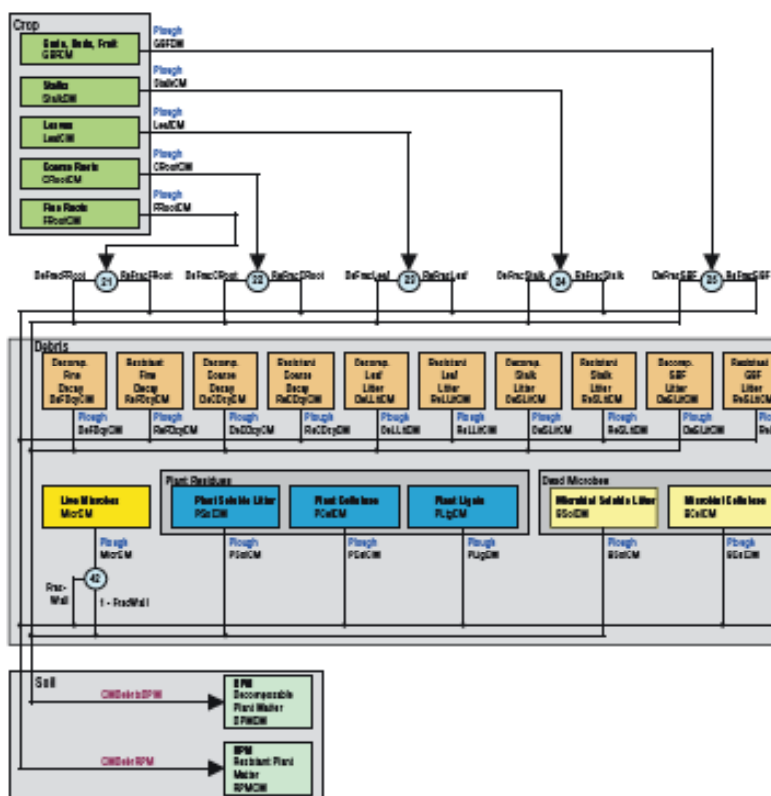




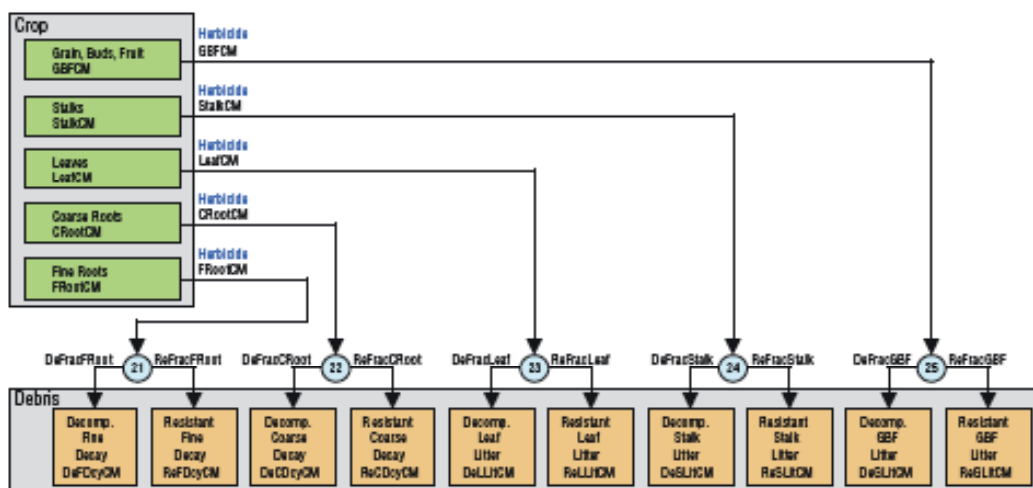
The *CAMAg* Model (b) Harvest

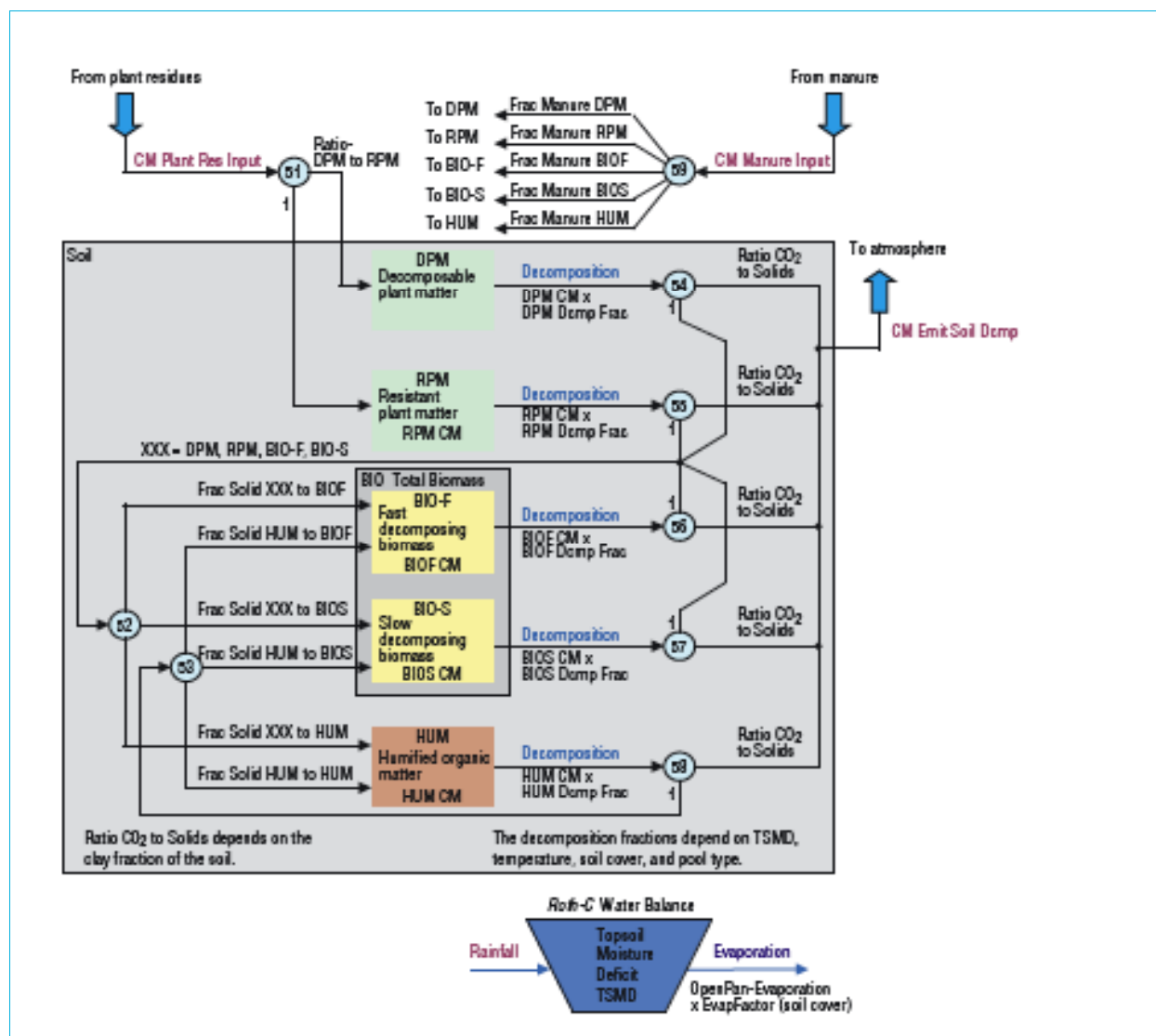


The CAMAg Model (d) Herbicide

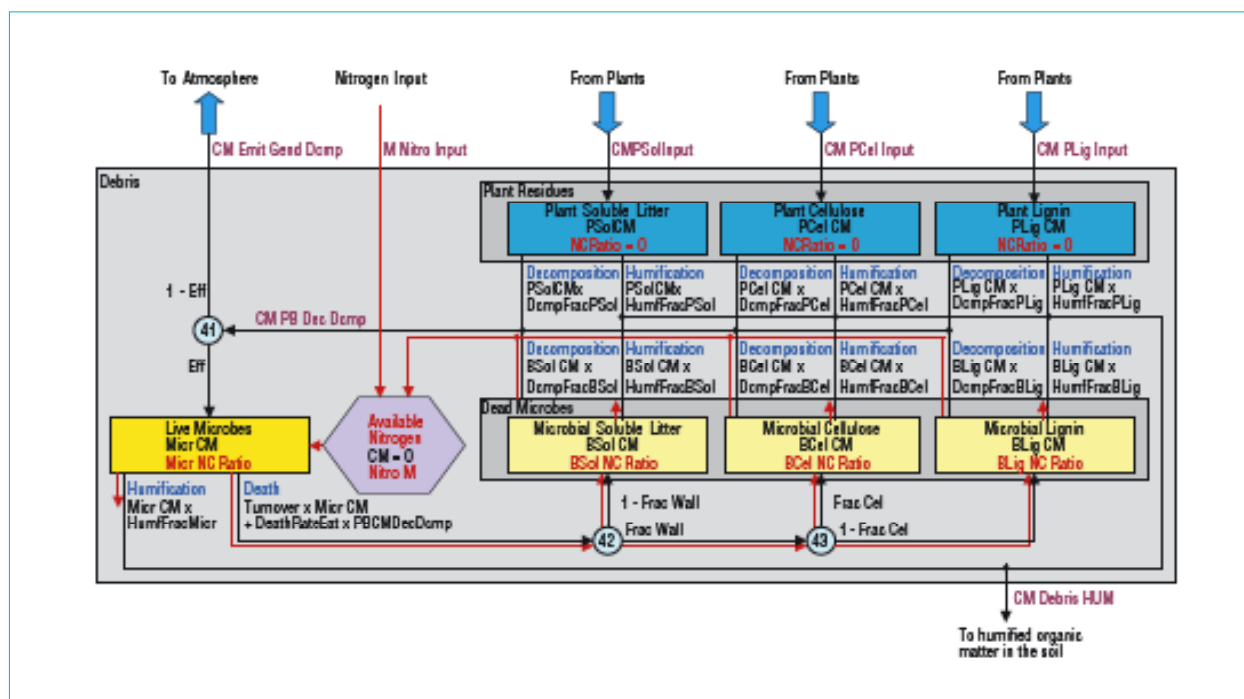


The CAMAg Model (c) Plough





The *Roth-C* Model



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 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 lands 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.B5.

Growth Modelling

The growth rates of *harvested native forests* (in $\text{t C ha}^{-1} \text{ yr}^{-1}$) are modelled by broad forest types and age classes (Table 7.B5) 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 $0.58 \text{ t C ha}^{-1} \text{ yr}^{-1}$ 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.B6).

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: Turnover for tree components

| Tree component | Turnover year ⁻¹ |
|----------------|-----------------------------|
| Branches | 0.065 |
| Bark | 0.095 |
| Leaves | 0.40 |
| Coarse Roots | 0.065 |
| Fine Roots | 0.73 |

Table 7.B2: Decomposition rates for debris pools used in the *harvested native forests* model

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

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.B1). A full description of the *FullCAM* model structure is provided in Appendix 7.A.

Table 7.B3: 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 |

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.B2. There is limited information on decomposition rates in the harvested native forests of Australia. The rates applied are considered to be best estimates based on the available information.

Carbon Fraction of Biomass

Studies of the carbon fractions of above and 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.B3).

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.B4) are drawn from the best available data, largely from the synthesis of data compiled by Snowden *et al.*, (2000) and the results of Ximenes and Gardner (2005) and Ximenes *et al.*, (2005).

Table 7.B4: 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 CO₂ Conversion

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

Table 7.B5: 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.B6: 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 |

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

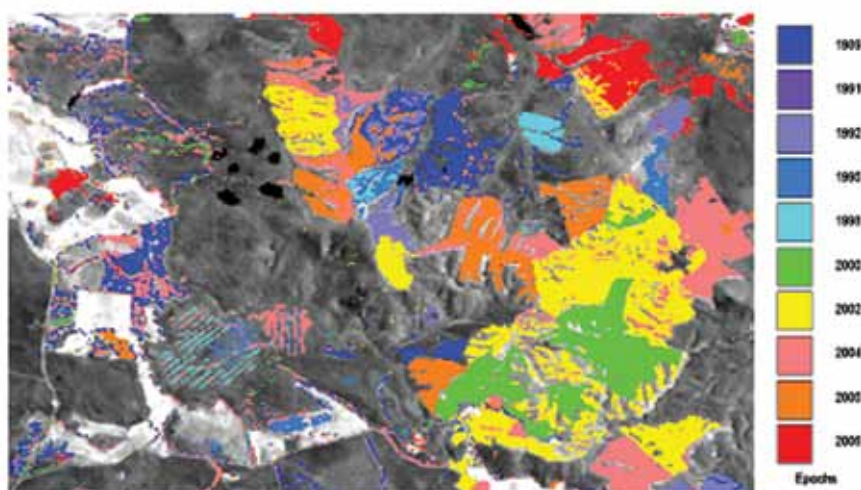
| Year | Area Harvested (ha) |
|------|---------------------|
| 1990 | 141,441 |
| 1991 | 135,928 |
| 1992 | 140,734 |
| 1993 | 144,259 |
| 1994 | 152,082 |
| 1995 | 149,306 |
| 1996 | 142,646 |
| 1997 | 137,893 |
| 1998 | 138,709 |
| 1999 | 132,550 |
| 2000 | 136,206 |
| 2001 | 148,557 |
| 2002 | 114,504 |
| 2003 | 111,090 |
| 2004 | 111,620 |
| 2005 | 99,363 |
| 2006 | 99,977 |
| 2007 | 103,686 |
| 2008 | 112,433 |
| 2009 | 81,387 |

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

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

As part of the ongoing development of the *harvested native forests* model, new methods utilising 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

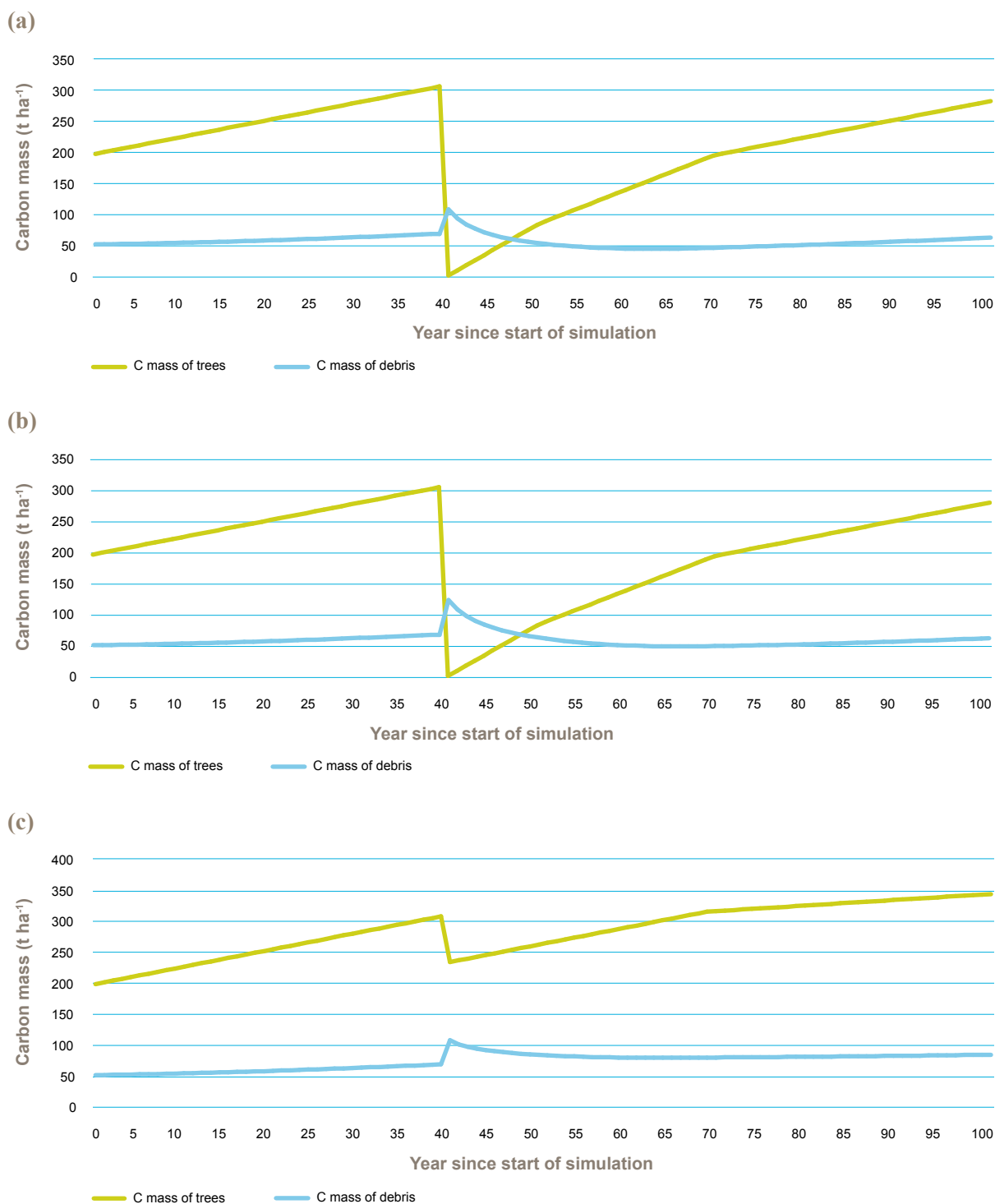
Ten broad silvicultural systems are represented in the model (Table 7.B8). These systems are designed to represent the range of harvesting systems employed in Australia throughout the 1990's and up to 2009. Each silvicultural system is modelled based on the unique combinations of forest age and forest 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

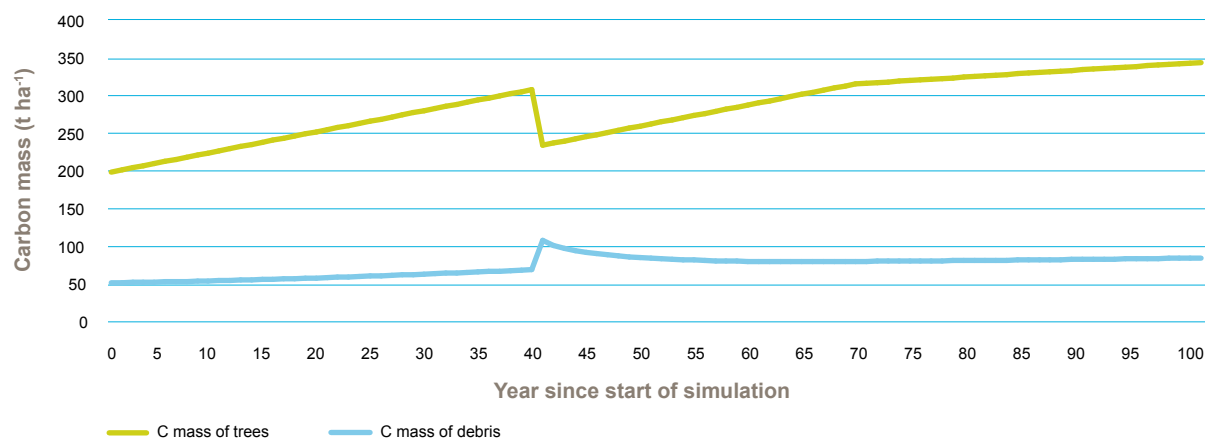
| Forest type | Silviculture | Percent of trees harvested | Post harvest management |
|--------------------------------------|----------------------------------|----------------------------|-------------------------|
| Tall dense eucalypt forest | Clearfell with pulpwood | 100% | Regeneration burn |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

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

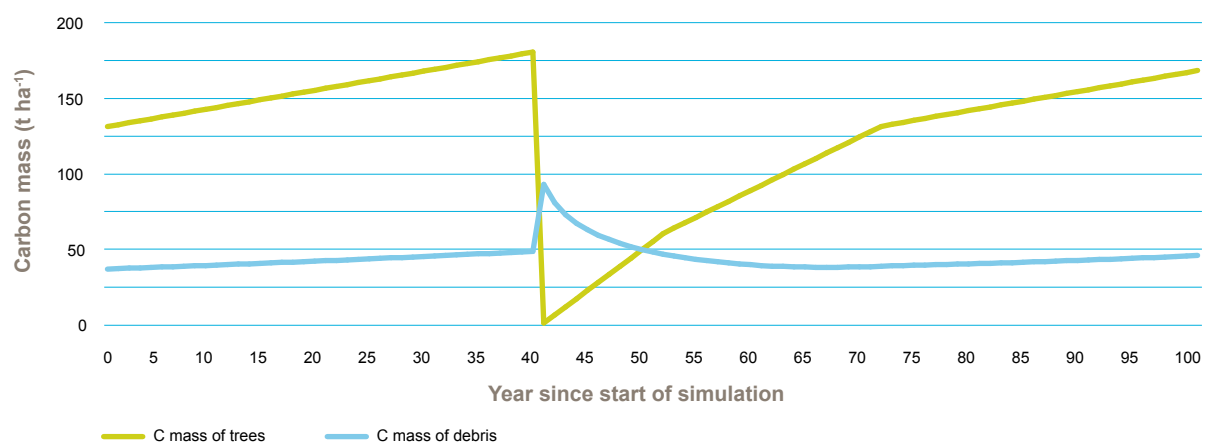
a) Tall dense eucalypt forest clearfell with pulpwood, b) Tall dense eucalypt forest clearfell without pulpwood, c) Tall dense eucalypt forest partial harvest with pulpwood, d) Tall dense eucalypt forest partial harvest without pulpwood, e) Medium dense eucalypt forest clearfell with pulpwood, f) Medium 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



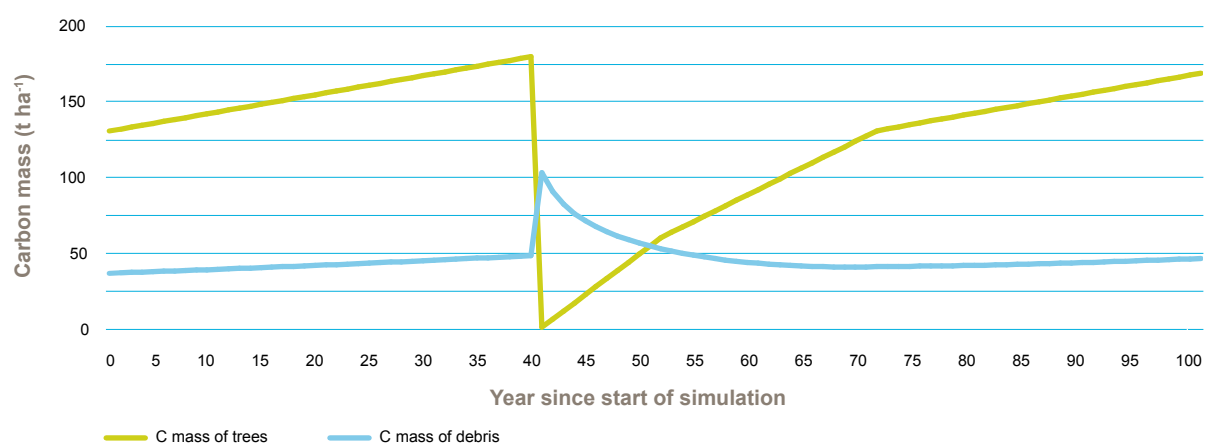
(d)

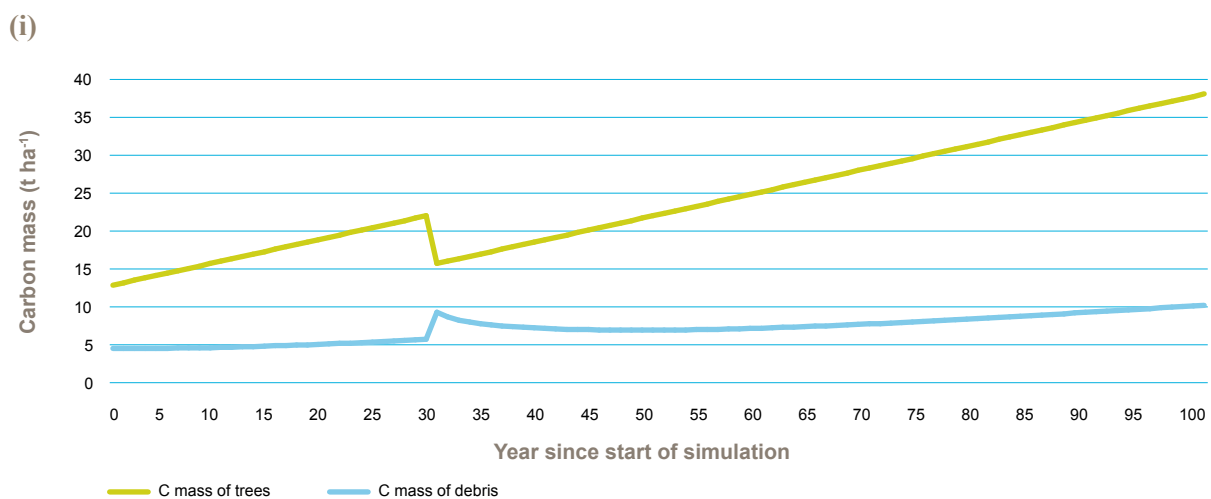
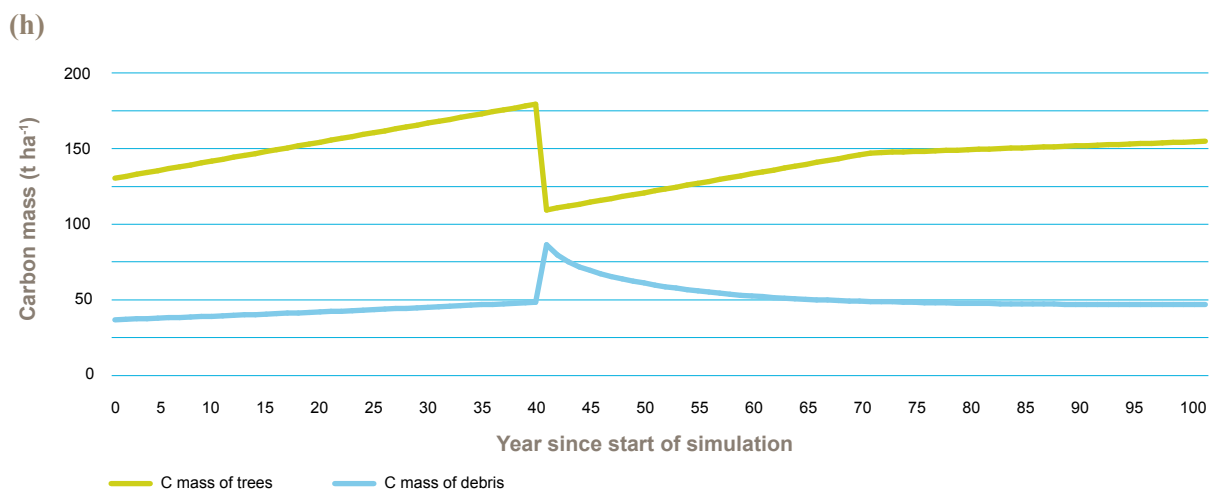
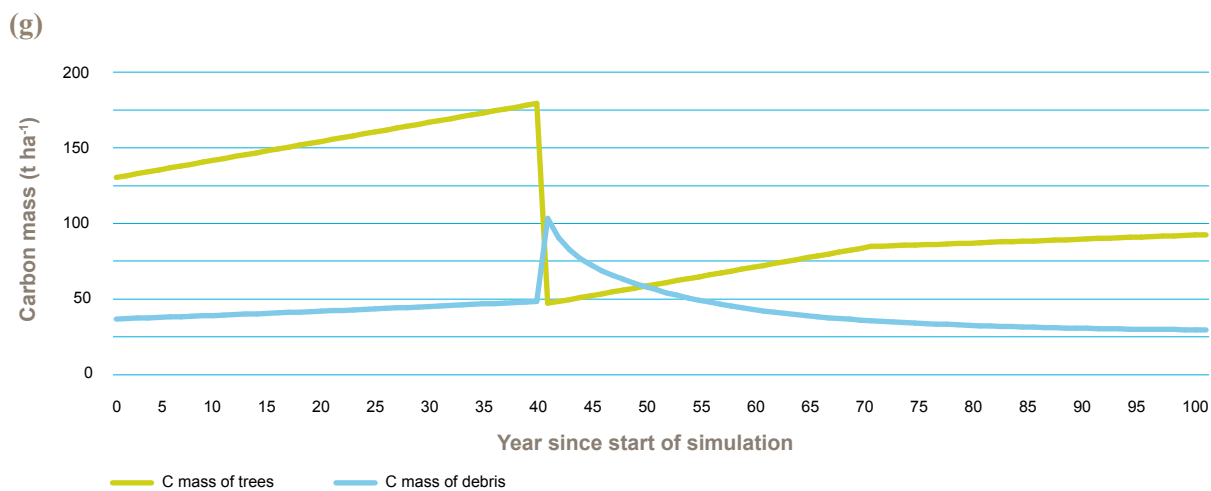


(e)

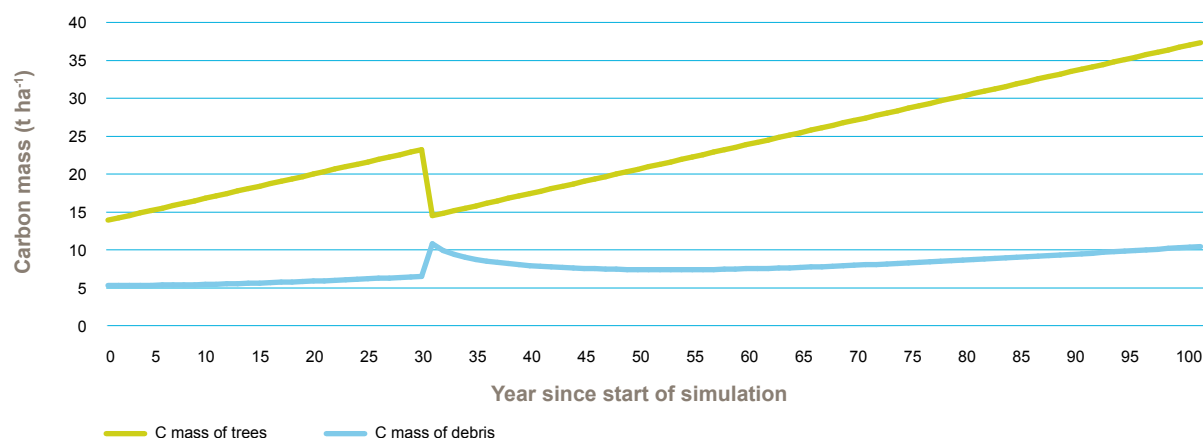


(f)





(j)



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

The 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* 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 key species and management practices within each National Plantation Inventory region were developed. In addition to the growth tables and thinning regimes of Turner and James (2002) the models require parameters for:

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

Table 7.C1 and Attachment 7.C1 show the relevant inputs, and the resultant carbon balances on a per hectare basis from the representative models for each plantation type. 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 in these plantations (Waterworth *et al.*, 2005). While it is unlikely that the volume at maturity (reflecting the longer term climate average) would be much affected, performance over a shorter period, such as a single inventory year, may yield above or below the expected growth due to the prevailing climate conditions. The potential impact of prevailing climate conditions during the time of reporting is described in Brack and Richards (2002).

Wood Density Estimates

Wood basic density estimates for each plantation species were extracted from the compendium of wood density estimates prepared by Ilic *et al.*, (2000) 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 (Polglase *et al.*, 2004), there is potential that the adopted wood densities are over-estimates for the early stages of plantation growth. However, as the average age of the pre-1990 plantations is much greater than the post 1990 plantations the overall effect is unlikely to be significant as lower densities occur when mass is least, that is, during early growth stages. Table 7.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 older even-aged and productive stands. Attachment 7.C1 provides a synopsis of the non-stem allocations used in each plantation type model.

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

Carbon Contents

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

Turnover and Decomposition Rates

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

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

Table 7.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

| Debris Component | Breakdown Rate yr ⁻¹ |
|-------------------|---------------------------------|
| Deadwood | 0.1 |
| Bark Litter | 0.5 |
| Leaf Litter | 1.0 |
| Coarse Dead Roots | 0.5 |
| Fine Dead Roots | 1.0 |

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

Table 7.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 | <i>Pinus radiata</i> | 440 | 52 | 51 | 52 | 53 | 46 | 49 | Average Sites: 54% thinning @ 13 years, 25% @ 18, 28% @ 23, CF @ 30 |
| Green Triangle | <i>Pinus</i> (other than <i>radiata</i>) | 440 | 52 | 51 | 52 | 53 | 46 | 49 | Average Sites: 54% thinning @ 13 years, 25% @ 18, 28% @ 23, CF @ 30 |
| NSW Northern Tableland | Southern Pine (<i>P. elliotti</i> , <i>P. taeda</i> , <i>Araucaria cunninghamii</i>) | 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 (<i>P. elliotti</i> , <i>P. taeda</i> , <i>Araucaria cunninghamii</i>) | 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 | <i>Pinus</i> (other than <i>radiata</i>) | 440 | 52 | 51 | 52 | 53 | 46 | 49 | Average Sites: 54% thinning @ 13 years, 25% @ 18, 28% @ 23, CF @ 30 |
| Tasmania | <i>Eucalyptus nitens</i> | 550 | 52 | 47 | 52 | 49 | 46 | 49 | All Sites: CF @ 30 |
| Tasmania | <i>Eucalyptus nitens</i> | 550 | 52 | 47 | 52 | 49 | 46 | 49 | All Sites: CF @ 15 |
| Tasmania | <i>Eucalyptus nitens</i> | 550 | 52 | 47 | 52 | 49 | 46 | 49 | All Sites: CF @ 25 |
| Tasmania | <i>Pinus radiata</i> | 440 | 52 | 51 | 52 | 53 | 46 | 49 | Average Sites: CF @ 35 |
| Tasmania | <i>Pinus</i> (other than <i>radiata</i>) | 440 | 52 | 51 | 52 | 53 | 46 | 49 | All Sites: CF @ 35 |
| Victoria (Central) | <i>Pinus radiata</i> | 440 | 52 | 51 | 52 | 53 | 46 | 49 | Average Sites: 34% thinning @ 15 years, 18% @ 22, 24% @ 28, CF @ 35 |
| Victoria (Central) | <i>Pinus radiata</i> | 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) | <i>Pinus radiata</i> | 440 | 52 | 51 | 52 | 53 | 46 | 49 | Average Sites: 33% thinning @ 15 years, 37% @ 20, CF @ 30 |

| Region(s) | Species | Density | CC% Leaf | CC% Branch | CC% Wood | CC% Bark | CC% Fine Roots | CC% Coarse Roots | Regime Description |
|-------------------|----------------------------|---------|----------|------------|----------|----------|----------------|------------------|---|
| Murray Valley | <i>Pinus radiata</i> | 440 | 52 | 51 | 52 | 53 | 46 | 49 | Average Sites: 47% thinning @ 14 years, 35% @ 22, 29% @ 29, CF @ 30 |
| Murray Valley | <i>Pinus radiata</i> | 440 | 52 | 51 | 52 | 53 | 46 | 49 | Average Sites: 47% thinning @ 14 years, 35% @ 22, CF @ 30 |
| Murray Valley | <i>Pinus radiata</i> | 440 | 52 | 51 | 52 | 53 | 46 | 49 | Very Good Sites: 44% thinning @ 14 years, 31% @ 18, 27% @ 23, CF @ 30 |
| Victoria and NSW | <i>Pinus radiata</i> | 440 | 52 | 51 | 52 | 53 | 46 | 49 | Average Sites: CF @ 30 years |
| Victoria and NSW | <i>Pinus radiata</i> | 440 | 52 | 51 | 52 | 53 | 46 | 49 | Average Sites: 65% thinning @ 16 years, CF @ 30 |
| Victoria and NSW | <i>Pinus radiata</i> | 440 | 52 | 51 | 52 | 53 | 46 | 49 | Average Sites: 65% thinning @ 16 years, 57% @ 24, CF @ 30 |
| Victoria and NSW | <i>Pinus radiata</i> | 440 | 52 | 51 | 52 | 53 | 46 | 49 | Average Sites: 65% thinning @ 16 years, 57% @ 24, 27% @ 30, CF @ 35 |
| Victoria and NSW | <i>Pinus radiata</i> | 440 | 52 | 51 | 52 | 53 | 46 | 49 | Poor Sites: 26% thinning @ 18 years, 32% @ 24, CF @ 30 |
| Victoria and NSW | <i>Pinus radiata</i> | 440 | 52 | 51 | 52 | 53 | 46 | 49 | Poor Sites: CF @ 30 years |
| Western Australia | <i>Eucalyptus globulus</i> | 550 | 52 | 47 | 52 | 49 | 46 | 49 | Clear fall @ 10 |
| Western Australia | <i>Pinus pinaster</i> | 470 | 52 | 51 | 52 | 53 | 46 | 49 | Average Sites: 65% thinning @ 18 years, 37% @ 25, CF @ 40 |
| Western Australia | <i>Pinus radiata</i> | 440 | 52 | 51 | 52 | 53 | 46 | 49 | Average Sites: 51% thinning @ 12 years, 39% @ 18, 32% @ 24, CF @ 35 |

Soil Carbon Modelling

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

The soil carbon estimates are based on the model developed by Polglase *et al.*, (2000) covering plantation forests aged from 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

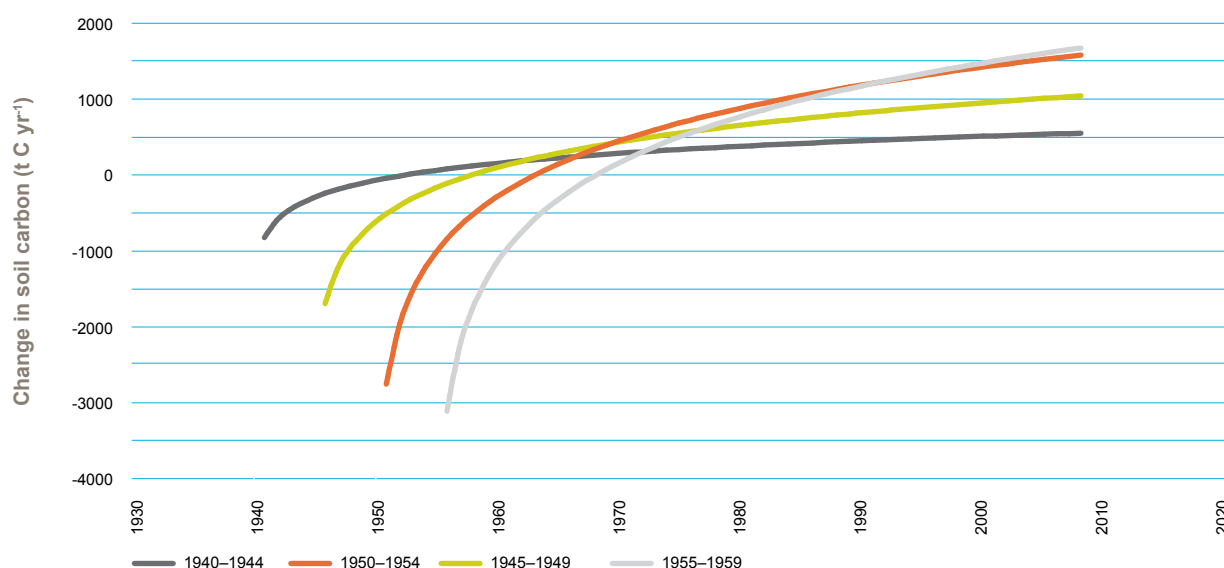
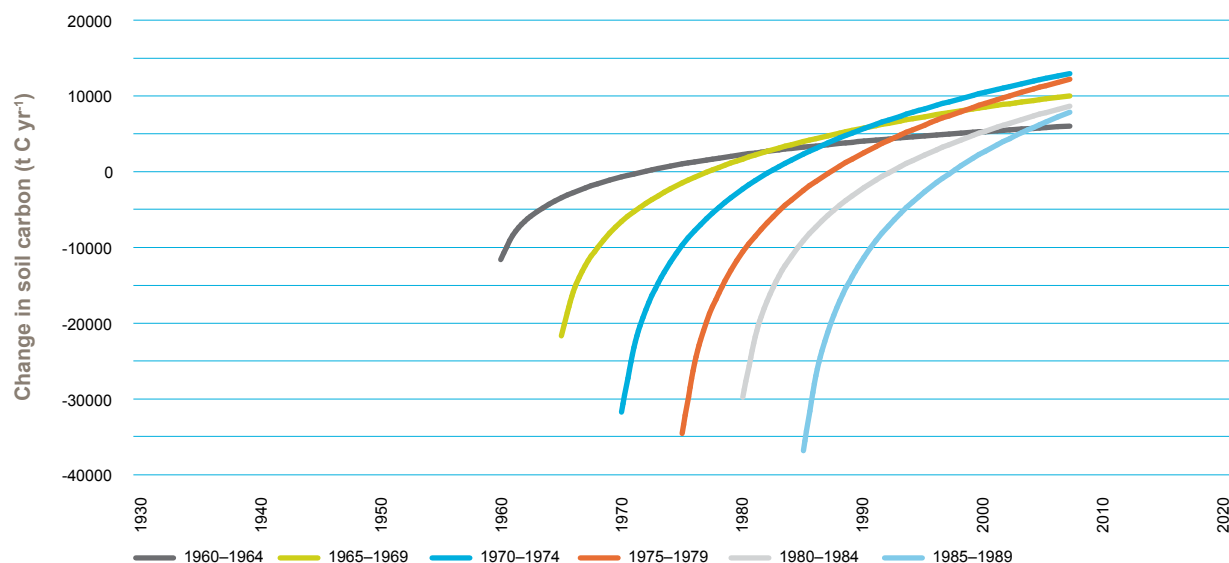


Figure 7.C2: Change in soil carbon (t C yr^{-1}) following plantation establishment from 1960 to 1989



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).

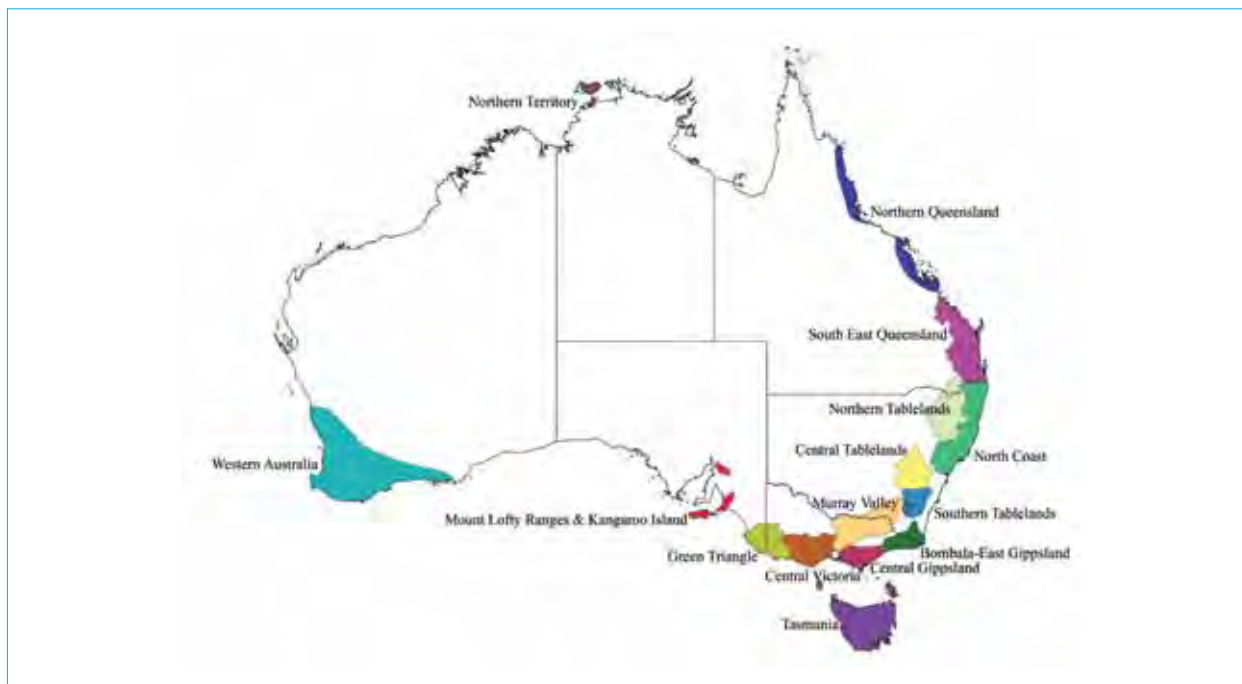
Allocations of the Short Rotation Hardwood (SRH), Long Rotation Hardwood (LRH) and Softwood (SW) classes are made to the region and species specific plantation models as described by Turner and James (2002).

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 |

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

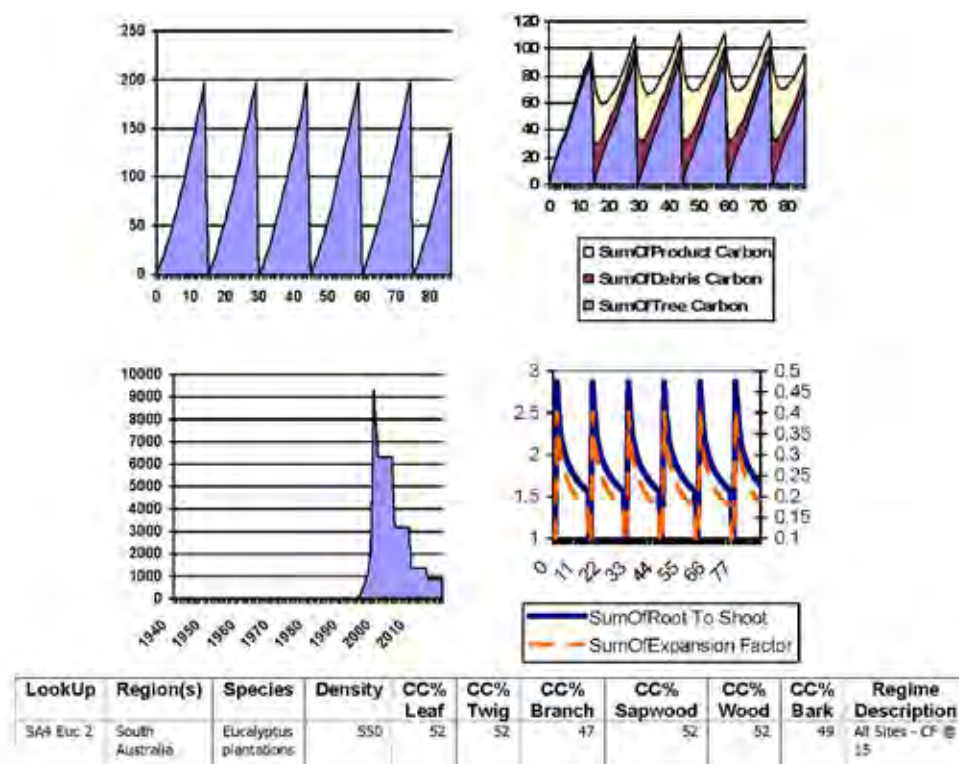
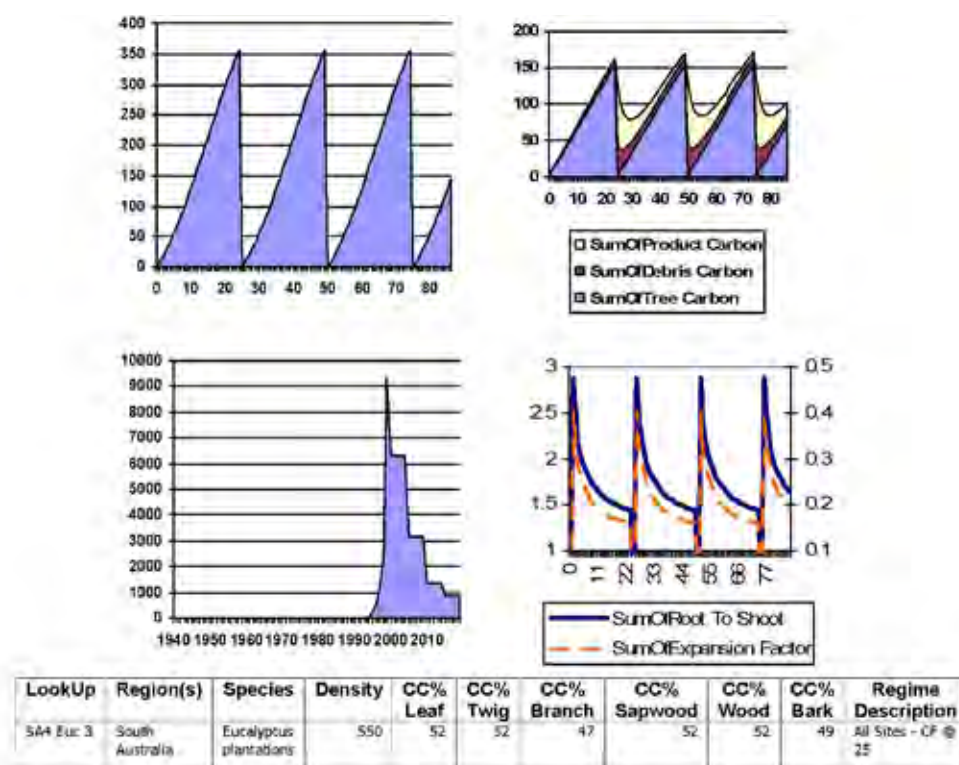
Figure 7.C3: The National Plantation Inventory regions

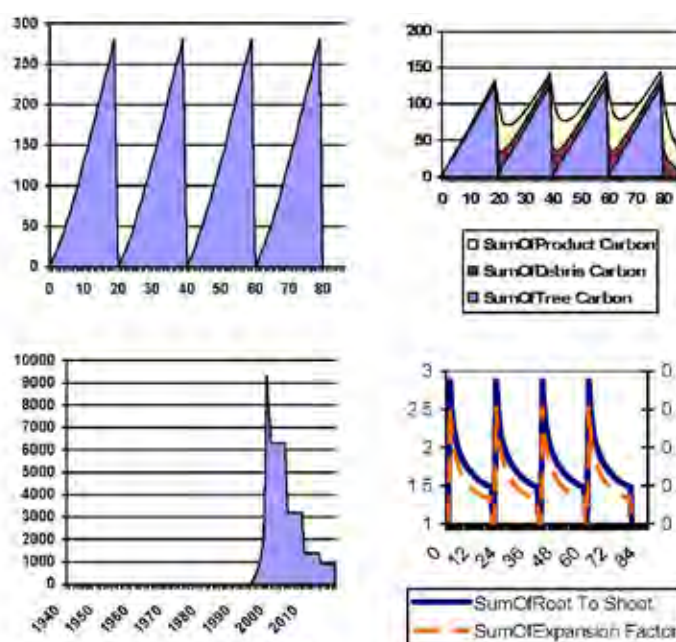


Calculations of total emissions and removals

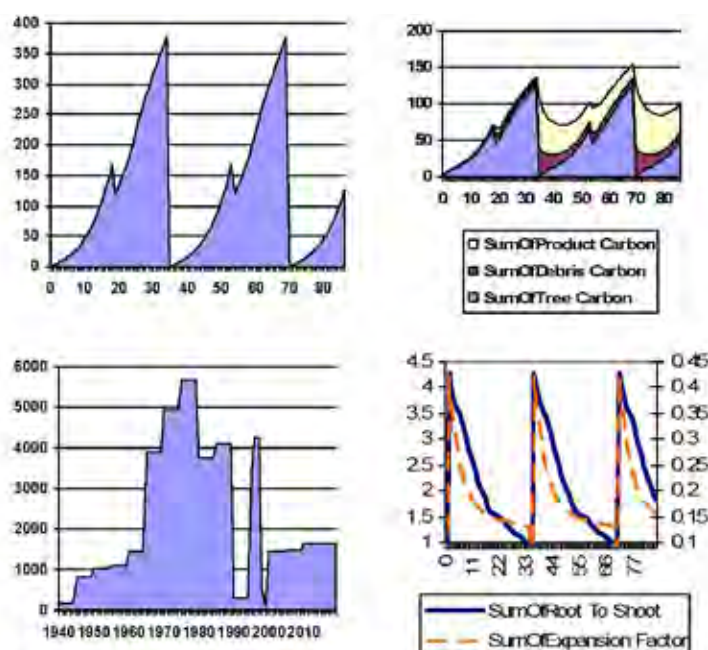
The 'Estate' module of *FullCAM* is used to scale each pre-1990 *plantation* model by the areas of each plantation type established over time. To do this the model interrogates the carbon balance for each plantation type at the relevant point in time to derive the overall account. The per hectare outcome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

Attachment 7.C1: Plantation Type Model Parameters and Outcomes

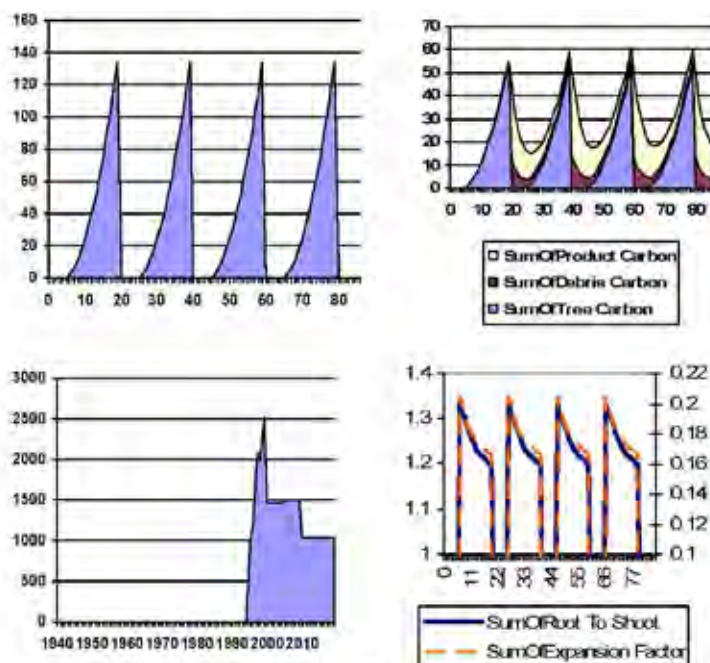




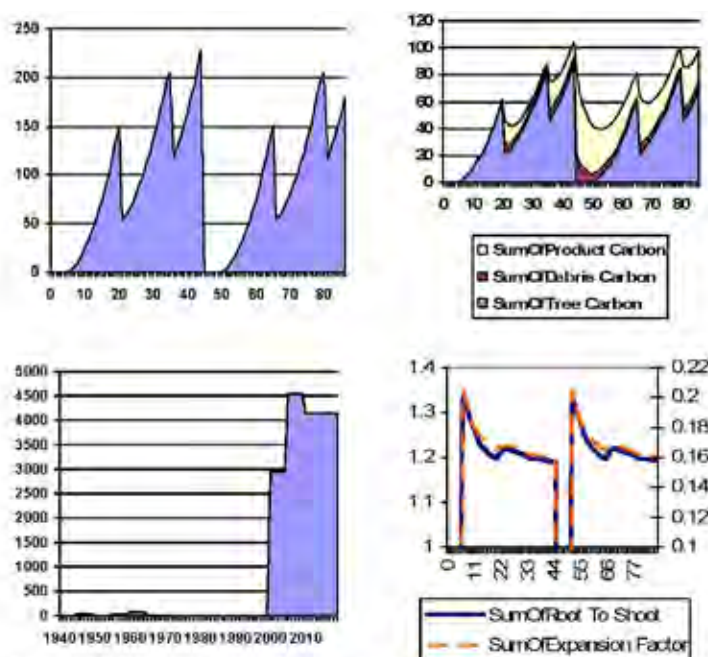
| LookUp | Region(s) | Species | Density | CC% Leaf | CC% Twlg | CC% Branch | CC% Sapwood | CC% Wood | CC% Bark | Regime Description |
|-----------|--------------------|---------------------------|---------|-------------|-------------|---------------|----------------|-------------|-------------|------------------------|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



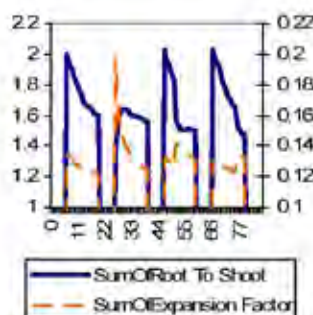
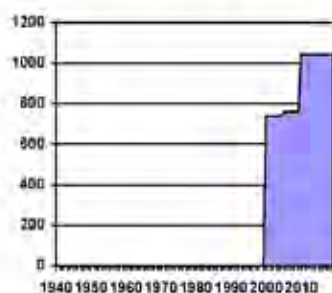
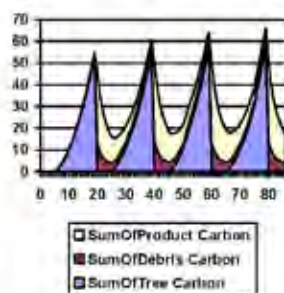
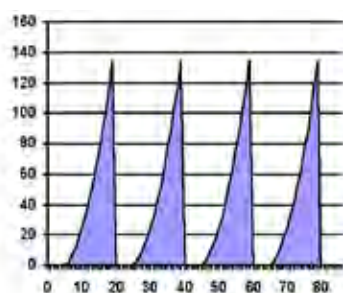
| LookUp | Region(s) | Species | Density | CC% Leaf | CC% Twlg | CC% Branch | CC% Sapwood | CC% Wood | CC% Bark | Regime Description |
|-------------------|------------|--|---------|-------------|-------------|---------------|----------------|-------------|-------------|---|
| Q61314 Strpine | Queensland | Southern Pine (<i>P. elliotii</i> , <i>P. brede</i> , <i>Asaucaia bunghamii</i>) | 440 | 52 | 52 | 51 | 51 | 52 | 53 | All Sites - 35% @ 18 years, CF @ 35 |



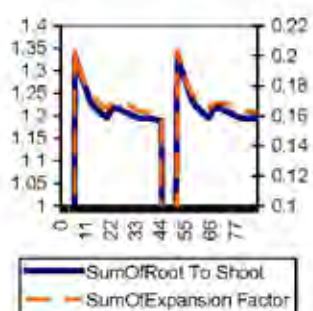
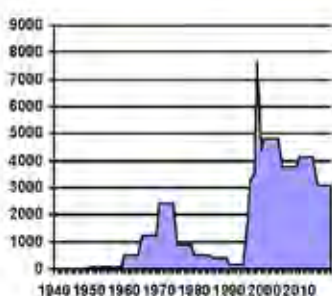
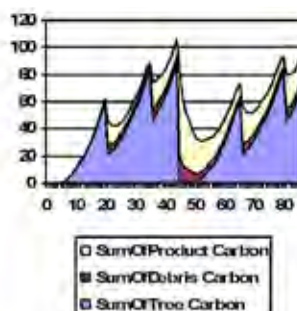
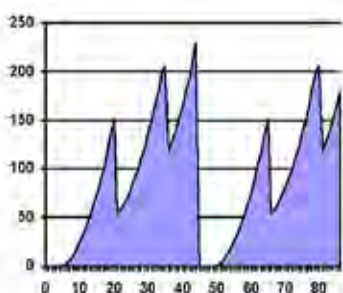
| LookUp | Region(s) | Species | Density | CC% Leaf | CC% Twig | CC% Branch | CC% Sapwood | CC% Wood | CC% Bark | Regime Description |
|------------------|------------|---------------------------|---------|-------------|-------------|---------------|----------------|-------------|-------------|------------------------|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



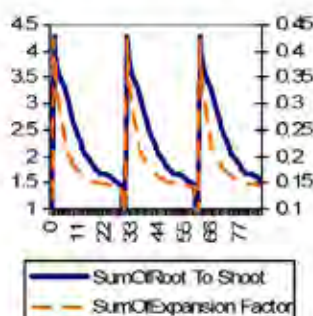
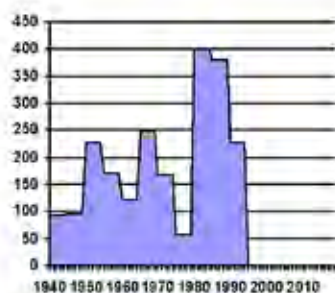
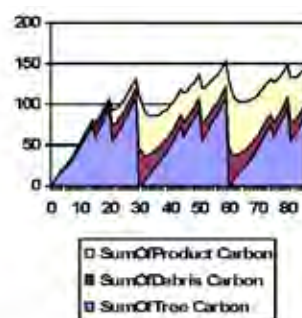
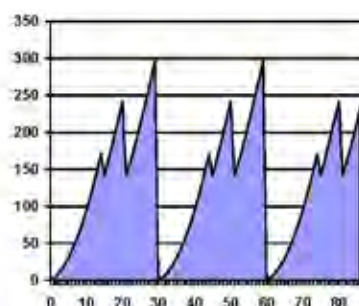
| LookUp | Region(s) | Species | Density | CC% Leaf | CC% Twig | CC% Branch | CC% Sapwood | CC% Wood | CC% Bark | Regime Description |
|------------------|------------|---------------------------|---------|-------------|-------------|---------------|----------------|-------------|-------------|--|
| Qld1314 Euc 4 | Queensland | Eucalyptus plantations | 550 | 52 | 52 | 47 | 52 | 52 | 49 | All Sites - 67% @ 30 years, 47% @ 35, CF @ 45 |



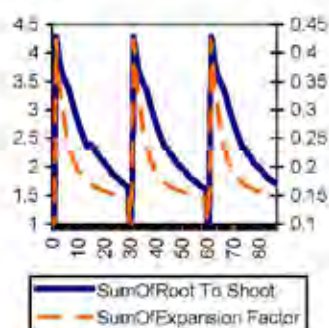
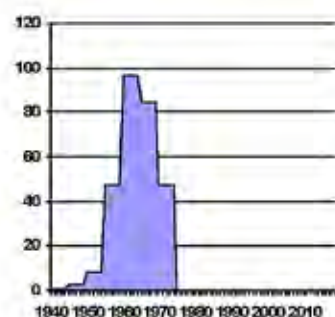
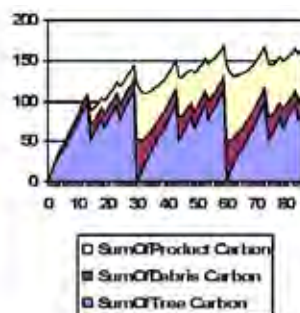
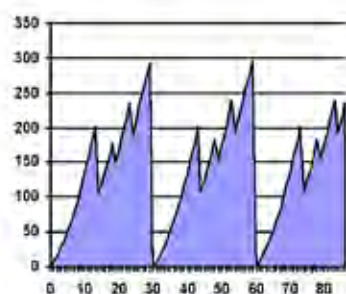
| LookUp | Region(s) | Species | Density | CC% Leaf | CC% Twig | CC% Branch | CC% Sapwood | CC% Wood | CC% Bark | Regime Description |
|---------------------|-----------|---------------------------|---------|-------------|-------------|---------------|----------------|-------------|-------------|------------------------|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



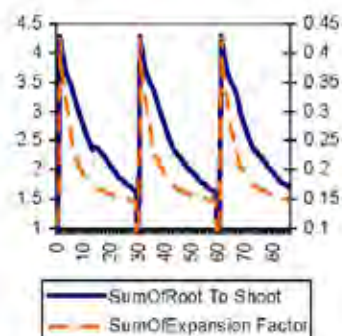
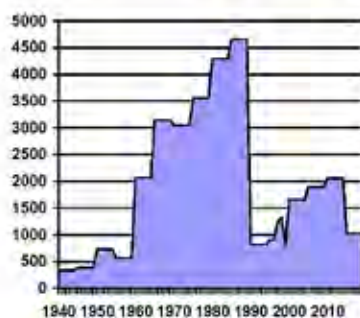
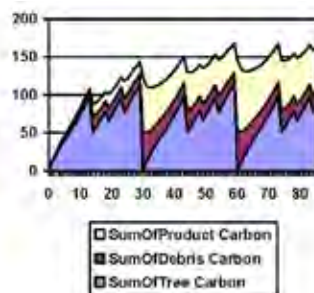
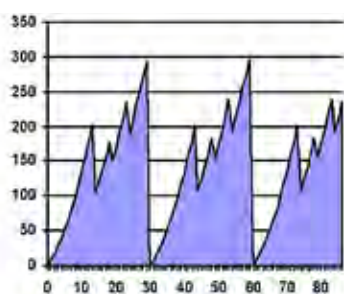
| LookUp | Region(s) | Species | Density | CC% Leaf | CC% Twig | CC% Branch | CC% Sapwood | CC% Wood | CC% Bark | Regime Description |
|---------------------|-----------|---------------------------|---------|-------------|-------------|---------------|----------------|-------------|-------------|--|
| NSW9101112 Euc 1 | NSW | Eucalyptus plantations | 550 | 52 | 52 | 47 | 52 | 52 | 49 | All Sites - 67% @ 20 years, 47% @ 25, CF @ 45 |



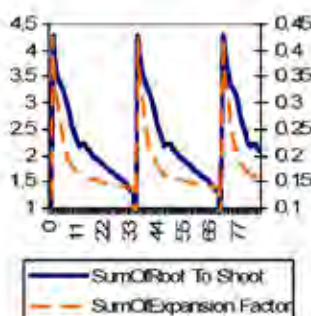
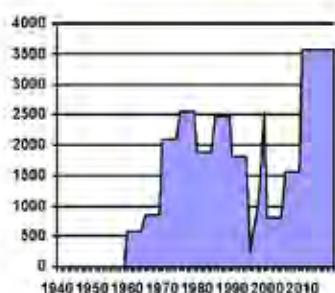
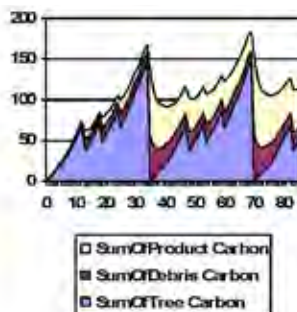
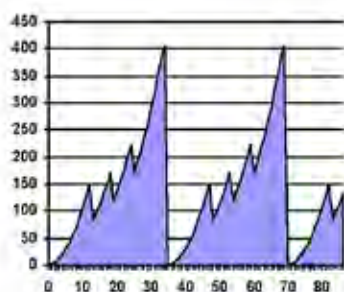
| LookUp | Region(s) | Species | Density | CC% Leaf | CC% Twig | CC% Branch | CC% Sapwood | CC% Wood | CC% Bark | Regime Description |
|--------------------|------------------------------|---|---------|-------------|-------------|---------------|----------------|-------------|-------------|--|
| NSW11 SH Pine 1 | NSW Northern Tableland | Southern Pine (<i>P. eliotii</i> , <i>P. lambii</i> , <i>Arucaria cunninghamii</i>) | 440 | 52 | 52 | 51 | 51 | 52 | 53 | Average Sites - 27% thinning @ 14 years, 47% @ 20, CF @ 30 |



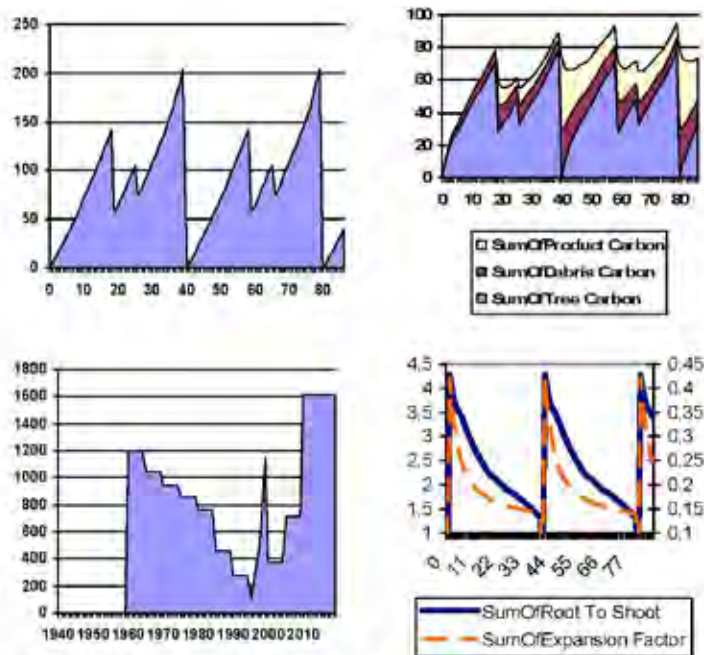
| LookUp | Region(s) | Species | Density | CC% Leaf | CC% Twig | CC% Branch | CC% Sapwood | CC% Wood | CC% Bark | Regime Description |
|------------------|-------------------|-------------------------------------|---------|-------------|-------------|---------------|----------------|-------------|-------------|---|
| GmTn3 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 |



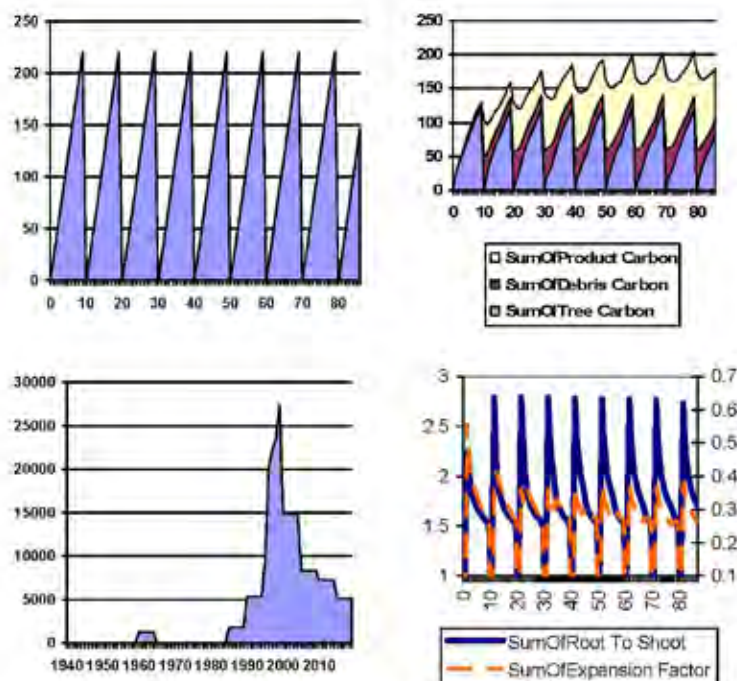
| LookUp | Region(s) | Species | Density | CC% Leaf | CC% Twig | CC% Branch | CC% Sapwood | CC% Wood | CC% Bark | Regime Description |
|------------------|-------------------|--------------------------|---------|-------------|-------------|---------------|----------------|-------------|-------------|---|
| GmTr3 P-rad 1 | Green Triangle | <i>Pinus radiata</i> | 440 | 52 | 52 | 51 | 51 | 52 | 53 | Average Sites - 54% thinning @ 13 years, 25% @ 15, 28% @ 23, CF @ 30 |



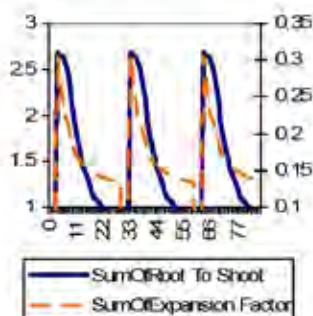
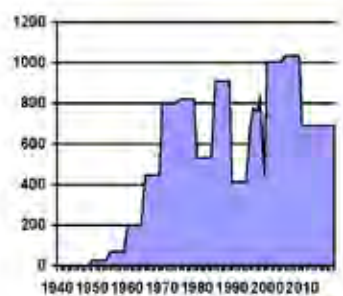
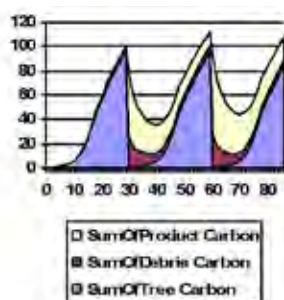
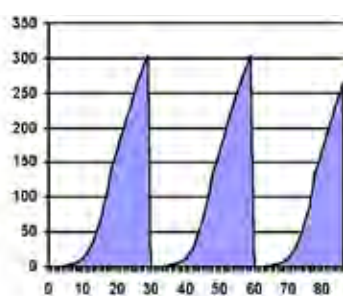
| LookUp | Region(s) | Species | Density | CC% Leaf | CC% Twig | CC% Branch | CC% Sapwood | CC% Wood | CC% Bark | Regime Description |
|----------------|---------------------|--------------------------|---------|-------------|-------------|---------------|----------------|-------------|-------------|---|
| WA1 P-rad 1 | Wester Australia | <i>Pinus radiata</i> | 440 | 52 | 52 | 51 | 51 | 52 | 53 | Average Sites - 51% thinning @ 12 years, 39% @ 15, 32% @ 24, CF @ 35 |



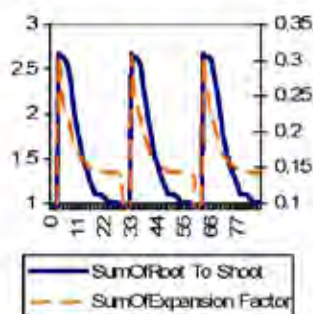
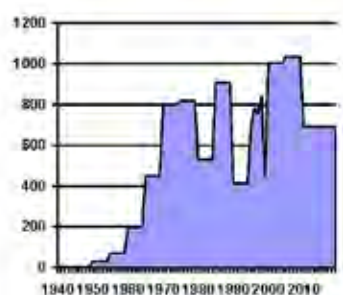
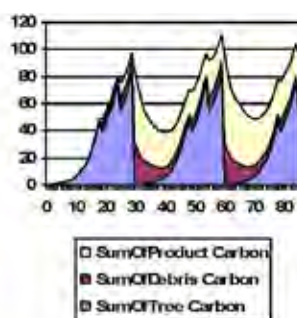
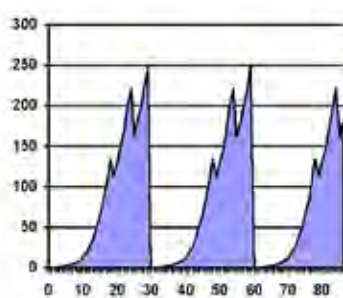
| LookUp | Region(s) | Species | Density | CC% Leaf | CC% Twig | CC% Branch | CC% Sapwood | CC% Wood | CC% Bark | Regime Description |
|--------------|-------------------|-----------------------|---------|-------------|-------------|---------------|----------------|-------------|-------------|--|
| WA1 F, pin 1 | Western Australia | <i>Pinus pinaster</i> | 470 | 52 | 52 | 51 | 51 | 52 | 53 | Average Sites - 65% thinning @ 18 years, 37% @ 25, CF @ 40 |



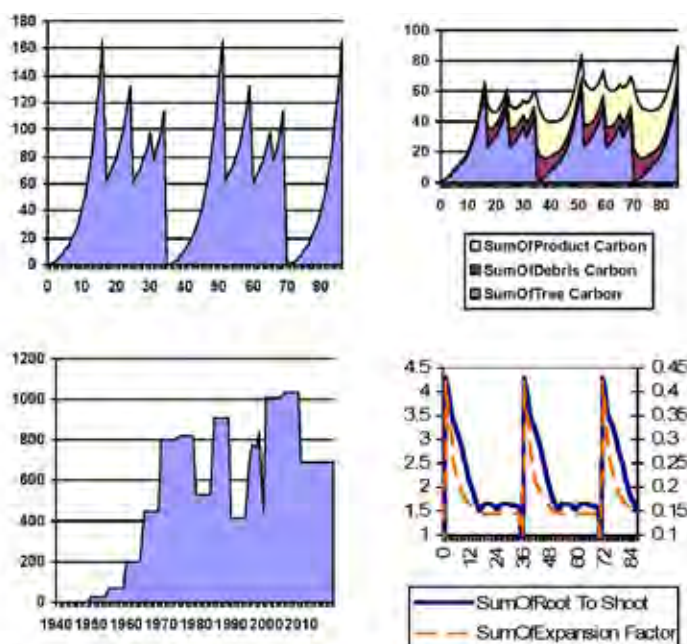
| LookUp | Region(s) | Species | Density | CC% Leaf | CC% Twig | CC% Branch | CC% Sapwood | CC% Wood | CC% Bark | Regime Description |
|---------------|-------------------|----------------------------|---------|-------------|-------------|---------------|----------------|-------------|-------------|-----------------------|
| WA1 E, glob 1 | Western Australia | <i>Eucalyptus globulus</i> | 550 | 52.8 | 49.8 | 47 | 48.7 | 50.7 | 49 | Clear fall @ 10 |



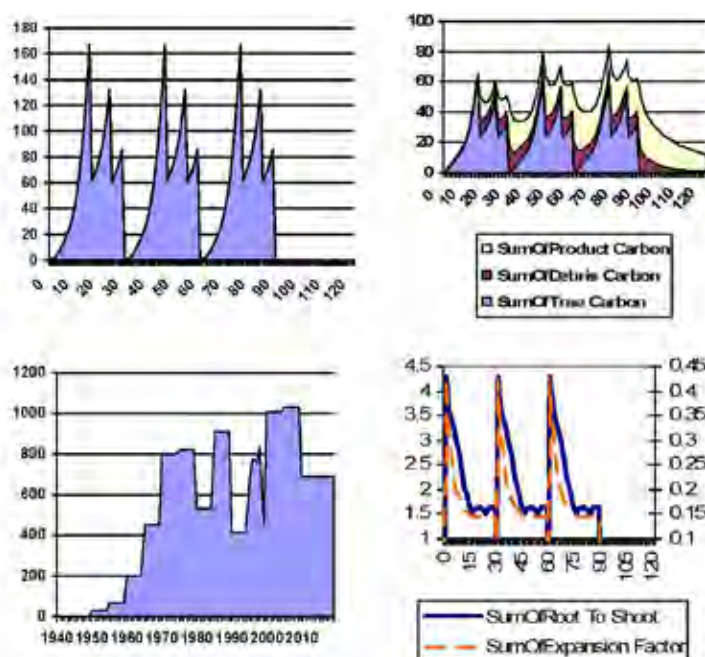
| LookUp | Region(s) | Species | Density | CC% Leaf | CC% Twig | CC% Branch | CC% Sapwood | CC% Wood | CC% Bark | Regime Description |
|------------------------|---------------------|----------------------|---------|-------------|-------------|---------------|----------------|-------------|-------------|-------------------------------|
| VicNSW891011 Prod 6 | Victoria and NSW | <i>Pinus radiata</i> | 440 | 52 | 52 | 51 | 51 | 52 | 53 | Poor Sites - CF @ 30 years |



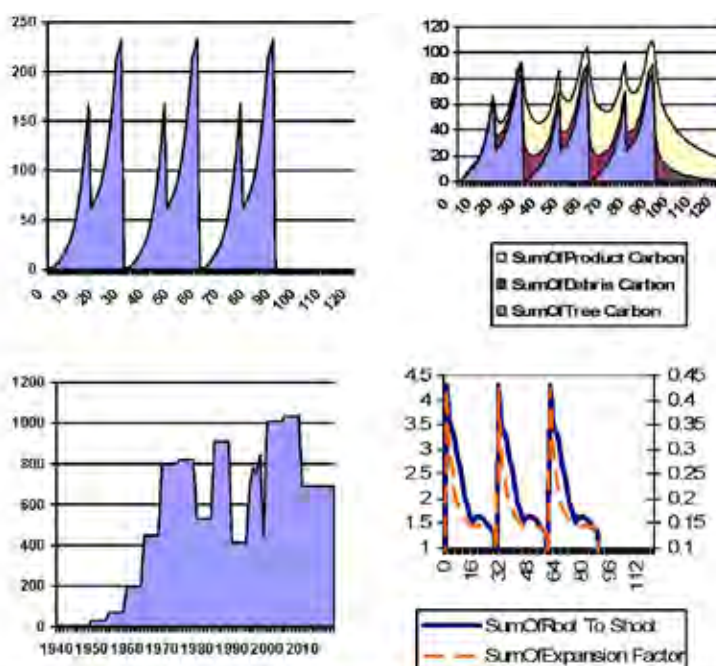
| LookUp | Region(s) | Species | Density | CC% Leaf | CC% Twig | CC% Branch | CC% Sapwood | CC% Wood | CC% Bark | Regime Description |
|------------------------|---------------------|----------------------|---------|-------------|-------------|---------------|----------------|-------------|-------------|---|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



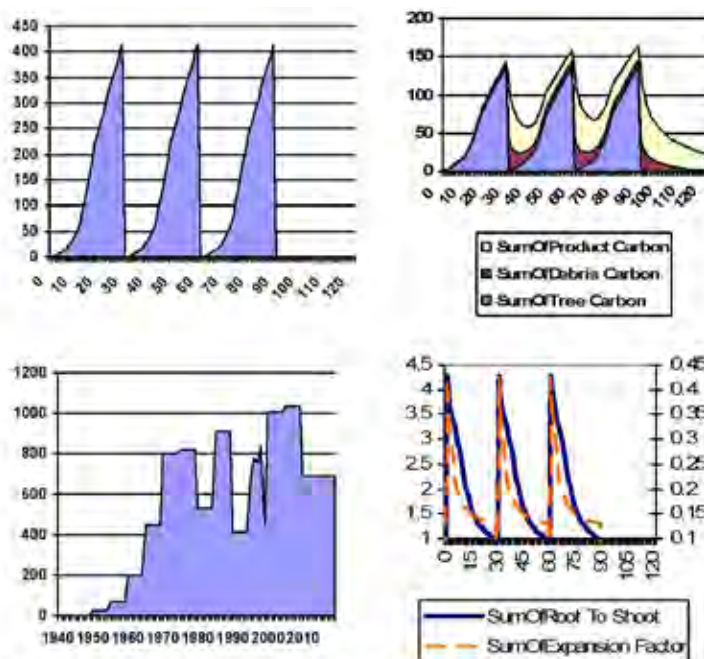
| LookUp | Region(s) | Species | Density | CC% Leaf | CC% Twig | CC% Branch | CC% Sapwood | CC% Wood | CC% Bark | Regime Description |
|-------------------------|---------------------|--------------------------|---------|-------------|-------------|---------------|----------------|-------------|-------------|---|
| VicNSW891011 Pinel 4 | Victoria and NSW | <i>Pinus radiata</i> | 440 | 52 | 52 | 51 | 51 | 52 | 52 | Average Sizes - 65% thinning @ 16 years, 57% @ 24, 27% @ 30, CF @ 35 |



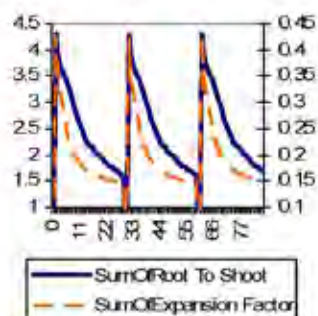
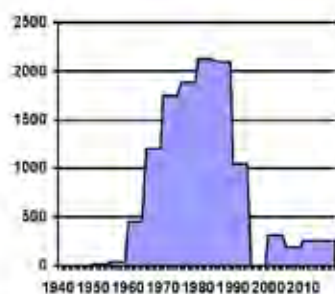
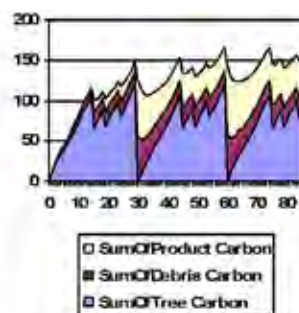
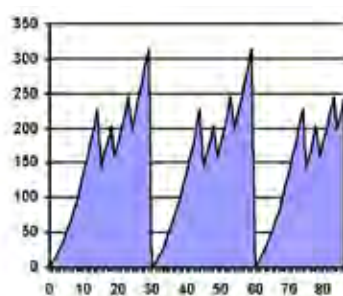
| LookUp | Region(s) | Species | Density | CC% Leaf | CC% Twig | CC% Branch | CC% Sapwood | CC% Wood | CC% Bark | Regime Description |
|-------------------------|---------------------|--------------------------|---------|-------------|-------------|---------------|----------------|-------------|-------------|--|
| VicNSW891011 Pinel 3 | Victoria and NSW | <i>Pinus radiata</i> | 440 | 52 | 52 | 51 | 51 | 52 | 52 | Average Sizes - 65% thinning @ 16 years, 57% @ 24, CF @ 30 |



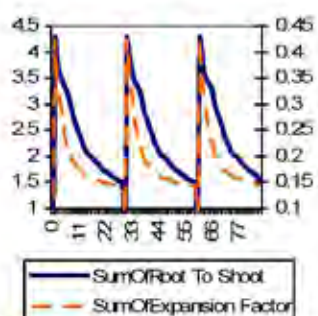
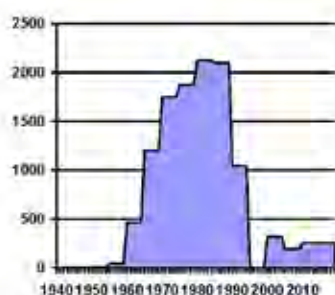
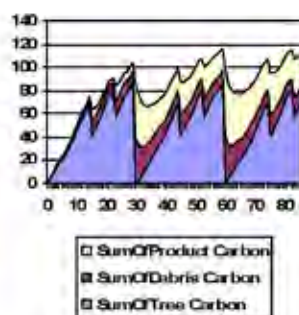
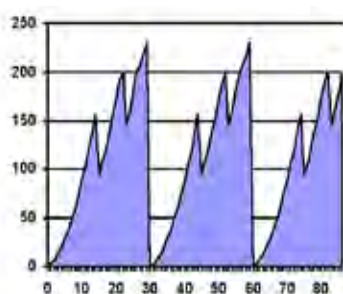
| LookUp | Region(s) | Species | Density | CC% Leaf | CC% Twig | CC% Branch | CC% Sapwood | CC% Wood | CC% Bark | Regime Description |
|------------------------|---------------------|--------------------------|---------|-------------|-------------|---------------|----------------|-------------|-------------|---|
| VicNSW891011 Prod 1 | Victoria and NSW | <i>Pinus radiata</i> | 440 | 52 | 52 | 51 | 51 | 52 | 53 | Average Sites - 65% thinning @ 16 years, CF @ 30 |



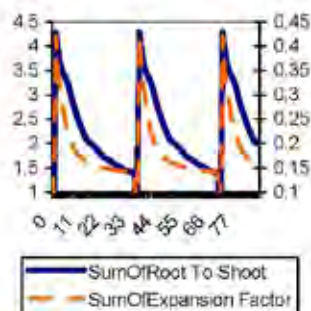
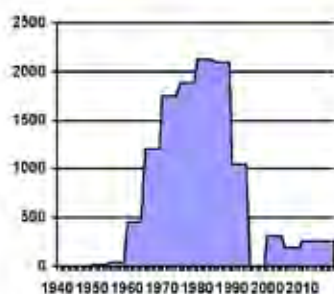
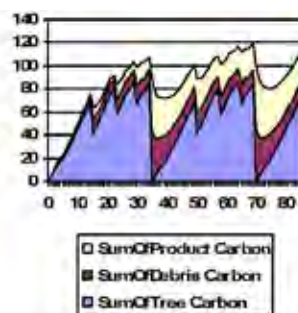
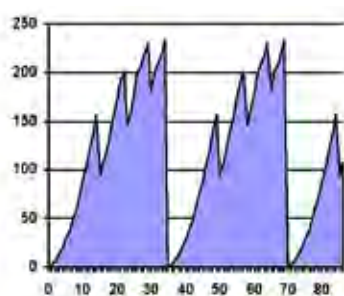
| LookUp | Region(s) | Species | Density | CC% Leaf | CC% Twig | CC% Branch | CC% Sapwood | CC% Wood | CC% Bark | Regime Description |
|------------------------|---------------------|--------------------------|---------|-------------|-------------|---------------|----------------|-------------|-------------|----------------------------------|
| VicNSW891011 Prod 1 | Victoria and NSW | <i>Pinus radiata</i> | 440 | 52 | 52 | 51 | 51 | 52 | 53 | Average Sites - CF @ 30 years |



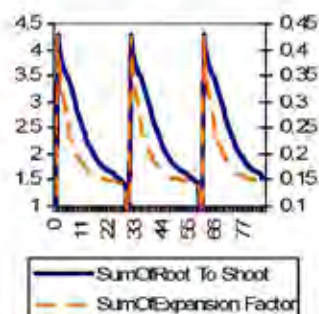
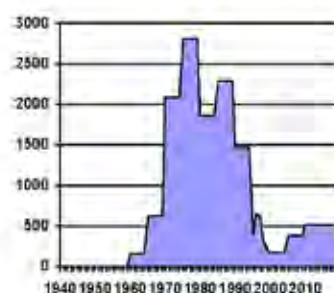
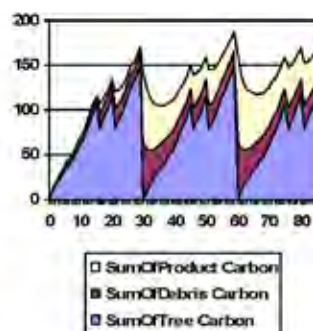
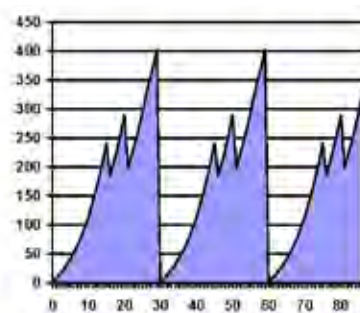
| LookUp | Region(s) | Species | Density | CC% Leaf | CC% Twig | CC% Branch | CC% Sapwood | CC% Wood | CC% Bark | Regime Description |
|-------------------|------------------|--------------------------|---------|-------------|-------------|---------------|----------------|-------------|-------------|---|
| VicNSW6 Prod 3 | Murray Valley | <i>Pinus radiata</i> | 440 | 52 | 52 | 51 | 51 | 52 | 53 | Very Good Sites - 44% thinning @ 14 years, 21% @ 18, 27% @ 23, CF @ 30 |



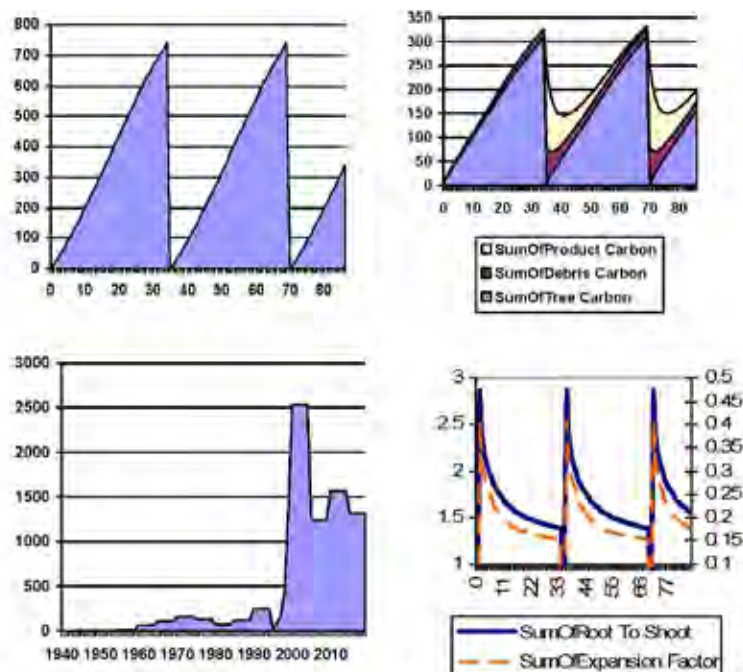
| LookUp | Region(s) | Species | Density | CC% Leaf | CC% Twig | CC% Branch | CC% Sapwood | CC% Wood | CC% Bark | Regime Description |
|-------------------|------------------|--------------------------|---------|-------------|-------------|---------------|----------------|-------------|-------------|--|
| VicNSW6 Prod 2 | Murray Valley | <i>Pinus radiata</i> | 440 | 52 | 52 | 51 | 51 | 52 | 53 | Average Sites - 57% thinning @ 14 years, 35% @ 22, CF @ 30 |



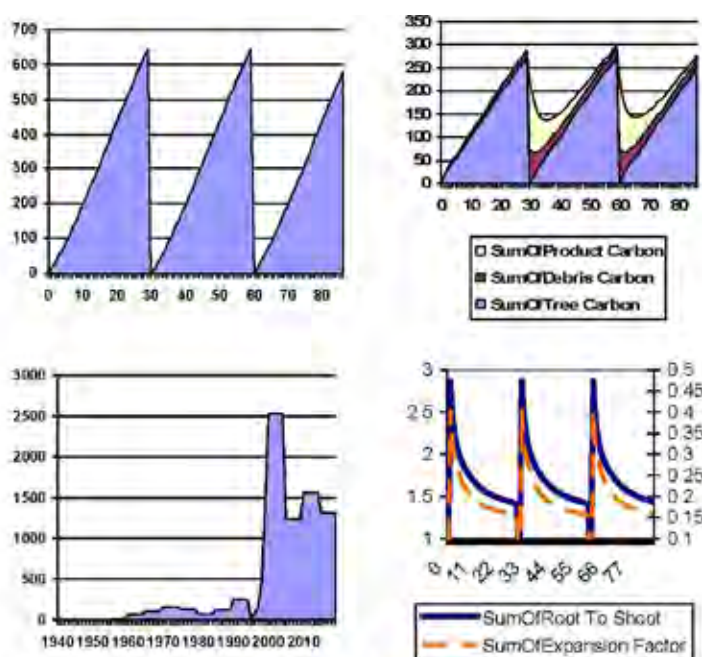
| LookUp | Region(s) | Species | Density | CC% Leaf | CC% Twig | CC% Branch | CC% Sapwood | CC% Wood | CC% Bark | Regime Description |
|--------------------|------------------|--------------------------|---------|-------------|-------------|---------------|----------------|-------------|-------------|--|
| VicNSW6 P.red 2 | Murray Valley | <i>Pinus radiata</i> | 440 | 52 | 52 | 51 | 51 | 52 | 53 | Average Sites - 47% thinning @ 15 years, 35% @ 22, CF @ 30 |



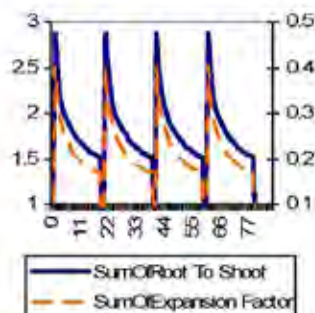
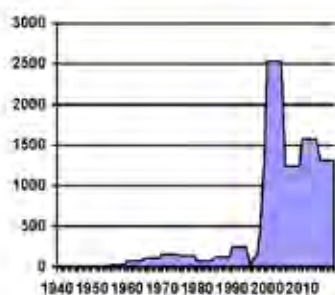
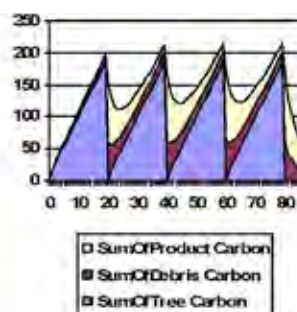
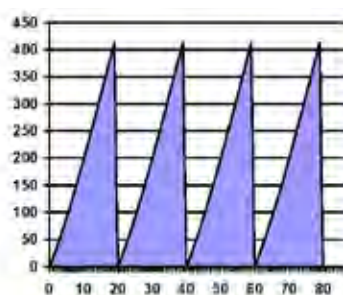
| LookUp | Region(s) | Species | Density | CC% Leaf | CC% Twig | CC% Branch | CC% Sapwood | CC% Wood | CC% Bark | Regime Description |
|-----------------|------------------------------------|--------------------------|---------|-------------|-------------|---------------|----------------|-------------|-------------|--|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



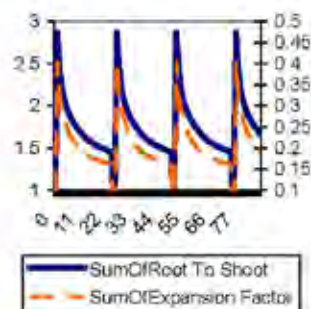
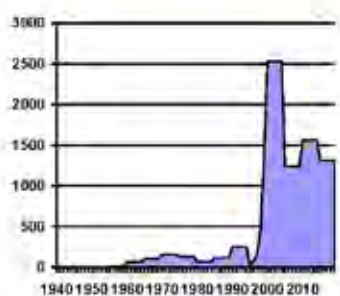
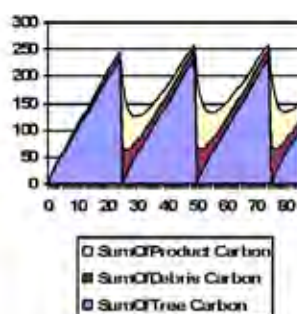
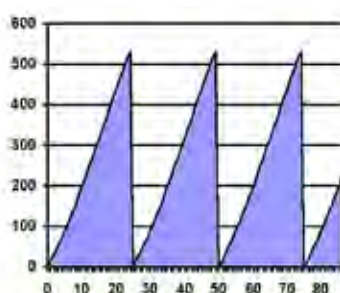
| LookUp | Region(s) | Species | Density | CC% Leaf | CC% Twig | CC% Branch | CC% Sapwood | CC% Wood | CC% Bark | Regime Description |
|------------|------------------------------------|---------------------------|---------|-------------|-------------|---------------|----------------|-------------|-------------|------------------------|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



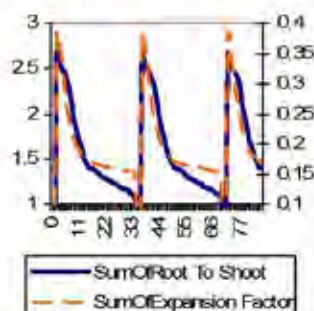
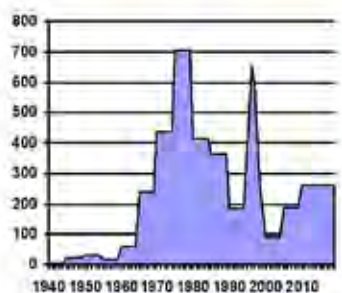
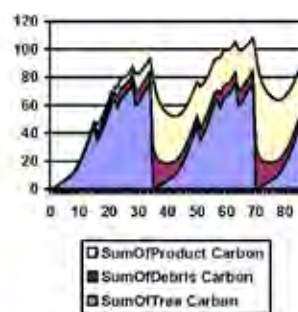
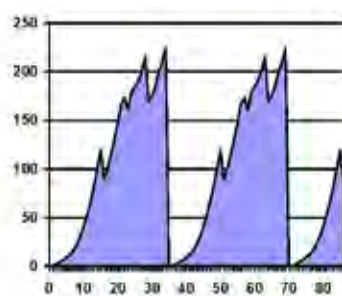
| LookUp | Region(s) | Species | Density | CC% Leaf | CC% Twig | CC% Branch | CC% Sapwood | CC% Wood | CC% Bark | Regime Description |
|------------|------------------------------------|---------------------------|---------|-------------|-------------|---------------|----------------|-------------|-------------|------------------------|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



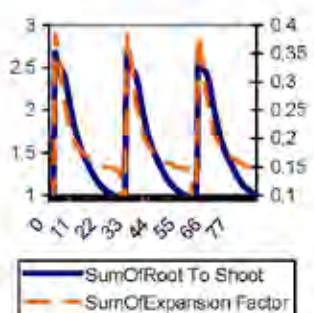
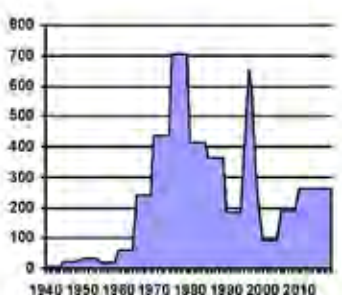
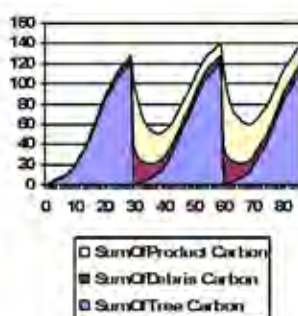
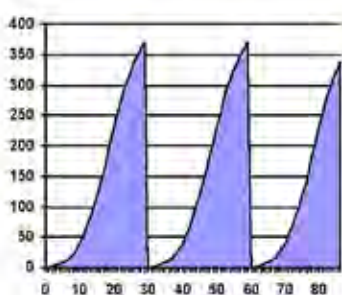
| LookUp | Region(s) | Species | Density | CC% Leaf | CC% Twig | CC% Branch | CC% Sapwood | CC% Wood | CC% Bark | Regime Description |
|------------|------------------------------------|---------------------------|---------|-------------|-------------|---------------|----------------|-------------|-------------|------------------------|
| Yic7 Euc 2 | Victoria (Central Gippsland) | Eucalyptus plantations | 550 | 52 | 52 | 47 | 52 | 52 | 49 | All Sites - CF @ 20 |



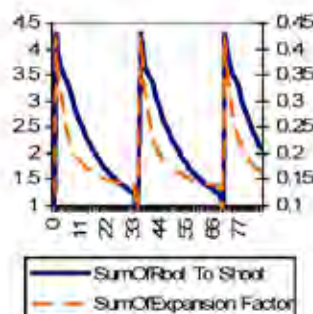
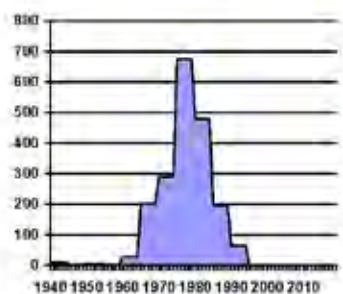
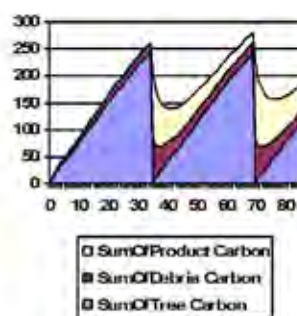
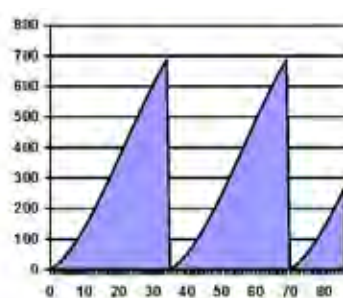
| LookUp | Region(s) | Species | Density | CC% Leaf | CC% Twig | CC% Branch | CC% Sapwood | CC% Wood | CC% Bark | Regime Description |
|------------|------------------------------------|---------------------------|---------|-------------|-------------|---------------|----------------|-------------|-------------|------------------------|
| Yic7 Euc 1 | Victoria (Central Gippsland) | Eucalyptus plantations | 550 | 52 | 52 | 47 | 52 | 52 | 49 | All Sites - CF @ 25 |



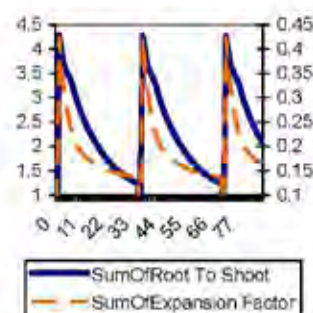
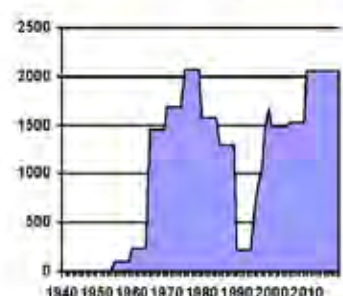
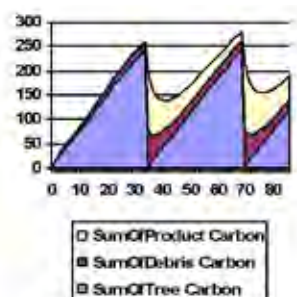
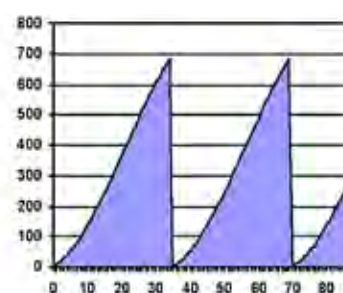
| LookUp | Region(s) | Species | Density | CC% Leaf | CC% Twig | CC% Branch | CC% Sapwood | CC% Wood | CC% Bark | Regime Description |
|-----------------|-----------------------|--------------------------|---------|-------------|-------------|---------------|----------------|-------------|-------------|----------------------------|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



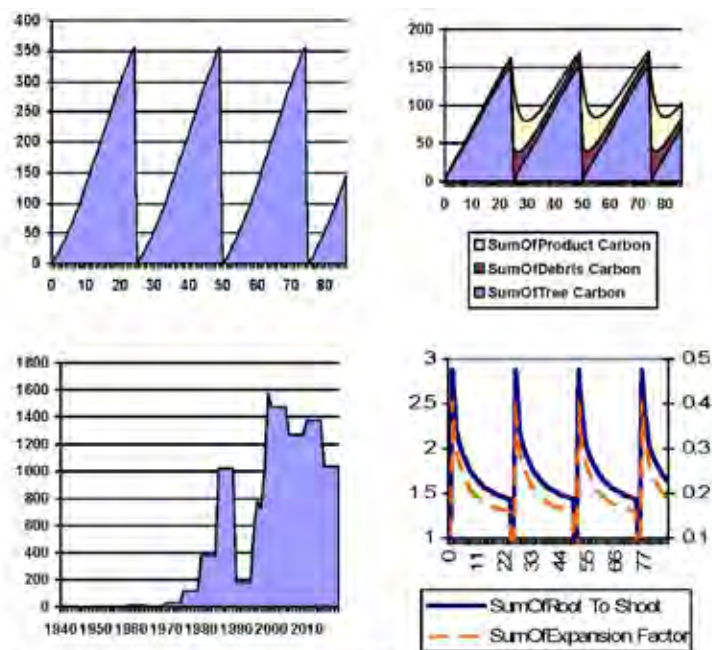
| LookUp | Region(s) | Species | Density | CC% Leaf | CC% Twig | CC% Branch | CC% Sapwood | CC% Wood | CC% Bark | Regime Description |
|-----------------|-----------------------|--------------------------|---------|-------------|-------------|---------------|----------------|-------------|-------------|--|
| Vic5 P.rad 1 | Victoria (Central) | <i>Pinus radiata</i> | 440 | 52 | 52 | 51 | 51 | 52 | 53 | Average Sites - 34% burning @ 15 years, 18% @ 22, 24% @ 30, CF @ 35 |



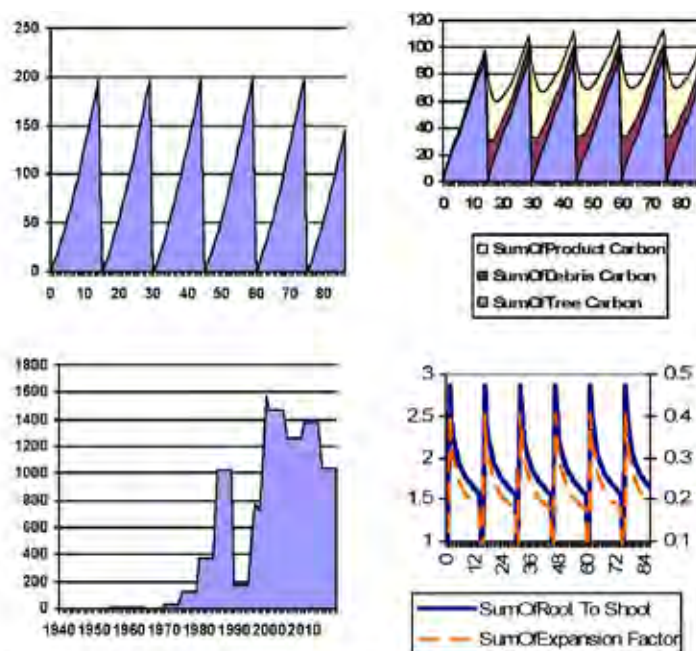
| LookUp | Region(s) | Species | Density | CC% Leaf | CC% Twig | CC% Branch | CC% Sapwood | CC% Wood | CC% Bark | Regime Description |
|-----------------|-----------|-------------------------------------|---------|-------------|-------------|---------------|----------------|-------------|-------------|------------------------|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



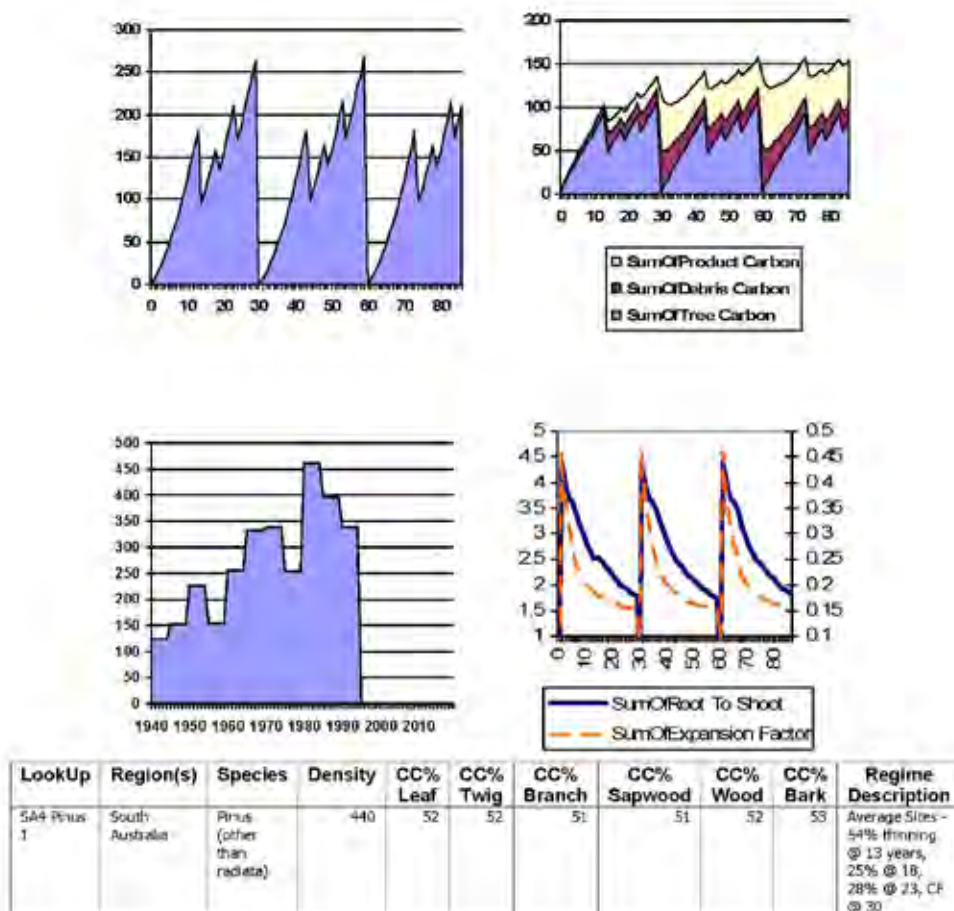
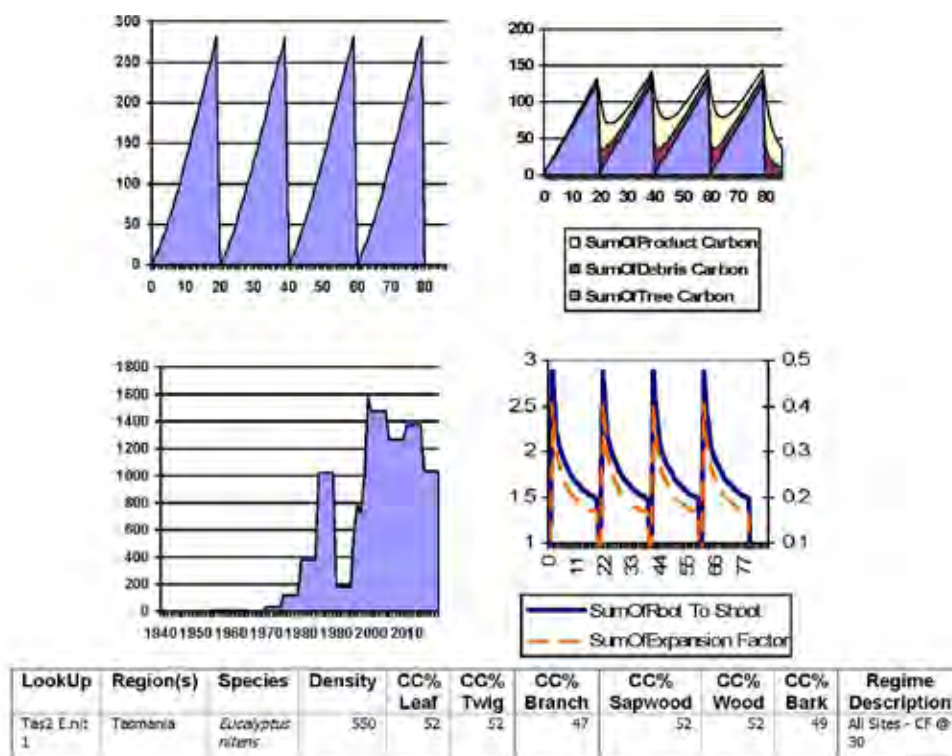
| LookUp | Region(s) | Species | Density | CC% Leaf | CC% Twig | CC% Branch | CC% Sapwood | CC% Wood | CC% Bark | Regime Description |
|-----------------|-----------|------------------|---------|-------------|-------------|---------------|----------------|-------------|-------------|----------------------------|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



| LookUp | Region(s) | Species | Density | CC% Leaf | CC% Twig | CC% Branch | CC% Sapwood | CC% Wood | CC% Bark | Regime Description |
|-----------------|-----------|--------------------------|---------|-------------|-------------|---------------|----------------|-------------|-------------|-----------------------|
| Tas2 E.nit 3 | Tasmania | <i>Eucalyptus nitens</i> | 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 | <i>Eucalyptus nitens</i> | 550 | 52 | 52 | 47 | 52 | 52 | 49 | All Sites - CF @ 15 |



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 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. The modelling methods and calibration have been published in the peer-reviewed literature (Waterworth et al., 2007, Waterworth and Richards, 2008)

Growth modelling and Management

Forest growth model

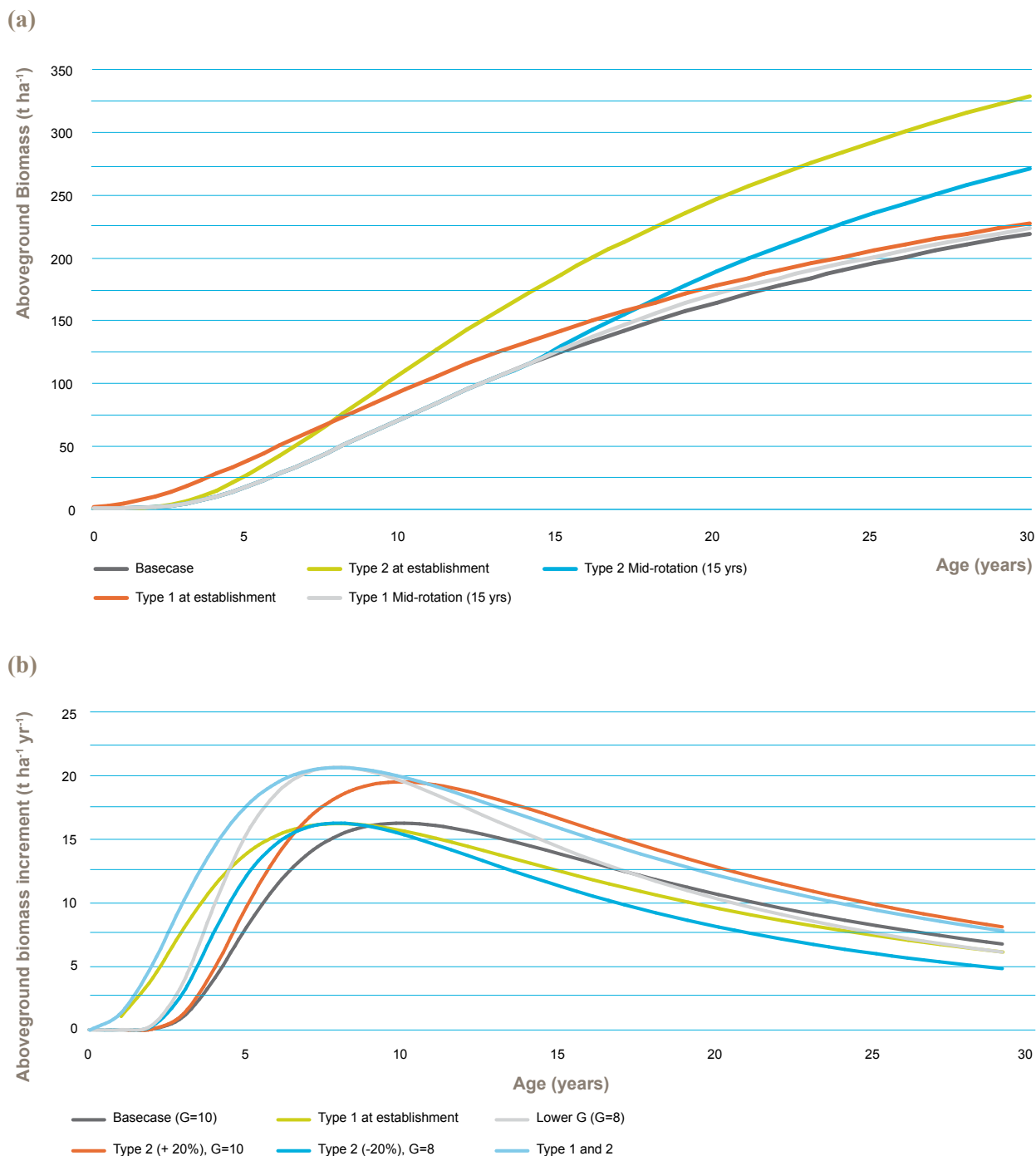
Understanding spatial and temporal variation in forest growth is important to developing accurate carbon accounts. Rainfall, temperature and soil fertility are significant determinants of the potential total biomass carrying capacity and the rate at which the forest approaches carrying capacity. Growth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

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

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

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

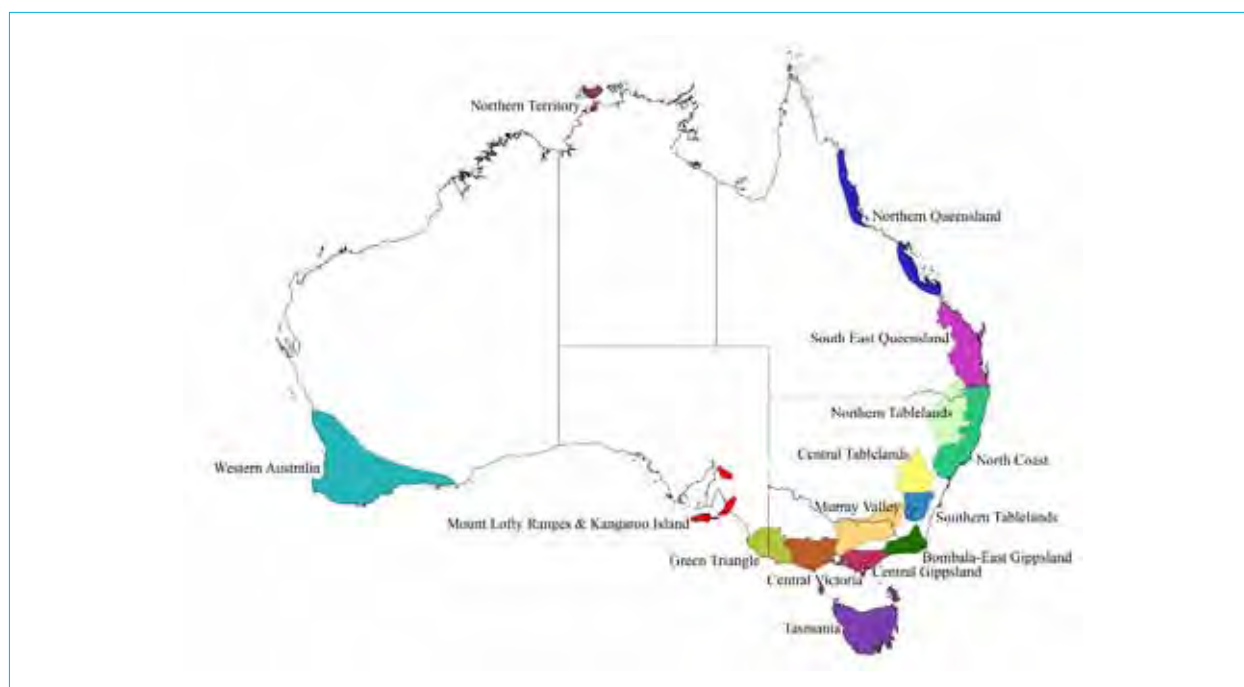
Figure 7.D1: Effect of Type 1 and Type 2 management practices on (a) cumulative and (b) annual growth



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

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

Figure 7.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. Regional long-term forest productivity index values of plantation areas in each National Plantation Inventory (NPI) region and State were determined by overlaying the long-term forest productivity index (P) spatial data, with areas of hardwood and softwood plantation as identified by the plantation type mapping from the 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), Snowden 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 Snowden 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 $12 \text{ m}^3 \text{ ha}^{-1} \text{ yr}^{-1}$, (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 $30 \text{ m}^3 \text{ ha}^{-1} \text{ yr}^{-1}$ in long rotation systems and $35 \text{ m}^3 \text{ ha}^{-1} \text{ yr}^{-1}$ 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 but *P. pinaster* is commonly established in low rainfall areas), the P for the dominant species was set values from regions with similar species and conditions, with the other species ranging from the minimum P value to the lowest P value of the dominant species. The MAVI and P data used for calibrating r are shown in Table 7.D1.

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

Table 7.D1: Range of FPI (*P*) values on which plantation types occur, the minimum, average and maximum growth rates (Mean Annual Volume Increment, m³ ha⁻¹ yr⁻¹) and rotation length

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

$$r = (\text{MAVI} \times \text{Rotation Length} \times \text{Basic Density} \times \text{Expansion Factor}) / M \dots \dots \dots (\text{Equation 1})$$

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.

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

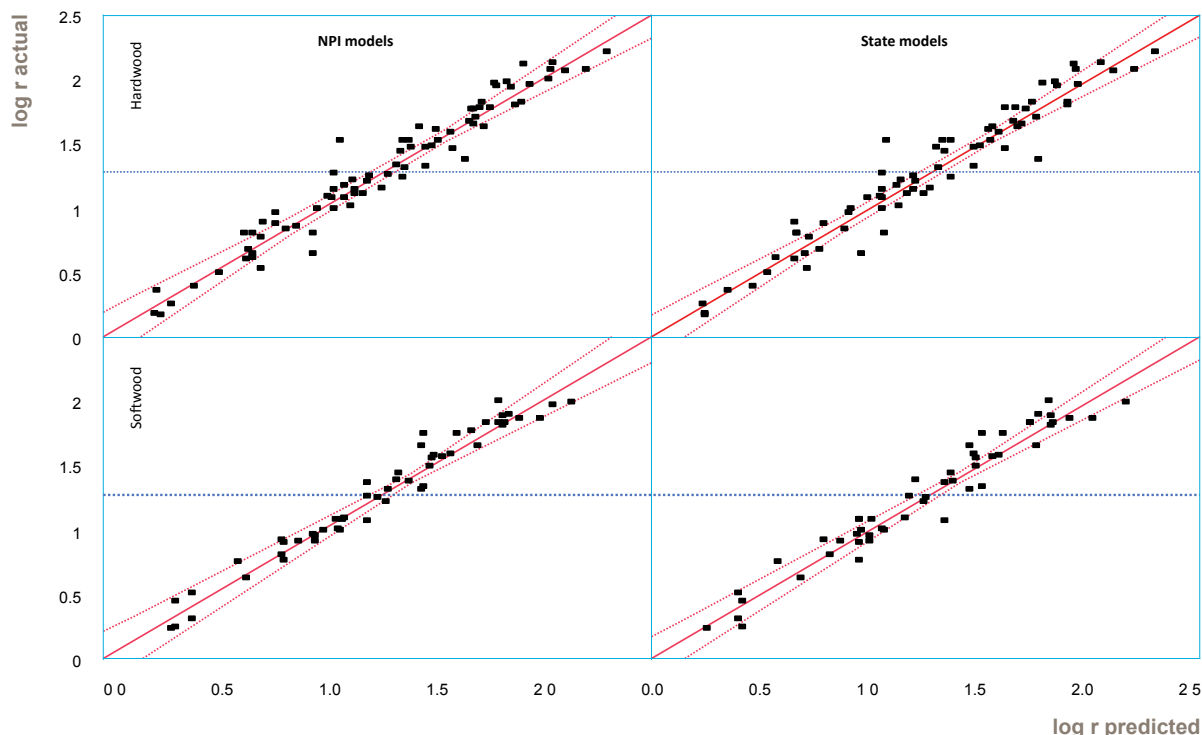
where *r* = non-endemic species multiplier

*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 ($\text{Max } I_B$) varies with species, site productivity and management. The age of $\text{Max } I_B$ 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 $\text{Max } I_B$ occurs at or around the time of canopy closure (Gower *et al.*, 1994; Ryan *et al.*, 1997; Law *et al.*, 2003). For the purpose of calibrating the model this was assumed to be the case.

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

In *FullCAM* the age of maximum biomass increment can be modified through direct manipulation of G or through applying Type 1 effects prior to G (see Appendix 7.A; Equation 5). Varying G affects both the age and magnitude of $\text{Max } I_B$. Where a Type 1 response is applied prior to G (i.e. between ages 0 and G), the effective age of $\text{Max } I_B$ 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 $\text{Max } I_B$ and the sum of Type 1 effects on early age growth due to management (Equation 3):

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

G_{man} = age of maximum biomass increment with management

G = age of maximum biomass increment assuming no management

$Tl_{\text{pre-g}}$ = sum of the Type 1 age advance events applied prior to G

For native ecosystems an age of maximum current annual growth increment (CAI) of 10 years is applied. Many commercial plantations are managed for aggressive early growth that shortens the period to harvest, thereby increasing economic gain. This is most evident in short rotation (approximately 10 year) pulpwood plantations. Silviculture, in particular a dense stocking rate of trees per hectare, is used to supply this early growth. In some instances this can bring the age of maximum current annual increment to being as low as 2-3 years after establishment. Each plantation type/management regime combination is assigned a specific age of maximum current annual increment based on location.

Calibration of G

Values for G were calibrated for each species within each NPI region based on rotation length and the approximate sum of Type 1 effects at planting. Canopy closure (effectively G_{man} in the model) in *P. radiata* plantations established over the last 20 years generally occurs between the ages of 7 and 12 years depending on site quality and management (Snowdon and James 2008). On poor quality sites with little management or site improvement it may take even longer. Improved establishment and early age management practices adopted in the last 20 to 30 years, in particular after the late 1970's, have reduced the age of canopy closure by about 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. However G_{man} does vary by region and time depending on management practices. Long-rotation eucalypt plantations are still relatively uncommon and little is known about their future management and prospects. Given the paucity of data it was assumed that long-rotation eucalypt plantations are similar in management to other long rotation systems, although they may reach canopy closure slightly earlier depending on growth conditions, as discussed below. To account for the effect of site productivity on G a simple linear relationship between G and M was included (Equation 4). The results of the calibration are shown in Waterworth *et al.*, (2007).

Canopy closure tends to occur much earlier in short rotation plantations due to species characteristics, higher stocking rates, more intensive management and better site/species matching. *Eucalyptus* species tend to reach canopy closure much more quickly than *Pinus* species given suitable conditions, and hence increase in mass much faster during the early stages of development (Myers *et al.*, 1996). Therefore G for short rotation plantations was set 2 to 3 years earlier than for long rotation systems.

Final model form used for post-1990 plantations

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

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:

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

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 $a \leq W$

$v * (a - W) / U$ if $a > W$ and $a \leq W + V$

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* 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 exclude scattered natural regrowth from plantation typing, thus ensuring that only direct human induced plantations are included in this sub-category; and
- use of the *FullCAM* model to allocate pixels between years to ensure a non-biased estimate of the area of plantation established between 1989 and 1991.

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

Table 7.D5: Annual plantation area from the NCAS remote sensing program 1990 to 2009

| Year | Area (ha) |
|------|-----------|
| 1990 | 52,894 |
| 1991 | 49,218 |
| 1992 | 52,432 |
| 1993 | 54,863 |
| 1994 | 51,980 |
| 1995 | 35,768 |
| 1996 | 37,903 |
| 1997 | 34,917 |
| 1998 | 43,495 |
| 1999 | 46,647 |
| 2000 | 72,906 |
| 2001 | 82,648 |
| 2002 | 77,084 |
| 2003 | 81,280 |
| 2004 | 78,813 |
| 2005 | 56,101 |
| 2006 | 49,689 |
| 2007 | 62,829 |
| 2008 | 61,360 |
| 2009 | 39,271 |

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 management regimes are assigned frequencies relative to the frequency of the range of plantation regimes within each region (Figure 7.D5). This allows time series management regimes to be developed for each plantation pixel through time (Figure 7.D5 (b)). The range of possible management actions is shown in Table 7.D6.

Table 7.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. |

| Management action | FullCAM event type | Effect in model | Standard event options |
|-------------------------------------|---|--|---|
| 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.

Figure 7.D4: (a) Each regime is assigned a relative frequency (a) occurring at a given point over time, allowing for (b) time series of management regimes to be developed. Source: Waterworth and Richards, 2008.

(a)

The screenshot displays the FullCAM software interface for selecting a management regime. At the top, there are dropdown menus for 'Location' (set to WA) and 'NPI' (set to Western Australia). Below these are input fields for 'Year Established' (1970 to 1973). The 'Conditions' section includes dropdowns for 'Forest class' (Conifer), 'Soil sandiness', 'Previous land use' (Pasture), and 'Max biomass range' (Low). The 'Suite of Activities' section features a small icon and a table of regimes. A link 'Go to Selected Regime with Ctrl-G' is visible. The table lists regimes with their frequencies and descriptions.

| Freq. | Regime |
|-------|---|
| 15 | P. pinaster; 1970-77; NoSitePrep; StripCult; StripPPWC; 3Thin; 2Prune; AtEst,1LateAg... |
| 150 | P. pinaster; Low; 1970-77; NoSitePrep; StripCult; StripPPWC; 3Thin; NoPrune; AtEst,1... |
| 5 | P. pinaster; 1970-77; NoSitePrep; StripCult; NoPPWC; 3Thin; 2Prune; AtEst,1LateAge... |
| 50 | P. pinaster; 1970-77; NoSitePrep; StripCult; NoPPWC; 3Thin; NoPrune; AtEst,1LateAg... |
| 3 | P. radiata; 1970-73; NoSitePrep; StripCult; StripPPWC; 2Thin; 2Prune; AtEst,1LateAge... |
| 38 | P. radiata; 1970-73; NoSitePrep; StripCult; StripPPWC; 2Thin; NoPrune; AtEst,1LateAg... |
| 1 | P. radiata; 1970-73; NoSitePrep; NoCult; StripPPWC; 2Thin; 2Prune; AtEst,1LateAgeF... |
| 2 | P. radiata; 1970-73; NoSitePrep; NoCult; StripPPWC; 2Thin; NoPrune; AtEst,1LateAge... |

(b)

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

The Species table contains information on tree species characteristics including forest growth model parameters, carbon allocation to tree components over time, biomass carbon percentages, basic wood density, turnover rates for each tree component, decay and product use data. 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.

Fertiliser Use

N₂O released from the application of N fertiliser on forests is reported as IE (agriculture). The amount of N applied to lands in Australia is obtained from national statistics of the amount of N purchased. It is not possible to split the use of N fertiliser between agriculture and forests.

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

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.

APPENDIX 7.E: OTHER NATIVE FORESTS

Background

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

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

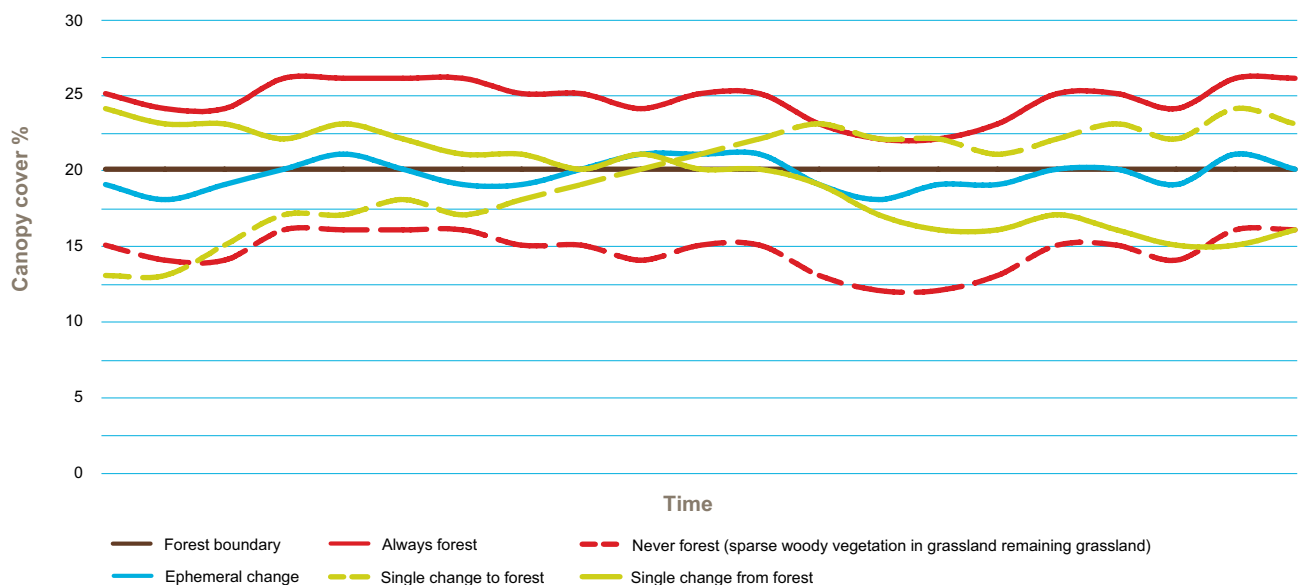
As most of the emissions and removals from these activities are driven by natural variability and natural disturbance, the effects are:

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

Trends in Forest Vegetation Cover in Other Native Forests

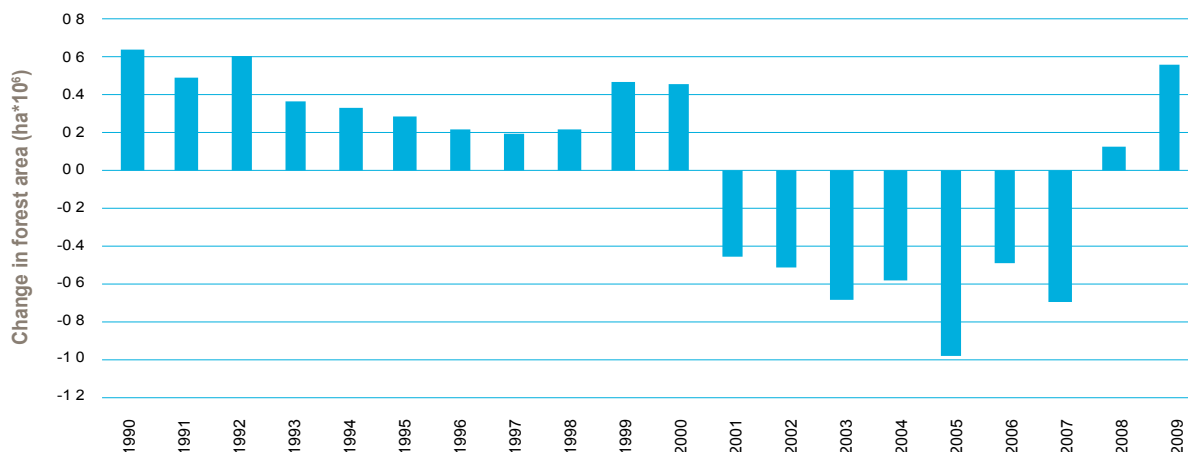
The mixture of climate effects, grazing, fire and recovery from land use change, and the regional differences in these processes gives rise to variability in forest cover over time. Figure 7.E1 shows the typical fluctuations in forest cover that occur around the prescribed canopy cover definition of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

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



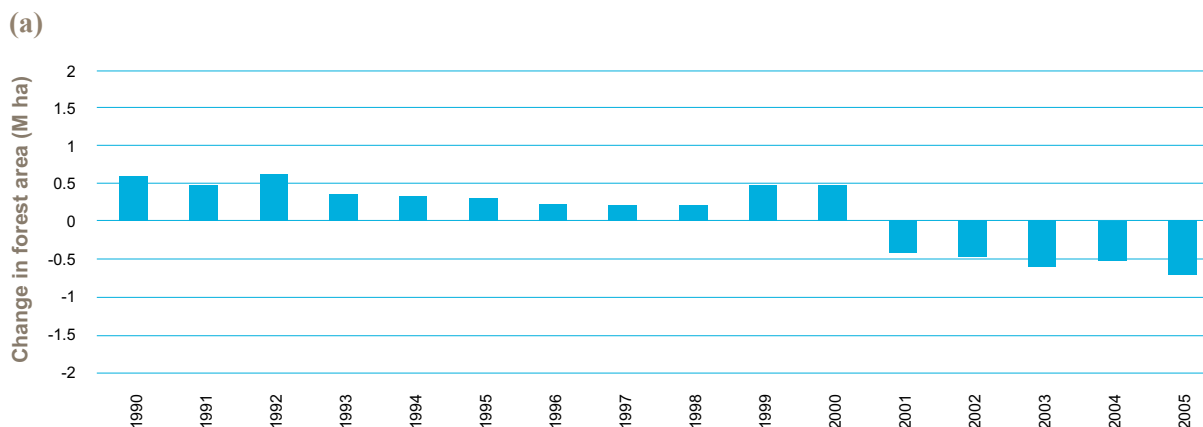
For the areas that exhibit a loss or gain in the area of forest, it is possible to extract these data from the time-series of remotely sensed data. Figure 7.E2 below shows the net national gains and losses in forest cover in *other native forests* since 1972. This represents the areas of forest cover 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 1990

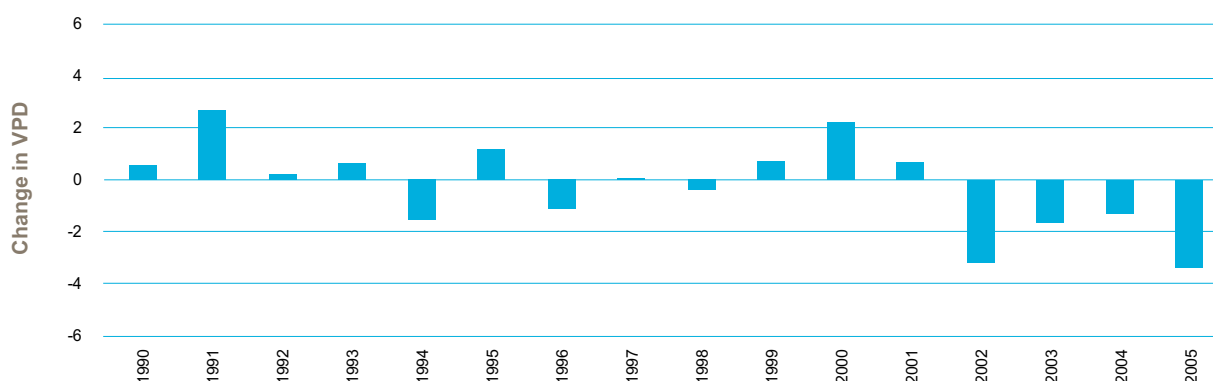


One of the first ways to contemplate attribution to a ‘cause’ for loss or gain is to look at the correlation of change with climate variation. This can be done at a national scale by comparing the gains and losses of forest area not attributable to anthropogenic land use change with a key climate variable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

Figure 7.E3: Annual change in forest area (a) and variation of Vapour Pressure Deficit (VPD) from long term average (b)

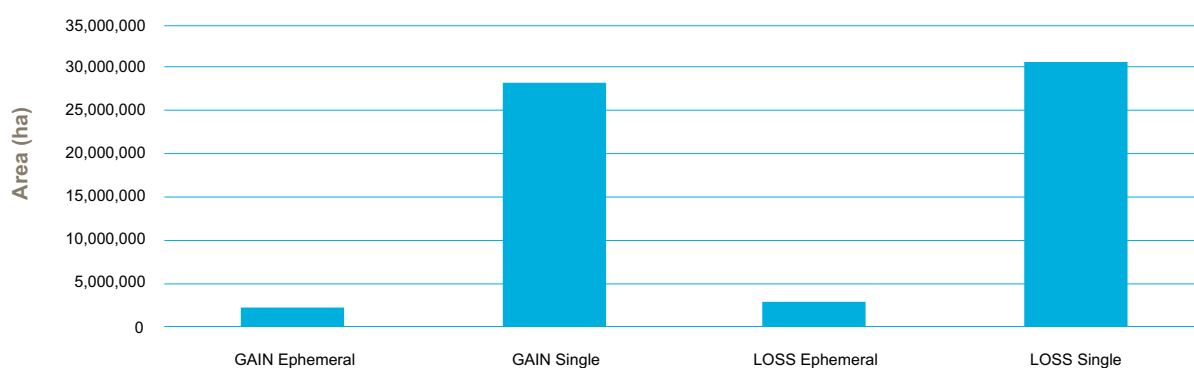


(b)



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



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

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

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

Methodology

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

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 CO₂ through wildfire and prescribed burning.

Annual changes in foliage mass

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

Ephemeral, Intermittent Change in Forest Cover

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

Changes in Leaf Area of Continuous Forest Cover

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

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

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

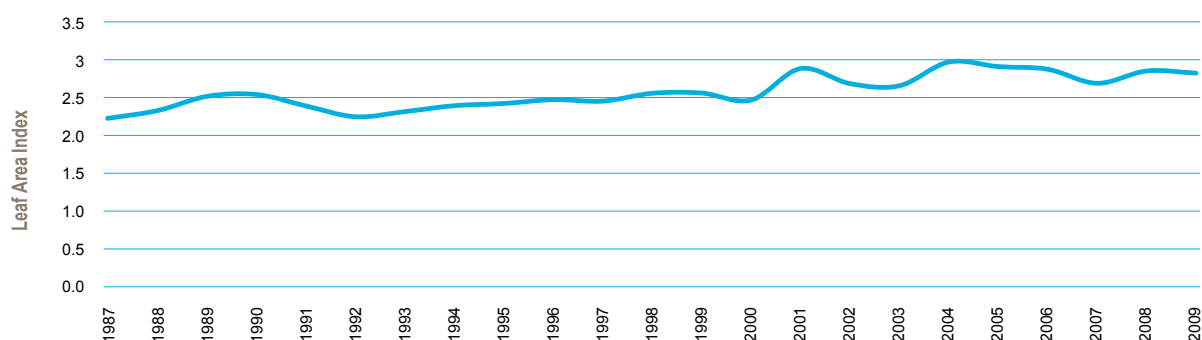
| Parameter | |
|---|------|
| Max LAI | 3.05 |
| Min LAI | 2.23 |
| LAI range | 0.82 |
| Leaf mass range (t C ha ⁻¹) | 0.20 |

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 (t C ha ⁻¹) | 10 |
| Years over which C is lost | 20 |
| Years over which C is gained | 20 |
| Effective growth rate (t C ha ⁻¹ yr ⁻¹) | 0.5 |
| Effective loss rate (t C ha ⁻¹ yr ⁻¹) | 0.5 |

Woody thickening

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

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

Burrows *et al.*, (2002) estimated an average aboveground biomass increment of 0.25 t C ha⁻¹ for areas subject to woody thickening. This was adjusted to include belowground biomass by applying a root:shoot ratio of 0.4 based on Snowdon *et al.*, (2000). This results in a total growth of 0.35 t C ha⁻¹ per year, which is equivalent to 1.28 t CO₂ 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 CO₂ ha⁻¹ yr⁻¹ = 12.2 Mt CO₂ per year. This value is applied for each year in the inventory.

Fire

The *other native forests* category includes CO₂ 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 CO₂ emissions from forest fires and CO₂ 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-CO₂ 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:

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

Where: A_{jk} = area of category burnt annually (ha),
 M_{jk} = mass of fuel burnt annually (Gg),
 FL_{jk} = fuel loading (dry weight) (Mg ha⁻¹) (Table 7.12 and 7.14),
 Z_{jk} = burning efficiency (Table 7.14).

Annual CO₂ emissions are calculated as:

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

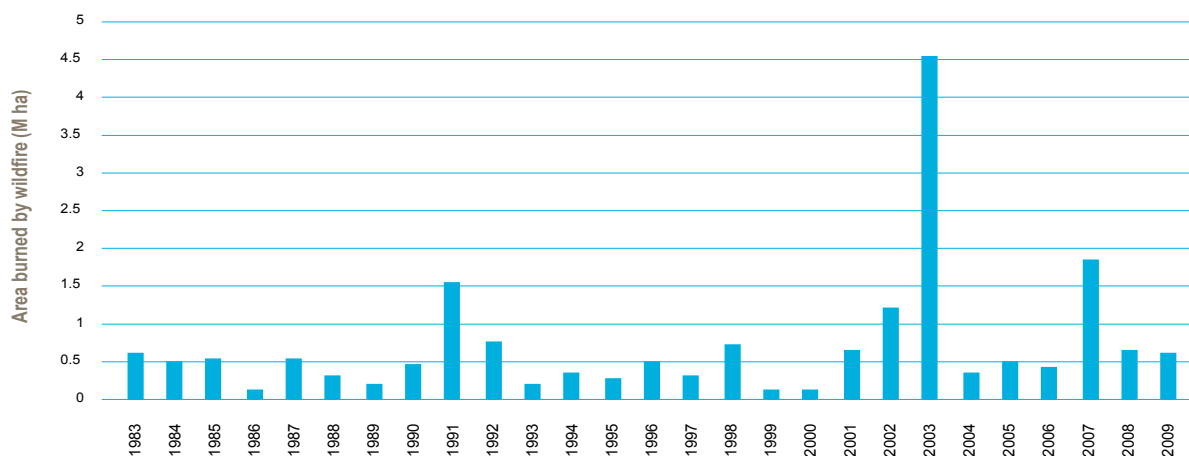
Where: E_{ijk} = annual emission of gas *i* from biomass burning (Gg),
 M_{jk} = mass of fuel burnt annually (Gg yr⁻¹),
 CC_{jk} = carbon mass fraction in vegetation (Table 7.15),
 C_i = 3.67 factor to convert from elemental mass of gas species *i* to molecular mass.

Annual CO₂ removals are calculated as:

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

Where: R_{ijk} = annual removals of CO₂ following biomass burning (Gg),
 $\sum M_{jk}$ = mass of fuel burnt over period t,
t = time required for carbon lost due to fire to be recovered (assumed to be 5 years),
 CC_{jk} = carbon mass fraction in vegetation (Table 7.11),
 C_i = 3.67, factor to convert from elemental mass of gas species *i* to molecular mass.

Figure 7.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.

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

| Year | Emissions (Mt CO ₂) | | | | | Total |
|------|---------------------------------|---------------------------------------|-------------------------|------------------|--------|--------|
| | Ephemeral change in forest | Leaf mass change in continuous forest | Single change in forest | Woody Thickening | Fire | |
| 1990 | -0.01 | -2.19 | -4.13 | -12.20 | 4.58 | -13.96 |
| 1991 | -0.01 | 14.38 | -4.90 | -12.20 | 58.76 | 56.03 |
| 1992 | -0.01 | 13.50 | -5.87 | -12.20 | 5.40 | 0.83 |
| 1993 | -0.01 | -6.53 | -6.96 | -12.20 | -23.61 | -49.31 |
| 1994 | -0.01 | -7.37 | -7.22 | -12.20 | -10.53 | -37.33 |
| 1995 | -0.01 | -2.78 | -7.63 | -12.20 | -18.26 | -40.88 |
| 1996 | 0.00 | -4.77 | -8.57 | -12.20 | -4.88 | -30.42 |
| 1997 | 0.00 | 1.86 | -9.63 | -12.20 | -3.04 | -23.02 |
| 1998 | 0.00 | -9.84 | -9.87 | -12.20 | 14.47 | -17.44 |
| 1999 | -0.01 | -0.29 | -10.57 | -12.20 | -16.01 | -39.07 |
| 2000 | -0.01 | 8.79 | -10.94 | -12.20 | -11.17 | -25.53 |
| 2001 | 0.01 | -39.12 | -10.01 | -12.20 | 13.45 | -47.87 |
| 2002 | 0.01 | 18.54 | -8.87 | -12.20 | 39.36 | 36.84 |
| 2003 | 0.02 | 2.61 | -7.52 | -12.20 | 188.60 | 171.50 |
| 2004 | 0.01 | -28.66 | -6.43 | -12.20 | -46.89 | -94.16 |
| 2005 | 0.02 | 5.47 | -4.96 | -12.20 | -40.71 | -52.37 |
| 2006 | 0.01 | 3.13 | -3.85 | -12.20 | -49.19 | -62.09 |
| 2007 | 0.02 | 16.33 | -2.46 | -12.20 | 24.89 | 26.57 |
| 2008 | 0.00 | -14.33 | -2.37 | -12.20 | -42.26 | -71.16 |
| 2009 | -0.01 | 2.51 | -1.20 | -12.20 | -11.81 | -22.71 |

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 *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 to Cropland and Grassland sub-categories

| Component | Forest | Agriculture |
|---------------------|--|----------------------------------|
| Living biomass | <i>CAMFor</i> – Forest Productivity Index and Tree Yield Formula | <i>CAMAg</i> – Crop yield tables |
| Dead organic matter | <i>CAMFor</i> | <i>CAMAg</i> |
| Soil carbon | <i>Roth-C</i> | <i>Roth-C</i> |
| 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

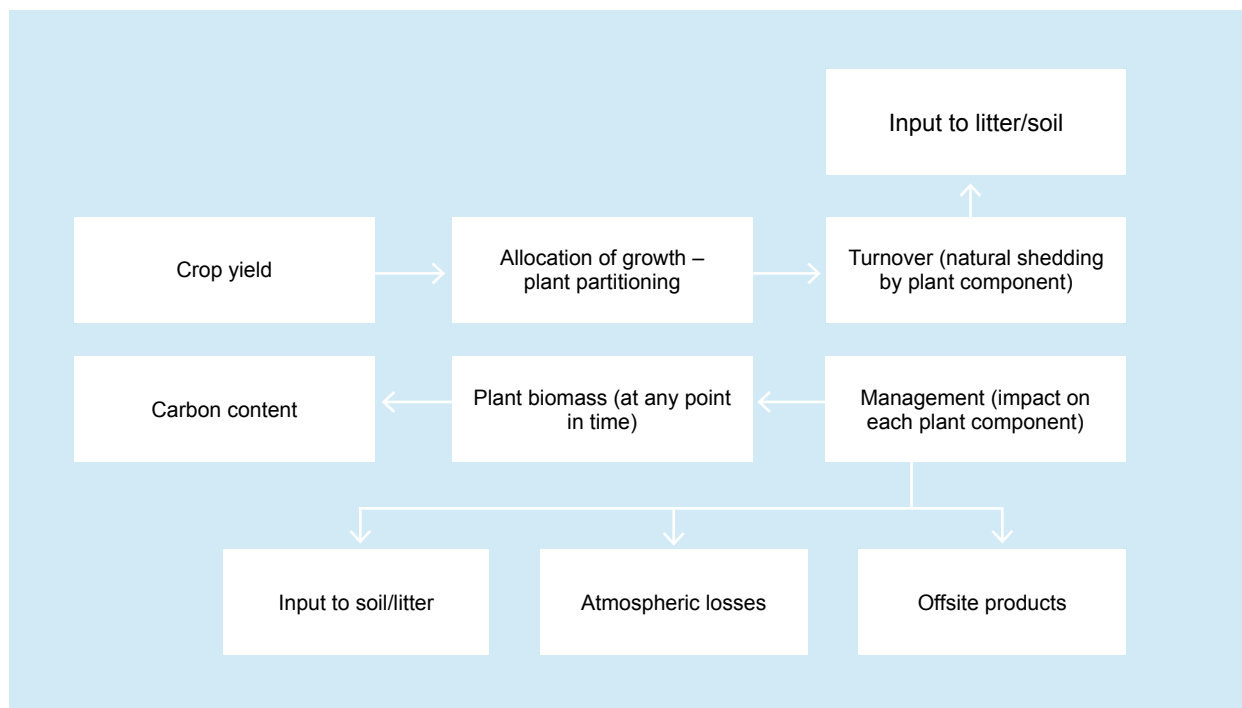


Table 7.F2: Plant partitioning by crop type

| 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 |
| 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 |

| 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) |
|------------------------------|--|---------------------------------------|---------------------------------------|---|---|
| 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 Contents of Crop and Grass Species

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

Initial Crop Litter Mass and Decomposition Rates

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

Table 7.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* category is modelled using the fully spatial, hybrid process-empirical method described in Appendix 7.A and detailed in Richards and Brack (2004a) and Waterworth *et al.*, (2007). 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.

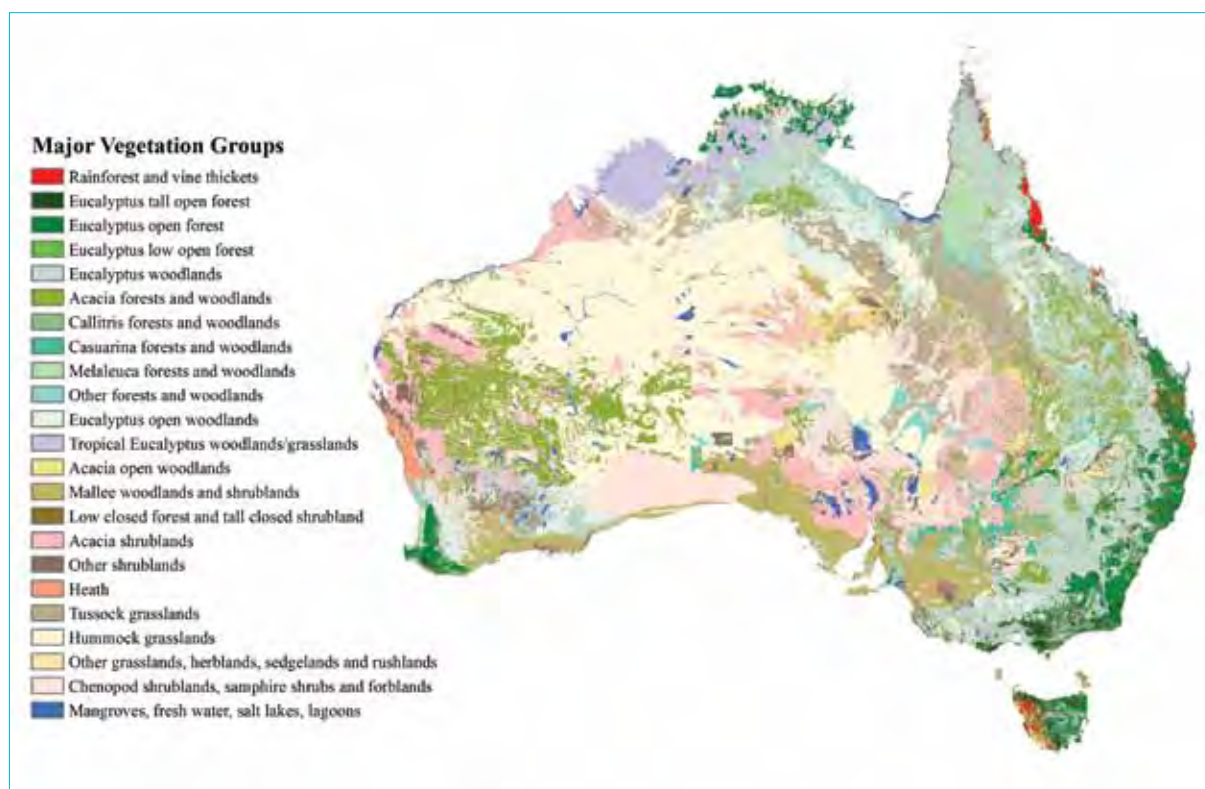
Forest Type Mapping

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* category, various forest characteristics (e.g., forest floor coarse woody debris and litter) are associated with the forest types extracted from the NVIS. The NVIS collates and provides, in a consistent taxonomy and classification, the best available vegetation maps from all available sources. Six levels of information are available (Table 7.F5). For the purposes of carbon accounting the Level III Major Vegetation Grouping (MVG) categories were applied. These vegetation types are described in Attachment 7.F1.

Table 7.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)



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 1 to 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 |

| 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) |
|--|--------------------------------------|---|-------------------------------------|---------------------------------------|---|---|
| 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 | Decomp-posable Fine Decay | Resistant Fine Decay | Decomp-posable Coarse Decay | Resistant Coarse Decay | Decomp-posable Leaf Decay | Resistant Leaf decay | Decomp-posable 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 Woodland and 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 | 0.1 | 0.1 | 3 | 1 | 0.2 | 1 | 1 | 2.5 |
| Chenopod Shrub, Samphire Shrub and Forbland | 1 | 0.2 | 0.1 | 0.1 | 3 | 1 | 0.2 | 1 | 1 | 2.5 |
| Unclassified Native Vegetation | 8 | 4 | 3 | 2 | 5 | 2 | 0.5 | 2 | 2 | 25 |

Tree pulling usually involves forming ‘wind rows’ for subsequent burning. Burning of wind rows follows a period of curing (drying), but combustion is still not always complete. 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 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 harpophylla*) and Mulga (*A. aneura*) dominate this group with mulga covering large parts of the arid interior of the continent. A series of other acacias such as Lancewood (*A. shirelyii*) and Myall (*A. pendula*) are also included. Mulga is one of the most widespread species on the continent, occurring on a series of forest, woodland and shrubland communities. The Mulga and Brigalow communities of eastern Australia have been extensively cleared for grazing and agriculture and in many regions only scattered remnants are found today. Mulga communities in the arid interior have not been subject to clearing to the same degree but many areas have been subject to modification by grazing pressures from cattle/sheep and feral animals, and increased macropod populations supported by the increased availability of water from bores.

Group 7. Callitris Forest and Woodland

Cypress Pine forests are found mostly in a series of discrete regions, notably in the Brigalow Belt, but also in the arid areas in South Australia and in association with mallee communities near the South Australia – Victoria border. Extensive areas have been cleared for grazing in the Brigalow Belt and in the Mallee bio regions in particular, but major areas are included in State Forests and other crown reserves in Queensland and New South Wales.

Group 8. Casuarina Forest and Woodland

Containing both Casuarina and Allocasuarina genera, these occur in a series of quite distinct communities, notably foredune (*C. equisetifolia*) communities, swamp (*C. glauca*) communities, riverine (*C. cunninghamiana*) and desert (*C. cristata*) communities. These communities have been extensively cleared in many coastal areas for agriculture, or for industrial uses or urban developments. Areas in the arid zone are subject to modification by grazing of domestic stock and from feral herbivores.

Group 9. Melaleuca Forest and Woodland

These cover substantial areas in the tropical north, but are also found in temperate climates most often in or adjoining coastal or montane wetlands. These communities have been extensively cleared in many coastal areas for agriculture or housing near major cities. Extensive areas remain in the tropical north, in particular southern Cape York Peninsula.

Group 10. Other Forest and Woodland

This is a diverse group of communities, some of which such as Banksia woodland are comparatively restricted in their extent, but may be locally abundant. It also includes a series of mixed communities of the arid zone, which are not dominated by any particular species. These communities have been extensively cleared in many coastal areas for agriculture or urban uses. Extensive areas remain in the arid zone but are subject to modification by grazing of domestic stock and from feral herbivores.

Group 11. Eucalyptus Open Woodland

These cover extensive areas of the arid zone or drier tropical north mostly with a shrubby or grassy ground layer. Little of this group has been cleared. Many areas have been subject to modification by grazing of domestic stock and from feral herbivores.

Group 12. Tropical Eucalyptus Woodland/Grassland

This group contains the so-called tall bunch-grass savannas of north Western Australia and related Eucalyptus woodland and Eucalyptus open woodland communities in the Northern Territory and in far north Queensland, including Cape York Peninsula. They are typified by the presence of a suite of tall annual grasses, notably *Sorghum* spp, but 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 Myrtaceae 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, Crypsopogon, 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 which are grown and harvested. The *cropland remaining cropland* sub-category covers an area of over 20 million hectares and includes lands under rotational and 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° and latitude of 25° resulting in significant geographical variation in the types of crops grown and climatic conditions (Unkovich *et al*, 2009). Climate variability is an important factor affecting changes in Australian crop production, with rainfall variation the main contributor to changes in crop yields from one year to another (ABARE, 2009e). Croplands are generally located along a broad inland fringe across the southern and eastern areas of Australia, with the highest yields commonly obtained in the south west and eastern regions. In the southern regions, cropland is dominated by wheat production, with barley, oats, lupins and canola being the other dominant crops. In the north wheat, sugarcane, sorghum and cotton production dominate.

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

Methodology

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

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

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).

For the current *cropland remaining cropland* estimates, management is not varied as comprehensive, spatially and temporally explicit management data for all of Australia’s croplands is not yet available. Hence variation in the live biomass, dead organic matter and soil pools is largely driven by crop production, which varies due to climate and improved breeding. Therefore emissions and removals from this sub-category follow climate effects on crop production.

Non-CO₂ 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 CO₂ (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 wetter 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 produce a productive 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 fixed planting schedules.

About 75% of the broadacre 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, as the drier districts become even more marginal (< 300mm annual rainfall), farmers are moving away from cropping systems and moving into extensive grazing enterprises which have become a more viable option with less risk associated with crop failure. Although national herd numbers for sheep have declined over the past 20 years cattle numbers have increased slightly (ABARE, 2008d).

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 sub-surface or "ground" water from the Great Artesian Basin which provides irrigation water for agriculture in regions of north-eastern Australia (ABS, 2008e).

Fertiliser application

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

Crop residue management

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

Mapping of Cropland remaining Cropland systems

The mapping of the extent of *cropland remaining cropland* systems is estimated using the National Land Use 2001/2002 (Version 3) Summary Statistics provided by the Bureau of Rural Sciences (<http://nlwra.gov.au/>). The area of cropping includes areas of both continuous cropping and areas under crop-pasture rotations.

Estimation of CO₂ emissions and removals

Carbon dioxide (CO₂) 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.

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* category is reported in Table 7.G1 which show strong variability due to climate.

Table 7.G1: Net CO₂ emissions and removals estimates for *Cropland remaining Cropland*

| Year | Net CO ₂ Emissions (Mt CO ₂ -e) |
|------|---|
| 1990 | -22.88 |
| 1991 | -23.62 |
| 1992 | -4.37 |
| 1993 | -24.48 |
| 1994 | -37.40 |
| 1995 | -10.36 |
| 1996 | -4.53 |
| 1997 | -18.13 |
| 1998 | 8.54 |
| 1999 | -5.99 |
| 2000 | -16.17 |
| 2001 | -24.01 |
| 2002 | 38.64 |
| 2003 | -27.13 |
| 2004 | -36.88 |
| 2005 | -50.89 |
| 2006 | 9.58 |
| 2007 | 18.04 |
| 2008 | -18.78 |
| 2009 | -25.78 |

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.

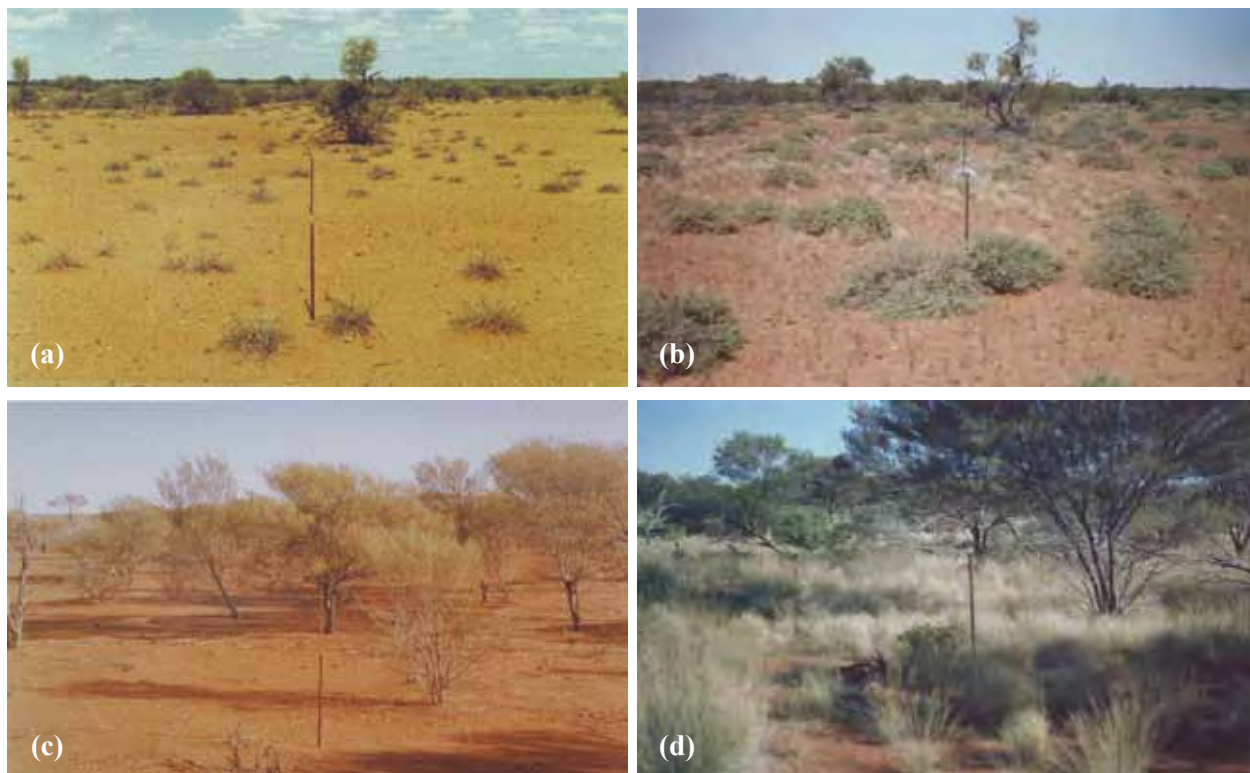
For the current *grassland remaining grassland* grass component estimates, management data are not varied because comprehensive data for all of Australia’s *grassland* are not yet available (as opposed to the *forest land converted to grassland* category where data are available). Hence variation in 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)



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

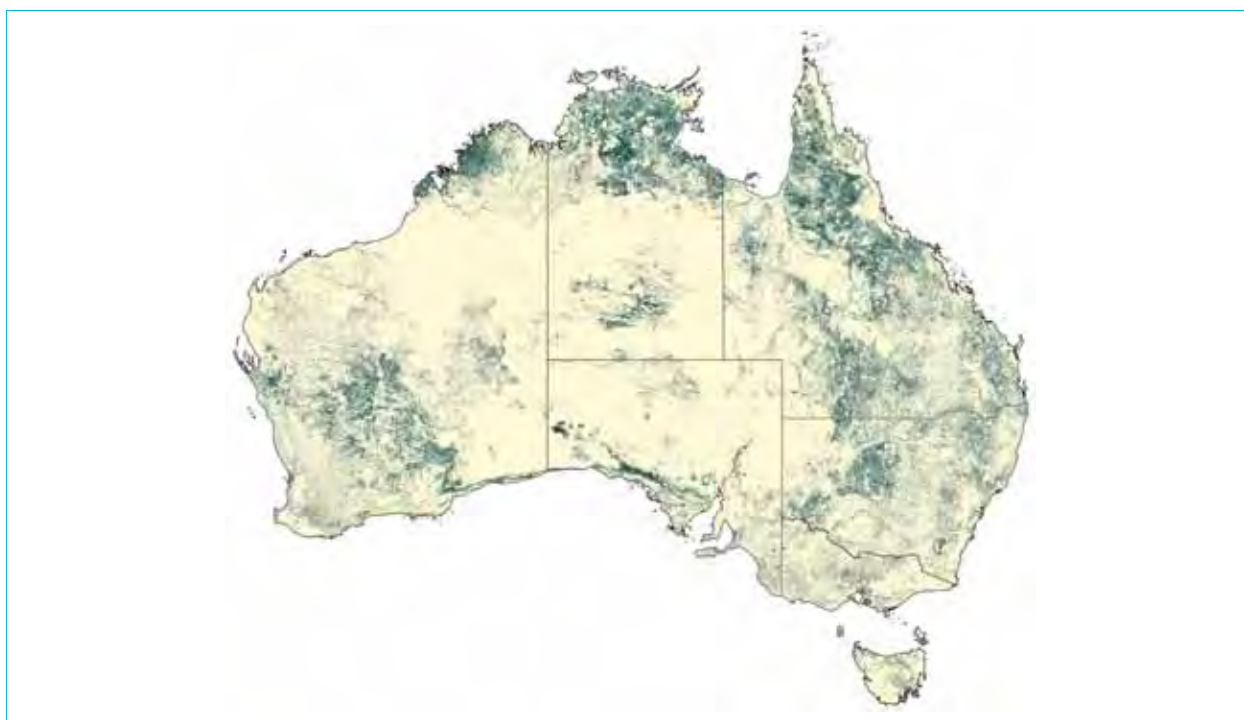
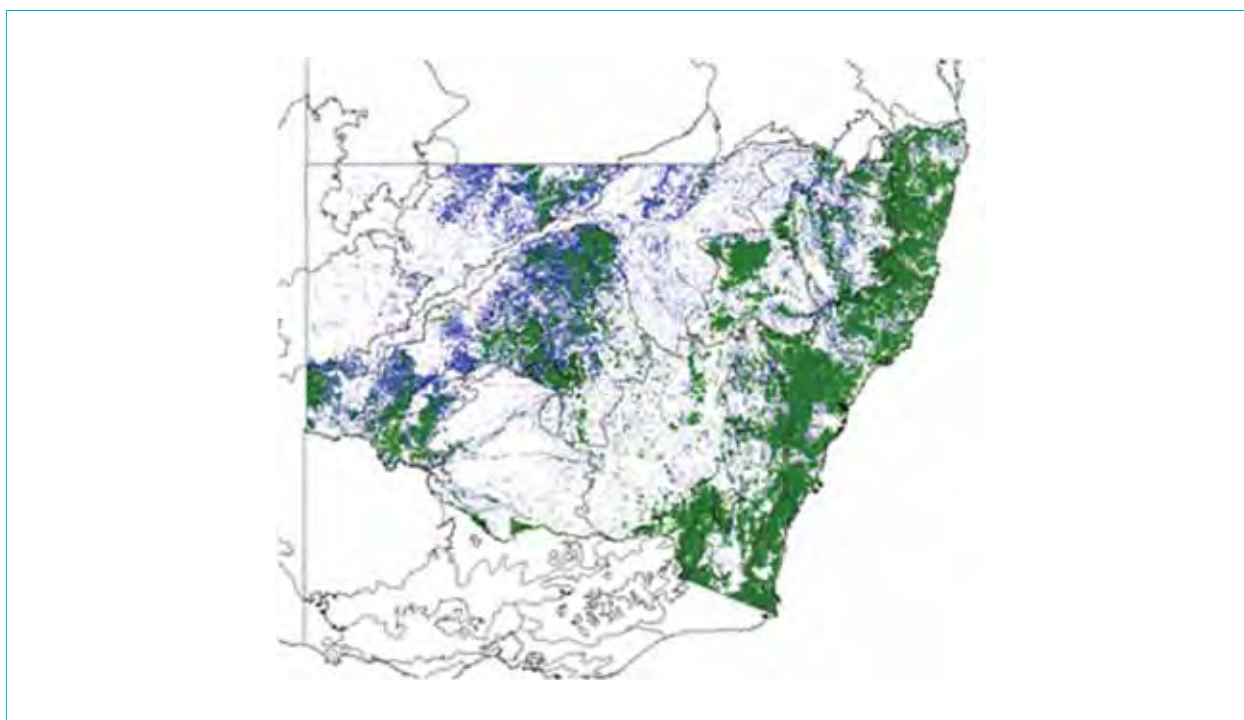


Figure 7.H3: Map of forest (green) and sub-forest woody vegetation (blue) for the area where the sparse change analysis has been verified



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

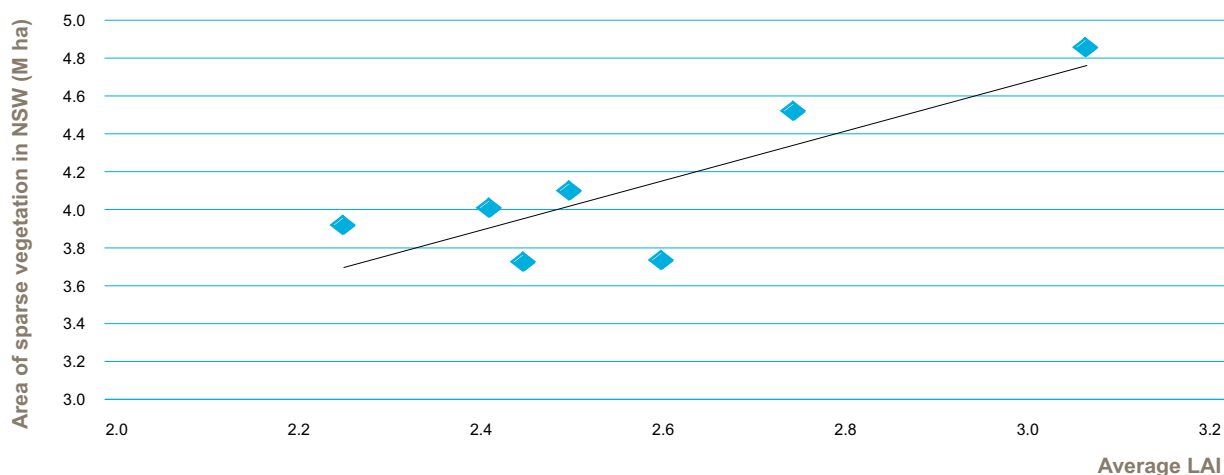
- used the recently completed shrubland extent base maps to determine the sub-forest woody vegetation extent; and
- used the time-series trends for change in areas where change is available (see Figure 7.H3) and applied this to the national extent.

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 $2 \text{ t DM ha}^{-1} \text{ yr}^{-1}$). The results of this analysis are shown in Table 7.H2.

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



Fires

Fires are the major natural disturbance in grasslands, and area burned varies from year to year. Fire in grass areas of the *grassland remaining grassland* sub-category are modelled as part of the Tier 3 *FullCAM* analysis. Fires in the shrubland component of the *grassland remaining grassland* sub-category are modelled using a Tier 2 method. 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-CO₂ 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 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 CO₂) for *grassland remaining grassland*

| Year | Emissions Mt CO ₂ | | | |
|------|------------------------------|--------|---------|--------|
| | Grass | Sparse | Fire | Total |
| 1990 | -3.93 | -16.43 | 1.30 | -19.07 |
| 1991 | 60.52 | 23.13 | -31.89 | 51.77 |
| 1992 | 54.15 | 20.64 | -11.24 | 63.55 |
| 1993 | 15.33 | -14.59 | -0.07 | 0.67 |
| 1994 | -1.09 | -8.85 | 8.68 | -1.25 |
| 1995 | 38.35 | -9.17 | 88.14 | 117.32 |
| 1996 | -17.58 | -11.79 | 20.50 | -8.88 |
| 1997 | 19.81 | -6.68 | -19.51 | -6.37 |
| 1998 | 58.21 | -13.63 | 47.37 | 91.95 |
| 1999 | 23.99 | -9.73 | 0.27 | 14.52 |
| 2000 | -75.23 | 15.97 | 44.78 | -14.48 |
| 2001 | -61.23 | -27.30 | 67.97 | -20.56 |
| 2002 | 143.70 | 24.60 | 40.89 | 209.20 |
| 2003 | 70.86 | -14.49 | -70.28 | -13.91 |
| 2004 | 41.87 | -38.10 | -101.48 | -97.71 |
| 2005 | 37.82 | -22.21 | 85.78 | 101.39 |
| 2006 | 180.35 | -7.22 | -121.55 | 51.58 |
| 2007 | 143.66 | 32.01 | 76.80 | 252.47 |
| 2008 | 58.65 | -24.89 | 101.41 | 135.18 |
| 2009 | 111.65 | -4.76 | -14.30 | 92.59 |

APPENDIX 7.I: HARVESTED WOOD PRODUCTS

Introduction

Harvested wood product CO₂ 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 7.11: 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 m³)

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 m³ 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 m³. Data sources used in the model for plywood was from ABARE (2009c) and the Plywood Association of Australia.

Particleboard and Medium Density Fibreboard (MDF)

The characteristics of these two wood panel boards are different, but their feedstock and end use product categories are similar. Their densities are, however, different. Particleboard and MDF plants are large-scale operations and they are usually located close to their resource. Both require low cost material as input using either small logs unsuited to sawmilling, or woodchips produced as a by-product of sawmilling. Most of the feedstock is from softwood plantations, although some regrowth hardwood is being used in a plant in Tasmania and some cypress pine is being used in a plant in Queensland. In terms of trade, Australia is a net exporter of particleboard and MDF. The industry source used for information on processing assumptions in the model was the Australian Wood Panels Association.

Pulp and Paper

Pulp and paper plants are very large-scale industries requiring large volumes of low cost resource. Plantation grown softwood fibre provides the major resource but hardwood and recycled fibre is also important. Accounting for this sector is complicated by the fact that recycled fibre is exported and pulp is imported. Australia has five pulp and paper mills. Production data is sourced from ABARE (2009c).

A complicating factor in the assumptions on waste with the pulp and paper stream is the fact that mills vary dramatically in their recovery according to type. Kraft pulp mills typically have a low yield of fibre (at 50%) whereas thermo-mechanical mills have a high yield (at 95%). The manufacture of recycled paper also results in a lower yield of fibre. Based on weighted inputs, a yield of 70% has been adopted.

Preservative Treated Softwood

Both hardwood and softwood can be preservative treated, but only softwood has been allocated a separate category. This is because treated sawn softwood has some use categories which are different to untreated softwood, whereas hardwood is usually treated so that the sapwood can be protected against borer attack and its use is then the same as for untreated hardwood.

Treated softwood poles and posts have also been included with sawn softwood, but treated hardwood poles and piles have been included with sleepers and other miscellaneous hardwood products. The ABARE statistics do not list treated timber of any description. The information used in the model has been obtained from the Timber Preservers Association of Australia.

Hardboard

The hardboard industry in Australia is quite small, with only two plants in operation. One is at Ipswich (Queensland) and the other is at Raymond Terrace (New South Wales). Hardwood is used for feedstock, sourced from pulp logs and sawmill residue.

The technology is quite old, but the products are unique and have niche markets that are likely to endure the competition from other panel products. Both hardboard producers were contacted during the study for manufacturing assumptions.

Hardwood Poles, Sleepers and Miscellaneous

The existing stock of hardwood transmission poles in Australia is reputed to number about 6,000,000 and production is estimated to be about 100,000 poles per annum, equivalent to about 75,000 m³ 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 m³ 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.

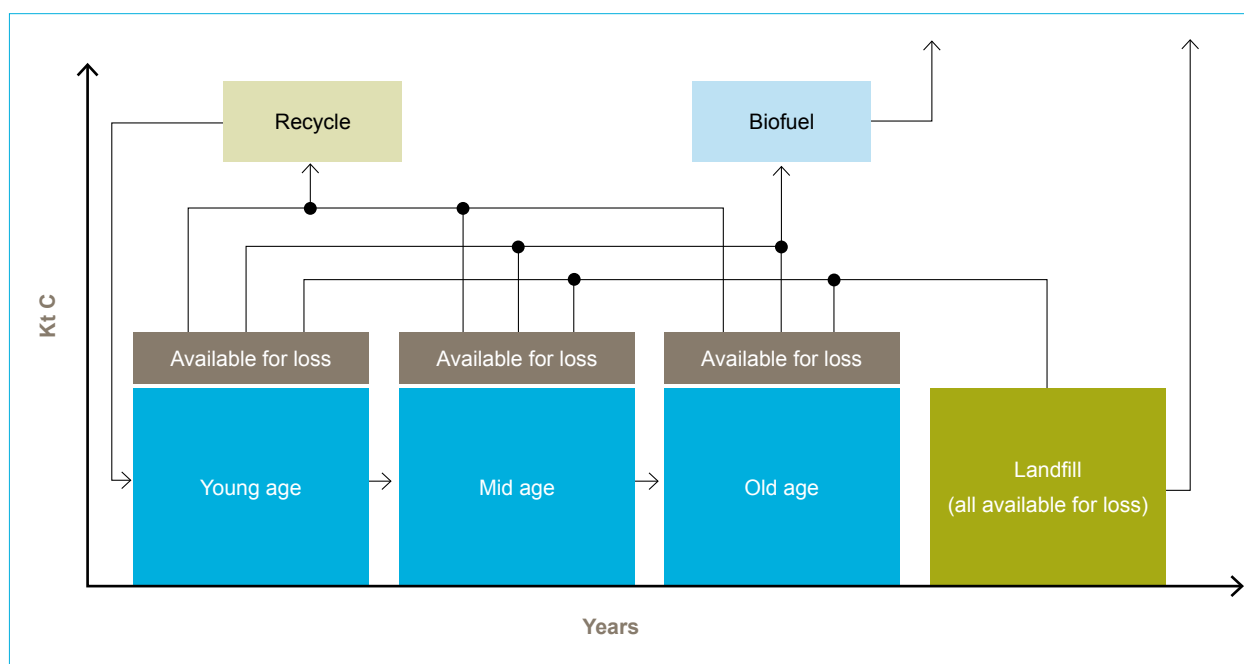
Log Exports

Total exports of coniferous logs reported by ABARE (2009c) consist of both sawlog and pulp log. New South Wales exports approximately 7,000 m³ 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.

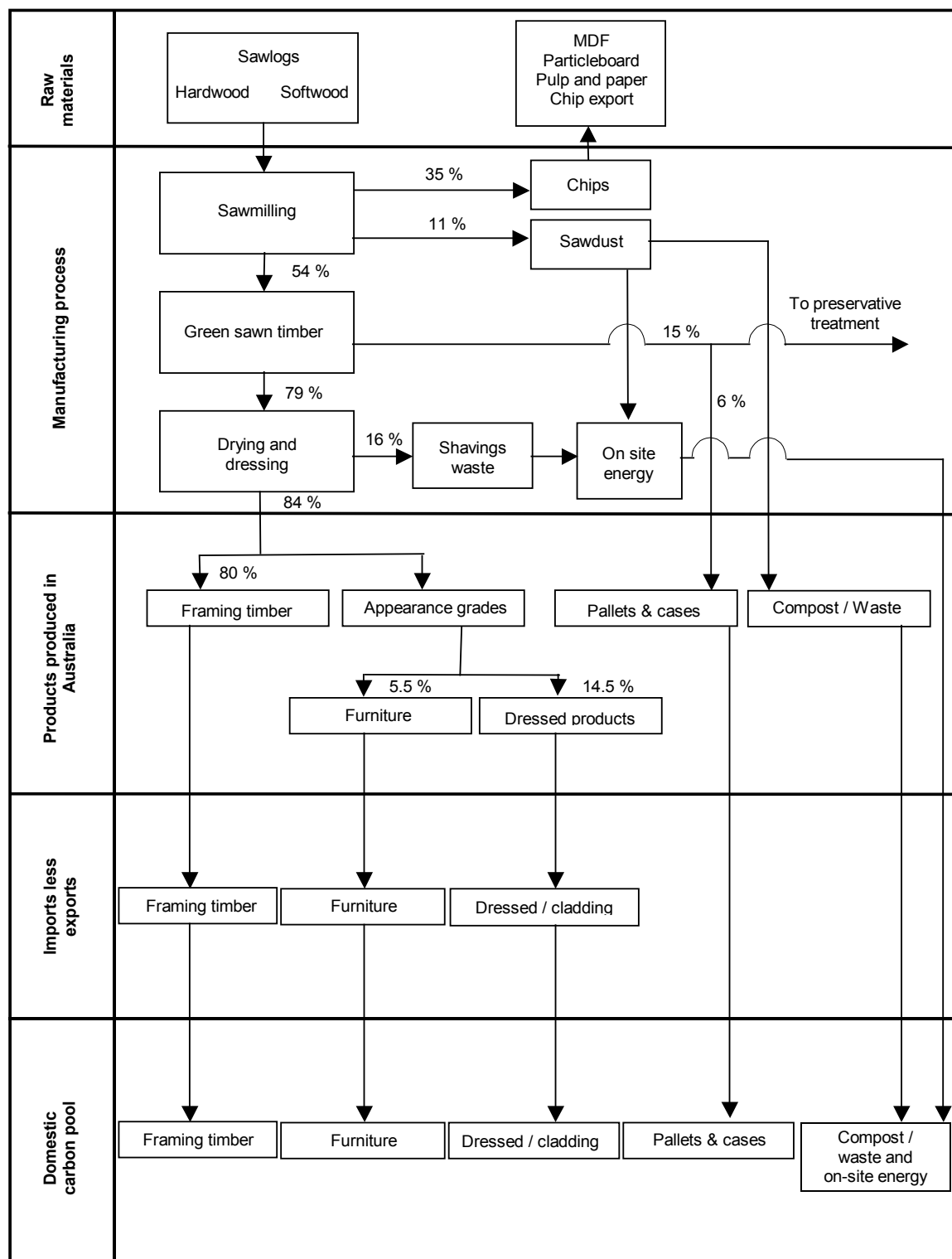
Table 7.I3: Carbon stock and emissions outcomes (kt C)

| Year | Domestic Production of Wood Products ^(a) | Imports of Wood Products | Exports of Wood Products ^(a) | Increase Due to Wood Products | Carbon Pool (excl. landfill) |
|------|--|--------------------------------|---|--|------------------------------------|
| | kt C | kt C | kt C | kt C | kt C |
| 1990 | 3,307 | 730 | 80 | 3,957 | 77,239 |
| 2000 | 3,791 | 920 | 313 | 4,398 | 90,408 |
| 2005 | 4,249 | 1005 | 479 | 4,775 | 97,431 |
| 2006 | 4,232 | 960 | 493 | 4,699 | 100,510 |
| 2007 | 4,114 | 985 | 500 | 4,622 | 101,858 |
| 2008 | 4,137 | 1056 | 468 | 4,777 | 103,359 |
| 2009 | 4,190 | 922 | 483 | 4,391 | 104,600 |

(a) Exports of wood products excluding exports of woodchips

Attachment 7.I1: Wood Flows by Sector

Figure 7.I2: National Carbon Accounting Model for Wood Products: Sawmilling wood flows *



* Percentages shown for softwood sawmilling, refer to model for hardwood and cypress pine

Figure 7.I3: National Carbon Accounting Model for Wood Products: Wood flows in preservative treated products

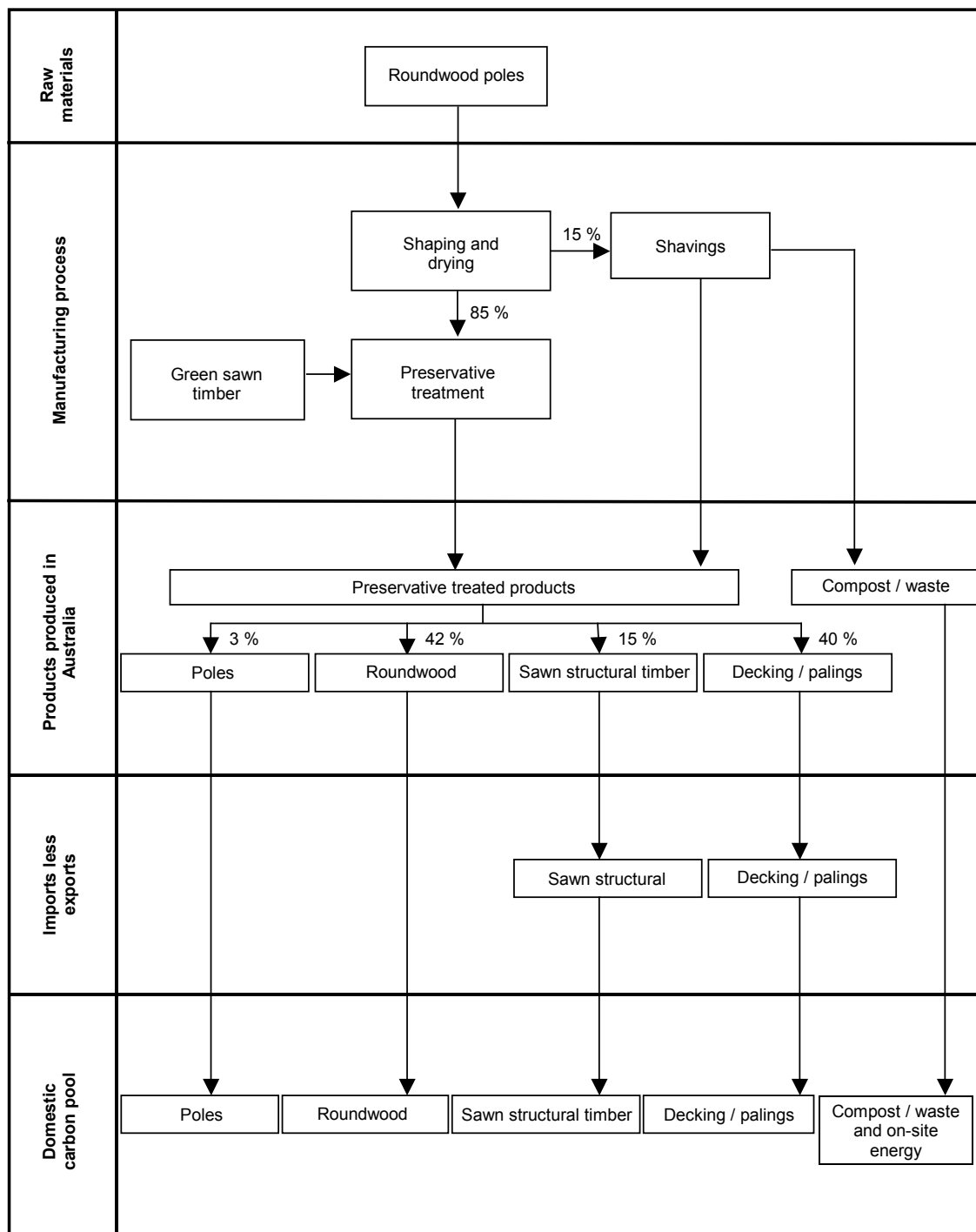


Figure 7.I4: National Carbon Accounting Model for Wood Products: Wood flows in plywood production

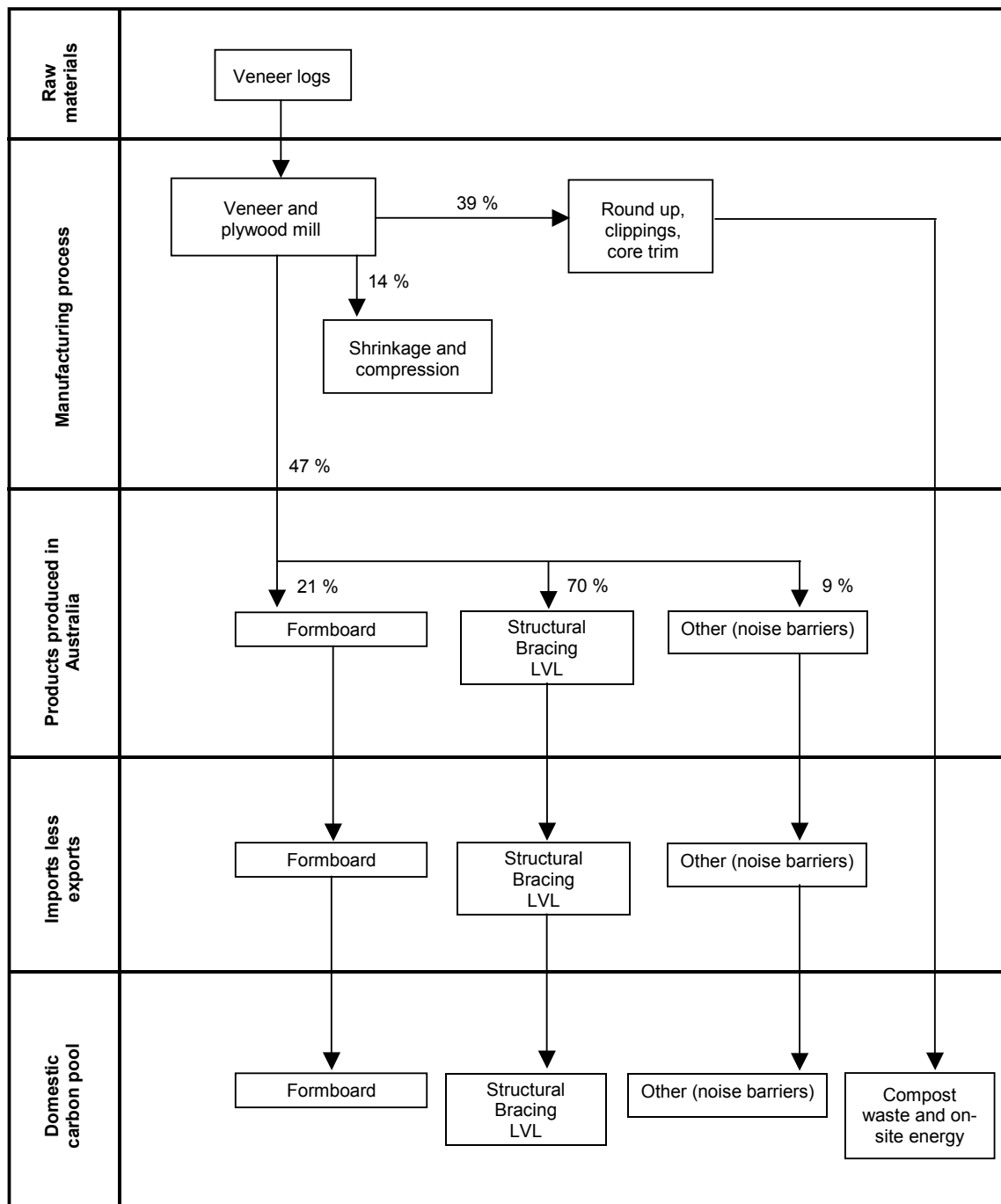
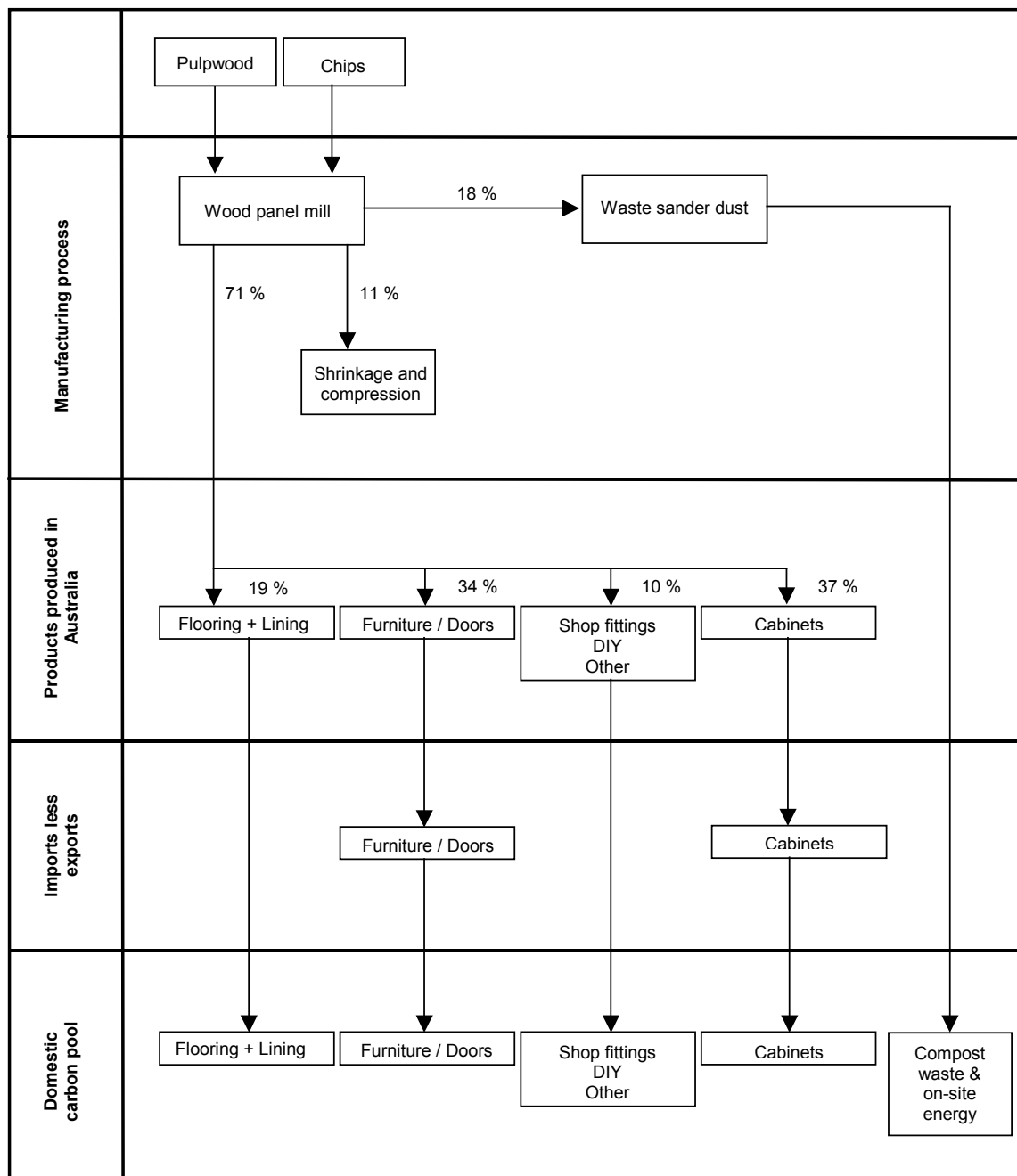


Figure 7.15: National Carbon Accounting Model for Wood Products: Wood flows in MDF and particleboard manufacture *



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

Figure 7.16: National Carbon Accounting Model for Wood Products: Wood flows in pulp and paper manufacture

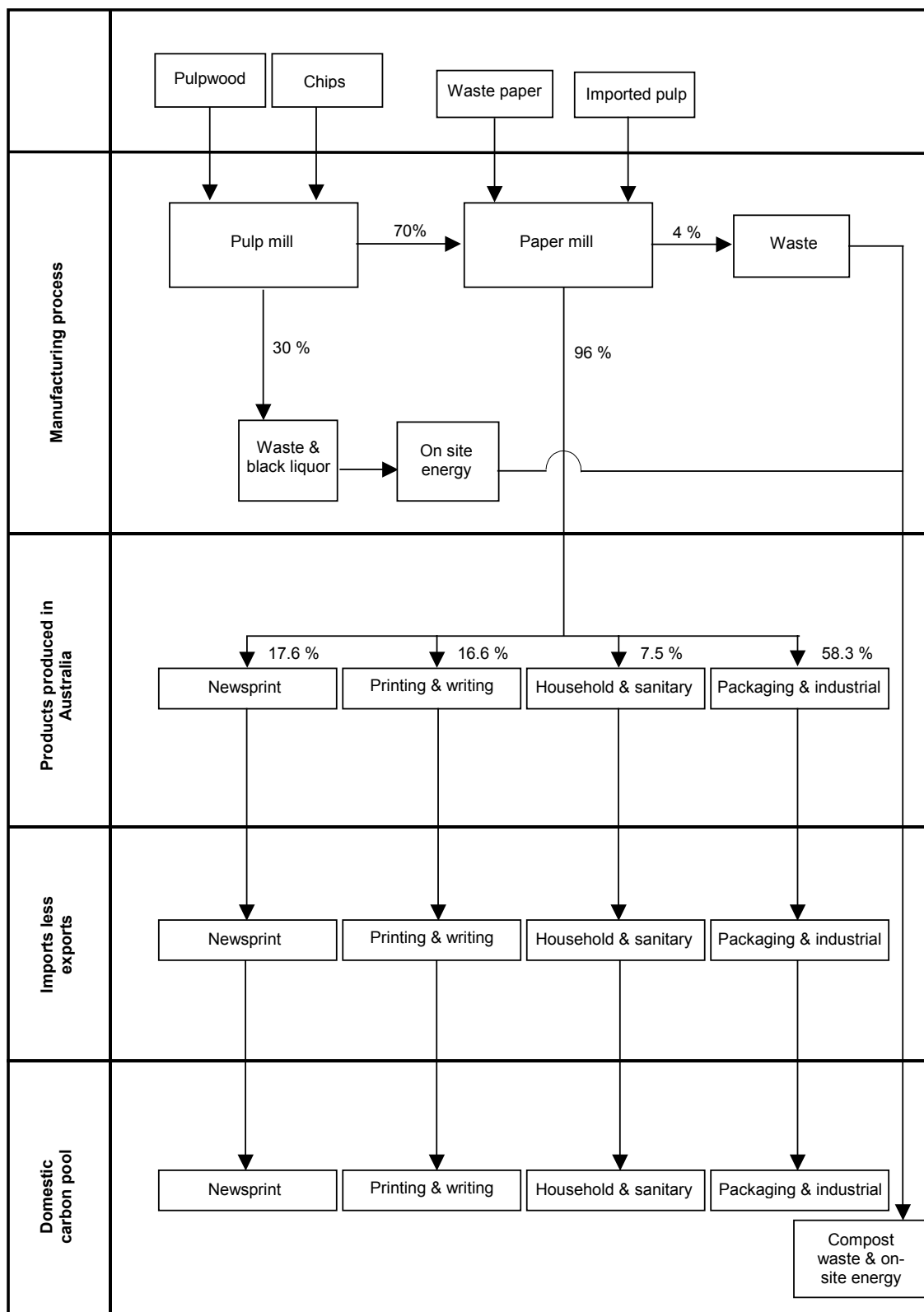
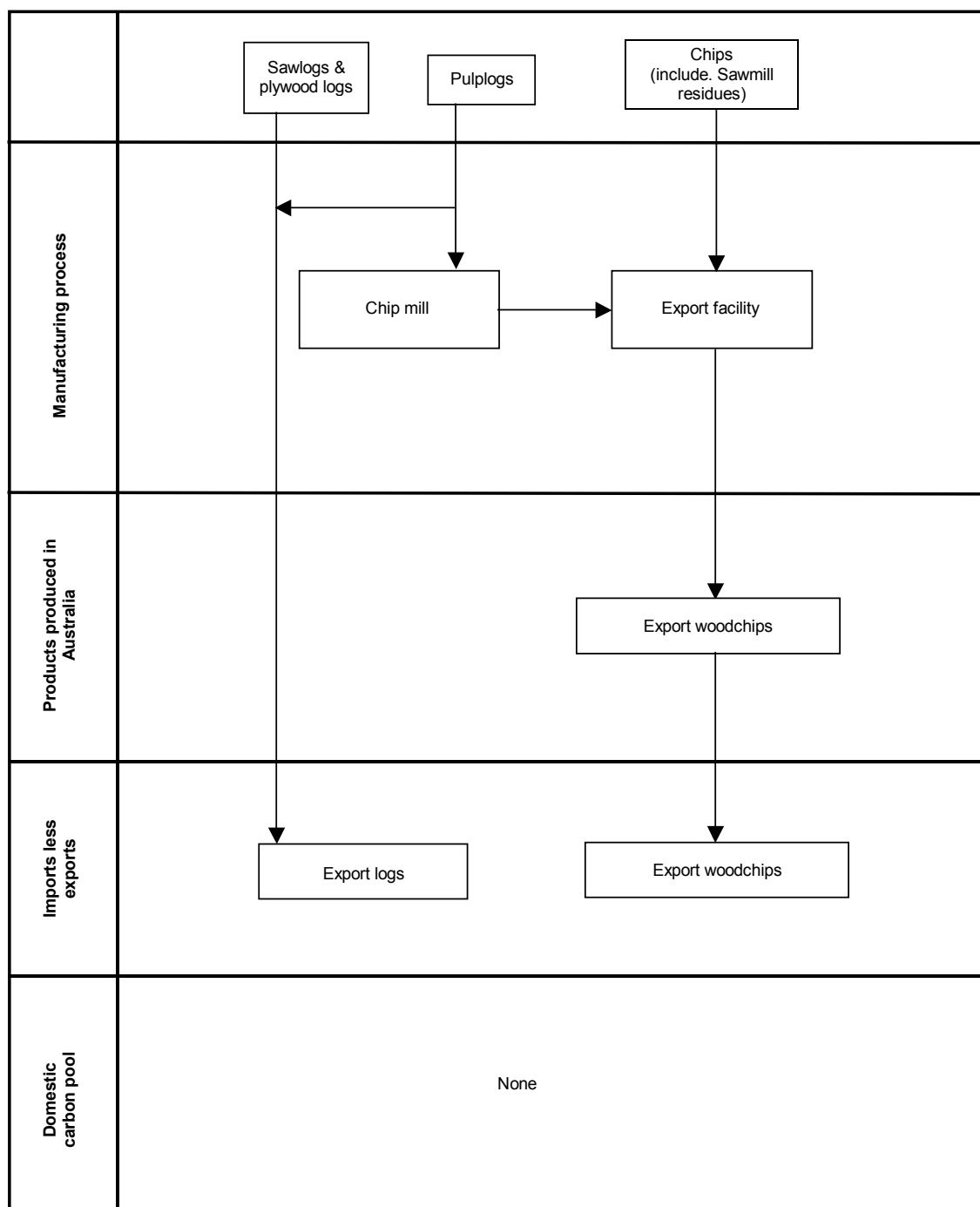


Figure 7.17: National Carbon Accounting Model for Wood Products: Wood flows in export woodchips and logs



APPENDIX 7.J CROSS-CUTTING ISSUES (QA/QC)

7.J.1 Introduction

Australia's National Carbon Accounting System (NCAS) uses Tier 3 methods to estimate emissions and an Approach 3 method to represent most land categories. 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 (IPCC, 2003). In addition, unlike Approaches 1 and 2, which use basic land-use data and land use surveys, Approach 3 uses direct and repeated assessments of land use from full spatial coverage (IPCC, 2003). Temporal and spatial variability of emissions estimates are reflected by the climate variables integrated into the Tier 3 models and the spatially explicit monitoring of land use and land use change.

Tier 3 and Approach 3 methods were judged necessary for estimating Australia's land sector emissions for several reasons. Firstly, land use conversion in Australia involves only a small fraction of the highly diverse and dynamic land area and therefore applying average carbon stocks and emissions factors for broad geographic region would lead to bias. Secondly, Australia's highly variable climate causes large differences in the biological drivers of emissions from year to year. Thirdly, the nature and pattern of land use change and ongoing management has varied considerably over time, which affects emissions. The approach of using a simple generalised emissions factor would not produce an unbiased estimate of emissions for land conversions that consist 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 remotely sensed time series of land cover change system 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 calibration, validation, verification, quality assurance, quality control, sensitivity and uncertainty analyses, and transparency and review than is normally applied to Tier 1 and Tier 2 methods.

This appendix defines and details the calibration, validation, verification, quality assurance, quality control, sensitivity and uncertainty analyses, and transparency and review applied to the calculation of Australia's greenhouse gas emissions from *Land-Use, Land-Use Change and Forestry* (LULUCF). These activities ensure that Australia's estimates are in line with the IPCC guidelines and guidance. It also describes the roles and responsibilities of the various organizations and agencies involved in each of the processes required to estimate and deliver the LULUCF emissions estimates and the national inventory report. The appendix is divided into the following sections:

Section 7.J.1 – Introduction and definitions

Section 7.J.2 – Input data and model development

Section 7.J.3 – Source category

Section 7.J.4 – Model and data management

Section 7.J.5 – Transparency and Review

7.J.1.1 Definitions

7.J.1.1.1 Calibration

Calibration is a fundamental process for NCAS model development that ensures that the models perform accurately and realistically for the ecosystems and conditions for which they were developed. Calibration requires high quality data that represent the range of conditions under which the model is required to perform.

Calibration data needs to be of high quality to ensure that the model parameters derived through calibration are accurate and do not produce biased emissions estimates. Calibration data is collected from new and existing research where strict measurement protocols have been implemented. Data which has been collected in time series is particularly valuable for calibration, especially for the soil carbon components of the models.

7.J.1.1.2 Validation

Validation data and processes are used by the NCAS to test that the calibration of the models does not produce biased emissions estimates. Validation data may be either the same or of a slightly lower quality than calibration data, but must still be of high quality to ensure that the results of the validation processes reflect reality. Validation data is independent of calibration data and is sourced from ongoing NCAS research and development programs, other government research programs (e.g., soil carbon analyses as part of Australia's Farming Futures program) or derived from other relevant research which has become available since the original calibration of the models. Validation by direct measurement provides the benefit that independent data can be used to assess model and land use attribution performance in detail (e.g., by carbon pool per pixel).

7.J.1.1.3 Verification

Verification is conducted by checking, in detail, land cover change areas and modelled emissions estimates. The model can also be tested against lower quality data that does not meet the strict criteria for calibration and validation data. This data is used by the NCAS to verify that models are responding correctly and that the estimates are within known ranges. Non-site specific data, such as regional averages (e.g., by soil type and vegetation type) that cannot be used for calibration or validation within the point specific model can be used to verify overall model performance.

7.J.1.1.4 Quality Assurance & Quality Control (QA/QC)

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 are done routinely by the NCAS to measure and control the quality of the inventory as it is being developed. This ensures the integrity, correctness and completeness of model inputs and outputs, at all stages of the modelling process. Such QC activities include:

- i. checking for errors in the derived input data;
- ii. checking the integrity of data sets on entry to model databases (prior to their use in models);
- iii. testing to ensure the integrity of the model code between versions (version control);
- iv. testing the sensitivity of model outputs and emissions estimates to changes in input data and model parameters; and,
- v. checking model results using auditing technique and implementation of policy specific rules.

7.J.1.1.5 Sensitivity & Uncertainty Testing

The methods of uncertainty testing described by the 2003 IPCC *Good Practice Guidance* are typically designed for Tier 1 and Tier 2 emissions factor based approaches. The fundamental approach of using *Monte Carlo* analysis for sensitivity and uncertainty testing in Tier 1 and Tier 2 remains relevant in Tier 3. However, methods for dealing with potential error propagation and inter-correlation of parameter uncertainties need to be applied to the models used in a Tier 3 inventory.

Monte Carlo analysis can be used to test the sensitivity and uncertainty of emissions estimates made using the NCAS. The *Monte Carlo* analysis determines:

- i. that the best estimate of emissions (most likely outcome) is not subject to bias;
- ii. parameter sensitivity to aid understanding of the drivers of uncertainty and guide improvement programs and verification priorities; and,
- iii. 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.

7.J.1.1.6 Transparency & Review

Australia ensures that information of the assumptions and methodologies used in its inventory are clearly explained, easily accessible and open to review. Transparency and review for a Tier 3 inventory approach are not the same as for Tiers 1 and 2. For Tiers 1 and 2 the focus is on the estimation of activity areas and the selection of appropriate emissions factors. For the models and datasets used in Tier 3 model-based systems, different approaches to transparency and review are required. The basis of transparency and peer review for the NCAS are founded on:

- i. periodic review;
- ii. published specifications, protocols and methods;
- iii. published verification results;
- iv. public release of models, tools and data; and,
- v. publications in peer reviewed journals and other literature.

7.J.1.1.7 Time-series consistency

A nationally consistent time-series of satellite data allows a country to monitor land use change, from which the net change of emissions and removals can be accounted. It allows for the spatially explicit detection of land use change, attribution of the type of land use change, and allows a country to develop baselines and reference years from which change can be monitored over time.

7.J.1.2 Roles & Responsibilities

Many organisations external to DCCEE are involved in the development, testing and maintenance of the NCAS. Table 7.J1 summarises the organisations involved in the development of NCAS and their roles and responsibilities.

External organizations (contributors) are generally engaged on a fee for service basis. The NCAS manages various contracts and financial administration procedures to ensure the engagement of the organizations in the development and maintenance of the NCAS. The processes undertaken to check the accuracy of data and information supplied by external contributors are detailed in later sections.

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 | NCAS GIS and Remote Sensing Unit |
| | | | Data generation and internal QA | External (GA) | Annual | NCAS GIS and Remote Sensing Unit |
| | | | Data delivered to DCCEE | External (GA) | Annual | Entry to image database |
| | Satellite data processing | 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 | NCAS GIS and Remote Sensing Unit |
| | | | QA on cloud cover masks | External (CSIRO) | Annual | NCAS GIS and Remote Sensing Unit |
| | | | Image mosaic analysis of new data | External (various contractors) | Annual | Technical specifications for mosaicing |
| | | | QA on mosaicing | External (CSIRO) | Annual | Manual for mosaicing |
| | | | | | | Naming standards for mosaic products and cloud masking |
| | | | QA/QC for mosaicing | External (CSIRO) | Annual | NCAS GIS and Remote Sensing Unit |

| Category | Sub-category | Activity | Quality Task | Responsibility | Frequency | Reports |
|------------|--|--|---|--------------------------------|-----------|---|
| Input data | Remote sensing for land cover and land use | 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 | NCAS GIS and Remote Sensing Unit |
| | | | Forest extent product QA | External (CSIRO) | Annual | NCAS GIS and Remote Sensing Unit |
| | | | Final products | External (CSIRO) | Annual | NCAS GIS and Remote Sensing Unit |
| Input data | Climate | Data are obtained from the Australian Bureau of Meteorology | QA and QC Checks on data integrity and spatial accuracy | External (ANU) | Annual | NCAS Technical report 23 |
| | | Check of data library | QA and QC on data entries | External (ANU) | Annual | NCAS Technical report 23 |
| | | Generation of initial surfaces | QA and QC on data outputs | External (ANU) | Annual | NCAS Technical report 23 |
| | | Accuracy checking of surfaces against individual station data | Validation of surfaces | External (ANU) | Annual | NCAS Technical report 23 |
| | | Checks include data integrity and that the data for each pixel in each time epoch conforms with expectations of normal data ranges | | DCCEE | Annual | Data only enters 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 (Unkovich <i>et al.</i> , 2009; Unkovich <i>et al.</i> , 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 database | 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 | NCAS Agriculture Unit |
| | | | | | | |
| Input data | Wood and Wood Products | Obtain data on forest product statistics published by the Australian Bureau of Agricultural and Resource Economics | QA/QC of forest product data | External (MBAC consulting, Jaakko Pöyry consulting, ANU, WebNet land resource services Pty Ltd) | Annual | NCAS Technical reports 8 and 24 |
| | | Enter data into model | QA/QC for data entry, check data for consistency with previous estimates | External, DCCEE and MBAC Consulting | Annual | NCAS internal process |
| | | | Enter new data into wood products model | DCCEE | Annual | NCAS internal process |

| Category | Sub-category | Activity | Quality Task | Responsibility | Frequency | Reports |
|---------------------|----------------------|--|--|----------------------------|-----------|--|
| 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 <i>et al.</i> , 2007; Brack <i>et al.</i> , 2006) |
| | Litter | | Ensure that estimates are within expected ranges | DCCEE and External | | NCAS Technical reports 14, 40 and Woldendorp & Keenan, 2005 |
| | Soils | Checks include the integrity and completeness of the relational database, and that data conform with expected ranges | Test 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 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 |
| | | 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 <i>et al.</i> , 2005 and 2007; Brack and Richards, 2002 |

7.J.1.2.1 Input data collection & preparation

Input data are obtained from a range of agencies external to DCCEE by either purchasing the data directly from the agency or using publicly available databases. Table 7.J2 lists the various data obtained and the agencies that contribute to the NCAS by providing the data. Analysis and preparation of data for use by the NCAS is conducted by both the external agencies and the NCAS.

Table 7.J2: 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 | CSIRO Mathematics, Informatics and Statistics GeoScience Australia (GA) NCAS GIS and Remote Sensing Unit Various private sector firms |
| Collection and collation of current and historical land use data | Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES) Australian National University (ANU) CSIRO Land and Water CSIRO Sustainable Ecosystems Department of Sustainability, Environment, Population and Communities (SEWPaC) |
| Collection of climate data and derivation of modelled climate surfaces | Australian Bureau of Meteorology (BOM) Australian National University (ANU) |
| Derivation of an Australia-wide soil type map | CSIRO Land and Water State and Territory Governments |
| Collection and collation of crop yield and management data | Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES) Australian Bureau of Statistics (ABS) CSIRO Land and Water |
| Collection and collation of forest growth and management data | Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES) Australian National University (ANU) CSIRO Sustainable Ecosystems NCAS Forest Inventory and Modelling Unit |
| Collection and collation of wood and wood products data | Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES) |

7.J.1.2.2 Model

The NCAS models are developed and tested internally by the NCAS code developers in conjunction with the NCAS teams responsible for the various aspects of the emissions inventory. Models are developed and improved upon in line with policy settings required for reporting to the UNFCCC and accounting under the Kyoto Protocol; and tested for operability. The development of the conceptual and functional specifications of the NCAS models is conducted by the NCAS in collaboration with various external agencies. Table 7.J3 lists the agencies responsible for and that contribute to the development and testing of the NCAS models used to estimate Australia's greenhouse gas emissions from the land sector.

Table 7.J3: 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 Code Developers |
| Defect management | NCAS Business Analyst |
| Business analysis and project management | NCAS Business Manager NCAS Business Analyst |
| Scientific guidance | NCAS Forest Inventory and Modelling Unit NCAS GIS and Remote Sensing Unit NCAS Agriculture Unit Australian National University CSIRO Land and Water CSIRO Livestock Industries CSIRO Sustainable Ecosystems NSW Department of Agriculture and Fisheries Queensland Department of Environment and Natural Resources and Water University of Western Australia Victorian Department of Primary Industries |

7.J.1.2.4 Emissions estimates and the National Inventory Report

The NCAS is responsible for delivering emissions estimates from the land sector (LULUCF) for both UNFCCC reporting and KP accounting. The NCAS is also responsible for the production of Volume 2, which pertains to the LULUCF sector, of Australia's National Inventory Report. The NIR is subject to annual internal review prior to release. The NCAS also uses independent experts to review the NIR.

7.J.1.2.5 Co-ordination with the National Inventory Team

Consolidation of Australia's greenhouse gas emissions estimates is conducted by the National Inventory Team in collaboration with the NCAS. The NCAS provides emissions estimates from the land sector (LULUCF) to the National Inventory Team. The National Inventory Team is responsible for collating emissions estimates across all sectors and delivering Australia's National Inventory Report to the UNFCCC. The NCAS and the National Inventory Team operate within a single division within the DCCEE and work closely to ensure that Australia's emissions inventory is in line with international guidelines and guidance.

7.J.2 INPUT DATA & MODEL DEVELOPMENT

7.J.2.1 Land cover change

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 on 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) which can occur because of mis-registration, where the same areas on both images are not comparable because one or both are geographically mis-positioned (Furby and Campbell, 2001). Mis-calibration can also occur where images are processed to different spectral qualities (e.g., brightness from sunlight and greenness from seasonal conditions) which lead to false detection of spectral change.

To ensure consistency of methods, and the provision of spatially accurate land cover change data through time, a detailed protocol of remote sensing specifications for land cover change was developed by Furby (2002) through extensive pilot testing (Furby and Woodgate, 2002). These specifications determine the exact way that images are acquired, processed and classified. The three primary QA/QC items associated with the use of satellite imagery to calculate land cover change are:

- i. Acquiring and selecting satellite imagery;
- ii. Satellite data processing, including registration, calibration and mosaicing; and,
- iii. 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).

7.J.2.1.1 Acquisition & selection of satellite imagery

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

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

7.J.2.1.2 Year 2000 Australian mosaic

A Year 2000 Australia mosaic serves as the rectification (geographical registration) and calibration (spectral consistency) base for the images from other years. The mosaic is formed from 369 Landsat 7 ETM+ scenes taken from July 1999 to September 2000. There were three steps in the process of creating the base image:

- i. Rectification (registration) base

A viewing-geometry approach was used to ortho-rectify the Landsat 7 ETM+ images for the year 2000, specifically the viewing-geometry and block adjustment model incorporated in the PCI software (PCI OrthoEngine). The viewing-geometry approach also required a height from a digital elevation model (DEM) as well as a map coordinate for each control point. Map coordinates for the ground control points are obtained from two sources: the Queensland Department of Environment and Resource Management (DERM; formerly known as Queensland Department of Natural Resources) and raster versions of the AUSLIG 1:100,000 map series.

ii. 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.

iii. 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.

7.J.2.1.3 Land cover resolution

To deal with the change in pixel size of the various Landsat sensors over time, and the need for spatially and temporally consistent integration with other spatial data used in the model, the ‘natural’ pixel size of the 1972 to 1988 Landsat MSS (57 m x 79 m) is re-sampled to a 50 x 50 m pixel. The 30 x 30 m native resolution of the Landsat TM and ETM+ data available after 1988 is produced as 25 x 25 m pixels.

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

All Landsat derived data are used at a consistent 25 m resolution for the full time series analysis by re-sampling the 50 m pixels (1972-1988 information products) into four 25 m pixels. The spatial-temporal model (see the Conditional Probability Network described below in the *Time Series Consistency* section) is important at this time, as it reduces the effect of “mixed” isolated and edge pixels in the overlap period. The period of the transition to the true 25 m data takes place prior to the period where it would have any significant effect on the first reported year of emissions (1990). The 50 m data resolution is effectively only used to run-in the model to establish forest age (if the forest is regrowth from non-forest land or in response to a forest removal since 1972) as lagged effects are small from all years except those immediately prior to 1990. The ability to determine, from 1990 onwards, the effects of land use change to 0.2 ha minimum areas is robust, given that this area is greater than the pixel resolution and the approach used removes mixed and other pixels which are temporally and spatially inconsistent.

Re-sampling Landsat TM and ETM+ data to 25 m pixels is common practice. Using a 50 m re-sample to provide consistency over the multiple resolutions of Landsat 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.

7.J.2.1.4 Registration & 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:

- i. 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;

- ii. if the registration accuracy appears doubtful, unacceptable or cannot be determined from the information provided, it is further investigated so that the exact nature of any problem can be described to the contractor for correction; and,
- iii. 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.

7.J.2.1.5 Mosaicing

All mosaiced images (quadrants and time slices) for a particular map sheet tile are assessed at the same time. The assessment of each image is performed in two stages:

- i. the information and data provided by the contractor is checked for completeness and the consistency of the mosaiced image assessed; and,
- ii. 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).

7.J.2.1.6 Thresholding

Two review processes are applied to the thresholding products. A quality assurance process is applied during and at the end of the thresholding stage of the processing. The aim of this quality assurance process is to ensure that the methodology has been correctly applied and that the intermediate and final products are consistent with the supplied ground data and with each other across stratification zone and map sheet boundaries. The assessment of the thresholding products is performed in several stages:

1. The information and data provided by the contractor after the single-date probability images are created (Step 8; see Furby, 2002) is checked for completeness. The adequacy and consistency of the analyses and the accuracy of the probability images is also assessed (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.

7.J.2.1.7 Time-series consistency

Remote sensing pilot testing demonstrated the need for time-series consistency in image data pre-processing, analysis, and subsequent formation of time-series forest/non-forest labels. The operational standards (Furby, 2002) give explicit emphasis through documented rule sets to each of these areas. For instance, although the processing is performed by different companies, all images are ortho-rectified using a standard algorithm (PCI Orthoengine) with standard inputs (a consistent digital elevation model). For time-series classification, these standards also include the use of a joint spatial-temporal model, in this case a conditional probability network (Caccetta, 1997; Caccetta *et al.*, 2003; Kiiveri *et al.*, 2001, 2003), for determining time-series of forest/non-forest labels. This process produces superior forest extent and change results compared to a process reliant on pair-wise differencing of image pairs. The use of pair-wise differencing methods can lead to change estimates that are affected by errors due to seasonally changing land management effects (introducing large contiguous areas of false change), or by subtle sampling differences where mixed pixels have varying composition of forest/non-forest from year to year (producing many isolated false change pixels or edge effects at forest boundaries).

The conditional probability network uses a series of spatial and temporal rules for determining forest/non-forest and forest change (forest and non-forest conversions). The temporal rules bias against unlikely events such as multiple one year conversions between forest and non-forest. The rules are particularly effective when the time between observations is less than that of a forest growth and harvest cycle. This is one of the reasons for having a relatively dense time-series sampling.

The spatial rules consider the labelling of a pixel in the context of its spatial surroundings, where labels that are consistent with the neighbouring labels are reinforced as opposed to those that are inconsistent (e.g., isolated pixels). The spatial and temporal rules work together providing spatial and temporal consistency, minimising temporally varying “mixed pixel” effects (due to spatially varying sampling from independent satellite overpass from year to year) and subsequent error in pixel and change labelling.

7.J.2.1.8 Attribution

Once the quality assurance processes have been applied, land cover change maps are created. Changes identified in cover change maps are then attributed for the determination of change as either human induced or natural effect/methodological artefacts. These include green flushing in images due to climate, terrain illumination variability, irrigation, water bodies and fire scars. Contractors use visual image backdrops in time-series for this discrimination. Results of this discrimination are then quality assured by DCCCE. This process provides for an additional independent process of checking the land cover results.

7.J.2.1.9 Plant typing

Validation of plantation type mapping accuracy was carried out against specifically collected field data showing plantation species, stocking, condition, age and extent. This validation data was collected during a national program of site visits. The recently completed plantation mapping achieved an accuracy of 91% in terms of both species and spatial referencing for plantations identified as post-1990 plantations (MBAC Consulting, *in prep.*). Incorrect forest typing (e.g., labelling hardwood as softwood and vice versa) contributed 5% of the error, with only 4% being incorrect for both location and type. These results provide considerable confidence in the methodology applied and allow for a spatial-temporal analysis of Australia’s plantation estate (see Appendix 7.D).

Methods for plantation typing of pre-1990 plantations are being developed. Similarly to post-1990 plantation typing (into hardwood and softwood plantations), softwood plantations pre-1990 are being distinguished from native forests using the Landsat MSS data from 1972-88. Validation of softwood plantation type mapping pre-1990 is currently being carried out by validating (and calibrating) against collected field data.

7.J.2.1.10 Improvement & Verification

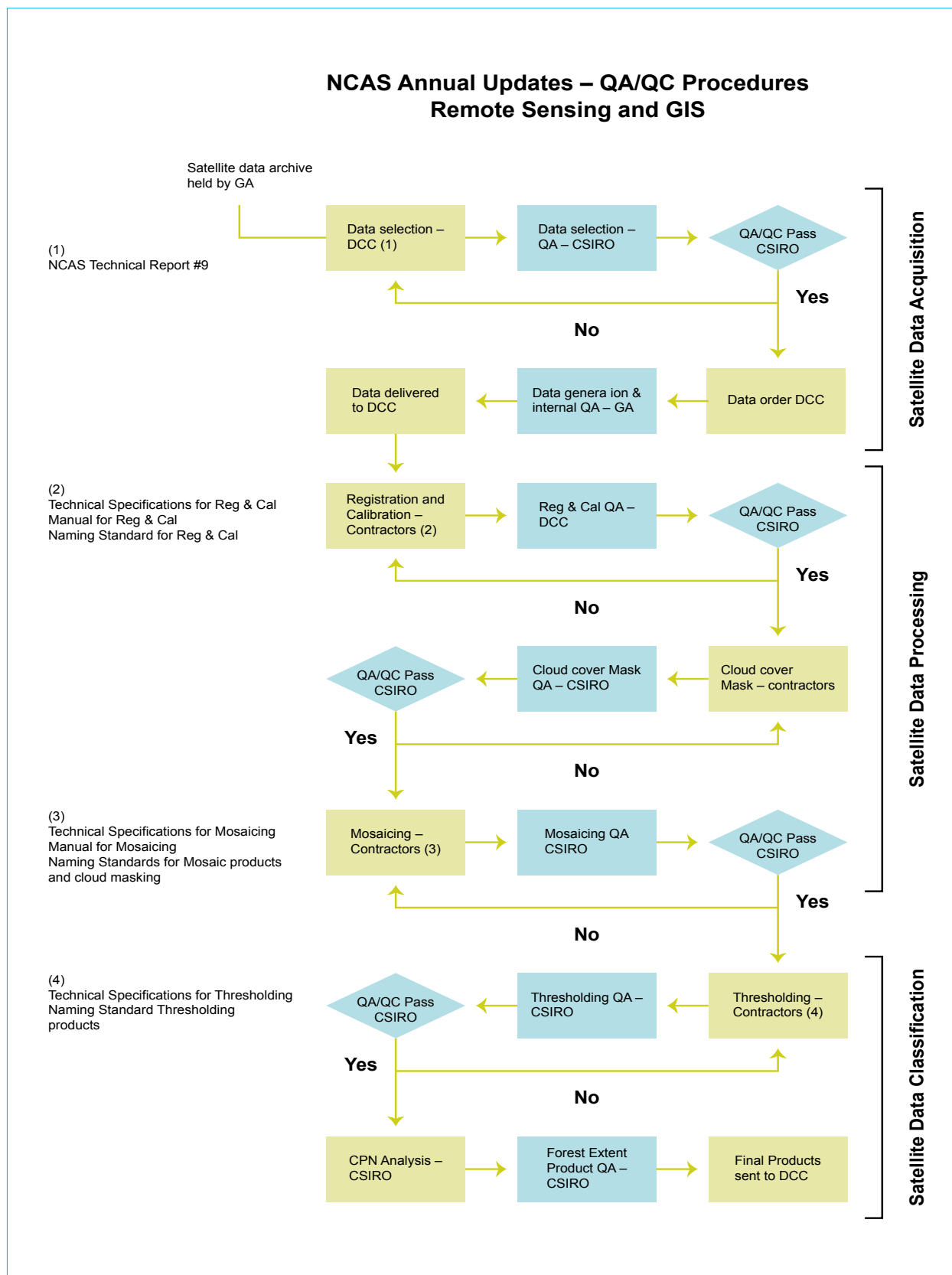
The verification of the remotely sensed land cover mapping is conducted within a continuous improvement and verification program. An independent program of checking the Landsat results is conducted by external agencies, both to verify the method (and hence the accuracy of the product) and to identify areas for improvement. This program involves checking the results of the land cover mapping against high resolution satellite and air photograph interpretation using a stratified sampling technique.

The first verification considered the initial time-series of change data from 1972-2000 and was done using air photograph comparisons. When the recommended improvements were implemented, with the update for the 2002 data, the full time-series was re-analysed to reflect the improvements (Lowell *et al.*, 2003; Jones *et al.*, 2004; Lowell *et al.*, 2005). Subsequent analysis has led to further improvements being implemented during the 2004 and 2005 updates. Since 2005, the verification of the change analyses has been done using very high resolution satellite data which has significantly improved the quality of the verification.

The initial independent assessment of the “raw” accuracy of the classification of forest and non-forest areas across the continent and over the period of 1972 – 2000 indicated that 94-98% of forest and 85-96% of non-forest vegetation was correctly classified (Jones *et al.*, 2004). Accuracy in the data used for estimated rates of change (afforestation/regrowth or deforestation) was higher than the above, because the process of manual attribution, described previously, was used to confirm or reject changes in cover in the final dataset.

Incremental method development beyond that described in Caccetta *et al.*, (2003), and applied throughout the current time-series, includes the implementation of terrain illumination correction (Wu *et al.*, 2004), and the use of ‘texture’-based analysis to map sparse vegetation extent and change (Caccetta and Furby 2004).

Figure 7.J1: Overview of QA/QC procedures associated with Land Cover Change calculations



7.J.2.2 Land use & land management

Land use and land management information is used 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*.

7.J.2.2.1 Land use mapping

Areas of *grassland remaining grassland* and *cropland remaining cropland* are obtained from the National Land Use 2001/2002 (Version 3) Summary Statistics provided by the Australian Bureau of Resource Economics and Sciences (ABARES) (formerly the Bureau of Rural Sciences, BRS) (http://adl.brs.gov.au/mapserv/landuse/docs/2001_02_Nat_Luse_Summary_Stats.pdf). This mapping combines remotely sensed data with regionally specific information on land use collected by the Australian Bureau of Statistics (ABS). As such the QA/QC procedures are implemented by ABARES and ABS. Prior to use in the 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 program to ensure that no double counting of land areas occurs.

7.J.2.2.2 Land management

Regionally specific information on land management practices were collated from a large range of sources. Swift and Skjemstad (2002) provided detailed information on agricultural land use and management in Australia (NCAS technical report 13) and Raison and Squire (2008) reported in detail forest management in Australia (NCAS technical report 32).

The land management data represent a composite of the best available and most comprehensive national information. A high degree of confidence can be placed in the data obtained owing to the various sources of information and direct regional knowledge of agency experts involved in collating the data. This confidence is furthered by the concurrence given during State-based workshops used for reviewing the data, thus providing a measure of quality assurance through expert review. Publication of the results has provided transparency and the opportunity for ongoing review. Any concerns about the veracity of the information were not identified throughout peer review or publication.

7.J.2.2.3 Crop yield & management

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 national time series of the best available crop yield data.

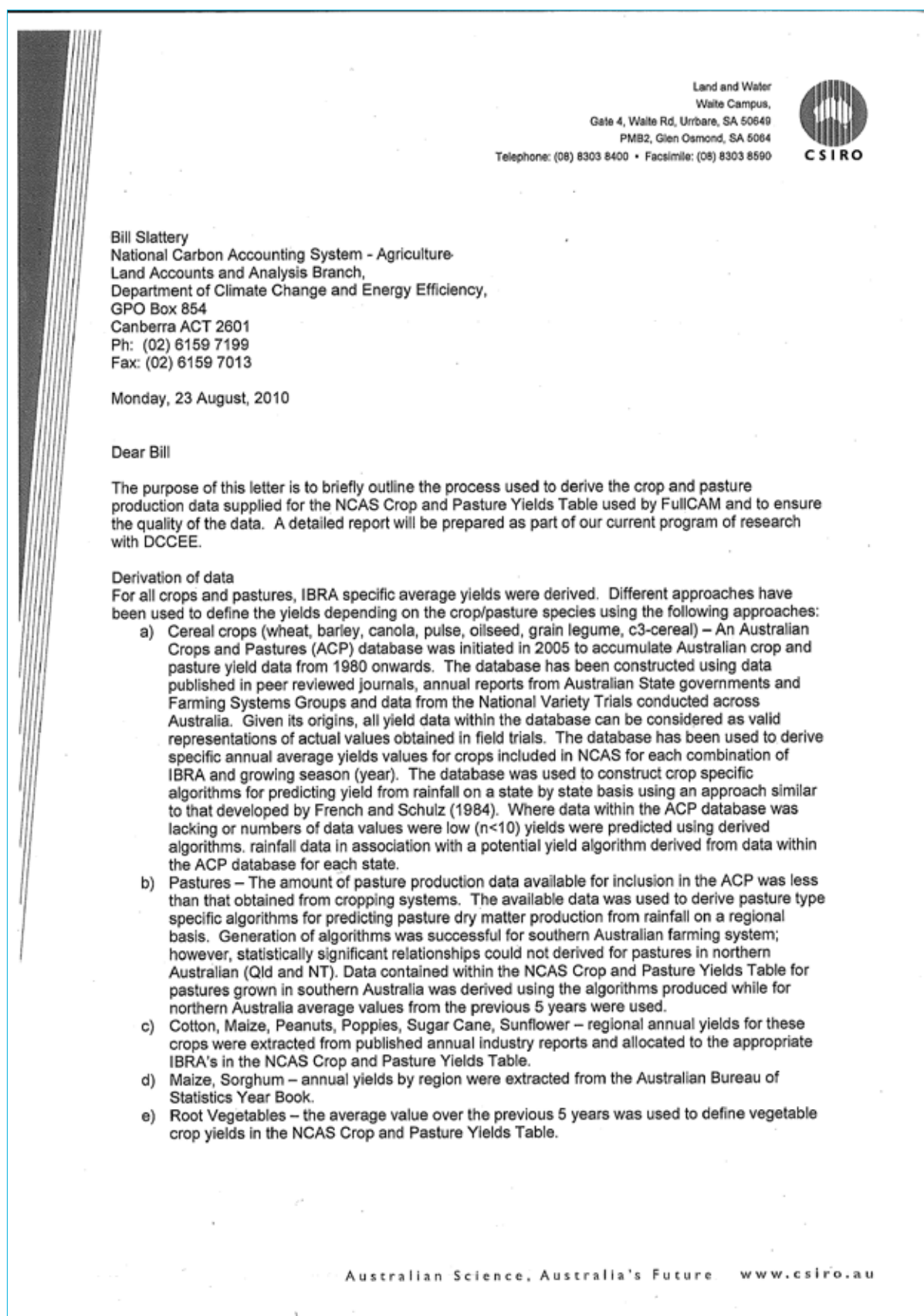
The CSIRO Land and Water is contracted by the DCCEE to supply a comprehensive annual crop and pasture yield database for the NCAS (Figure 7.J2). The majority of the available data that is imported into the database is obtained from ABS and ABARES, of which both agencies had collected annual crop and pasture yield data through national statistical surveys at the statistical local area (SLA) for the grains, grazing and dairy industries. These national surveys also provide detailed information on farm inputs (e.g., fertiliser, irrigation, sowing rates, and crop species), production (e.g., crop yields and pasture cut for hay) and economic performance for the grains, grazing and dairy sectors, which comprise more than 70 per cent of Australian farm business units. In addition, data is also obtained from research papers and reports, and farming systems annual reports (e.g., Birchip Cropping Group, Mingenew and Minnepa Farming Group, Central West Farming Services) for the major crops and pastures in Australia (Unkovich *et al.*, 2009).

These data are disaggregated to the Interim Biogeographical Regionalisation of Australia (IBRA, Version 4, Thackway & Cresswell, 1995) scale, and also differentiate between stubble management practices, crop species, crop rotations and crop distribution according to soil type (Swift and Skjemstad, 2002). Quality control for consistency of yield against previous years, constrained by climate, is conducted at

the sub-IBRA scale by comparing the current year's yield against the previous year's yield. All data are checked for consistency from the previous year and any values exceeding a variance of greater than 10% of upper and lower limits are checked against industry databases where there is available data. If data are unavailable for any given region a calculation of yield is derived using a growth function (Unkovich *et al.*, 2009) using regionally specific climate data (provided by the NCAS) and again checked for a 10% variance.

The 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 and soil classification and are recorded accordingly.

Figure 7.J2: Letter outlining the processes used to derive the crop and pasture yield data supplied for the NCAS.



Quality Assurance protocols for data entered into NCAS Crop and Pasture Yields Table

- 1) All data used to construct the NCAS Crop and Pasture Yields Table have come from peer reviewed scientific journals, industry publications and reports or the National Variety Trials. All data used has been subjected to review and its quality confirmed.
- 2) Were algorithms were derived to predict yields, only algorithms that were statistically significant ($\alpha=0.05$) were used.
- 3) Where a lack of data existed within the ACP database or no statistically significant relationship between rainfall and yield could be defined, average values from the previous 5 years within the NCAS Crop and Pasture Yields Table were used.
- 4) All yield data, irrespective of the method by which it was generated, was subjected to an analysis to ensure that it did not fall outside of a window equivalent to 10% variation above the maximum or 10% below the minimum yield values found across all years (1970-2008) in the NCAS Crop and Pasture Yields Table. Where values differed from the maximum or minimum values by more than 10%, the values were altered to either (1.10 x maximum) or (0.9 x minimum), respectively.
- 5) On completion of the data entry, the temporal trends for all combinations of management by soil by IBRA were plotted and examined to confirm that no extreme yield data was produced and entered into the NCAS Crop and Pasture Yields Table.

References

French, R.J. and Schultz, J.E. 1984. *Aust. J. Agric. Res.* **35**, 743-775

Regards



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7.J.2.2.4 Forest growth & management

The estimation of carbon stock change requires an estimation of tree biomass, including changes due to growth and loss from land clearing and forest harvest for both agricultural and forestry land systems. While there were several possible methods for estimating biomass for the NCAS, the only feasible approach for a continental scale biomass inventory was the use of a hybrid of process and empirical growth modeling, integrated with land use data obtained from the NCAS remotes sensing program.

CSIRO Sustainable Ecosystems (formerly Forestry and Forest Products) was engaged to compile a database of existing biomass measurements from published and unpublished studies. Research studies were only included if they had adequately reported methods, because this information is required to establish confidence in the robustness of the data (Richards and Brack, 2004a). Quality control of the data-set included the stipulation that measurements had undergone scientific peer review prior to publication (Raison *et al.*, 2003). Included data are representative of Australia's major vegetation types, ranging from savannahs to rainforests (Richards and Brack, 2004a). The biomass data was accompanied with information on the site (location, IBRA region, climate and soil type), the vegetation (tree age, vegetation type and management) and the methods for deriving allometric equations (biomass measurement, variables, tree number and DBH) developed for the tree plot. The calibration data covers the range of age classes from regrowth to senescent (old-growth) and therefore the potential variation in field biomass conditions.

The assessment of published and unpublished research studies, papers and reports also provided information on gaps in data. This allowed for tree or stand sampling to occur in areas of data gaps to provide a more comprehensive database of forest biomass. To ensure the quality and consistency of ongoing data collection for forest biomass, the NCAS together with Snowdon *et al* (2002) (NCAS technical report 13) developed a set of sampling protocols through a series of workshops. These protocols describe the measurement techniques and sampling procedures that need to be met to be considered of a suitable quality for calibration and validation of the NCAS model. These protocols ensure that DCCEE was in receipt of biomass data that had been sampled in a consistent and validated manner.

In addition to compiling biomass measurements, CSIRO Sustainable Ecosystems was also engaged to review forest management practices in Australia (Raison & Squire, 2008) (NCAS technical report 32). Forest management activities, such as site preparation, weed control, stocking rates, thinning, pruning, fertiliser application and irrigation impact on forest carbon stocks, growth rates and total site carrying capacity. Under the direction of the NCAS and CSIRO, a team of qualified and experienced people with a strong background and long experience in forest management were tasked to collect and synthesize detailed management information from published literature, records and reports held by State agencies, and discussions held with retired foresters and senior staff within agencies. A comprehensive detailed report of the approach taken, the experts involved and the findings can be viewed in NCAS technical report 32.

The approach of using Landsat data was that it provided fine-resolution data on disturbance history estimates back to the early 1970s which can then be used to estimate stand age. The time-series of Landsat data allows the NCAS to locate forest disturbance clearing and reforestation both spatially and temporally. The forest type disturbed/cleared is determined by integrating the disturbance history mapping and the vegetation mapping of the National Vegetation Information System prepared by the National Land and Water Resources Audit. The forest type reforested is determined by the Landsat data which is used to classify forests into three broad types, softwood plantations, hardwood plantations and native forests.

7.J.2.3 Climate

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.

The DCCEE engages the Australian National University (ANU) to provide the NCAS with robust climate data for the modelling period (1970 to present). The attributes of climate data provided to the NCAS include mean monthly rainfall, vapour pressure deficit, pan evaporation, average temperature, minimum temperature, maximum temperature and frost days all of which are obtained or directly derived from the Australian Bureau of Meteorology (BOM). A Digital Elevation Model (DEM) is also used for the production of climate surfaces. Monthly climate surface maps of each attribute are derived using the ANUCLIM (McMahon *et al.*, 1995) climate modelling software (Kesteven *et al.*, 2004) developed by the ANU.

The QA/QC process associated with the climate data, particularly the derivation of monthly climate surfaces, is to minimize errors arising from the data used in the spline functions that produce the output climate surfaces by ensuring that the best available, highest quality input data is used. This is achieved by validating the input data used to generate monthly climate surfaces produced in ANUCLIM, and validating the output climate surfaces.

Three quality control aspects are associated with the production of climate surfaces. The first is examination of the completeness and quality of input monthly average climate data obtained from the BOM. Daily BOM data are accompanied by a quality control flag indicating whether or not the data have been quality controlled by the BOM. The minimum requirement for the calculation of monthly statistics is a 20-day record of quality controlled data for the average, maximum and minimum temperature variables, and a 25-day record of quality controlled data for rainfall and the number of frost day variables. Furthermore, only those years with a full 12 months of data are used to calculate the climate surfaces.

The second quality control aspect is to obtain a DEM with sensible drainage properties, stream lines, contour lines and cliff lines. Version 2 of the 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 metres and 20 metres for most of the continent. Standard errors are larger in upland areas with steep and complex terrain where the largest errors can exceed 200 metres (Hutchinson *et al.*, 2001; Kesteven *et al.*, 2004).

The third quality control aspect associated with climate data is to examine spatial location of weather stations, and the influence that errors in these data have on fitting the climate surfaces. For example, an error of 200 m altitude in a station location can equate to several degrees of temperature in a mountainous region. To fit multivariate climate surfaces the values of independent variables need to be known at the data point, and meteorological stations should be accurately located in position and elevation. However, the BOM have used various methods to geo-locate weather stations, with older locations being the least accurate. The BOM provided a base station dictionary (23 May 2001) with the supplied monthly climate data (Kesteven *et al.*, 2004). The station dictionary provided site number, latitude and longitude, elevation, location description and the start and finish year of operation (Kesteven *et al.*, 2004). This version of the BOM station dictionary was compared with a 1998 dictionary held by the Fenner School of Environment and Society at the Australian National University. Any station with a difference greater than 0.1° in position or 50 m in elevation was checked by visually locating the station using any available satellite imagery, topographic maps or aerial photographs. The correct geo-location of the station is then used in the model. The effect of the geo-location of weather stations on modelled climate surfaces is examined using variance statistics. The climate surface modelling output includes variance statistics

of model residuals (RMSE) that are used to assess the extent of difference between the modelled result and actual weather station data. These residuals indicate how well the predicted climate measurement matches the actual climate measurement for a month and location. The highest 100 residuals are extracted and examined further. If these residuals indicate a geo-location error, then the location of that weather station is corrected and the model re-run. If there is no geo-location error associated with the climate surface then the station is included in the model. The climate surfaces, including all model results, have been submitted to the Australian National University's Fenner School of Environment and Society for independent QA/QC. Detailed checking of procedures and output statistics led to the conclusion that the development of the models represented application of best practice and yielded robust results.

7.J.2.4 Soils

The NCAS requires maps of soil type and pre-cleared soil carbon to calculate soil carbon stock changes due to land use change, ongoing management and climatic conditions. These maps provide: i) pre-clearing soil carbon stocks at a 250 m spatial resolution; and, ii) soil type description that are used to derive water holding capacity and soil clay content that determines the rate of decomposition of plant residues and the allocation of carbon to the different soil pools (Richards, 2001; Webb, 2002).

Data for the development of soil type maps was extracted from the best available resource inventory information held by state and territory governments and was subject to expert review prior to being incorporated. Initially, a comprehensive data search was conducted to determine the extent of existing chemical and physical information for sites that had not been cleared. Organic carbon contents were determined for soil profiles then averaged for each of the Soil Orders, Principal Profile Forms or Groups within each IBRA region. Where site data were scarce or non-existent, data from similar soils in the same or neighbouring IBRA region were used (Webb, 2002). Soil clay content was also taken from these inventories and supplemented with available research data. Soil carbon content was corrected to methodological standards where the initial method of measurement was known; otherwise the data were considered unusable and were not included in the final product.

In deriving the soil carbon map the comparability among existing soil carbon measurements arising from the use of different analytical methods needed to be resolved. Soil organic carbon measurements are normally derived from combustion in a LECO furnace. However, the method historically used to derive soil carbon values for many sites is the Walkley and Black (1934) wet oxidation method. This method has evolved over time in the major laboratories, such as by including a heating step during oxidation (Heanes, 1984) and, thus, has produced results that have varied over time. In a separate study 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, NCAS technical report 14) 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.

7.J.2.4.1 Soil type

Spatial soil coverage for all Australian states and territories are identified through the Atlas of Australian Soils and broad scale land system mapping together with regionally specific data to produce high resolution (>1:50,000) coverage that could be overlayed on to IBRA regions (Webb, 2002). Where possible the use of land-based soil surveys and geomorphic maps were used to validate the broader scale soil type maps within an IBRA region. In addition, regional expertise was obtained at the state and territory level for the major soil types within each of the IBRA regions. This provided an estimate of the major soil types within an IBRA region and the extent of different land uses for each of these soil types. The process of developing the maps is described in Webb (2002), which was supported by the development of soil sampling protocols and standardised laboratory methods (McKenzie *et al.*, 2000).

7.J.2.4.2 Initial soil carbon

The distribution and extent of soil carbon is not uniform in the Australian landscape, and is influenced by factors such as soil type, soil moisture, climate, land cover and land use. Spatially explicit information about the underlying soil carbon potential in the top 30 cm of soil is required to accurately model soil carbon flux using 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.

At the time of NCAS development 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.

Since then, the Australian government has invested in an on-going research program that in partnership with industry and research organisations (universities, state government departments, and CSIRO), obtains high quality data to support the development, verification and validation of its inventory. This research program is administered by the Department of Agriculture, Forestry and Fisheries (DAFF) and provides data from research projects to DCCEE for on-going inventory improvement.

There are two key areas of soil research activity that provide data to DCCEE, these include research and development activities related to soil carbon stock changes and soil nitrous oxide fluxes under different crops, management practices, soil types and climate. These activities are spread across Australia with more than 2,500 individual soil sampling sites located in four major agro-ecosystems.

7.J.4.5 FullCAM Model

A central part of the NCAS is the development of the Full Carbon Accounting Model (*FullCAM*). *FullCAM* is a hybrid process-empirical model that calculates emissions and removals using a mass-balance approach for both forest and agricultural systems, and transitions between them.

FullCAM is used to calculate emissions and removals for the *forest land converted to grassland*, *forest land converted to cropland*, *grassland converted to forest land*, *cropland remaining cropland* and *grassland remaining grassland* sub-categories. This model utilises data from a variety of sources and accounts for the effects of climate, site, species and management on growth.

7.J.4.5.1 Forest growth

The forest growth model in *FullCAM* is calibrated for use in both native forest systems and plantation systems. It includes the effects of management on growth, climate, soil type and water holding capacity, and fertility and forest productivity.

As part of the development of the forest growth model, a forest productivity index (index of biomass productivity) was developed which expresses the variability that is both spatial and temporal. The forest productivity index (FPI) was developed for the NCAS and uses the monthly climate surfaces (Kesteven *et al* 2004) in conjunction with CSIRO's national soil moisture holding capacity and fertility mapping, the nine second (250m) digital elevation mapping version 2.0, and Normalised Difference Vegetation Information Index data of the environmental resources information network (Waterworth *et al*, 2007). The products from this include monthly 1 km grids of FPI from 1970 presented as an index ranging from 0 to 30 on an annualized basis, and 250 m grids of long-term average FPI that also includes slope and aspect effects (Waterworth *et al* 2007).

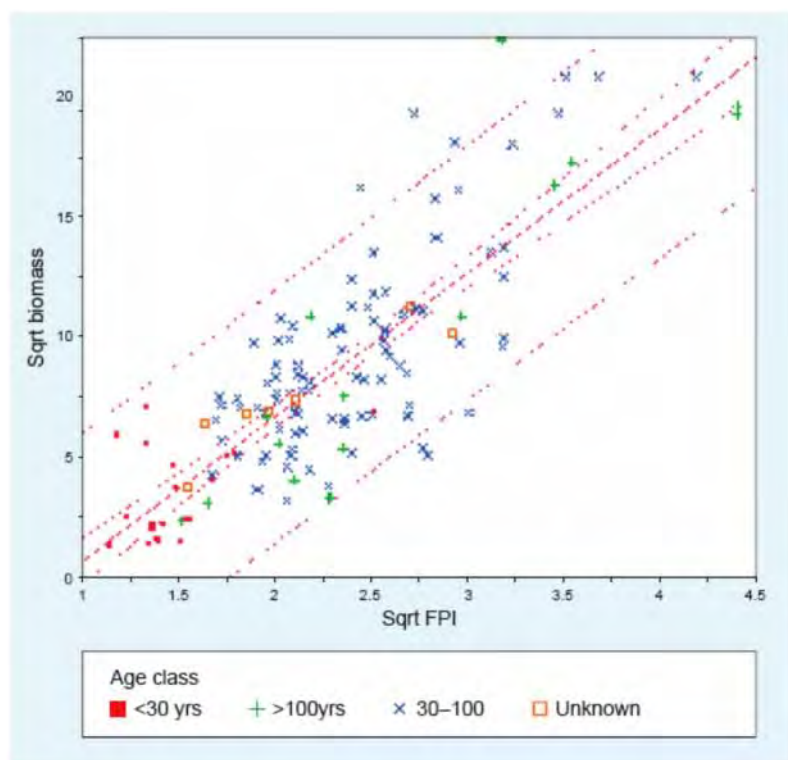
The FPI was then correlated with available above-ground biomass measurements reflecting a range of potential forest conditions and prior disturbance histories (except those with visible evidence of recent disturbance). That is, biomass data for sites with no reported recent disturbance were plotted against the calculated long-term average productivity (Figure 7.J3).

The relationship between aboveground biomass and FPI was used to derive a map of potential site biomass at maturity (Richards & Brack, 2004). The potential (site) biomass estimate represents the biomass which growth will generally approach. The regression, which considers biomass accumulated against the long-term average productivity of the site, was found to have a significant correlation ($P < 0.01$, $r^2 = 0.68$) (Equation (1)) (Richards & Brack, 2004). A square root transformation was required to meet assumptions of normality and homogeneity (Figure 7.J3).

$$M = (6.011 \times \sqrt{P} - 5.291)^2 \dots\dots\dots (1)$$

Where P is the long-term average forest productivity index and M is the above-ground biomass in t dry matter ha^{-1} .

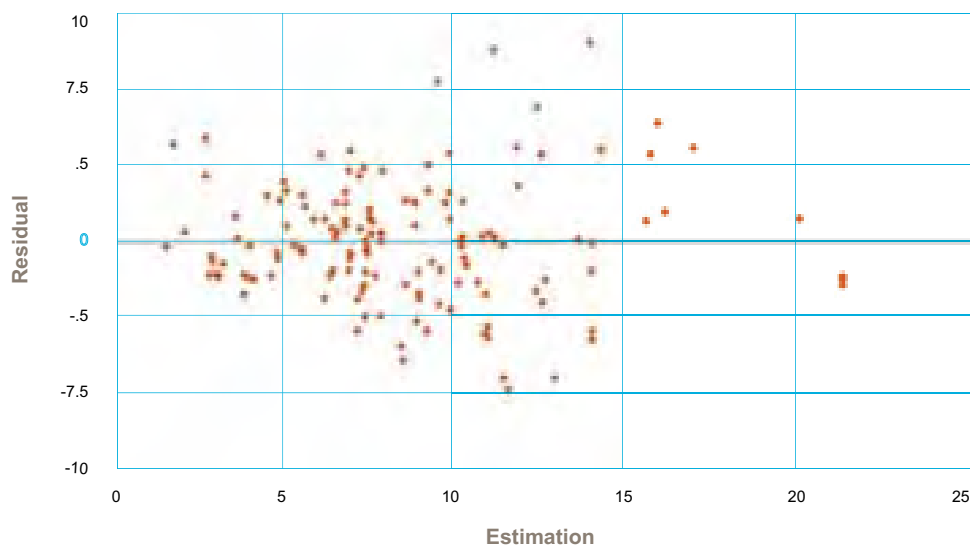
Figure 7.J3: Plot data of square-root-transformed data



The goodness of fit of Equation (1) to the measured data confirms that a robust relationship exists between the productivity mapping and measured aboveground biomass estimates. The outer 95% confidence limits (outer pair of dotted lines) show the reliability for predicting biomass at any individual site. The inner 95% confidence intervals (inner pair of dotted lines) show the high degree of confidence in the line of best fit being able to represent the variability in the field data at the national scale. It applies throughout the continuum of productivity across the forest estate as a whole. The model shows that the potential (site) biomass estimates is an accurate and unbiased representation of the forest estate (excluding young regrowth) as can be gauged from available data. A key benefit of the hybridisation of process modelling (through the productivity mapping) and empiricism (through known measures), is that estimates will be constrained to actual conditions (measured biomass estimates) and actual growth, not that of optimal growth.

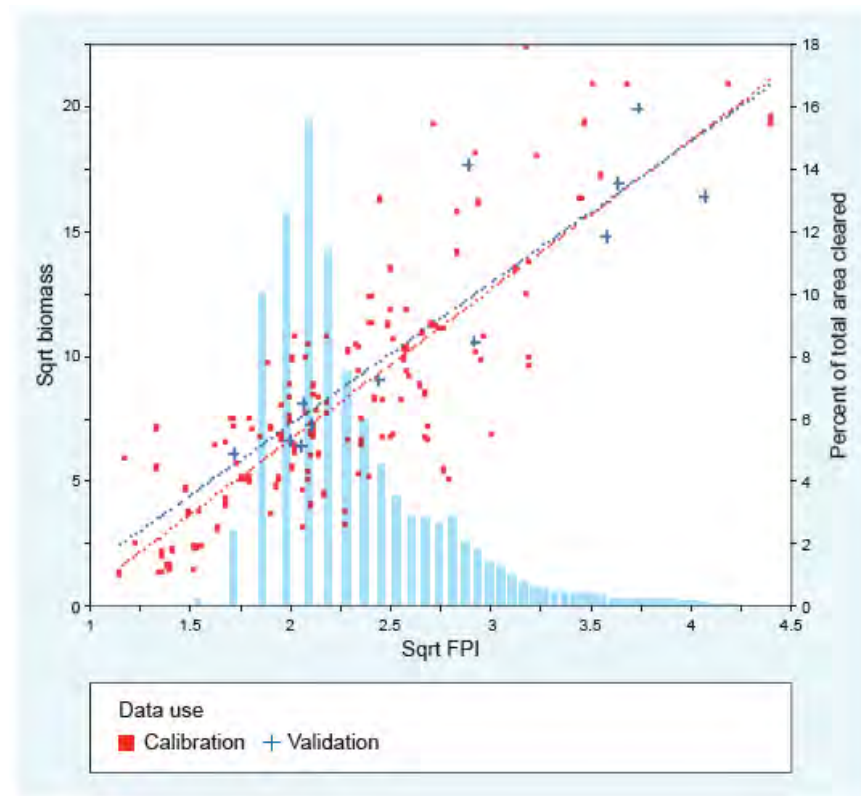
While the goodness of fit and lack of bias in error estimates (Figure 7.J4) provides confidence in the application of Equation (1) as a model to predict biomass at maturity, there is an obvious scatter in the data. This is attributable to the range of age classes and forest histories used in the model, 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.J4: Error distribution for equation 1



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 commissioned a research project to weigh all trees at three forest sites of varying productivity but with similar disturbance histories (Ximenes *et al.*, 2005, 2006). 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 either near maturity or at maturity with little evidence of recent disturbance. Validation tests show no significant difference between the validation and calibration data (Figure 7.J5). 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.J5: Calibration and validation data for the initial assumed biomass estimates



Note: The background histogram represents percentage of the area reported under forest land converted to cropland and grassland by forest productivity index.

The NCAS also utilises data collected by other agencies for verifying the biomass relationship. This data is typically of a lower quality (i.e., no direct biomass measurements) that precludes its use in calibration or validation. However, such data is valuable for testing the veracity of the model and identify possible areas for improvement. Verification data still needs to be of a reasonable standard to be accepted. In particular, the data must be accurately geo-referenced and the exact methods used to collect the data documented to ensure that it is consistent with good measurement practice.

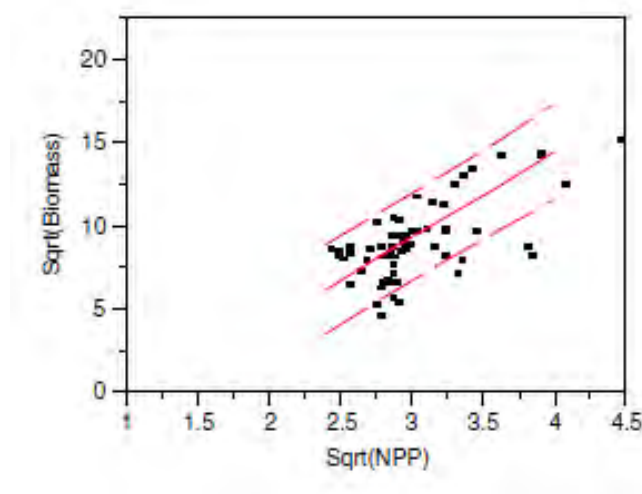
A key example of this verification approach is outlined in Brack *et al.* (2006). As part of a separate study funded by the Bureau of Rural Sciences (BRS) to estimate stem volume, MBAC Consulting conducted a field inventory of south-east Queensland. This data was made available to the NCAS for verification. Brack *et al.* (2006) converted this basic inventory data to biomass estimate using a generalized allometric equation from Snowdon *et al* (2002) to verify the biomass relationship. The biomass data had several limitation:

- i. the disturbance history of the plots was unclear and many appeared to be younger regrowth;
- ii. many of the plots had large gaps where no trees existed, which would lead to an underestimation of biomass;
- iii. the applicability of the allometric equation to the sites was not tested; and
- iv. the sites only covered a small range of the FPI values.

Despite these limitations, there was still a significant relationship between the FPI and biomass (Figure 7.J6). The equation produced lower initial biomass estimates than the NCAS biomass equation but this is likely a function of the points listed above.

Further verification work is planned and the NCAS is actively working with state agencies to collect and collate additional data.

Figure 7.J6: Regression of FPI and biomass (t ha^{-1}) with 90% confidence interval. Biomass estimated from Snowden *et al.* (2000) allometrics and MBAC Consultants (2003) inventory data. Source: Brack *et al.* (2006)



7.J.4.5.2 Agricultural growth

Crop yields are highly sensitive to changes in 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 rainfall variations, such as droughts, lead to large differences in the crop yield between years. This variability is often regionally specific and results in large changes in total biomass of agricultural crops and therefore the amount of residue returned to the soil. This in turn leads 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 a trend analysis is conducted annually. This trend analysis considers the effects of rainfall because simply excluding data with large inter-annual variation does not recognise the effects of climate on crop productions and would lead to the exclusion of valid data. 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) to ensure that data is within the expected range.

The agricultural growth model component of *FullCAM* reflects the impacts of management on carbon accumulation and allocates masses to various product pools within plants and to decomposable and resistant organic residues (Richards, 2001). The model uses the crop yield data and the proportional allocation of dry matter to different plant components to estimate annual dry matter accumulation in agricultural ecosystems. The proportional allocation of dry matter to plant components were determined from estimates by expert field agronomists and include allocation to roots (above and below-ground), GBF (grains, buds and fruit), stalks and leaves.

Fixed harvest indices have been used to estimate total crop biomass of croplands from statistical data on crop yields in both the USA (Prince *et al.*, 2001) and Canada (Bolinder *et al.*, 2007). Their harvest indices are given in Table 7.J4, along with the average values from the Australian database for dryland crops. With the exception of grain sorghum and sunflower, the values in the Australian dataset tend to be lower than those indicated by both Prince *et al.*, (2001) and Bolinder *et al.*, (2007). A review of the harvest index under Australian conditions indicates that a higher quantity of residues would be returned per unit of production than noted in other regions of the world. In addition, none of the abovementioned studies considered variation in harvest index or included such an exhaustive assessment of crop harvest index as the Australian study (Unkovich *et al.*, 2010).

Table 7.J4: 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 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.4.5.3 Debris

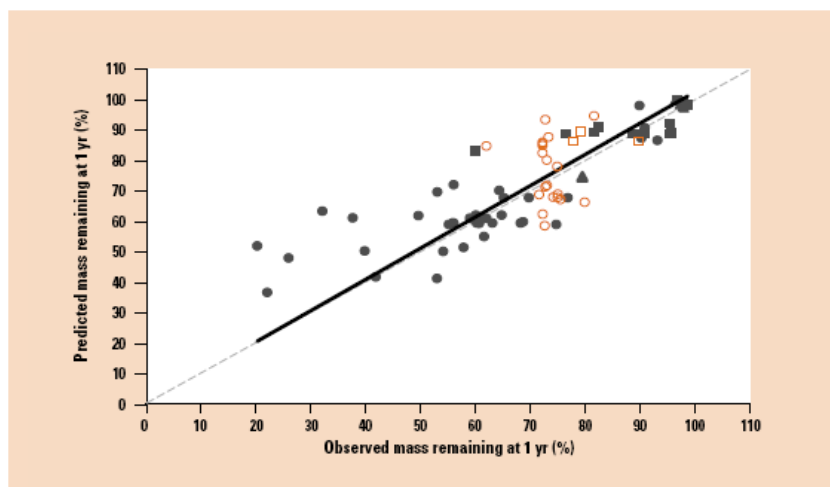
To estimate debris accumulation and loss, the NCAS model was calibrated and validated using litter decomposition rates taken from studies conducted around the world, representing a range of environmental settings within forest and agriculture. Half the dataset is used to calibrate algorithms and the other half is used to validate decomposition predictions (Paul *et al.*, 2004).

To calculate the decay rate of plant material before it enters the soil pool two groups of parameters used are calibrated: i) decomposable fraction of plant residues, and ii) rate constants for decomposition of decomposable and resistant debris pools of plant residues. The model was set-up to run using field measured rates of plant residues and observed climate conditions. For forest systems the model was run for one year, then for the number of years corresponding to field measured published data. For agriculture, the model was run for a number of pilot agricultural systems over several years, then for the number of years corresponding to field measured and published data (Jeff Baldock, CSIRO Land and Water, *pers. comm.*). The simulated mass of aboveground dry matter available to enter the soil pool as plant debris is compared to that observed in published studies. Rates of decomposition in the model are then adjusted so that the simulated mass remaining best matches the field measured data from similar environmental settings.

A model efficiency index (EF) is calculated as the difference between the field-measured and model-simulated mass of litter remaining. Values of EF can be positive or negative with a maximum and minimum value of 1 and -1, respectively. A positive value indicates that the simulated values describe the trend in the measured data better than the mean of the observations, with a value of 1 indicating a perfect fit. A negative value indicates that the simulated values describe the trend in the measured data to a lesser extent than a mean of the observations. Deviations of predicted mass remaining, or predicted litter accumulation, are assessed using the mean square error (MSE). The smaller the MSE the better the model explains the data.

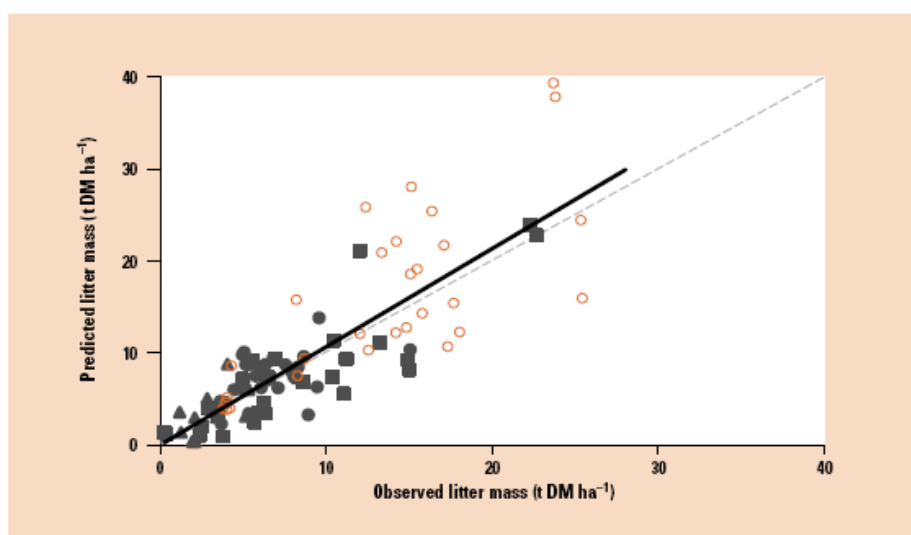
Once calibrated, the model predicted the observed mass remaining after one year of decomposition with an EF of 0.65 and a MSE of $117 \text{ g}^2 \text{ 100 g}^{-2}$ (Paul *et al.*, 2004). The line of best fit between field measured and simulated data had a slope near unity (1.03) with an R^2 of 0.57 (Figure 7.J7).

Figure 7.J7: Relationship between observed mass remaining after one year of decomposition of eucalypt leaf (●), eucalypt bark (▲), eucalypt dead wood (■), pine needles (●) and pine dead wood (□) from the calibration dataset, and that predicted using *CAMFor*. Dashed line represents the 1:1 line. Solid line represents the linear function of best fit when forced through the origin (Slope=1.03, $R^2=0.57$, $n=80$). Model EF and MSE were 0.65 and 177 $g^2\ 100\ g^{-2}$, respectively



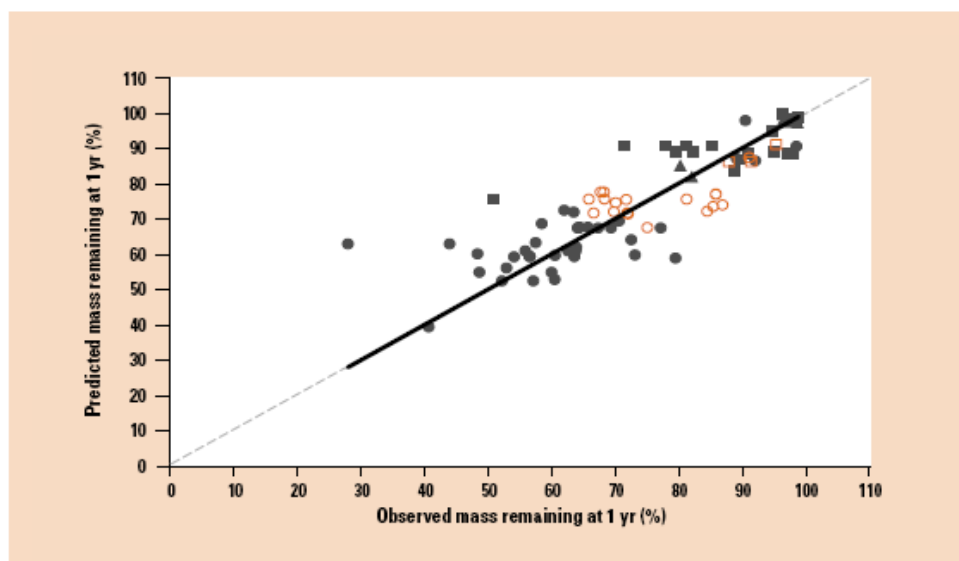
Using the validation data, the model predicted mass remaining with an EF of 0.70 and an MSE of 80 $g^2\ 100\ g^{-2}$. The line of best fit between field measured and simulated mass remaining after one year had an R^2 of 0.60 (Figure 7.J8).

Figure 7.J8 Relationship between observed mass remaining after one year of decomposition of eucalypt leaf (●), eucalypt bark (▲), eucalypt dead wood (■), pine needles (●) and pine dead wood (□) from the validation dataset, and that predicted using *CAMFor*. Dashed line represents the 1:1 line. Solid line represents the linear function of best fit when forced through the origin (Slope=1.00, $R^2=0.60$, $n=83$). 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 100+ years with an EF of 0.65 and a MSE of 15 $t^2\ ha^{-2}$ (Paul *et al.*, 2004). The line of best fit between measured and simulated litter mass had a slope near unity (1.06) and an R^2 of 0.67 (Figure 7.J9).

Figure 7.J9: 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 t² ha⁻², respectively



7.J.4.5.4 Soils

Calibration

After an extensive search for existing sites that met the requirements of time-series data collection for model calibration, two agricultural and seven forestry sites were selected. One agricultural site was located on a monsoonal subtropical environment with heavy clay soil and the other was located in a temperate Mediterranean climate with a light textured soil. At each agricultural site, archival soil samples (0-30 cm depth) collected throughout the life of the trials were fractionated into particulate organic carbon (POC), charcoal (char-C) and humic (HUM) pools (Skjemstad and Spouncer, 2003). These pools were then used to initialise the model (RPM set to POC, IOM set to char-C, HUM set to TOC minus POC minus char-C) at the first time of sampling. It was found that at both sites, adjusting the default resistant plant matter (RPM) pool decomposition rate constant modifier from 0.3 to 0.15 rectified any divergence in the results. No other changes were necessary. Following the agriculture model calibration, the forestry model calibration was completed using seven forestry sites:

- i. *Eucalyptus globulus* in the low rainfall region, south-west of Western Australia;
- ii. *E. globulus* in the high rainfall region, south-west of Western Australia;
- iii. *Pinus radiata* in the Green Triangle region of South Australia and Victoria;
- iv. *E. grandis* in south-eastern Queensland and north-eastern New South Wales;
- v. *P. radiata* in the south-eastern highlands New South Wales;
- vi. *E. globulus* in south-eastern Gippsland, Victoria; and
- vii. *E. nitens* in the Tasmanian highlands.

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

Validation and verification

The soil carbon model used to predict changes in soil carbon caused by shifts in agricultural practice was independently calibrated and validated (Skjemstad and Spouncer 2003). The results were found to be sensitive to the partitioning of carbon between the various soil fractions (Janik *et al.*, 2002; Skjemstad *et al.*, 2004; Paul and Polglase, 2004b).

Model validation used existing time-series data and new paired-site comparisons to test model predictions of change. Calibration of the model demonstrated that the measured soil carbon fractions (POC, HUM and Char-C pools) fitted well with the modelled carbon pools (RPM, HUM and IOM) as defined in the NCAS model, provided that the decomposition rate constant (k_{RPM}) 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 (Skjemstad and Spouncer, 2003). A full description of the model calibration and validation results for agriculture can be found in Skjemstad and Spouncer (2003).

For long-term rotation trials and other sites sampled from the same location on a temporal basis, validation of the model was found to be very good. For new paired sites, validation of the model was more variable. In many cases, apparent poor performance of the model could be attributed to spatial heterogeneity and inadequate pairing of the sampling sites. Overestimation of modelled plant inputs at the paired sites was also identified as a possible issue. For Tier 3 methods that model soil carbon changes over time due to land use change, the associated errors in sampling are minimised, but remain an issue for the development of the spatial soil data inputs to the model. In general terms the coefficient of variation for modelled outputs of soil carbon is around 5% (Janik *et al.*, 2002), whereas the coefficient of variation for measured soil carbon is 15–40% (McKenzie *et al.*, 2000; Janik *et al.*, 2002). Further details are provided in NCAS technical reports 34 (Murphy *et al.*, 2003), 37 (Harms and Dalal, 2003) and 38 (Griffin *et al.*, 2003).

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.

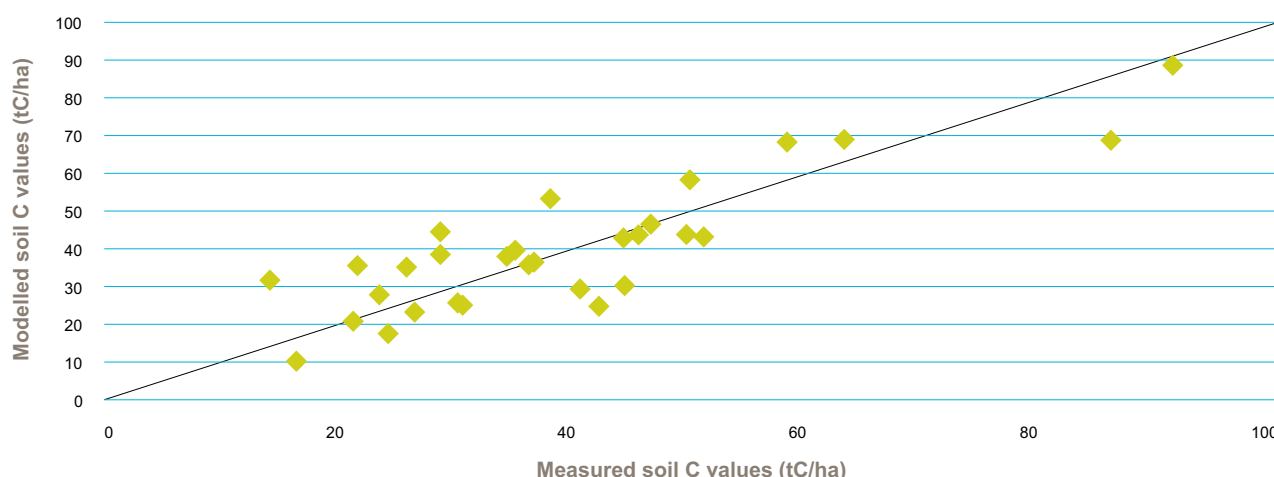
To validate the soil carbon model, the initial soil carbon measurements from 32 of the 53 paired sites (average of 29.5 t C ha⁻¹) were compared to the pre-clearing soil carbon values used by the NCAS (average of 29.6 t C ha⁻¹). In addition to the 53 paired sites, another 22 soil pairs (an undisturbed 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.J10) 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 Skjemstad and Spouncer (2003), but a lower level of variance than would be expected from a field measurement due to sampling error alone (up to 40% CV; McKenzie *et al.* 2000).

The regression analysis of measured and NCAS modelled data (Figure 7.J10) demonstrates that the logic used to establish a pre-clearing soil carbon layer for Australian soils as a basis for modelling under different management practices can be used with a high degree of confidence to estimate current soil carbon values. Therefore, for national inventory reporting requirements 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.

Figure 7.J10: Measured versus modelled soil carbon data collated from 29 sites across a range of soil types in northern and southern Australia



7.J.4.5.5 Sensitivity & Uncertainty

Sensitivity and uncertainty 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 of the specific inputs identified through 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).

Brack and Richards (2002) have provided the basis for the uncertainty analysis using the @Risk *Monte Carlo* capabilities attached to *FullCAM*. The analysis undertaken took advantage of the progression from treating all parameters as ‘uncertain’ with ranges of potential values, to describing the potential ‘variance’ within many parameters in terms of a probability distribution.

Dealing with quantified variance rather than constrained uncertainty within *Monte Carlo* analyses in *FullCAM* makes it possible to consider the correlation between variables and parameters and the likelihood of any single or interacting circumstance occurring. When the *Monte 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.

Biomass analyses

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 greatly reducing uncertainty (Richards and Brack, 2004a).

As shown in Snowdon *et al.*, (2000) there is limited information available on root-to-shoot ratios for tree species. The 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.

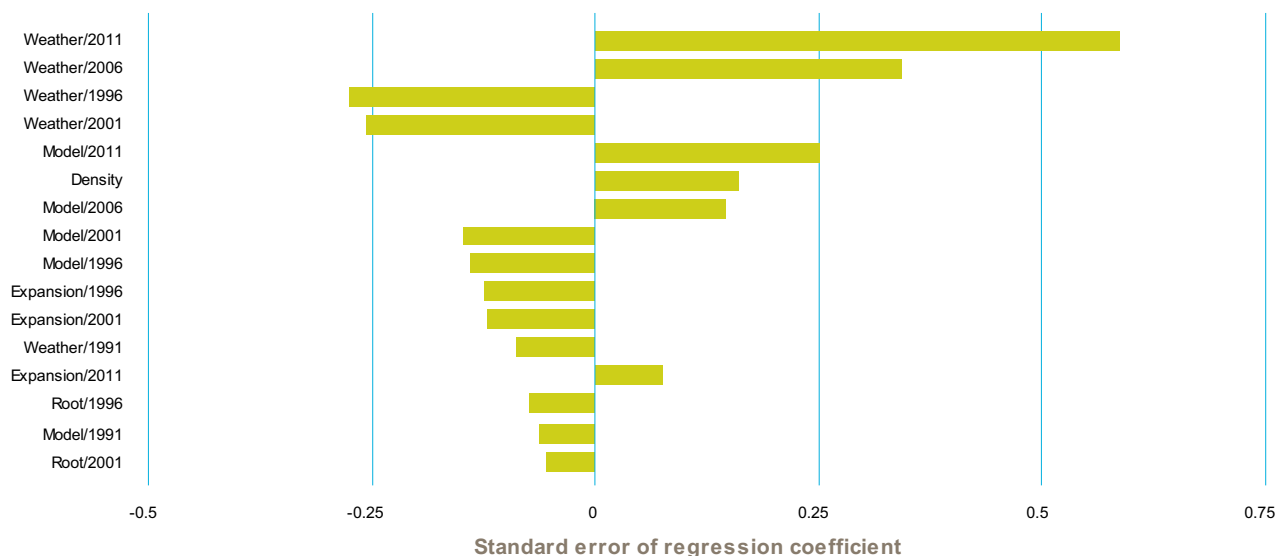
Brack and Richards (2002) modelled the performance of an individual stand using growth rates determined according to the observed growth variance around rainfall variability, error in allocating a growth index for the relevant growth model, and known variance or uncertainty in other key parameters. The key output for consideration is shown in Figure 7.J11.

The tornado graph (Figure 7.J11) 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.J12 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.

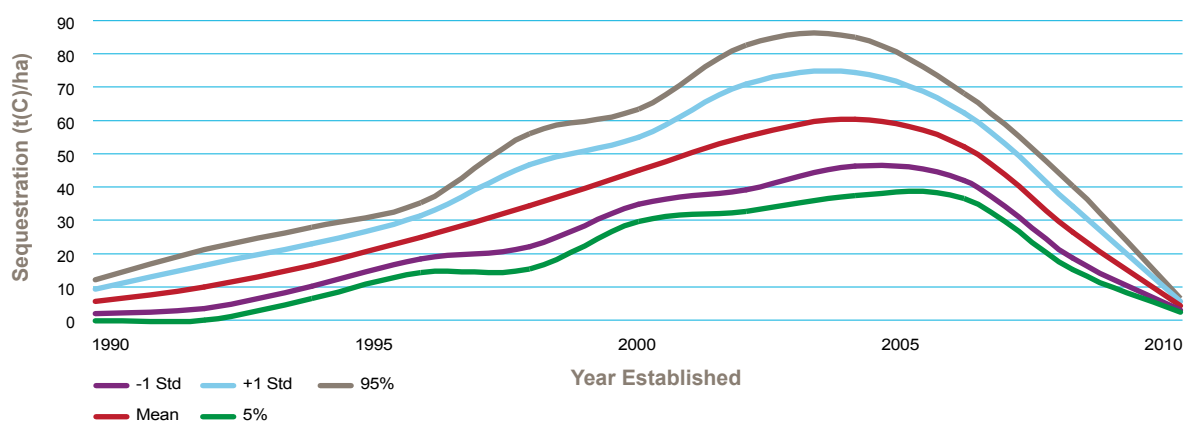
To take such individual stand-based uncertainty analyses to a national scale by simplistically extrapolating high and low outcomes would yield unrealistic results. The use of a 'low' base and the lower standard deviation is founded on the unlikely potential for below average rainfall for all plantation 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.J11: 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.J12: Variability in stand performance by age of stand



Source: Brack and Richards (2002)

Soil analyses

The most extensive sensitivity testing in the NCAS 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 IPCC Good Practice Guidelines.

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.J5). These pools have a rapid turnover rate and consequently have reduced impact on soil carbon content in the longer term. In contrast to the slower decomposition rates of the HUM and RPM pool leads to these pools being the more important in the longer term.

Table 7.J5: Predicted carbon change (tC ha⁻¹) for a + 10% change in C pool variables over a 20-year period

| Variable | 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 the soil carbon due to uncertainties in each variable is the product of the sensitivity and the standard deviation of the estimate of that variable. The actual sensitivity for each variable is determined by fitting a polynomial to the predicted data, and then differentiating at the required values of the variable. When sensitivity data are combined with estimates of their uncertainty, the variables that will potentially cause the greatest uncertainty in the modelling process may be indicated. For example, the uncertainty analysis for plant input data (i.e., grain yield, root, and aboveground dry matter (AGDM)), demonstrated that all of the soil carbon pools showed moderate uncertainty, but small changes in the RPM pool had a significant impact upon model uncertainty (Table 7.J6).

Table 7.J6: Summary of model response to changes in rate constants and plant input data

| Variable | Response | Expected Variability | Uncertainty | Contribution to uncertainty | 20 year change (tC ha ⁻¹) |
|--------------------------------|----------|----------------------|---------------|-----------------------------|---------------------------------------|
| Decomposition rate of BIO pool | Very low | High | Moderate | Very small | < 0.1 |
| Decomposition rate of DPM pool | Very low | High | Moderate | Very small | < 0.1 |
| Decomposition rate of RPM pool | Moderate | High | Moderate | Significant | 1.1 |
| Decomposition rate of HUM pool | Moderate | High | Moderate-High | Moderate | 0.4 |
| Ratio AGDM:Grain yield | Moderate | High | Moderate | Significant | 1.4 |
| Root:AGDM | Low | High | High | Significant | 0.8 |
| TOC:TDM | High | Low | Low | Small | 1.2 |

Source: Janik *et al.*, (2002)

In regard to time scale of the simulation, those variables with rapid rate constants are likely to have less impact on the carbon simulations than those with longer time scales, but the impact will be greatest at or near clearing. The high sensitivity of soil total organic carbon (TOC) to variables associated with the RPM pool and RPM rate constant carries on throughout the 30-year simulation period (Table 7.J7). The response to the IOM pool is only moderately sensitive at the start of the simulation but becomes increasingly more sensitive at longer simulation periods.

Table 7.J7: Summary of model responses to changes in soil variables

| Variable | Response | Variability | Uncertainty | Contribution to uncertainty | Range (tC ha ⁻¹) |
|---------------------------------|---------------|-------------|---------------|-----------------------------|------------------------------|
| Percent clay | Small | Large | Moderate | Small | < 0.1 |
| RPM pool (tC ha ⁻¹) | Moderate-High | High | Moderate | Significant | 1.5 |
| IOM pool (tC ha ⁻¹) | Moderate | High | Low- Moderate | Moderate | 0.3 |

Source: Janik *et al.*, (2002)

The response of the model to changes in the soil variables is summarised in Table 7.J8, including the values of the soil carbon within the individual pools. The prediction of soil carbon is fairly insensitive to the amount of clay in the soil (Janik *et al.*, 2002). The final estimate is affected by less than 0.1 tC ha⁻¹ when the clay content was varied between 5 and 70%, but is increasingly sensitive with very low clay content.

7.J.4.5.6 Model outputs & checking

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 verification 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*, *forest land converted to grassland* and *grassland converted to forest land* sub-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.3 SOURCE CATEGORY

Australia reports on *forest land remaining forest land*, *forest land converted to grassland*, *forest land converted to cropland*, *grassland converted to forest land*, *grassland remaining grassland* and *cropland remaining cropland*. This section describes the QA/QC activities associated with the emissions estimates for each of the reporting sub-categories.

7.J.3.1 Forest land remaining forest land

7.J.3.1.1 Harvested native forests

Data on forest extent (area), age class and growth that are used in the *harvested native forests* model were derived from Australia's National Forest Inventory (NFI). This data has also been published as part of Australia's National Greenhouse Gas Inventory and as such is publicly available, and subject to domestic and international review.

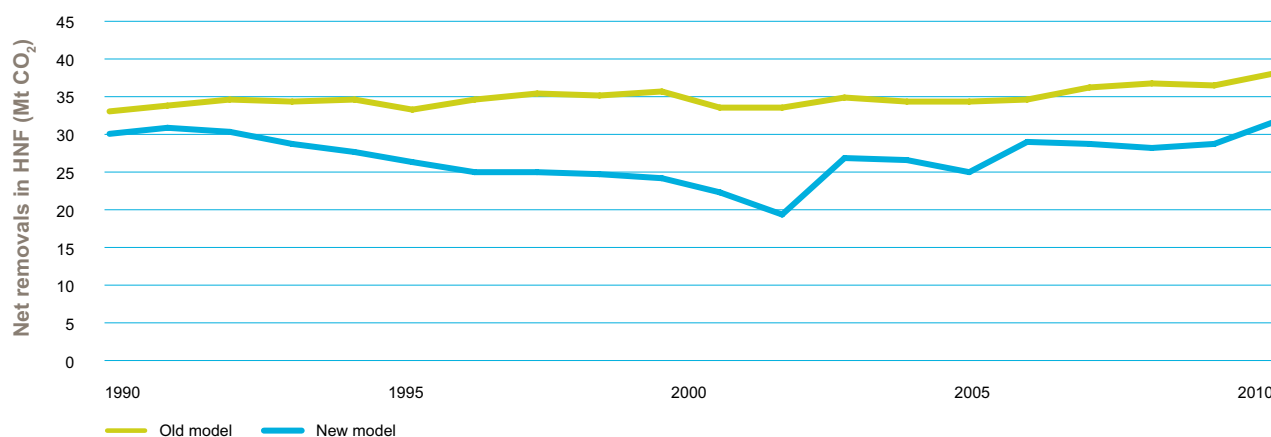
The estimates of growth rates by forest type are sourced from the NFI and can be verified against independent data published by the Resource Assessment Commission Forest and Timber Inquiry findings (Resource Assessment Commission, 1991; Resource Assessment Commission, 1992a,b). Additionally, growth rates reported for important harvested forest types in Australia were based on the data available from the Research Working Group of the Standing Committee on Fisheries and Forestry of the Australian Government (West and Mattay, 1993). Comparisons show that the growth rates used for the NCAS are within the range of those described by the Resource Assessment Commissions (lower estimate) and West and Mattay (higher estimate).

Data on harvest areas was obtained from a combination of annual reports of Australian State agencies, financial statements, and spatial harvest area data. This data has been subject to state review processes and financial auditing. Data on stem to whole tree conversions, carbon contents and wood densities are within the ranges published in 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).

The NCAS commissioned a team of highly qualified experts to collect and synthesise native forest information on a state-by-state and topic-by-topic basis. Information was sourced from peer-reviewed published literature, 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. Due in part to high variability in the quality and accessibility of data, expert judgment was essential to derive the data and complete 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 judgment 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 also applied.

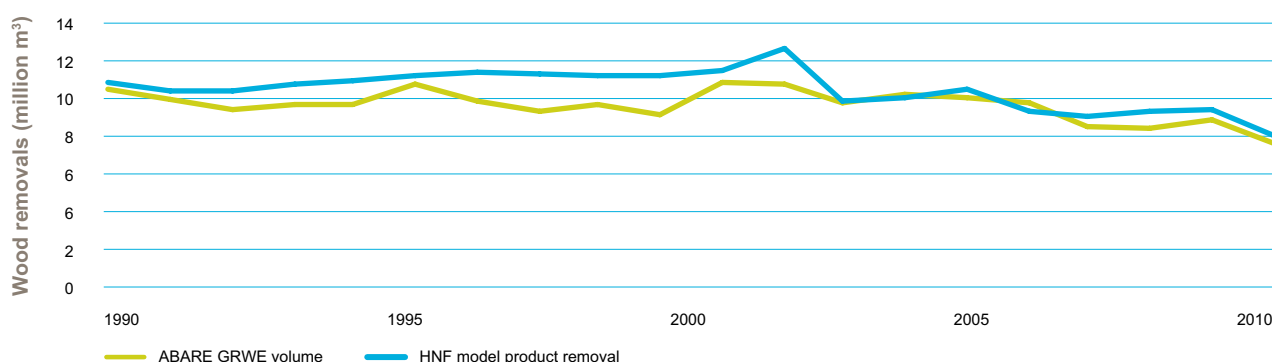
The *harvested native forests* model was verified by comparing the emissions estimated for the current inventory (using the *FullCAM* model) with those estimated using a Tier 2 model (Figure 7.J13). The current estimates produce lower net removals than previously estimated, and display greater variability by including the effects of age-based forest growth, debris accumulation and the effects of management. The impact of using the area harvested to estimate emissions and removals is clearly observed with peak harvest areas during the mid 1990s with a sharp increase in 2001, before a significant decrease in the annual area harvested through the 2000s. The reduction in the harvested area has been driven by a reduction in the maximum allowable harvest volume in many of the harvested native forests in Australia (Montreal Process Implementation Group for Australia 2008). This has been driven by improved resource information particularly forest yield, as well as reductions in the areas of forests where harvesting is permitted (Montreal Process Implementation Group for Australia 2008).

Figure 7.J13: Estimated net removals in Harvested Native Forests, new Tier 2 model compared to the former model used in previous inventories



The outputs of the *harvested native forests* model were verified against independent data on annual roundwood removals drawn from national statistics on forest products production and consumption (ABARE, 2009c) (Figure 7.J14). The total carbon removed from the forest as forest products was converted back to stem volume assuming a stemwood carbon percentage of 52% (see Table 7.B6 in Appendix 7.B) and average wood basic density of 750 kg m⁻³. From 2000 onwards (where the area harvested data is the most certain), the model output and roundwood data are similar. During the 1990s the *harvested native forests* model estimates slightly higher product removal. However, the estimates show similar trends and provide confidence in the model.

Figure 7.J14: National statistics on roundwood removals compared to product removal estimated from the Harvested Native Forests model



7.J.3.1.2 Pre-1990 plantations

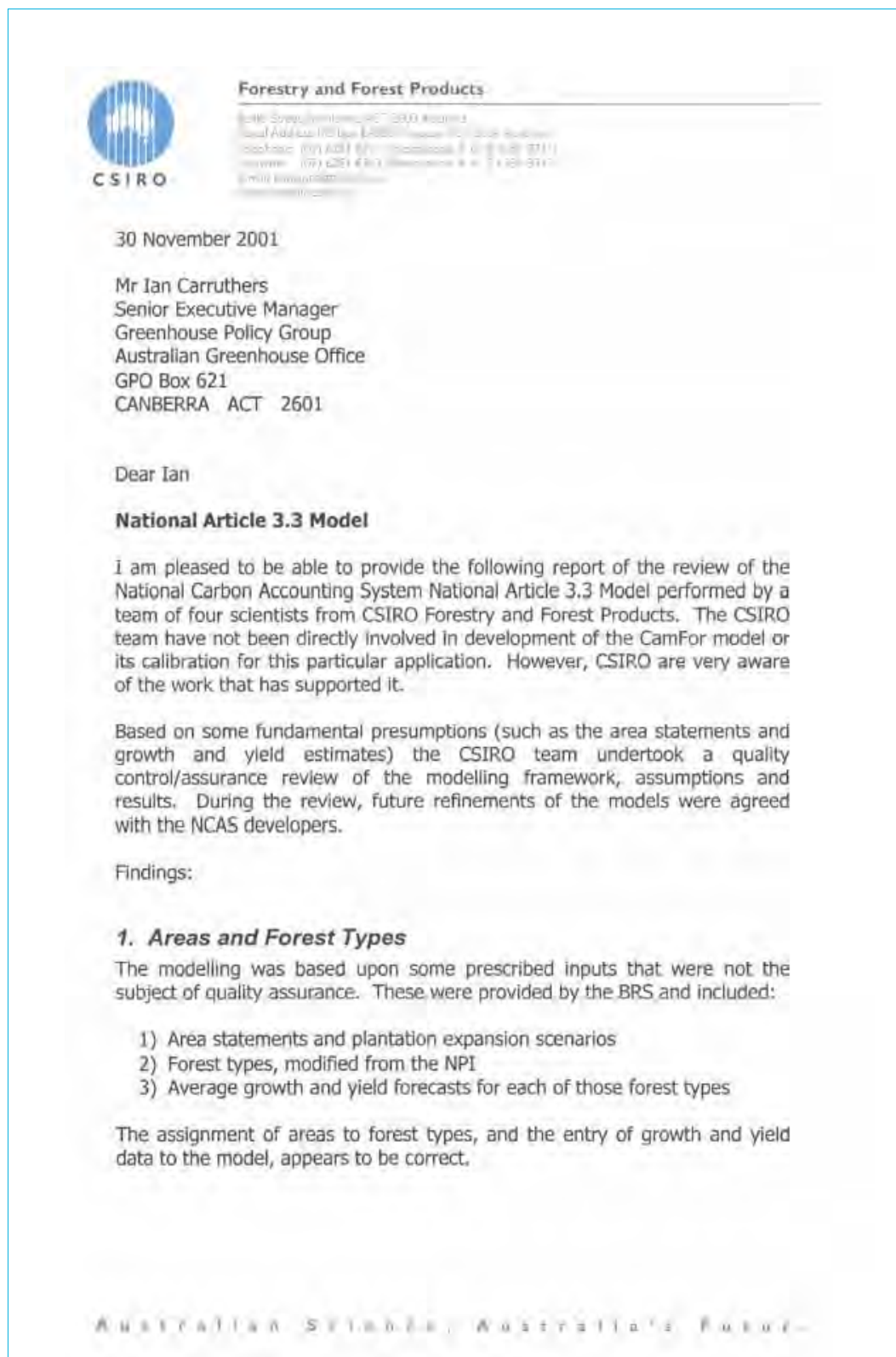
Modelling of pre-1990 plantations is not currently implemented spatially but uses area extent data from the National Forest Inventory (NFI) based on the 14 National Plantation Inventory regions (see Figure 7.C3). Biomass (including the effects of ongoing management) and soil carbon are also estimated in the model.

The data used in the model to estimate emissions and removals in the pre-1990 *plantations* sub-category are based from several different sources. Growth is calculated using stem volume and yield data obtained from Australia's National Plantation Inventory which was then annualised by Turner and James (2002). The NFI perform QA/QC on this data. 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).

The soil carbon estimates are based on the model developed by Polglase et al. (2000) and was used to estimate soil carbon change following the establishment of plantations between 1940 and 1989. Forest extent data used for estimating soil carbon was obtained from the NFI.

An independent review of the models used to estimate emissions and removals in the *Plantations* category was undertaken by CSIRO (see Figure 7.J15).

Figure 7.J15: Letter outlining the results of the analysis undertaken by CSIRO Sustainable Ecosystems (formerly Forestry and Forest Products)



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
Chief Research Scientist

7.J.3.1.3 Other native forests

Carbon stock change and emissions from *other native forests* were estimated using four sub-models to represent the important processes occurring in *other native forests* at the national scale. These include:

- i. Permanent changes in forest extent due to climate;
- ii. Ephemeral changes in forest extent due to climate;
- iii. Foliage mass loss in permanent forest due to climate; and
- iv. Controlled burning and wildfire.

In addition, the data required for each of these models include the time-series of the forest balancing term from the land area matrix, the national leaf area index provided by the NCAS GIS and Remote Sensing Unit, and wildfire areas which are supplied by CSIRO Sustainable Ecosystems (based in Darwin). Quality control processes for the forest balancing term data and its use within sub-model (i) and (ii) were performed by the NCAS. The leaf area index (LAI) time-series data was, up until 2009, obtained from the environmental resources information network (ERIN). The LAI for 2009 was obtained from the bureau of meteorology (BOM) and appended to the time series of ERIN data. This approach will be replaced by the sparse data method this is currently being developed. The controlled burning and wildfire data is calculated based on fires that are supplied by CSIRO Sustainable Ecosystems and sourced from state and remote sensing fire area estimates. These data have had extensive QA/QC applied at their source.

7.J.3.2 Forest land converted to cropland and grassland

Forest land converted to cropland and grassland emissions estimates are based on the Tier 3 Approach 3 model and national time-series of Landsat satellite data. Verification of the use of the Tier 3 model to estimate emissions from this sub-category was performed and compared against the 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 Tier 2 model accounts for emissions from both conversion of 'mature' forest, the regrowth of forest on previously cleared land and the subsequent re-clearing of a proportion of this regrowth.

The emissions include:

- i. Emissions from residue burning (CO₂ and non-CO₂);
- ii. Emissions from decay of dead organic matter;
- iii. Emissions from release of carbon from the soil; and
- iv. Emissions from burning of dead organic matter.

The annual area converted or re-cleared was obtained from the NCAS remote sensing program 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 by overlaying the areas cleared from the remote sensing analysis on the National Vegetation Information System (NVIS; see Appendix 7.A).

The biomass of each forest class that is removed by conversion was obtained from Snowdon *et al.* (2002) (Table 7.J8). Areas of previously cleared land that re-grew to forest are assumed to achieve their original biomass in 20 years. The biomass of forest subject to re-clearing is 30% of the mature biomass. A proportion of the cleared biomass is burnt in the year of clearing, with the remaining debris decaying linearly for 10 years. Following clearing areas of land are allocated to either grassland or cropland based on the NCAS remote sensing program.

Emissions of soil carbon following conversion are estimated by allocating the land to cropland or grassland and linearly increasing or decreasing the initial soil carbon stock (Table 7.J8) by a percent per year (Table 7.J9) for 20 years. Soil carbon is not included in regrowing forests.

Net emissions from forest clearing were calculated as the difference between emissions and removals. Both CO₂ and non-CO₂ emissions from land clearing were incorporated.

Non-CO₂ (CH₄ and N₂O) emissions were estimated by multiplying the CO₂ emissions from onsite burning and onsite burning of debris with a 'non-CO₂ to CO₂' coefficient. The non-CO₂ to CO₂ coefficient incorporates the ratio of mass of non-CO₂ gas to the mass of carbon it contains, the ratio of non-CO₂ gas emitted to carbon emitted, the ratio of the amount of CO₂ with equivalent greenhouse gas effect to an amount of non-CO₂ gas and the fraction of CO₂ that is carbon by weight.

Both aboveground and belowground (based on root to shoot ratios) biomass was incorporated for estimating CO₂ emissions from burning and forest decay (Table 7.J8). Forest debris was assumed to decay over a period of 10 years (IPCC, 2003). The removal of CO₂ 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 CO₂ emission from the soil carbon pool was calculated as the difference between the ultimate loss of carbon from the soil (that is, the amount of carbon a soil could lose) and the amount of carbon remaining in the soil after a fraction has been lost during that year (Table 7.J8).

Table 7.J8: 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 |
| Initial soil carbon [‡] (t C ha ⁻¹) | 70 | 73 | 42 |

[#] Aboveground biomass.

^{*} Used for all States and Territories.

[‡] Used to calculate ultimate loss of soil carbon.

Table 7.J9: Tier 2 'default' coefficients used to estimate emissions and removals from soil carbon pool following conversion from forest and forest types

| Core parameters | Pasture | Grass | Crops |
|--|---------|-------|-------|
| % loss of soil carbon following conversion from forest [‡] | -5 | 10 | 30 |
| Ultimate loss of soil carbon from closed forest (tC ha ⁻¹) | -3.50 | 7.00 | 21.00 |
| Ultimate loss of soil carbon from open forest (tC ha ⁻¹) | -3.65 | 7.30 | 21.90 |
| Ultimate loss of soil carbon from woodland forest (tC ha ⁻¹) | -2.10 | 4.20 | 12.60 |

[‡] Used to calculate ultimate loss of soil carbon.

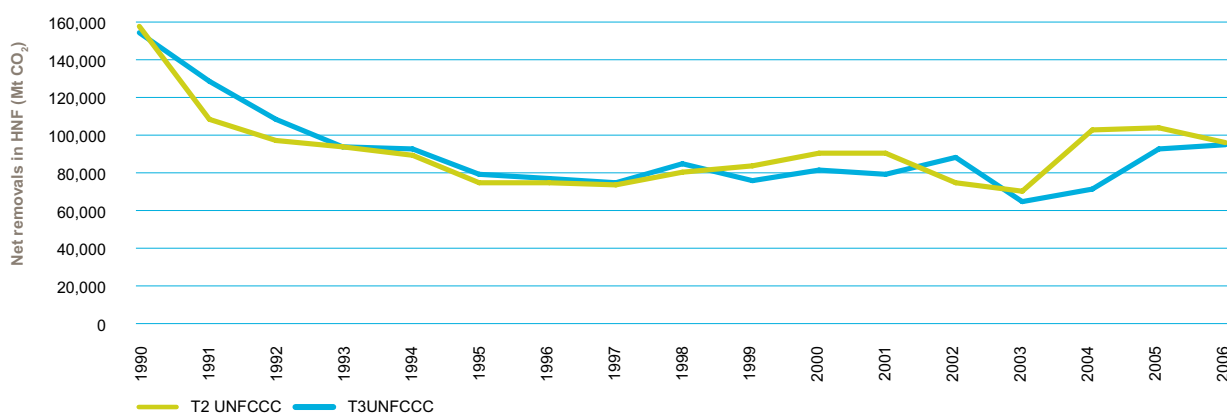
The Tier 3, Approach 3 model for land use change was carried out with the *FullCAM* model. *FullCAM* integrates information drawn from the land cover change program, productivity surfaces and other ancillary data to estimate emissions and removals from land use change (Richards, 2002). A full description 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.J16). 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, CO₂ 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.J16: Total emissions (Gg CO₂-e) output from Tier 2 and Tier 3 methodology from 1990 to 2006



Soils under cropland

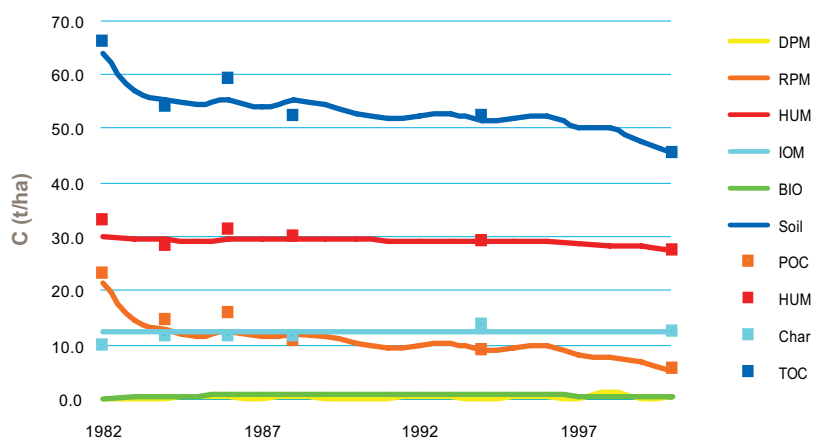
The extensive verification data collected during model development provided guidance on the general results expected under different cropping systems. In most southern Australian continuous cropping systems there is a loss of soil carbon which stabilises within 10 to 30 years following land conversion (see Figure 7.J17). Conversely, the crop-pasture rotational systems typically yield an increase in soil carbon (Figure 7.J18). In northern 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.

Both Guo and Gifford (2002) and Skemstad and Spouncer (2003) have shown that continuous cropping, crop and pasture rotations and continuous pasture will each drive specific patterns of soil carbon change after a land use conversion. Under a continuous cropping system, most soil carbon is lost early after clearing, with losses slowly decreasing over time. Under a crop-pasture rotation system, soil carbon gradually increases over time. As the crop-pasture rotations are a far more prevalent production system in Australia than continuous cropping, by a ratio of 3:1, the sub-category *forest land converted to cropland* yields an overall removal but with significant variation due to climate.

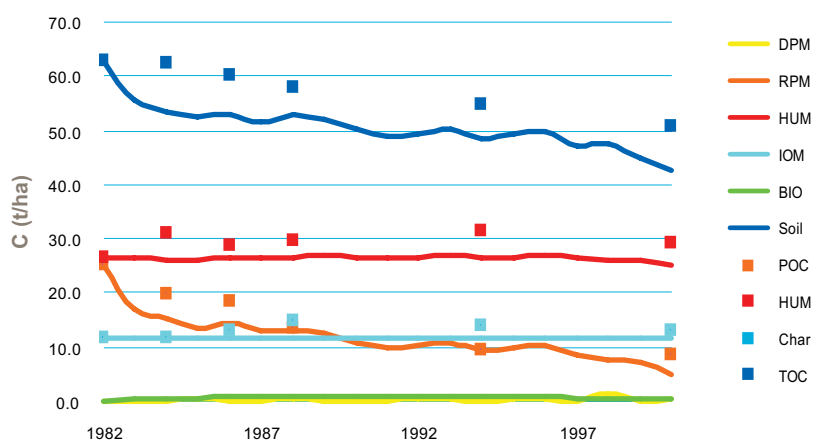
Figure 7.J17: (a)-(f) Changes in soil carbon (■ measured and: modelled) under continuous cropping

(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)

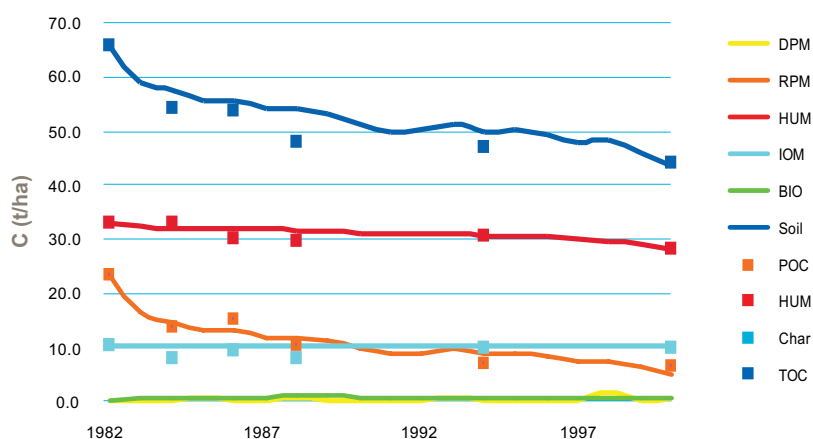
(a) Brigalow cropping (soil 64)



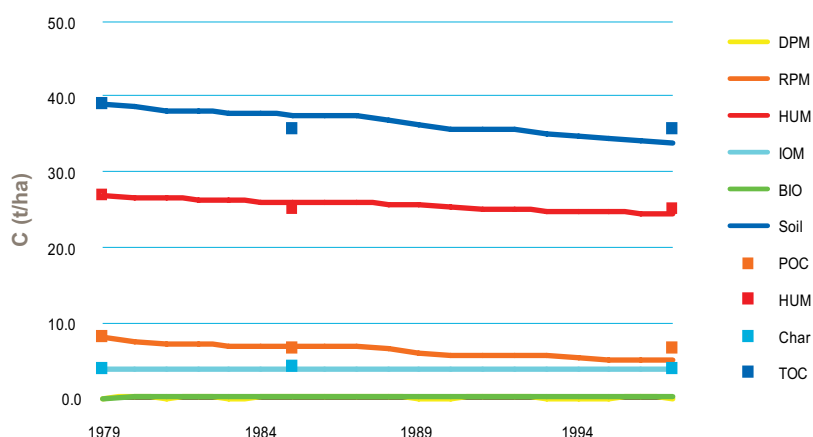
(b) Brigalow cropping (soil 65)



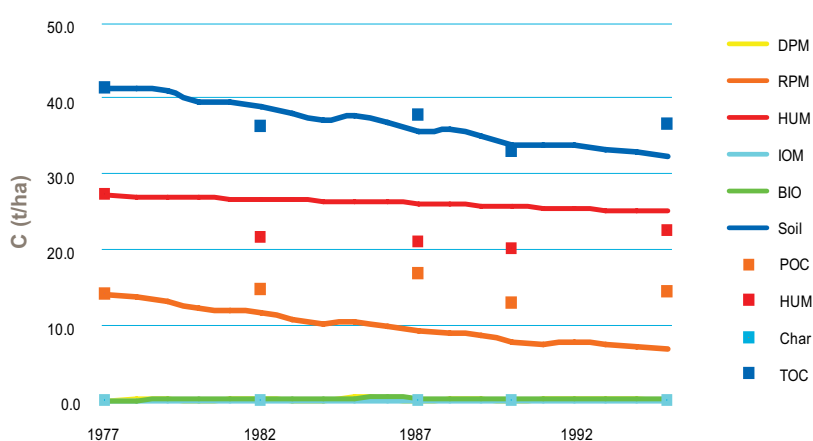
(c) Brigalow cropping (soil 66)



(d) Tarlee continuous wheat



(e) Gibson continuous wheat



(f) Salmon Gums continuous wheat

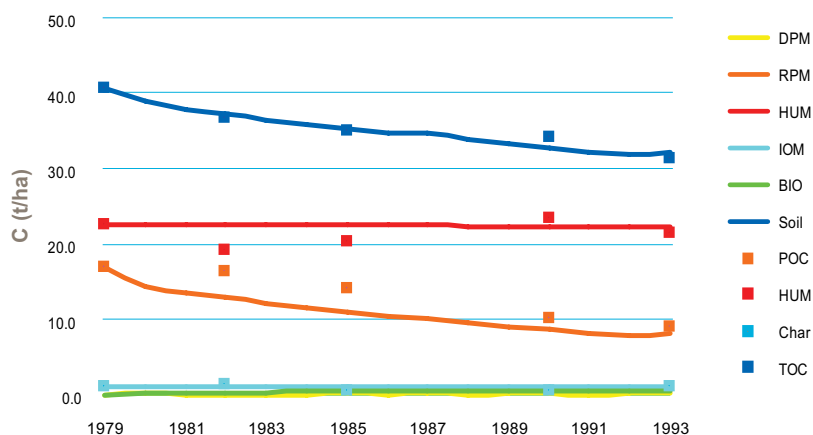


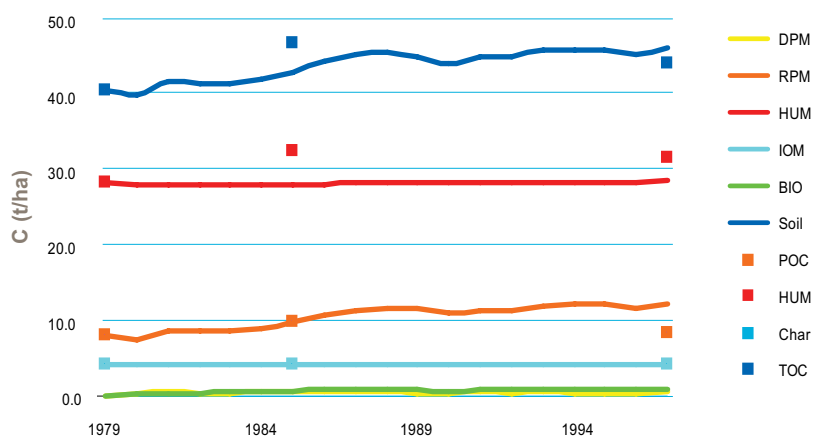
Figure 7.J18 shows changes in soil carbon under crop and pasture rotation systems. Unlike the continuous cropping systems shown in Figure 7.J17, the crop-pasture systems typically show an increase in soil carbon. The amount of increase will depend on the pattern of the crop-pasture rotations and the crop types used. In almost all crop-pasture systems there is an initial loss of soil carbon following land use change, but this loss stabilises over time often leading to a net uptake. When changes in soil carbon due to land use change begin to stabilise, any future net increase or decrease in soil carbon is predominantly due to

change in management, and due to 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. For example, higher yields in crop production increase residue inputs to the soil and therefore results in an increase in soil carbon.

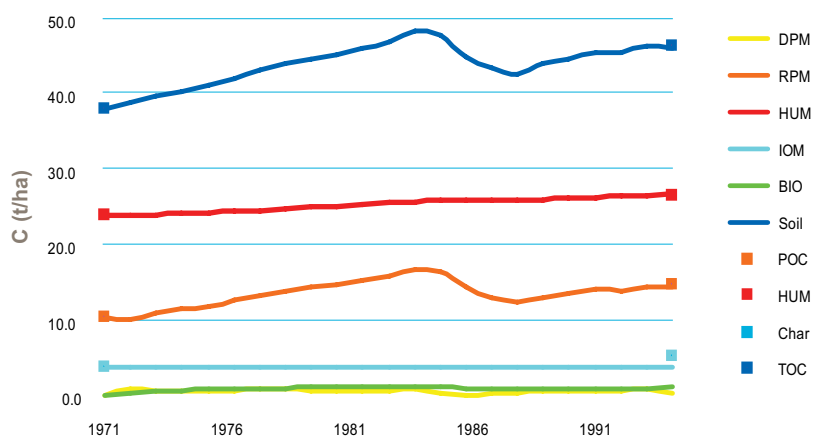
Figure 7.J18: (a)-(i) Changes in soil carbon (■ measured and; modelled) under crop: pasture

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 carbon)

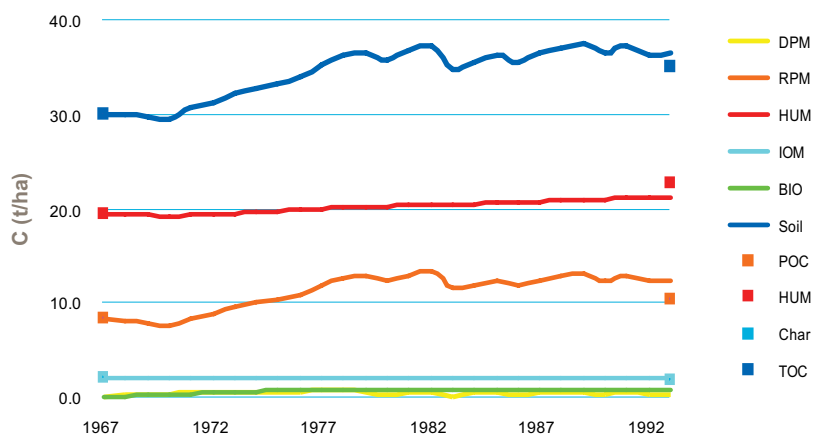
(a) Tarlee wheat / pasture



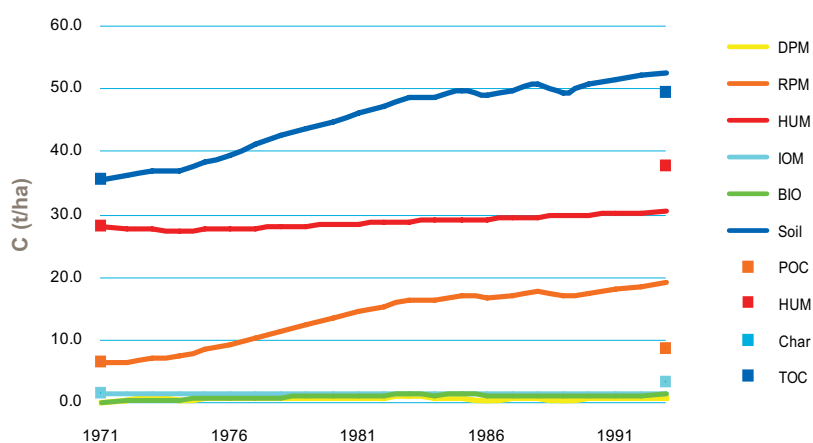
(b) Glenorchy wheat / pasture



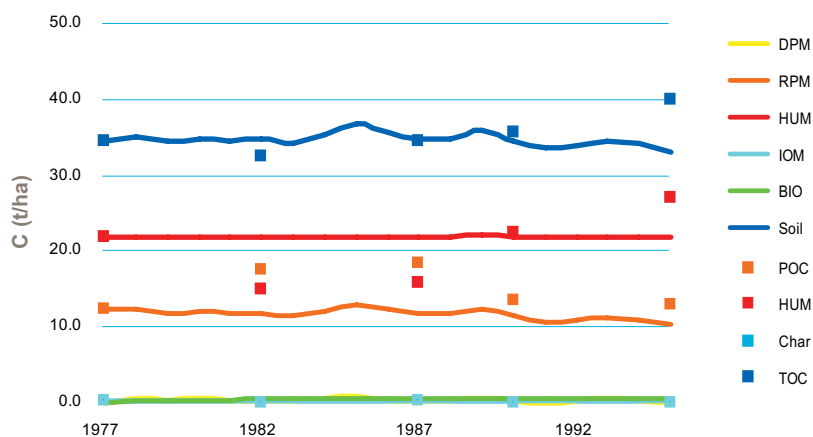
(c) Freeling barley / pasture



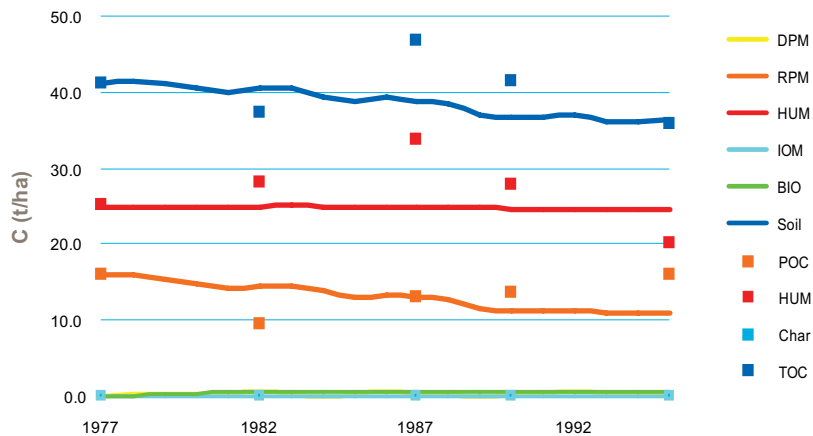
(d) Padthaway wheat / pasture



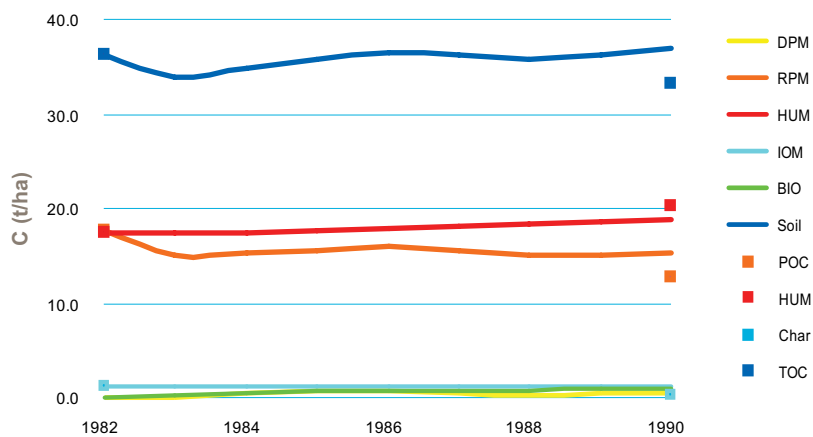
(e) Gibson pasture / wheat / lupins plot 16



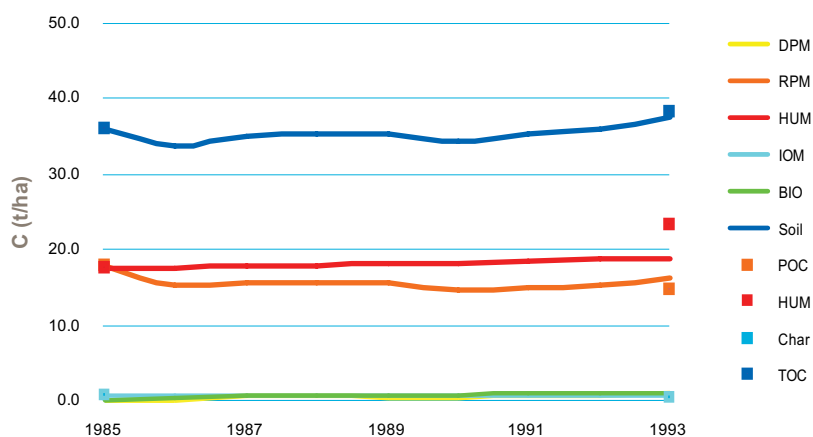
(f) Gibson pasture / wheat / lupins plot 27



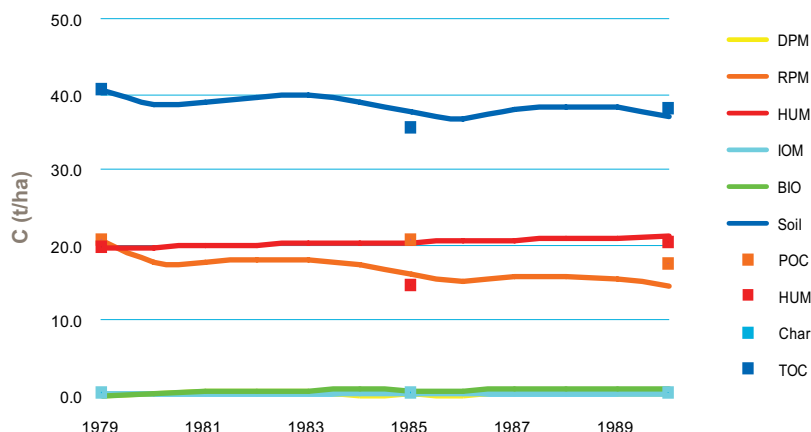
(g) Salmon Gums wheat / 3 pasture



(h) Salmon Gums wheat / 3 pasture



(i) Salmon Gums 3 wheat / 3 pasture



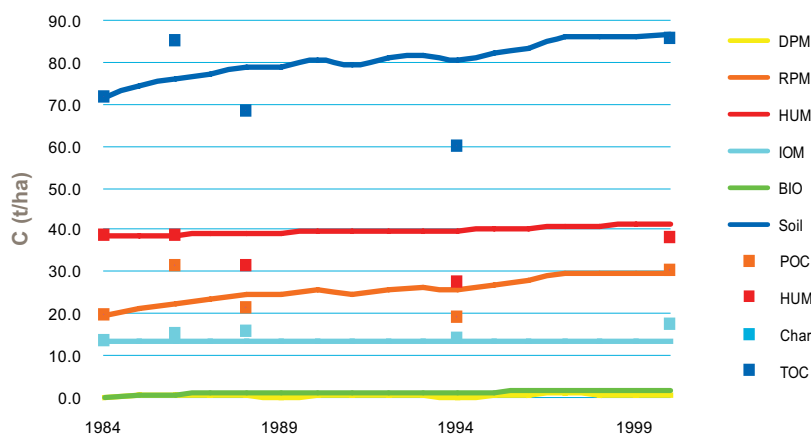
Soils under grassland

The grassland category covers a much wider range of climates and soil types than cropland. Figure 7.J19 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.

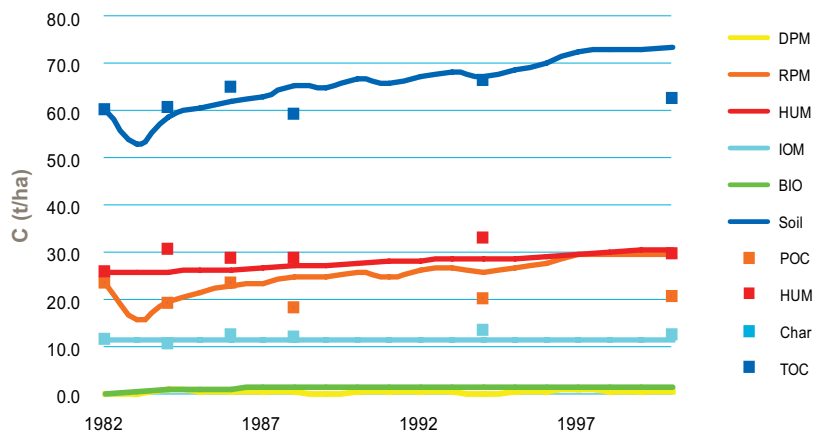
Figure 7.J19: (a)-(o) Changes in soil carbon (■ measured and: modelled) under continuous pasture

(Key: DPM – decomposable plant material; RPM: resistant plant material; HUM – humic matter; IOM inert organic matter; BIO- biological matter; Soil – total soil carbon; POC – plant organic carbon; HUM – humic matter; Char – char; TOC – total organic matter)

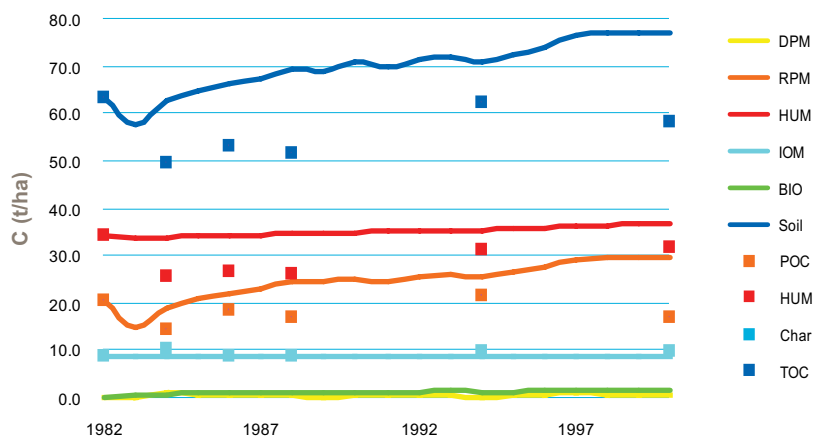
(a) Brigalow pasture (soil 67)



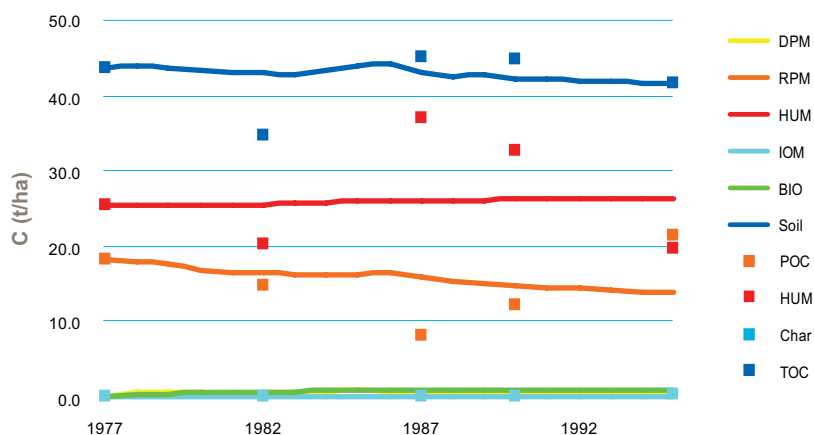
(b) Brigalow pasture (soil 68)



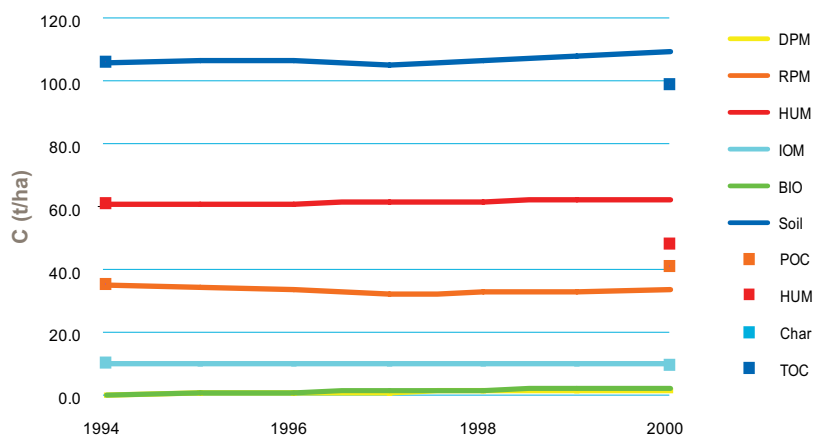
(c) Brigalow pasture (soil 69)



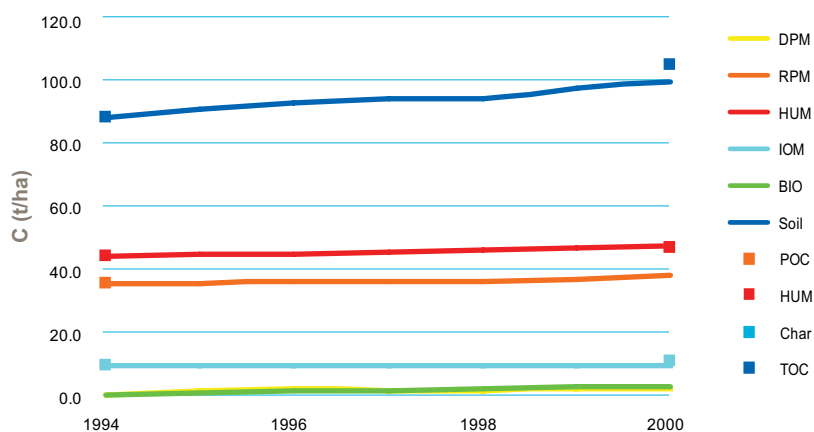
(d) Gibson continuous pasture



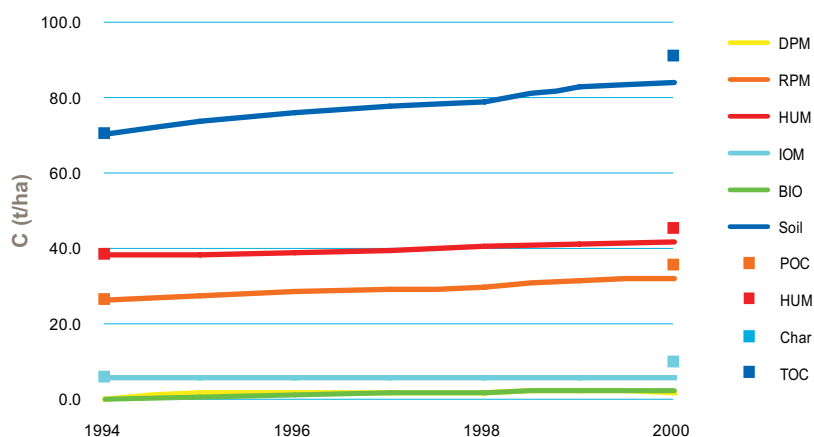
(e) Hamilton permanent pasture, Plot 10



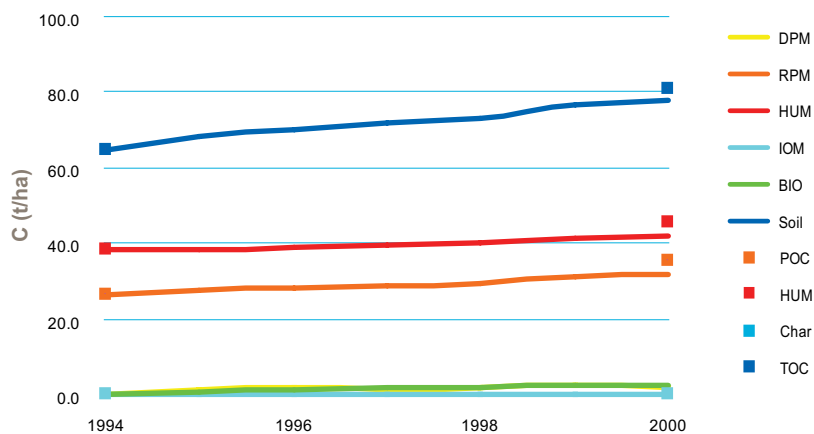
(f) Hamilton permanent pasture, Plot 11



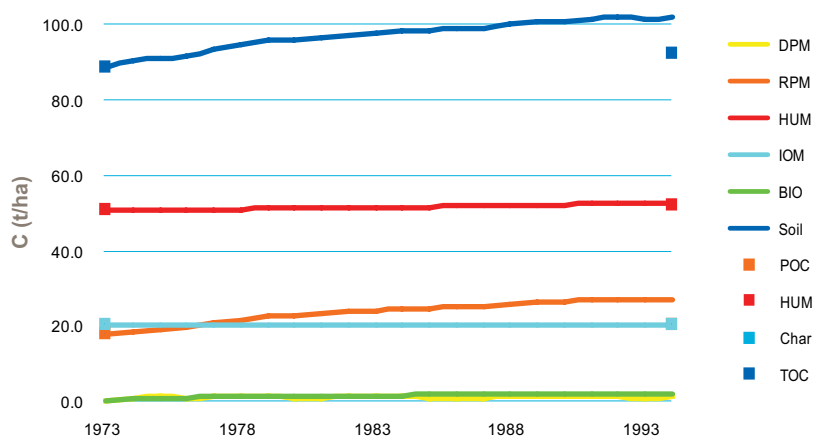
(g) Hamilton permanent pasture, Plot 12



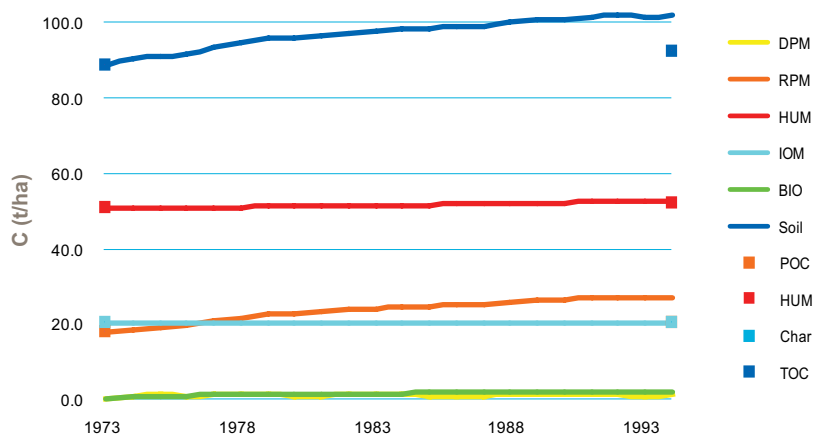
(h) Hamilton permanent pasture, Plot 12 (Char-C corrected)



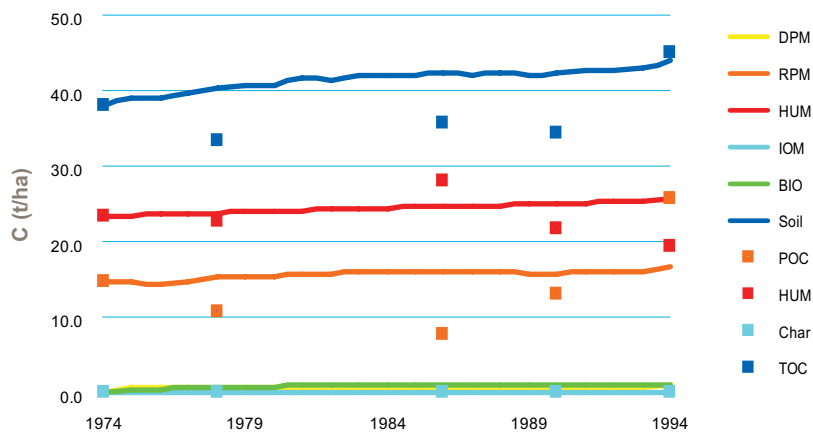
(i) Glencoe permanent pasture



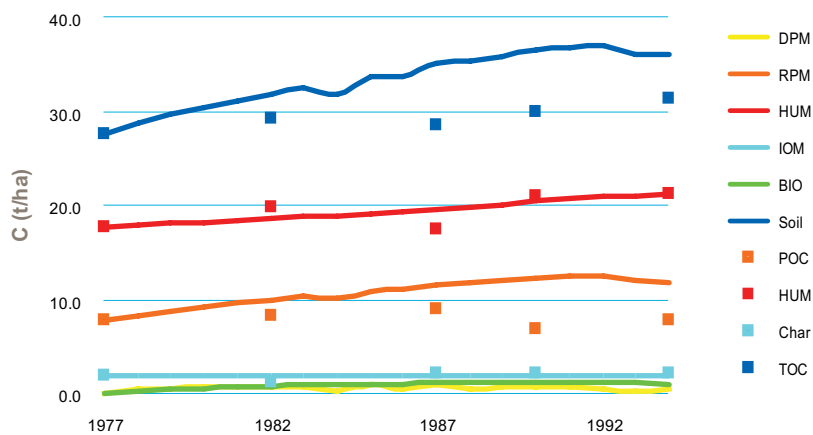
(j) Victor Harbour permanent pasture wheat



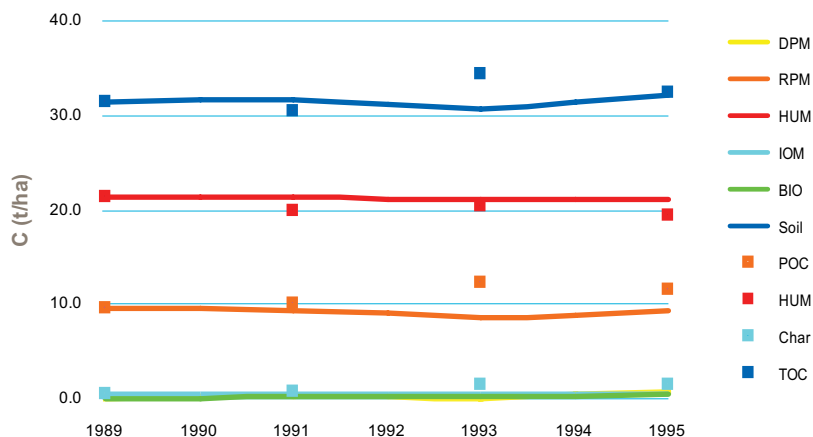
(k) Newdegate continuous pasture



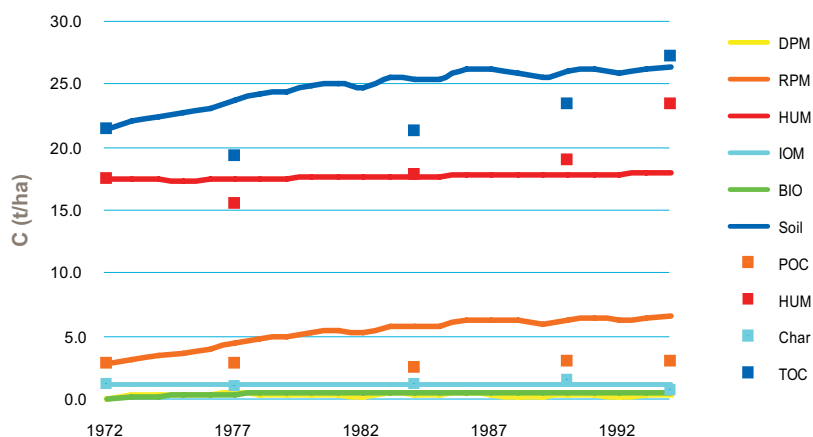
(l) Merredin (heavy) continuous pasture



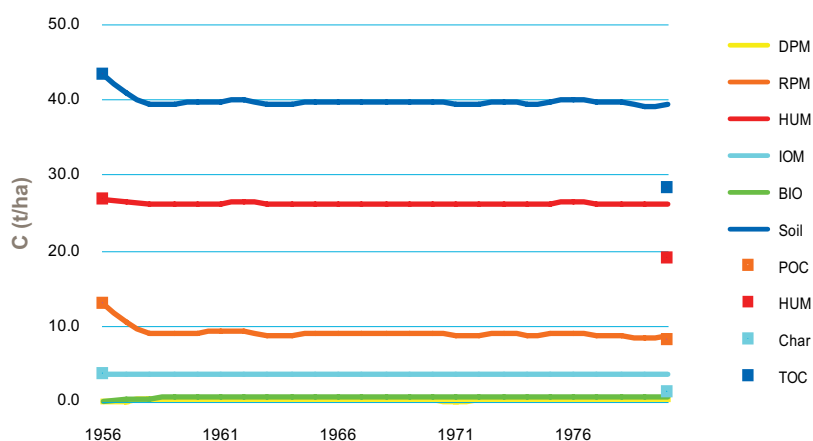
(m) East Beverley continuous pasture



(n) Chapman continuous pasture



(o) Billa Billa pasture for 25 years

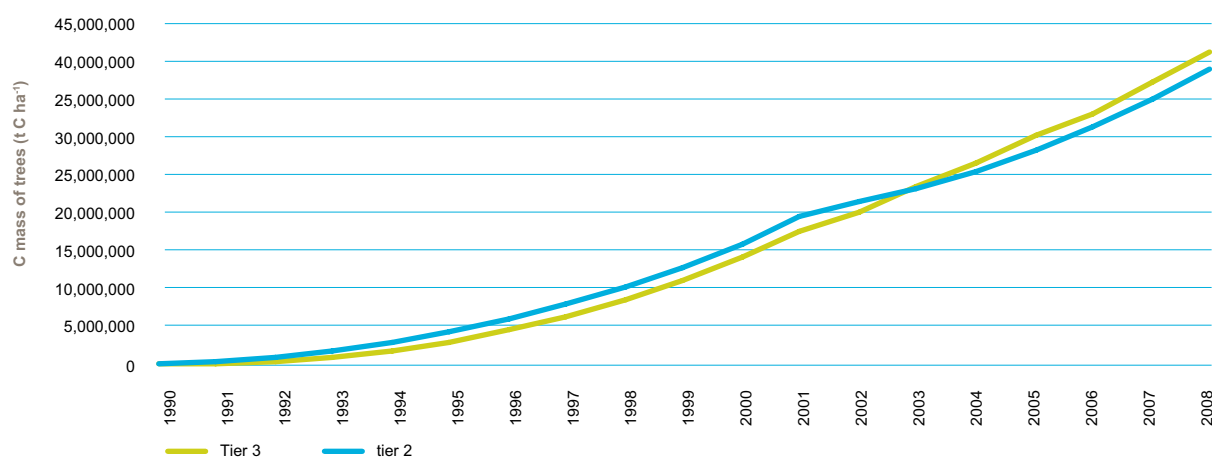


7.J.3.3 Grassland converted to forest land

To conduct 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 model in early years and slightly lower in later years.

Figure 7.J20: Carbon mass of trees (tC 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.J20) and yield rate of tree stem mass (Figure 7.J21) showed very close agreement between the two models. This is not surprising given that the Tier 2 model uses 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.

The results of the Tier 3 soil carbon model (Figure 7.J22) 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.J21: Yield rate of tree stem mass ($\text{dmt ha}^{-1} \text{yr}^{-1}$) output from Tier 2 and Tier 3 methodology from 1990 to 2008

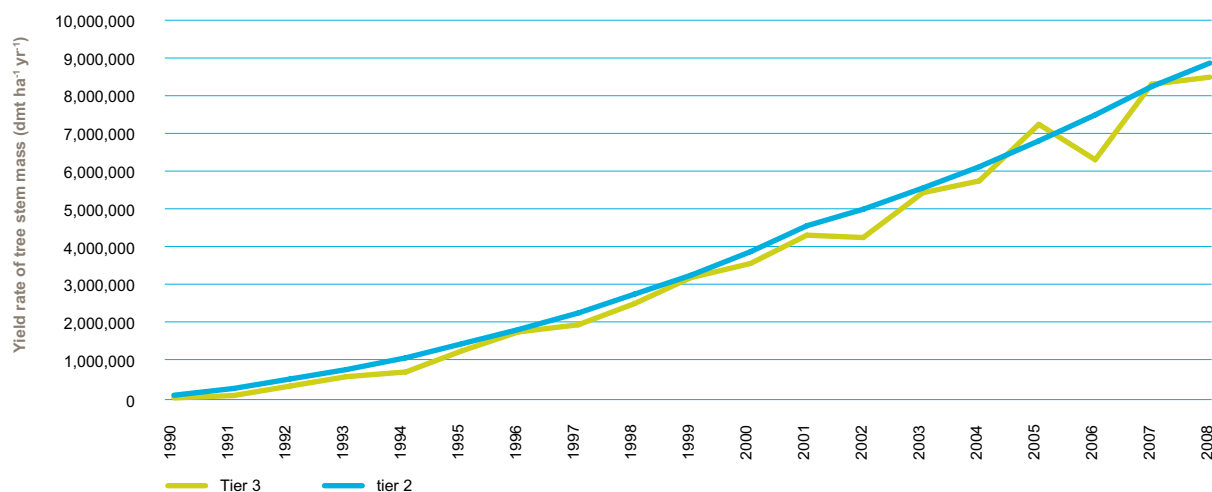
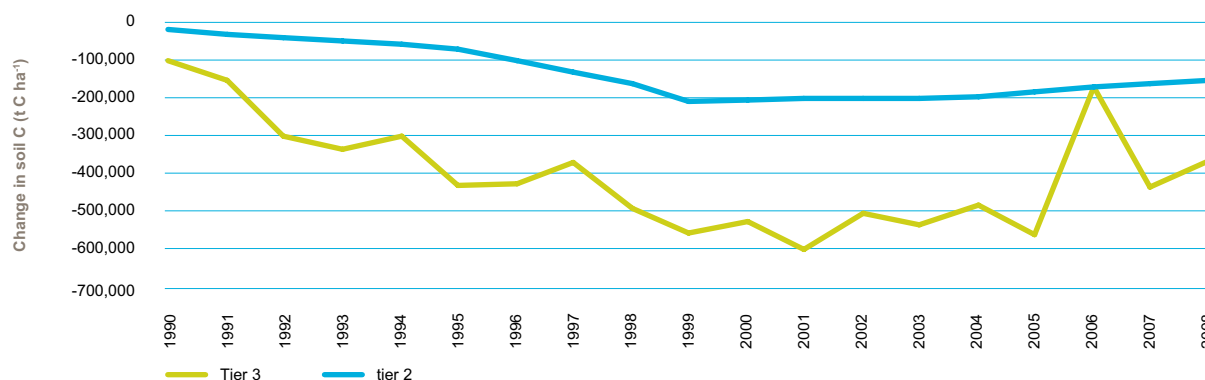


Figure 7.J22: Soil carbon (t C) output from Tier 2 and Tier 3 methodology from 1990 to 2008



7.J.3.4 Cropland remaining cropland

The crop yield database for *cropland remaining cropland* was a subset of the crop yield database that was compiled for the forest land converted to cropland and grassland sub-categories with the exclusion of grasses that were not part of a crop-pasture rotation regime. There are some grass species in the *cropland remaining cropland* crop yield database to account for crop-pasture rotations under a cropping system.

Crop yield data is collated and quality assured by CSIRO Land and Water before it is received by the NCAS. The NCAS performs another quality assurance and quality control process on the crop yield data before it is entered into *FullCAM*. Crop yield data was primarily based on ABARES and BRS data for crop yields; however, there were gaps in the crop yield data across locations in Australia. As such, CSIRO Land and Water incorporated a methodology to fill the gaps in the crop yield data across those locations. Therefore, from 2004 onward, gaps in the crop yield data from ABARES and BRS were gap-filled using climate derived modeling of plant yield/growth for the gaps in data at a State-IBRA-Soil location. The gap-filled data is then cross-referenced with previous yields from that State-IBRA-Soil location to ensure that the updated data remains within 10% of the variance of the historical yield (back from 1970). The climate data is received by CSIRO Land and Water from the Australian National University and is the same climate dataset that is received by the NCAS as part of its spatial inputs.

Carbon stock change and emissions estimates for *cropland remaining cropland* were determined spatially using *FullCAM*. Outputs of the spatial simulation were reviewed and evaluated against the outputs from the previous inventory. All quality control processes of outputs are conducted internally by the NCAS.

7.J.3.5 Grassland remaining grassland

The *grassland remaining grassland* sub-category incorporates grasslands as well as sub-forest woody vegetation (sparse or shrubby vegetation) that is not classified as forest under Australia's UNFCCC definition of forest. The grassland component of the sub-category is modelled using *FullCAM* (Tier 3). The sub-forest woody vegetation component ('sparse') is modelled using Tier 2 Excel spreadsheet models.

The crop yield database is used for the grassland component of the grassland remaining grassland sub-category. The database was a subset of the crop yield database that was compiled for the forest land converted to cropland and grassland accounts with the exclusion of crops that were not part of a perennial pasture system. The quality assurance and control process of acquiring and inputting crop yield data that is used in *grassland remaining grassland* is the same as that performed for *cropland remaining cropland*. Outputs of the spatial simulation were reviewed and evaluated against the outputs from the previous inventory. All quality control processes of the outputs are conducted internally by the NCAS.

Carbon stock change and emissions estimates for the sparse component of *grassland remaining grassland* is calculated in excel spreadsheet models. The sparse component also incorporates sparse fires and sparse transitions (between grassland and sparse). The fire data for the sparse component is collated and quality assured by CSIRO Sustainable Ecosystems (Darwin) before being received by the National Inventory Team. Once the fire data is received by the NCAS, it undergoes a quality control process by comparing the most recent data to the previous year's data. The sparse transitions use the updated LAI data as per *other native forests* which had already undergone QA/QC processes.

7.J.3.6 Harvested wood products

A national database of domestic wood production, including import and export quantities, has been maintained in Australia since the 1930's. This consistent and detailed collection of time-series data provides a sound basis for the development of a national wood products model. Wood product data are available through the Australian Forests Products Statistics published quarterly by the Australian Bureau of Agricultural and Resource Economics and Sciences (ABARE, 2008c). Data are also available through the Levies Management Unit of the Department of Agriculture, Fisheries and Forests, on behalf of the Forest and Wood Products Research and Development Corporation (FWPRDC), and are also published by the relevant State Forest Services and these provide a valuable crosscheck on ABARES data. Jaakko Pöyry Consulting were initially engaged by the NCAS to develop a national carbon accounting model for wood products based on ABARES, FWPRDC and State data. This work provided the precursor model to that adopted by NCAS.

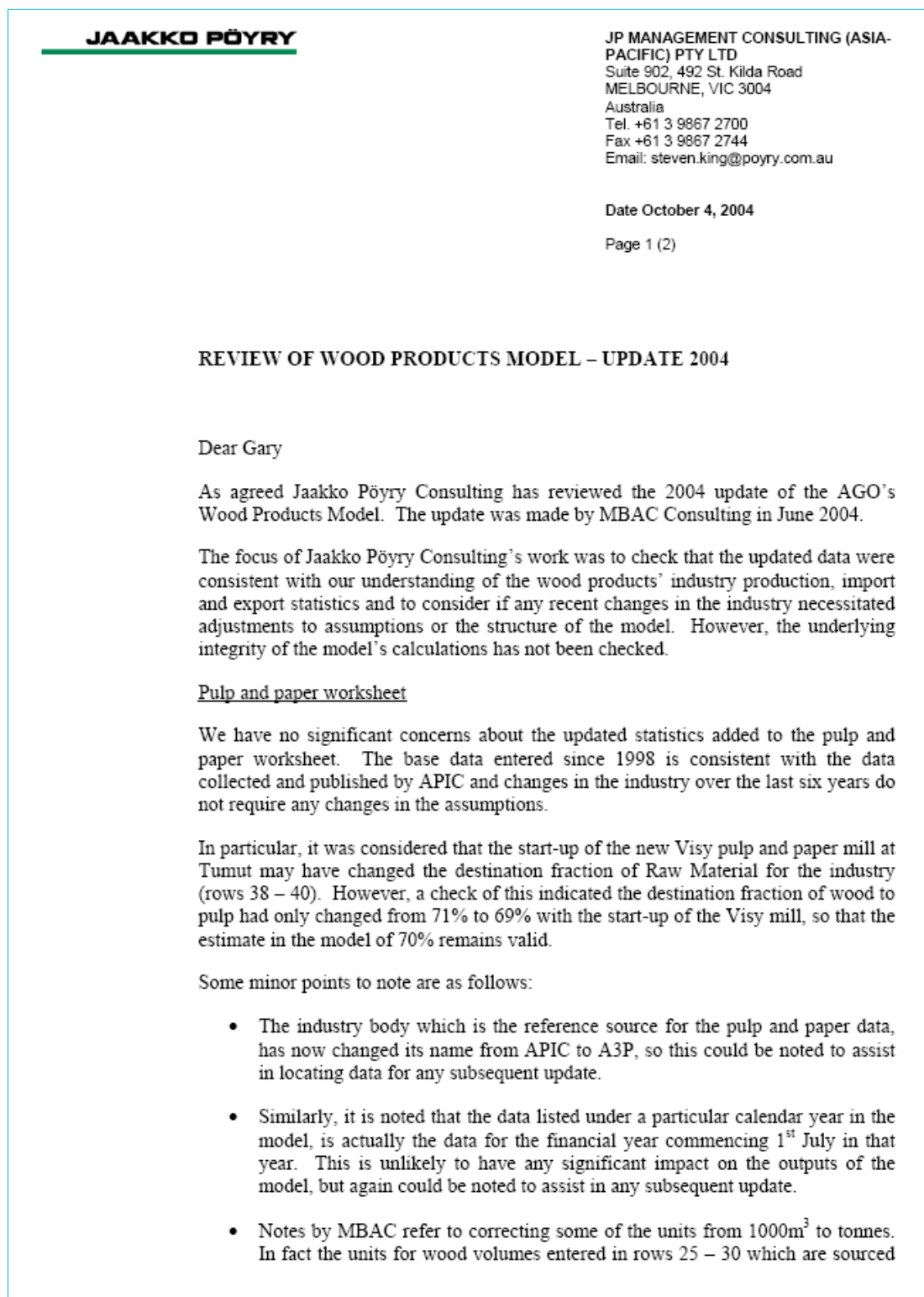
An independent review of the models used to estimate emissions in the wood products category was undertaken by Jaakko Pöyry Consulting (see Figure 7.J23).

Once data on production inputs, processing flows and initial stocks were determined other model calibration requirements included:

- i. the age at which material moves from young to medium and from medium to old pools;
- ii. the amount of each age class for each product pool exposed to loss;
- iii. the rate of loss from each age class in each product pool; and,
- iv. the fraction of loss from each age class, in each product pool, to each of landfill, recycling, bioenergy and the atmosphere.

The model estimates used are presented in Tables 7.J10 and 8.5 (in Chapter 8).

Figure 7.J23: Letter outlining the results of the analysis undertaken by Jaakko Pöyry Consulting



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.

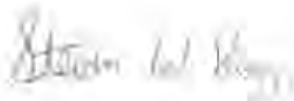
- Some of the data in the model is in dry tonnes and some is in air dried or "as produced" tonnes. Typical moisture content of paper is 4-8%, which could be allowed for in the model.
- Some paper, particularly, printing and writing grades has a significant content of filler or pigment, up to 20%, which 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%.

Solid wood worksheets

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 King
Consultant

Table 7.J10: Decomposition rates and maximum possible loss

| Pool | YOUNG | | MEDIUM | | OLD | |
|------|------------|------------------------|------------|------------------------|------------|------------------------|
| | Loss Yr -1 | Max. Possible Loss (%) | Loss Yr -1 | Max. Possible Loss (%) | Loss Yr -1 | Max. Possible Loss (%) |
| 1 | 1.0 | 0.60 | 0.500 | 0.65 | 0.333 | 0.90 |
| 2 | 0.333 | 0.30 | 0.167 | 0.50 | 0.100 | 0.90 |
| 3 | 0.10 | 0.15 | 0.050 | 0.65 | 0.033 | 0.45 |
| 4 | 0.05 | 0.25 | 0.033 | 0.65 | 0.020 | 0.80 |
| 5 | 0.033 | 0.20 | 0.020 | 0.55 | 0.011 | 0.95 |

With the consistent and comprehensive monitoring of wood production in Australia since 1944, and the confidence in this data gained through cross-verification with other datasets, little uncertainty will likely be derived from the production data. The most likely sources of uncertainty will be derived from the allocation to decomposition and recycling pools, and the rates of decomposition in those pools. To test the relative importance of the pool ages and decomposition rates, *Monte Carlo* analyses were implemented using the @Risk add-in software (Palisade 1997) to the Tier 2 wood products carbon model. The principal model parameters of interest are the decomposition rates within pools (e.g., losses from service life and landfill) and transfers (e.g., to recycling, bioenergy and landfill). *Monte Carlo* analysis samples values from within specified ranges (probability distributions) for nominated parameters within repeated applications of the model. Probability distributions for values within ranges for each variable can be nominated, as can positive and negative correlations between variables so that sampling can reflect these correlations. In this application the nominated probability distributions were ‘triangular’, that is, values within the ranges sampled formed a triangular distribution around a central expected value. No correlations between variables were specified, so that value selection was random within the triangular probability distributions.

The life cycle pools affected and the distributions of their possible values for the *Monte Carlo* analyses are shown in Tables 7.J11, 7.J12, 7.J13 and 7.J14. Distributions of possible outcomes were stabilised over 100,000 model iterations. The Tornado Graph (Figure 7.J24) shows the relative importance of each input variable to the overall uncertainty in the model outcome. The effects of uncertainty in the carbon stock estimates in 1990 and 2004 national harvested wood product emissions estimates can be derived by looking at the annual stock change for the 0.10, 0.50 and 0.90 levels of confidence in potential stock outcome.

Table 7.J11: 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.J12: 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 |

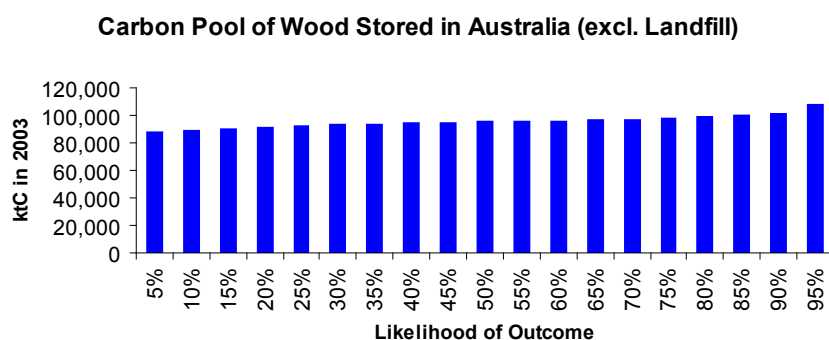
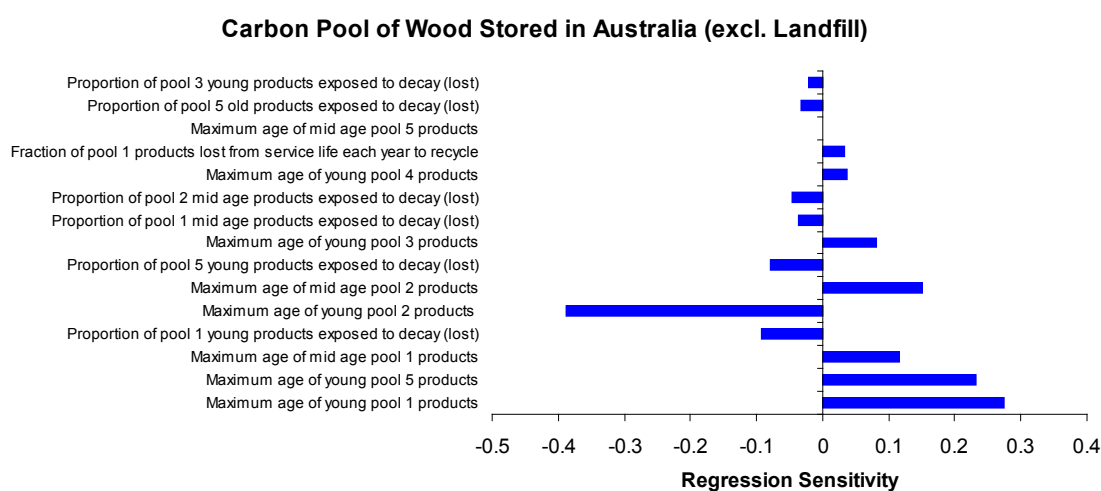
Table 7.J13: Pool fractions exposed to decomposition uncertainty ranges used in the *Monte Carlo* Analysis

| 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.J14: 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.J24: Results of the @Risk sensitivity analyses



7.J.4 MODEL & DATA MANAGEMENT

7.J.4.1 Model versions

The model software development life cycle involves stages of requirements, analysis, design, implementation, verification and maintenance. Testing activities associated with *FullCAM* fall across the design, implementation, verification and maintenance domains of the software development life cycle, because the development of *FullCAM* follows an agile, or iterative, development philosophy. An iterative development philosophy was 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.

FullCAM 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.

Errors or inconsistencies in model versions are managed using Fogbugz, a web-based project management application. Fogbugz is used to record bugs, errors and feature requests identified during *FullCAM* development or by *FullCAM* end-users. Cases are recorded in Fogbugz as either bugs or features, then assessed, 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.

7.J.4.2 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.

7.J.4.3 Backup & 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 was 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.

7.J.4.4 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 TRANSPARENCY & REVIEW

As with the methods for uncertainty and sensitivity analysis, the approach to transparency and peer review will differ for a Tier 3 (spatially explicit) approach from those used in a Tier 1 or Tier 2 (area by emissions factor) approach. For Tier 1 and Tier 2 the focus is on the determination of area estimates and the selection of appropriate emissions factors. For the complex Tier 3 methods, which incorporate models and large datasets, different approaches to transparency and peer review are required. Transparency and review of the NCAS is founded on:

- i. published specifications, protocols and methods;
- ii. published verification results;
- iii. public release of models, tools and data ; and,
- iv. publication in peer reviewed journals or other literature.

7.J.5.1 Published specification, protocols & methods

Throughout the development and implementation of the NCAS, strategic reports and technical reports (six series of reports) were written detailing the development and strategic plans and the framework around which the NCAS has been developed. This also includes the development of the *FullCAM* model which underpins the NCAS, and the methods and data for verification, validation and calibration of the *FullCAM* model. All reports are accessible by the public via the DCCEE website (<http://pandora.nla.gov.au/pan/102841/20090728-0000/www.climatechange.gov.au/publications/index.html>).

7.J.5.1.1 NCAS Technical Report Series 1

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7.J.5.1.6 NCAS Technical Report Series 6

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7.J.5.2 Public release of models, tools & data

In 2005, the National Carbon Accounting Toolbox (NCAT) was released to the public (Figure 7.J25). The NCAT was released as a pack with a CD and DVD. The CD included a copy of the *FullCAM* model (version 3.10) as well as the six series of NCAS technical reports. The DVD was a Data Viewer providing the user with a visual record of landscape and vegetation change in Australia since 1972, as well as a 30 year record of regional climate statistics, including average temperature and rainfall. Over 10,000 copies of the NCAT have been distributed nationally and internationally since 2005. The NCAS has also provided training to external stakeholders on the use of the NCAT.

Figure 7.J25: The publically available National Carbon Accounting Toolbox pack, released in 2005.



The NCAS maintains transparency by also releasing data to state and territory governments, science research agencies (e.g., CSIRO) and national government departments (e.g., ABS) when requested. The data may be required by the governments or agencies to assist with policy development or as part of research and development function. Depending on the requirements of the government and agency, the NCAS provides them with the required data and any associated metadata. It is most often the case that state and territory governments and science research agencies do not have the processing power to obtain outputs from the data NCAS provides; therefore NCAS will assist by processing the input data and supplying the required output data.

7.J.5.3 Publications in peer review journals or other literature

In addition to the technical reports published by the NCAS, the NCAS has also had published, peer-reviewed papers in scientific journals. These are listed below. Additional to the NCAS having had papers published in peer-reviewed journals, external stakeholders who collaborated with the NCAS and who have been involved with the development of the NCAS have also published papers in peer-reviewed journals. This collaboration (with NCAS and external stakeholders) has resulted in the formulation of methodologies and data that have been used to assist in developing, validating and calibrating the *FullCAM* model.

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