APPENDIX 7.B: PLANTATIONS

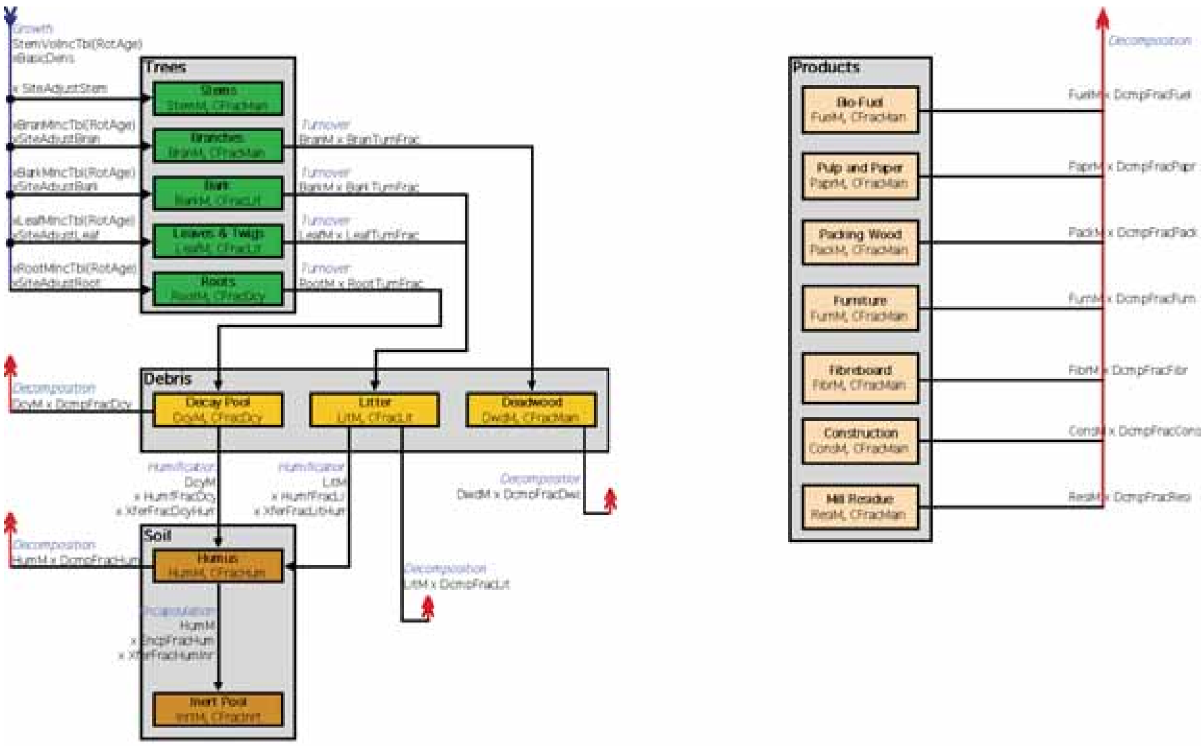
Introduction

The Australian Government's capacity for carbon accounting in plantations has been developed through 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 reported in this paper do not as yet reflect an implementation of the full form of Tier 3 emissions estimation and Approach 3 land representation that will be used eventually.

Model Development

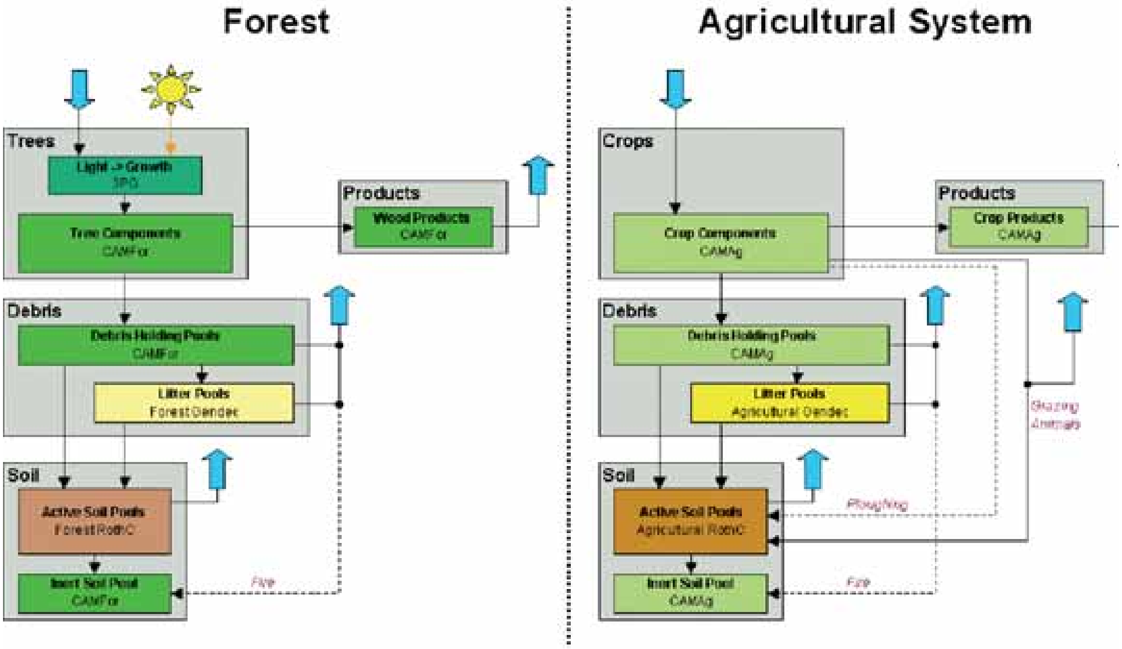
Model development for the NCAS started with the point-based and spatial 'estate' Excel versions of the *CAMFor* model (Richards and Evans 2000a). *CAMFor* (Figure 7.B1) was then integrated with the *Roth-C* soil carbon model (Jenkinson et. al., 1987, Jenkinson et. al.,1991), the *3-PG* forest growth model (Landsberg and Waring 1997) and the *GENDEC* litter decomposition model (Moorhead and Reynolds 1991; Moorhead et. al., 1999). The individual models can be applied independently or in various combinations within the model framework. For example, *CAMFor* can take data inputs from user entered data tables, from *3-PG* or from a generalised, productivity driven growth formula.

Figure 7.B1: The CAMFor Model Pool Structure



Once the testing of the forest model was complete the development of an agricultural equivalent model was undertaken, around a new model, *CAMAg* (Richards and Evans 2000b), to replicate the role of *CAMFor*. The forest and agricultural applications were then integrated into the *FullCAM* model (Richards 2001b; Richards and Evans 2004), providing the capacity for spatial (GIS) application, with transitions between agricultural and forest systems, or mixed systems such as agroforestry and grazed woodlands. The ability to change agricultural and forest species over time was also introduced into *FullCAM* (Figure 7.B2). The *FullCAM* model provides the framework for the integration of the model program calibration and verification activities, land use and management systems, remotely sensed land cover change information and collated (tabular) data such as crop yield and wood density.

Figure B2: The FullCAM model pool structure



The Current Approach Plantations Carbon Accounting

The approach to estimating emissions from plantations will evolve and be refined as the NCAS develops. Initially, as reported here, it employs growth increment tables based on the work of Turner and James (2001), as developed from the National Forest Inventory (National Forest Inventory 1997a and 1997b) wood flow estimates (National Forest Inventory 2000). Areas of relevant plantation types have been derived from Australia's National Plantation Inventory establishment estimates.

While it has been shown that in the medium to long term, soil carbon contents do not change for most plantations (Polglase et. al., 2000), it has also been identified that there are frequently short term losses (later recovered in most situations) and some instances of long term losses or gains (Paul et. al., 2002b). Work is currently underway to develop the capacity for soil carbon accounting for the range of plantation situations. Initial work (Paul et. al., 2002b, 2003a and 2003b) shows the potential for the development of this capacity. However, as the ages of the plantations in this account are over an extended range, the initial losses will be counterbalanced by accumulation in older plantations in any one reporting year.

The model capability for the NCAS is also being extended to consider the non-CO_2 gases which may arise from activities such as fertiliser application, burning and decomposition giving rise to nitrous oxide and methane production. These gases and their potential impact have not been considered in the current analyses, but are not expected to be significant.

Model Implementation

The plantation area data provided by Spencer (2001) is reported on the basis of the 14 National Plantation Inventory regions (Figure 7.B3). Three broad classes of forest are defined as 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).

Figure 7.B3: The National Plantation Inventory Regions

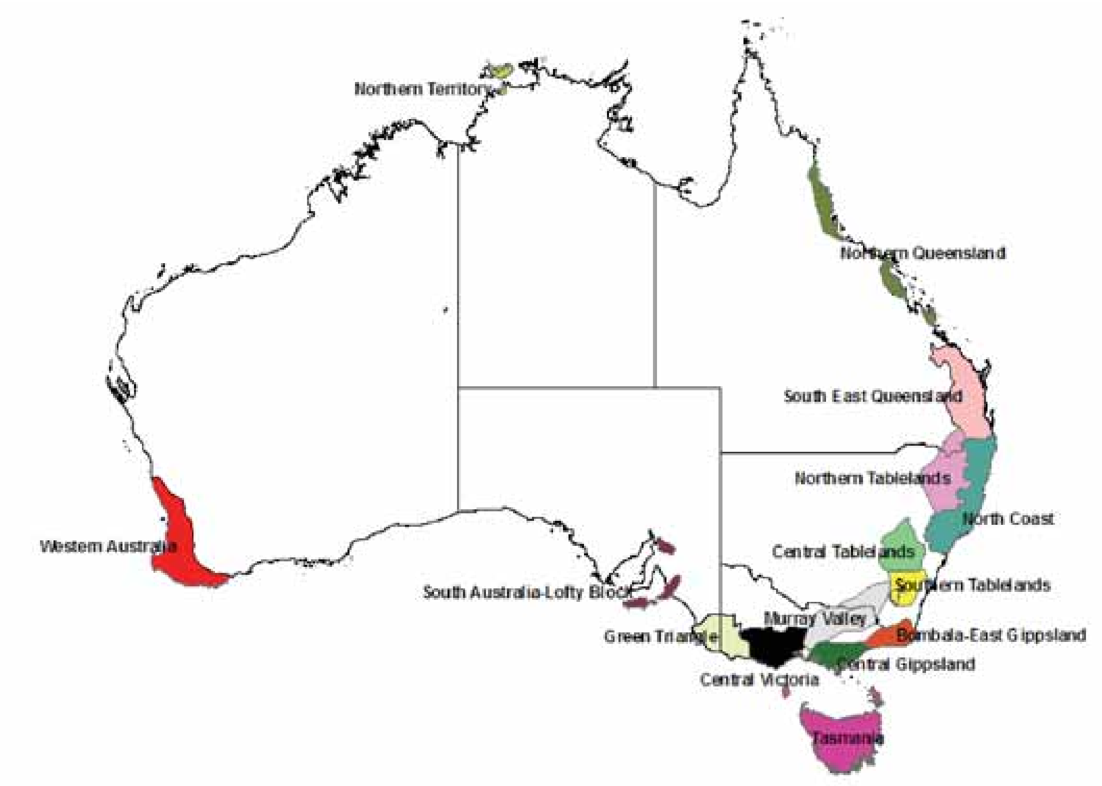


Table 7.B1: Estimates of Areas (ha) of Plantation Establishment (Spencer et al., 2001)

Region	Green Triangle3	Green Triangle 3	NSW 11	NSW 9101112	NSW 9101112	Qld 1314	Qld 1314	Qld 1314	SA 4	SA 4	SA 4	SA 4	Tas 2	Tas 2	Tas 2	Tas 2	Tas 2	Vic 5
Type	P. radiata 1	Pinus 1	Sth Pine 1	Euc 1	Euc 2	Euc 1	Euc 2	SthPine 1	Euc 1	Euc 2	Euc 3	Pinus 1	E. nitens 1	E. nitens 2	E. nitens 3	P. radiata 1	Pinus 1	P. radiata 1
Age Class				45 yr CF	20 yr CF	45 yr	20 yr		20 yr	15 yr	25 yr 6		20 yr	15 yr	25 yr			
1972	3048	47	167	2406	0	1	0	4930	0	0	0	339	30	30	30	1682	289	437
1973	3048	47	167	2406	0	1	0	4930	0	0	0	339	30	30	30	1682	289	437
1974	3048	47	167	2406	0	1	0	4930	0	0	0	339	30	30	30	1682	289	437
1975	3555	0	56	892	0	1	0	5693	0	0	0	253	120	120	120	2071	676	704
1976	3555	0	56	892	0	1	0	5693	0	0	0	253	120	120	120	2071	676	704
1977	3555	0	56	892	0	1	0	5693	0	0	0	253	120	120	120	2071	676	704
1978	3555	0	56	892	0	1	0	5693	0	0	0	253	120	120	120	2071	676	704
1979	3555	0	56	892	0	1	0	5693	0	0	0	253	120	120	120	2071	676	704
1980	4292	0	400	510	0	0	0	3766	1	1	1	462	377	377	377	1580	479	416
1981	4292	0	400	510	0	0	0	3766	1	1	1	462	377	377	377	1580	479	416
1982	4292	0	400	510	0	0	0	3766	1	1	1	462	377	377	377	1580	479	416
1983	4292	0	400	510	0	0	0	3766	1	1	1	462	377	377	377	1580	479	416
1984	4292	0	400	510	0	0	0	3766	1	1	1	462	377	377	377	1580	479	416
1985	4657	0	381	393	0	1	0	4092	12	12	12	397	1020	1020	1020	1287	196	364
1986	4657	0	381	393	0	1	0	4092	12	12	12	397	1020	1020	1020	1287	196	364
1987	4657	0	381	393	0	1	0	4092	12	12	12	397	1020	1020	1020	1287	196	364
1988	4657	0	381	393	0	1	0	4092	12	12	12	397	1020	1020	1020	1287	196	364
1989	4657	0	381	393	0	1	0	4092	12	12	12	397	1020	1020	1020	1287	196	364
1990	675	0	227	110	0	0	135	471	196	196	196	279	203	203	203	348	101	123
1991	675	0	227	110	0	0	135	471	196	196	196	279	203	203	203	348	101	123
1992	675	0	227	110	0	0	135	471	196	196	196	279	203	203	203	348	101	123
1993	675	0	227	110	0	0	135	471	196	196	196	279	203	203	203	348	101	123
1994	675	0	227	110	0	0	135	471	196	196	196	279	203	203	203	348	101	123
1995	1177	0	0	1345	0	0	548	2107	129	129	129	0	498	498	498	613	0	163
1996	1181	0	0	2669	0	0	657	2532	331	331	331	0	655	655	655	801	0	267
1997	1613	0	0	2890	0	0	1142	2513	689	689	689	0	608	608	608	982	0	244
1998	1728	0	0	6320	0	0	1087	325	1328	1328	1328	0	838	838	838	1336	0	132
1999	1073	0	0	3611	0	0	1373	63	5305	5305	5305	0	1327	1327	1327	1541	0	86
2000	1660	0	0	4800	740	2940	1460	1460	6320	6320	6320	0	1473	1473	1473	1480	0	90
2001	1660	0	0	4800	740	2940	1460	1460	6320	6320	6320	0	1473	1473	1473	1480	0	90
2002	1660	0	0	4800	740	2940	1460	1460	6320	6320	6320	0	1473	1473	1473	1480	0	90
2003	1660	0	0	4800	740	2940	1460	1460	6320	6320	6320	0	1473	1473	1473	1480	0	90
2004	1660	0	0	4800	740	2940	1460	1460	6320	6320	6320	0	1473	1473	1473	1480	0	90

Region	Vic5	Vic7	Vic7	Vic7	Vic7	Vic7	Vic NSW 6	Vic NSW6	Vic NSW6	Vic NSW 891011	Vic NSW 891011	Vic NSW 89101	VIC NSW 891011	VIC NSW 891011	Vic NSW 891011	WA1	WA1	WA1
Type	P. radiata 2	Euc 1	Euc 2	Euc 3	Euc 4	P. radiata 1	P. radiata 1	P. radiata 2	P. radiata 3	P. radiata 1	P. radiata 2	P. radiata 3	P. radiata 4	P. radiata 5	P. radiata 6	E. glob. 1	P. pina-ster 1	P. radiata 1
Age Class		25 yr	20 yr	30 yr	35 yr												10 yr	
1972	437	160	160	160	160	2089	1749	1749	1749	800	800	800	800	800	800	19	938	2081
1973	437	160	160	160	160	2089	1749	1749	1749	800	800	800	800	800	800	19	938	2081
1974	437	160	160	160	160	2089	1749	1749	1749	800	800	800	800	800	800	19	938	2081
1975	704	132	132	132	132	2815	1876	1876	1876	819	819	819	819	819	819	18	854	2559
1976	704	132	132	132	132	2815	1876	1876	1876	819	819	819	819	819	819	18	854	2559
1977	704	132	132	132	132	2815	1876	1876	1876	819	819	819	819	819	819	18	854	2559
1978	704	132	132	132	132	2815	1876	1876	1876	819	819	819	819	819	819	18	854	2559
1979	704	132	132	132	132	2815	1876	1876	1876	819	819	819	819	819	819	18	854	2559
1980	416	71	71	71	71	1856	2126	2126	2126	531	531	531	531	531	531	50	766	1878
1981	416	71	71	71	71	1856	2126	2126	2126	531	531	531	531	531	531	50	766	1878
1982	416	71	71	71	71	1856	2126	2126	2126	531	531	531	531	531	531	50	766	1878
1983	416	71	71	71	71	1856	2126	2126	2126	531	531	531	531	531	531	50	766	1878
1984	416	71	71	71	71	1856	2126	2126	2126	531	531	531	531	531	531	50	766	1878
1985	364	119	119	119	119	2289	2099	2099	2099	908	908	908	908	908	908	1734	450	2475
1986	364	119	119	119	119	2289	2099	2099	2099	908	908	908	908	908	908	1734	450	2475
1987	364	119	119	119	119	2289	2099	2099	2099	908	908	908	908	908	908	1734	450	2475
1988	364	119	119	119	119	2289	2099	2099	2099	908	908	908	908	908	908	1734	450	2475
1989	364	119	119	119	119	2289	2099	2099	2099	908	908	908	908	908	908	1734	450	2475
1990	123	373	373	373	373	591	475	475	475	230	230	230	230	230	230	6770	172	1106
1991	123	373	373	373	373	591	475	475	475	230	230	230	230	230	230	6770	172	1106
1992	123	373	373	373	373	591	475	475	475	230	230	230	230	230	230	6770	172	1106
1993	123	373	373	373	373	591	475	475	475	230	230	230	230	230	230	6770	172	1106
1994	123	373	373	373	373	591	475	475	475	230	230	230	230	230	230	6770	172	1106
1995	163	51	51	51	51	784	809	809	809	548	548	548	548	548	548	10060	174	385
1996	267	170	170	170	170	1283	809	809	809	618	618	618	618	618	618	20981	376	830
1997	244	340	340	340	340	1172	809	809	809	598	598	598	598	598	598	23131	646	1428
1998	132	967	967	967	967	635	809	809	809	666	666	666	666	666	666	24326	959	2119
1999	86	2917	2917	2917	2917	412	809	809	809	354	354	354	354	354	354	28588	1730	3825
2000	90	2530	2530	2530	2530	180	320	320	320	1007	1007	1007	1007	1007	1007	14880	367	813
2001	90	2530	2530	2530	2530	180	320	320	320	1007	1007	1007	1007	1007	1007	14880	367	813
2002	90	2530	2530	2530	2530	180	320	320	320	1007	1007	1007	1007	1007	1007	14880	367	813
2003	90	2530	2530	2530	2530	180	320	320	320	1007	1007	1007	1007	1007	1007	14880	367	813
2004	90	2530	2530	2530	2530	180	320	320	320	1007	1007	1007	1007	1007	1007	14880	367	813

Allocations of the Short Rotation Hardwood (SRH), Long Rotation Hardwood (LRH) and Softwood (SW) classes are made to the region and species specific Plantation Types described by Turner and James (2001). Table 7.B2 shows the Plantation Types for which growth increment (yield) tables are available. The yields, in terms of bole volume, are shown in Attachment 7.B1.

Table 7.B2: Plantation Types and Management Regimes

Species	Region	Regime
Pinus pinaster	Western Australia	Average sites – 65% thin @ 18yrs, 37% @ 25yrs and clearfall @ 40yrs
Pinus radiata	Western Australia	Average sites – 51% thin @ 12yrs, 39% @ 18yrs, 32% @ 24yrs, clearfall @ 35yrs
Pinus radiata	Victoria, NSW	Poor sites – clearfall @ 30yrs
Eucalyptus globulus	Western Australia	Clearfall @ 10yrs
Pinus radiata	Victoria, NSW	Average sites – 65% thin @ 16yrs,m 57% @ 24yrs, 27% @ 30yrs, clearfall @ 35yrs
Pinus radiata	Victoria, NSW	Poor sites – 26% thin @ 18yrs, 32% @ 24yrs, clearfall @ 30yrs
Pinus radiata	Victoria, NSW	Average sites – 65% thin @ 16yrs, clearfall @ 30yrs
Pinus radiata	Victoria, NSW	Average sites – 65% thin @ 16yrs, 57% @ 24yrs, clearfall @ 30 years
Pinus radiata	Murray Valley	Very Good sites – 44% thin @ 14yrs, 31% @ 18yrs, 27% @ 23yrs, clearfall @ 30yrs
Pinus radiata	Victoria, NSW	Average sites – clearfall @ 30yrs
Pinus radiata	Murray Valley	Average sites – 47% thin @ 14yrs, 35% @ 22yrs, 29% @ 29yrs, clearfall @ 30yrs
Pinus radiata	Murray Valley	Average sites – 47% thin @ 14yrs, 35% @ 22yrs, clearfall @ 30yrs
Eucalyptus spp	Vic(Central Gippsland)	All sites – clearfall @ 35yrs
Pinus radiata	Vic(Central Gippsland)	Average sites – 33% thin @ 15yrs, 37% @ 20 yrs, clearfall @ 30yrs
Eucalyptus spp	Vic(Central Gippsland)	All sites – clearfall @ 20 yrs
Eucalyptus spp	Vic(Central Gippsland)	All sites – clearfall @ 30yrs
Pinus radiata	Victoria (Central)	Average sites – clearfall @ 30yrs
Eucalyptus spp	Victoria (Central)	All sites – clearfall @ 25yrs
Pinus spp (not radiata)	Tasmania	All sites – clearfall @ 35yrs
Pinus radiata	Victoria (Central)	Average sites – 34% thin @ 15yrs, 18% @ 22yrs, 24% @ 28yrs, clearfall @ 35yrs
Eucalyptus nitens	Tasmania	All sites – clearfall @ 25yrs
Pinus radiata	Tasmania	Average sites – clearfall @ 35yrs
Eucalyptus nitens	Tasmania	All sites- clearfall @ 30yrs
Eucalyptus nitens	Tasmania	All sites – clearfall @ 15yrs
Eucalyptus spp	South Australia	All sites – clearfall @ 25yrs
Pinus spp (not radiata)	South Australia	Average sites – 54% thin @ 13yrs, 25% @ 18yrs, 28% @ 23yrs, clearfall @ 30yrs
Eucalypt spp	South Australia	All sites – clearfall @ 25yrs
Pinus spp (not radiata)	South Australia	Average sites – 54% thin @ 13yrs, 25% @ 18yrs, 28% @ 23yrs, clearfall @ 30yrs
Eucalypt spp	South Australia	All sites – clearfall @ 20yrs
Eucalypt spp	South Australia	All sites – clearfall @ 15yrs

Species	Region	Regime
Eucalypt spp	Queensland	All sites – clearfall @ 20yrs
Southern Pines	Queensland	All sites – 35% thin @ 18yrs, clearfall @ 35yrs
Eucalypt spp	NSW	All sites – clearfall @ 20yrs
Eucalypt spp	Queensland	All sites – 67% thin @ 20yrs, 47% @ 35yrs, clearfall @ 45yrs
Southern Pine	NSW Northern Tableland	Average sites – 27% thin @ 14yrs, 47% @ 20yrs, clearfall @ 30yrs
Eucalypt spp	NSW	All sites – 67% thin @ 20yrs, 47% @ 35yrs, clearfall @ 45yrs
Pinus radiata	Green Triangle	Average sites – 54% thin @ 13yrs, 25% @ 18yrs, 28% @ 23yrs, clearfall @ 30yrs
Pinus spp (not radiata)	Green Triangle	Average sites – 54% thin @ 13yrs, 25% @ 18yrs, 28% @ 23yrs, clearfall @ 30yrs

Within the *FullCAM* model, as implemented for the national plantation estate, *CAMFor* equivalent models for each of the Plantation Types were developed. Additional information, beyond the growth tables and thinning regimes of Turner and James (2001) shown in Table 7.B6 and Attachment 7.B1, for each Plantation Type included:

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

Table 7.B6 and Attachment 7.B1 provide snapshots of the relevant inputs, and the resultant carbon balances on a per hectare basis from each of the Plantation Types. These snapshots are incorporations of the information collated by the NCAS as individual model implementations for each Plantation Type.

The 'Estate' module of *CAMFor* as contained within the *FullCAM* is then used to calculate the results of the implementation of the individual Plantation Type models on the basis of the new 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, 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).

Identifying Lands Converted to Forest Land

Lands converted to Forest land can be identified and classified to Plantation Type since 1990. This is because the remotely sensed (Landsat satellite) data has only been analysed over this period. Further analysis is planned to identify lands converted to plantation since the commencement of the Landsat archive in 1972. The time-series data is able to identify areas where plantations have been established on land with a prior non-forest land use. The areas are shown in Table 7.B3.

Table 7.B3. Areas of Land Converted to Forest

Year	Area (ha)
1990	85,269
1991	86,183
1992	77,105
1993	72,850
1994	71,976
1995	50,535
1996	50,535
1997	50,535
1998	64,420
1999	66,411
2000	86,856
2001	86,856
2002	87,764
2003	87,976
2004	77,275
2005	55,303

Growth Tables and Thinning Regimes

Turner and James (2001) 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 each Plantation Type represented. To determine the CAI, the estimates of total volume produced (from a per cent thin or clearfall) by age, by region, by species and by 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 (2001).

The empiricism of the estimates masks the influences of climate variability giving average performance over the time of measurement. It has been shown (Brack unpub.) that a variable climate will affect a variability in growth over time. 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 density estimates were extracted from the compendium prepared by Ilic et. al. (2000) for the NCAS. While many native forest species have few, and in some instances no, reported wood density estimates, plantation species are relatively well studied and reported. However, wood density is most commonly measured at the time of harvest, reflecting a mature state.

As it is commonly accepted that wood density increases with tree age, there is a potential that the adopted wood densities are over-estimates for the early stages of plantation growth. However, the overall effect is unlikely to be significant as lower densities occur when mass is least, that is, during early growth stages. Also, as plantations are generally harvested well before individual tree maturity (generally as total growth increment begins to taper) it is unlikely that the maximum potential density will be achieved at the time of harvest. Table B6 and Attachment 7.B1 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 below ground partitioning of biomass (Keith et. al., 2000, Eamus et. al., 2000, Snowdon et. al., 2000) have shown that both above and below ground variability reduces, as do non-stem allocations, as site biomass increases. Greatest uniformity, and therefore least variability, tends to occur in even-aged and productive stands. Attachment 7.B1 provides a synopsis of the non-stem allocations used in each Plantation Type model.

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

Carbon Contents

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

Leaf and Root Turnover

The turnover rate of leaves affects both the amount of fine litter on the forest floor and subsequently most of the aboveground contribution to soil carbon. The turnover rate of roots (largely fine roots) is taken to be a direct input to soil carbon.

As this implementation of the model has not considered soil carbon, the rates of turnover of both leaves and fine roots are relatively unimportant. The key attributes of the assigned rates are that they are realistic and do not operate at rates high or low enough to either reduce below reasonable expectation, the mass of attached leaves and live roots, or create unrealistically high or low levels of litter.

A simple reality check can be performed directly from observations of model results. 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 soil carbon accounting is implemented.

Table 7.B4: 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

Slash Decomposition

Subsequent to harvest there is often large quantities of slash (stumpage, branches etc.) left on the forest floor to decompose. The rates of decomposition applied in the model have been guided by the work of Mackensen and Bauhus (1999) for the NCAS. Table 7.B5 shows the decomposition rates applied.

Table 7.B5: Slash Decomposition Rates

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

Table 7.B6: Wood Densities and Carbon Contents

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

Region(s)	Species	Density	CC% Leaf	CC% Twig	CC% Branch	CC% Sap-wood	CC% Wood	CC% Bark	CC% Fine Roots	CC% Coarse Roots	Regime Description
Victoria (Central Gippsland)	Eucalyptus plantations	550	52	52	47	52	52	49	46	49	All Sites - CF @ 20
Victoria (Central Gippsland)	Eucalyptus plantations	550	52	52	47	52	52	49	46	49	All Sites - CF @ 30
Victoria (Central Gippsland)	Eucalyptus plantations	550	52	52	47	52	52	49	46	49	All Sites - CF @ 35
Victoria (Central Gippsland)	*Pinus radiata*	440	52	52	51	51	52	53	46	49	Average Sites - 33% thinning @ 15 years, 37% @ 20, CF @ 30
Murray Valley	*Pinus radiata*	440	52	52	51	51	52	53	46	49	Average Sites - 47% thinning @ 14 years, 35% @ 22, 29% @ 29, CF @ 30
Murray Valley	*Pinus radiata*	440	52	52	51	51	52	53	46	49	Average Sites - 47% thinning @ 14 years, 35% @ 22, CF @ 30
Murray Valley	*Pinus radiata*	440	52	52	51	51	52	53	46	49	Very Good Sites - 44% thinning @ 14 years, 31% @ 18, 27% @ 23, CF @ 30
Victoria and NSW	*Pinus radiata*	440	52	52	51	51	52	53	46	49	Average Sites - CF @ 30 years
Victoria and NSW	*Pinus radiata*	440	52	52	51	51	52	53	46	49	Average Sites - 65% thinning @ 16 years, CF @ 30
Victoria and NSW	*Pinus radiata*	440	52	52	51	51	52	53	46	49	Average Sites - 65% thinning @ 16 years, 57% @ 24, CF @ 30
Victoria and NSW	*Pinus radiata*	440	52	52	51	51	52	53	46	49	Average Sites - 65% thinning @ 16 years, 57% @ 24, 27% @ 30, CF @ 35
Victoria and NSW	*Pinus radiata*	440	52	52	51	51	52	53	46	49	Poor Sites - 26% thinning @ 18 years, 32% @ 24, CF @ 30
Victoria and NSW	*Pinus radiata*	440	52	52	51	51	52	53	46	49	Poor Sites - CF @ 30 years
Western Australia	*Eucalyptus globulus*	550	52.8	49.8	47	48.7	50.7	49	46	49	Clear fall @ 10
Western Australia	*Pinus pinaster*	470	52	52	51	51	52	53	46	49	Average Sites - 65% thinning @ 18 years, 37% @ 25, CF @ 40
Western Australia	*Pinus radiata*	440	52	52	51	51	52	53	46	49	Average Sites - 51% thinning @ 12 years, 39% @ 18, 32% @ 24, CF @ 35

Uncertainty Analysis

Brack and Richards (2002) have provided the basis for uncertainty analysis using the @Risk *Monte Carlo* capabilities attached to the *FullCAM* model. The analysis undertaken took advantage of the progression from treating all parameters as 'uncertain' with ranges of potential values, to described 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 a high rainfall both 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 associated with decreased decomposition rates.

If correlations are not prescribed combinations such as increased growth and decreased decomposition rates (a negative correlation) are as likely to be selected as a positive correlation, yet they are not likely in reality. This inclusion of unrealistic scenarios will considerably increase perceived uncertainty in model outcomes. The result is that a simple multiplicative array of potential (yet unrealistic) extreme results increases uncertainty ranges, as the generally ameliorating impacts of correlated inputs are not acknowledged.

Brack and Richards (2002) modelled the performance 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.B4.

The 'tornado' graph shows the sources of uncertainty of model parameters and variables in order of their importance to uncertainty in the model outcome. It is clear from the analysis that, on an individual stand basis and in this instance, predictions are more prone to climate based variation than any other influence.

Figure B5 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 say a 'low' based 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, 'near average' conditions will be achieved.

Figure 7.B4: 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.

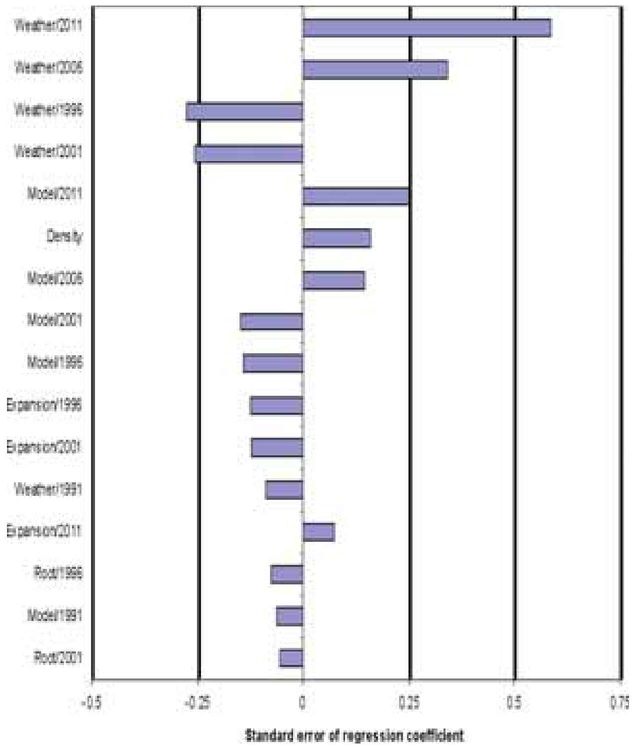
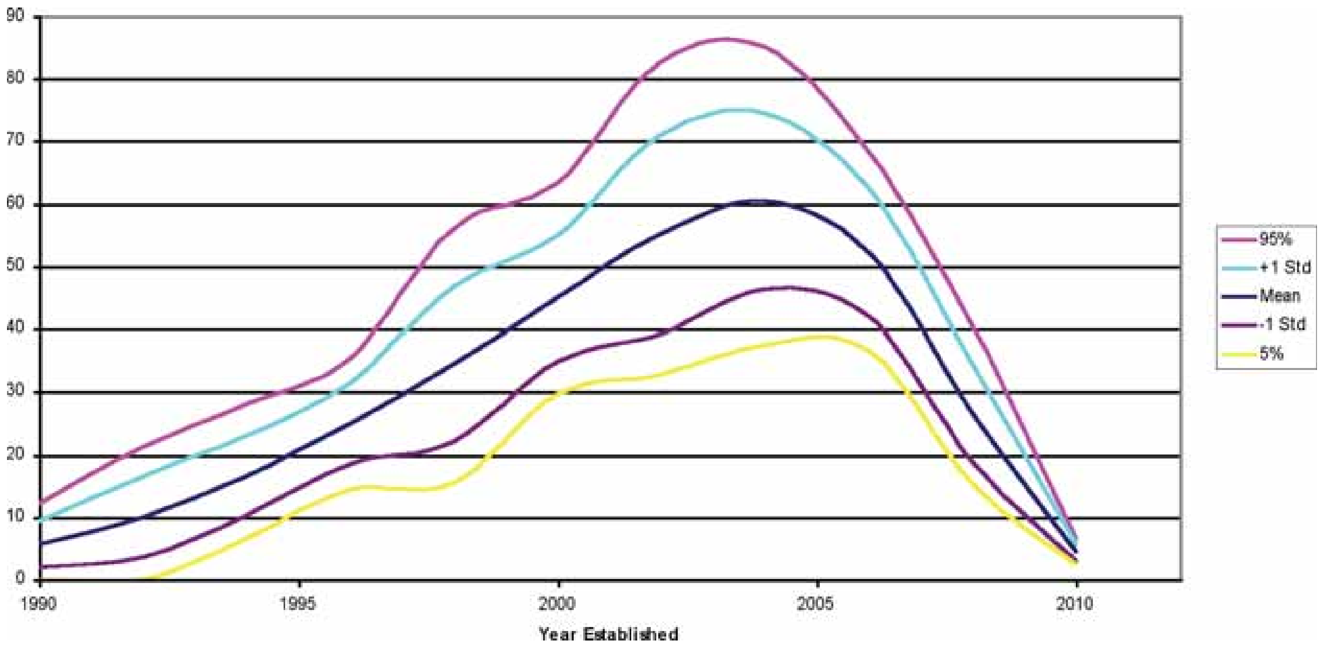
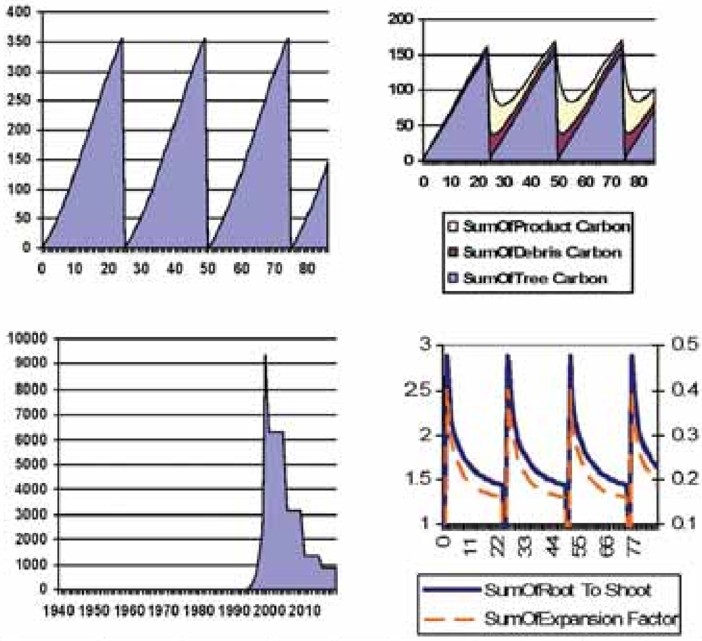


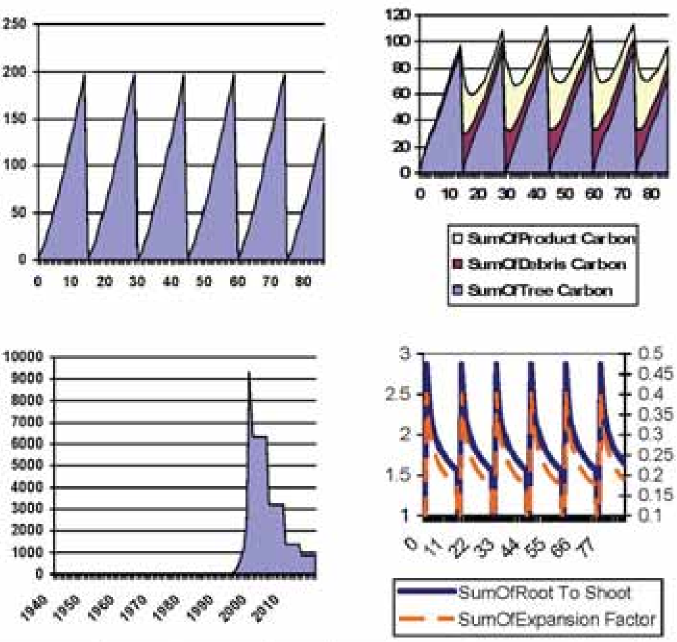
Figure 7.B5. Variability in Stand Performance by Age of Stand (from Brack and Richards 2002)



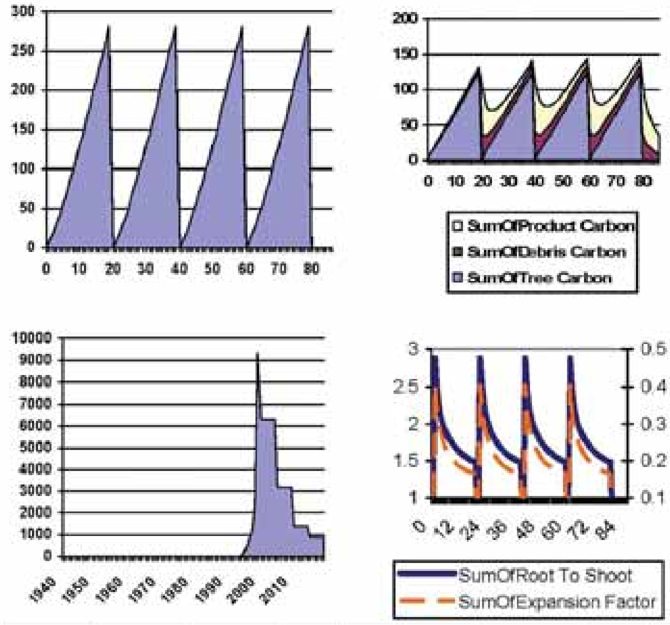
Attachment 7.B1: Plantation Type Model Parameters and Outcomes



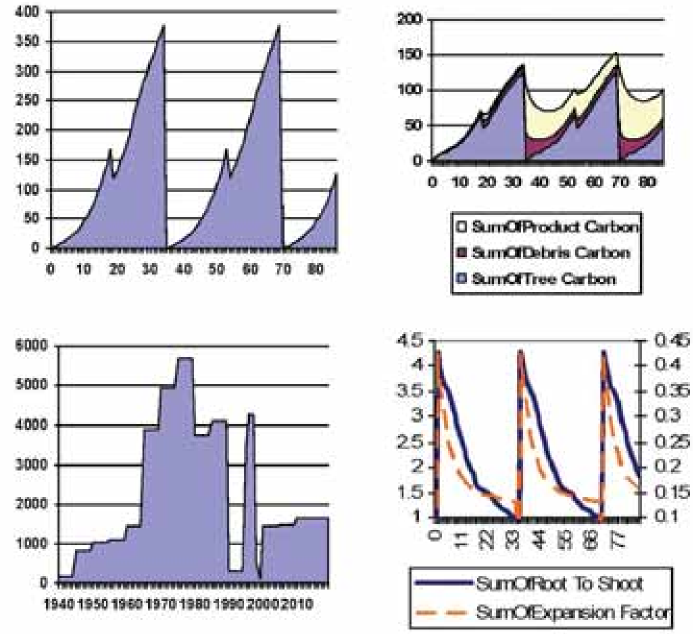
LookUp	Region(s)	Species	Density	CC% Leaf	CC% Twig	CC% Branch	CC% Sapwood	CC% Wood	CC% Bark	Regime Description
SA4 Euc 3	South Australia	Eucalyptus plantations	550	52	52	47	52	52	49	All Sites - CF @ 25



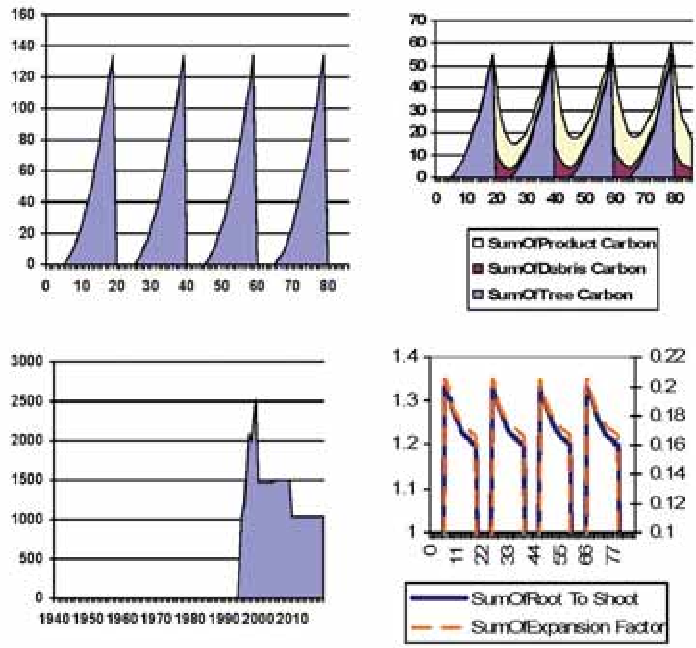
LookUp	Region(s)	Species	Density	CC% Leaf	CC% Twig	CC% Branch	CC% Sapwood	CC% Wood	CC% Bark	Regime Description
SA4 Euc 2	South Australia	Eucalyptus plantations	550	52	52	47	52	52	49	All Sites - CF @ 15



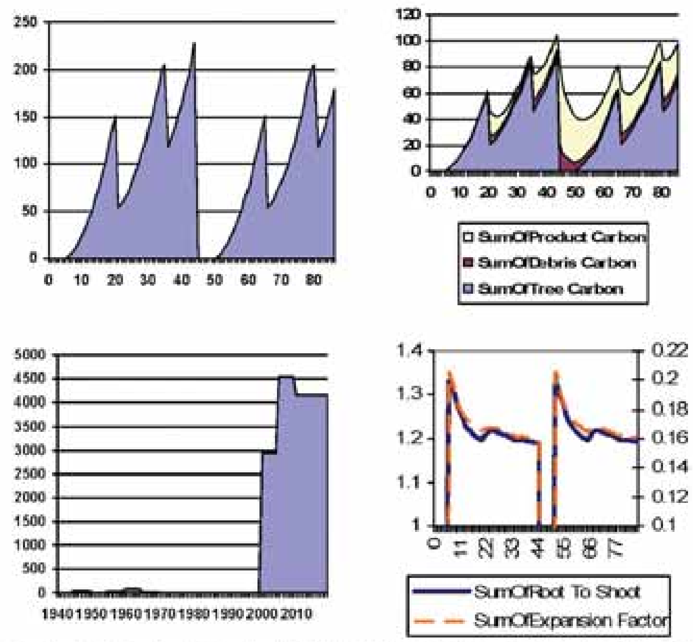
LookUp	Region(s)	Species	Density	CC% Leaf	CC% Twig	CC% Branch	CC% Sapwood	CC% Wood	CC% Bark	Regime Description
SA4 Euc 1	South Australia	Eucalyptus plantations	550	52	52	47	52	52	49	All Sites - CF @ 20



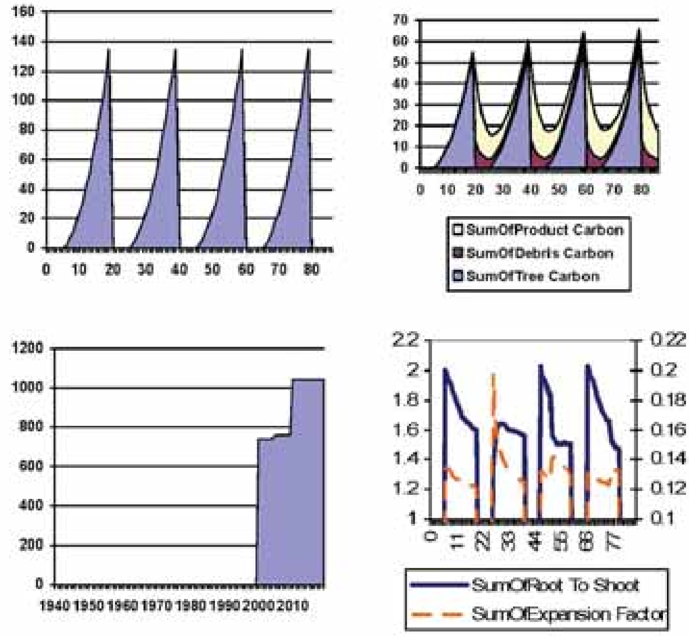
LookUp	Region(s)	Species	Density	CC% Leaf	CC% Twig	CC% Branch	CC% Sapwood	CC% Wood	CC% Bark	Regime Description
Qld1314 SthPine	Queensland	Southern Pine (*P. elliotti, P. taeda, Araucaria cunninghamii*)	440	52	52	51	51	52	53	All Sites - 35% @ 18 years, CF @ 35



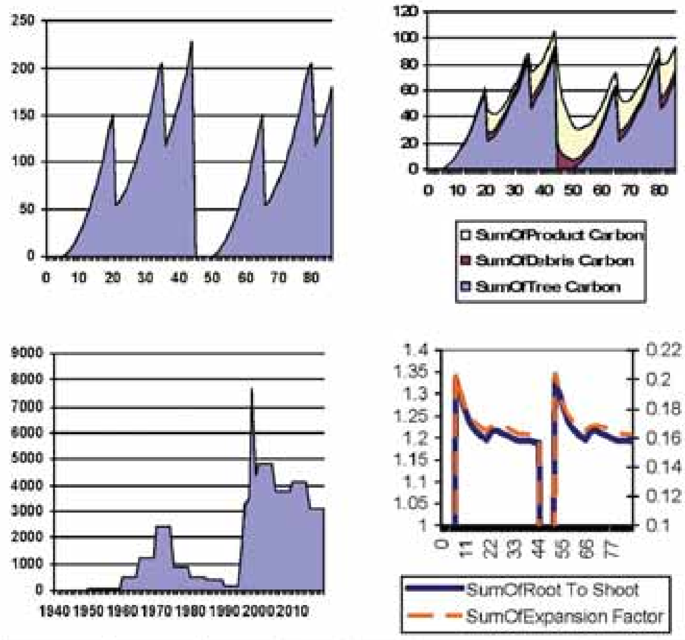
LookUp	Region(s)	Species	Density	CC% Leaf	CC% Twig	CC% Branch	CC% Sapwood	CC% Wood	CC% Bark	Regime Description
Qld1314 Euc 2	Queensland	Eucalyptus plantations	550	52	52	47	52	52	49	All Sites - CF @ 20



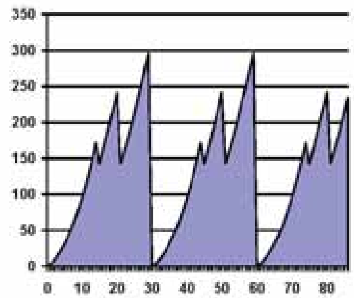
LookUp	Region(s)	Species	Density	CC% Leaf	CC% Twig	CC% Branch	CC% Sapwood	CC% Wood	CC% Bark	Regime Description
Qld1314 Euc 1	Queensland	Eucalyptus plantations	550	52	52	47	52	52	49	All Sites - 67% @ 20 years, 47% @ 35, CF @ 45

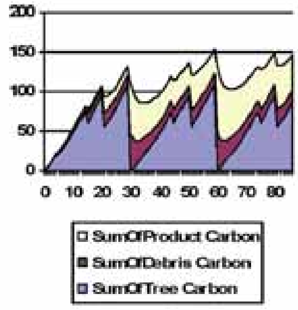


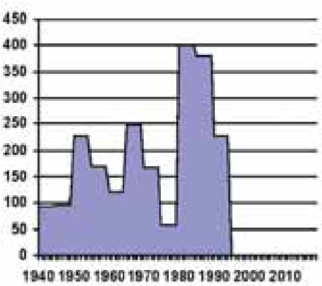
LookUp	Region(s)	Species	Density	CC% Leaf	CC% Twig	CC% Branch	CC% Sapwood	CC% Wood	CC% Bark	Regime Description
NSW9101112 Euc 2	NSW	Eucalyptus plantations	550	52	52	47	52	52	49	All Sites - CF @ 20

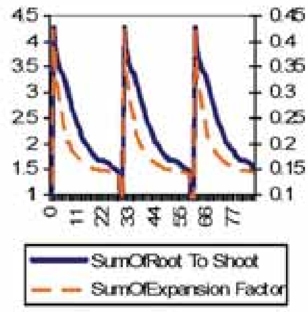


LookUp	Region(s)	Species	Density	CC% Leaf	CC% Twig	CC% Branch	CC% Sapwood	CC% Wood	CC% Bark	Regime Description
NSW9101112 Euc 1	NSW	Eucalyptus plantations	550	52	52	47	52	52	49	All Sites - 67% @ 20 years, 47% @ 35, CF @ 45

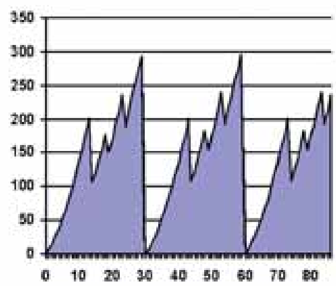


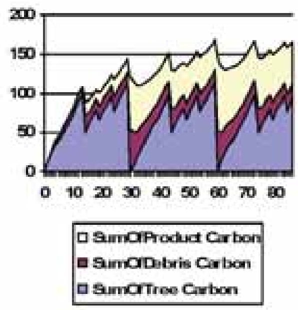


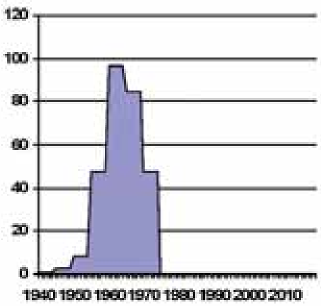


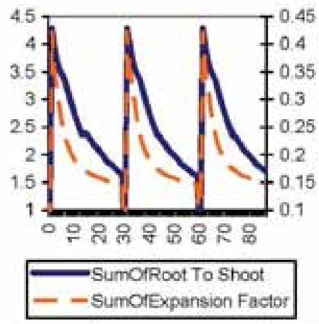


LookUp	Region(s)	Species	Density	CC% Leaf	CC% Twig	CC% Branch	CC% Sapwood	CC% Wood	CC% Bark	Regime Description
NSW11 SthPine 1	NSW Northern Tableland	Southern Pine (*P. elliotti, P. taeda, Araucaria cunninghamii*)	440	52	52	51	51	52	53	Average Sites - 27% thinning @ 14 years, 47% @ 20, CF @ 30

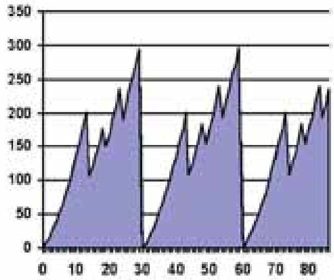


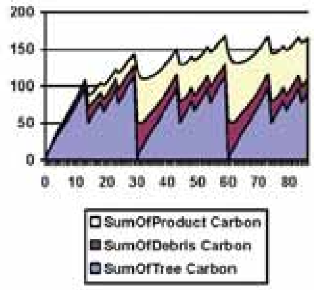


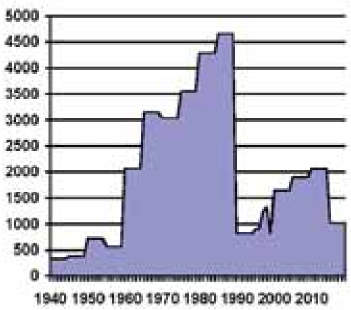


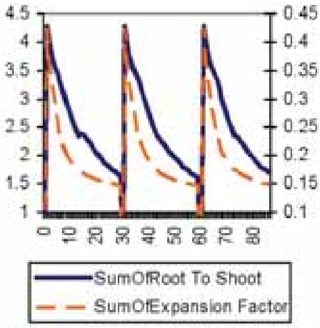


LookUp	Region(s)	Species	Density	CC% Leaf	CC% Twig	CC% Branch	CC% Sapwood	CC% Wood	CC% Bark	Regime Description
GrnTri3 Pinus 1	Green Triangle	Pinus (other than radiata)	440	52	52	51	51	52	53	Average Sites - 54% thinning @ 13 years, 25% @ 18, 28% @ 23, CF @ 30

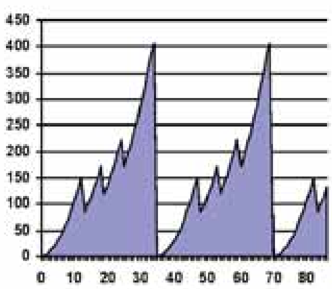


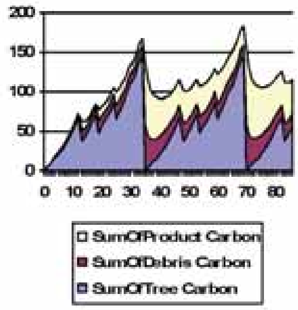


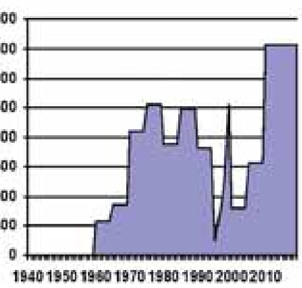


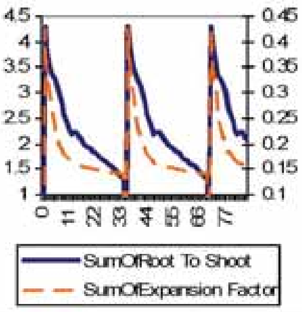


LookUp	Region(s)	Species	Density	CC% Leaf	CC% Twig	CC% Branch	CC% Sapwood	CC% Wood	CC% Bark	Regime Description
GmTri3 P.rad 1	Green Triangle	*Pinus radiata*	440	52	52	51	51	52	53	Average Sites - 54% thinning @ 13 years, 25% @ 18, 28% @ 23, CF

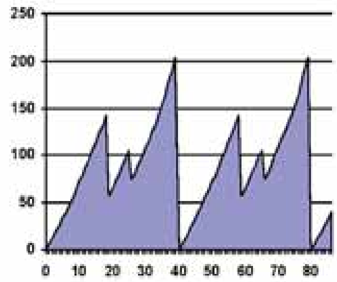


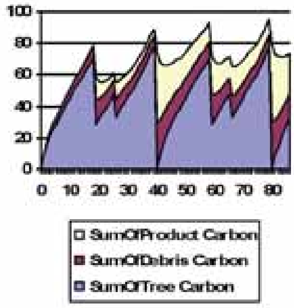


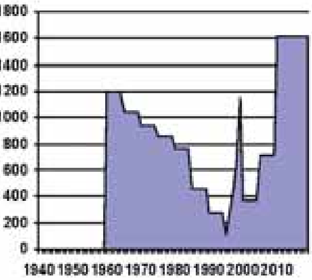


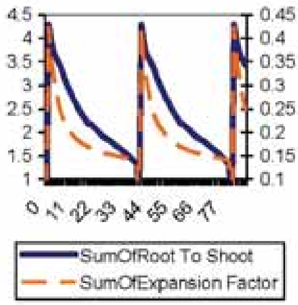


LookUp	Region(s)	Species	Density	CC% Leaf	CC% Twig	CC% Branch	CC% Sapwood	CC% Wood	CC% Bark	Regime Description
WA1 P.rad 1	Wester Australia	*Pinus radiata*	440	52	52	51	51	52	53	Average Sites - 51% thinning @ 12 years, 39% @ 18, 32% @ 24, CF @ 35

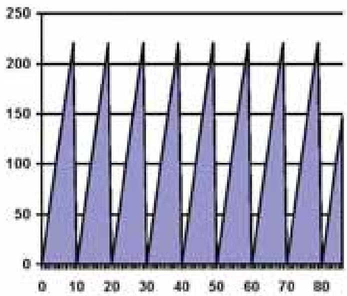


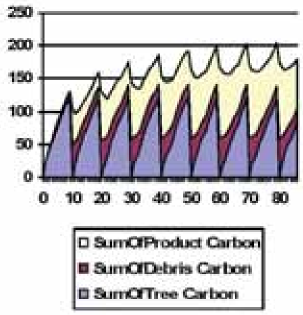


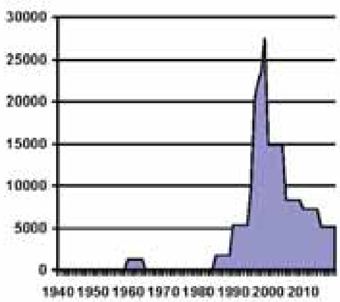


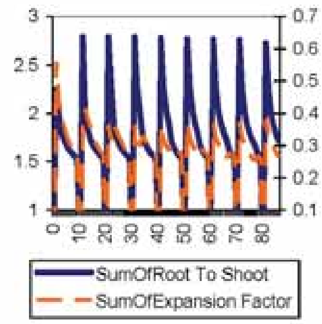


LookUp	Region(s)	Species	Density	CC% Leaf	CC% Twig	CC% Branch	CC% Sapwood	CC% Wood	CC% Bark	Regime Description
WA1 P.pin 1	Wester Australia	*Pinus pinaster*	470	52	52	51	51	52	53	Average Sites - 65% thinning @ 18 years, 37% @ 25, CF @ 40

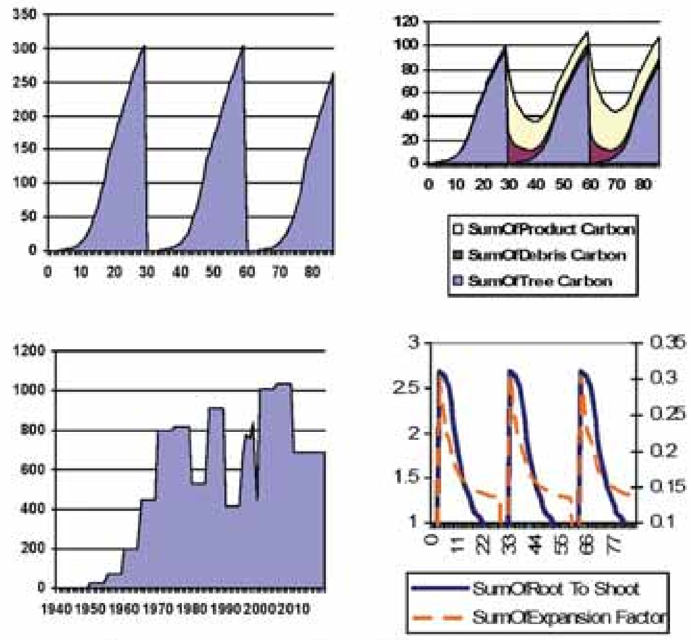




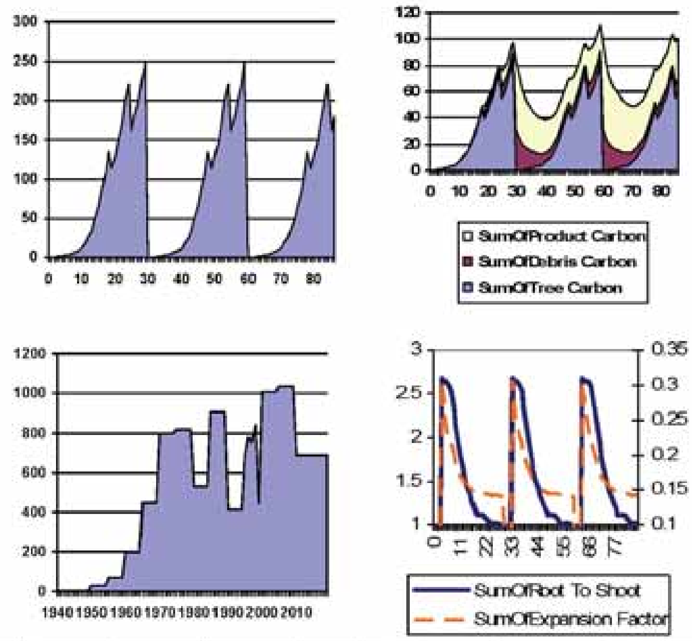




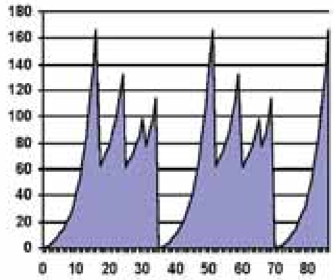
LookUp	Region(s)	Species	Density	CC% Leaf	CC% Twig	CC% Branch	CC% Sapwood	CC% Wood	CC% Bark	Regime Description
WA1 E.glob 1	Wester Australia	*Eucalyptus globulus*	550	52.8	49.8	47	48.7	50.7	49	Clear fall @ 10

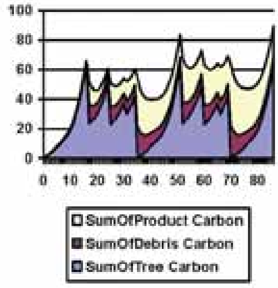


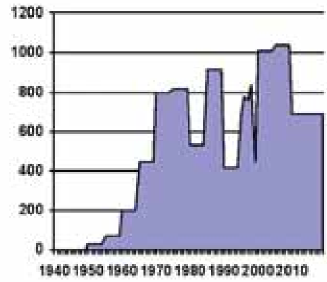
LookUp	Region(s)	Species	Density	CC% Leaf	CC% Twig	CC% Branch	CC% Sapwood	CC% Wood	CC% Bark	Regime Description
VicNSW891011 P.rad 6	Victoria and NSW	*Pinus radiata*	440	52	52	51	51	52	53	Poor Sites - CF @ 30 years

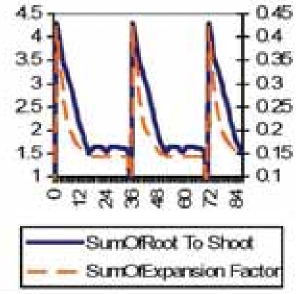


LookUp	Region(s)	Species	Density	CC% Leaf	CC% Twig	CC% Branch	CC% Sapwood	CC% Wood	CC% Bark	Regime Description
VicNSW891011 P.rad 5	Victoria and NSW	*Pinus radiata*	440	52	52	51	51	52	53	Poor Sites - 26% thinning @ 18 years, 32% @ 24, CF @ 30

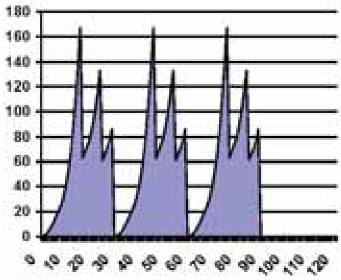


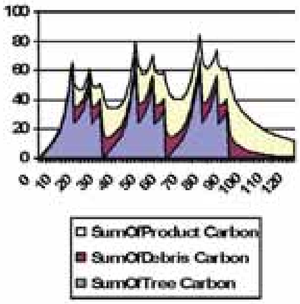


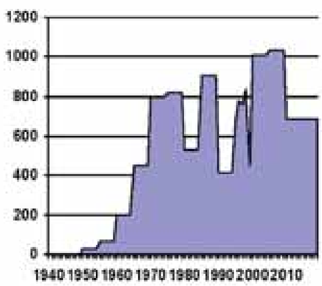


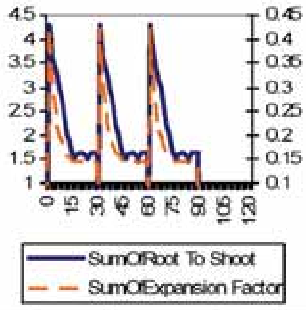


LookUp	Region(s)	Species	Density	CC% Leaf	CC% Twig	CC% Branch	CC% Sapwood	CC% Wood	CC% Bark	Regime Description
VicNSW891011 P.rad 4	Victoria and NSW	*Pinus radiata*	440	52	52	51	51	52	53	Average Sites - 65% thinning @ 16 years, 57% @ 24, 27% @ 30, CF @ 35

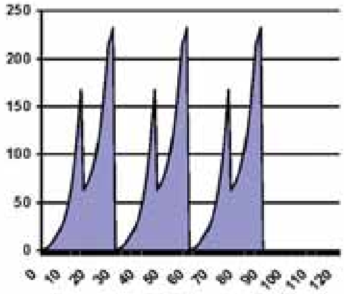


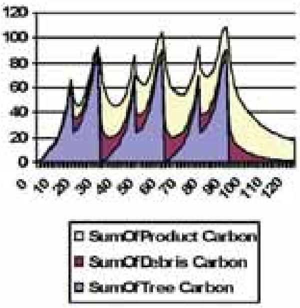


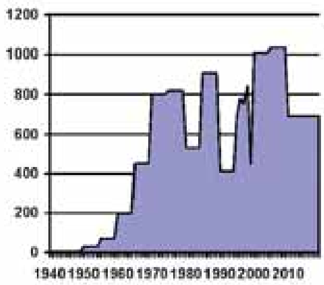


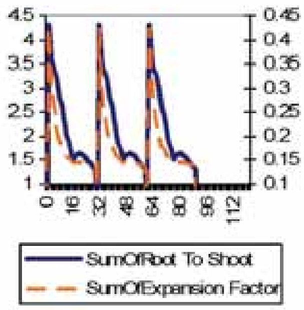


LookUp	Region(s)	Species	Density	CC% Leaf	CC% Twig	CC% Branch	CC% Sapwood	CC% Wood	CC% Bark	Regime Description
VicNSW891011 P.rad 3	Victoria and NSW	*Pinus radiata*	440	52	52	51	51	52	53	Average Sites - 65% thinning @ 16 years, 57% @ 24, CF @ 30

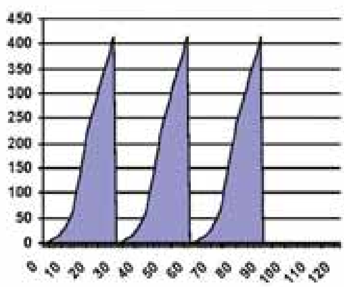


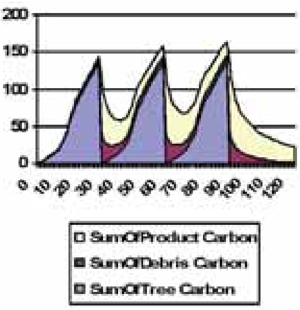


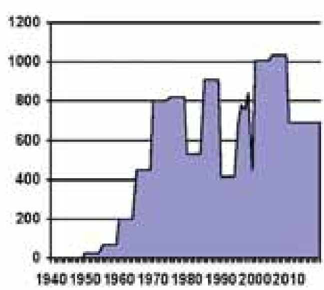


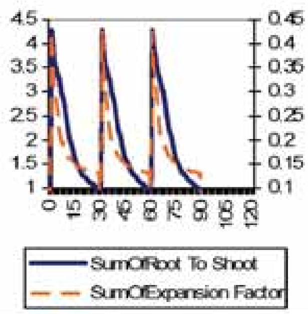


LookUp	Region(s)	Species	Density	CC% Leaf	CC% Twig	CC% Branch	CC% Sapwood	CC% Wood	CC% Bark	Regime Description
VicNSW891011 P.rad 2	Victoria and NSW	*Pinus radiata*	440	52	52	51	51	52	53	Average Sites - 65% thinning @ 16 years, CF @ 30

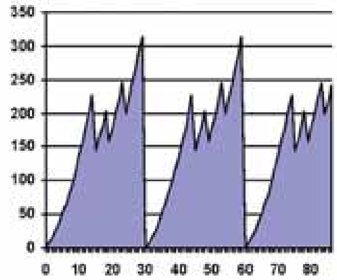


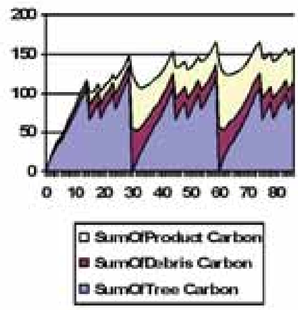


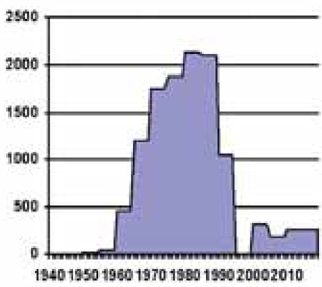


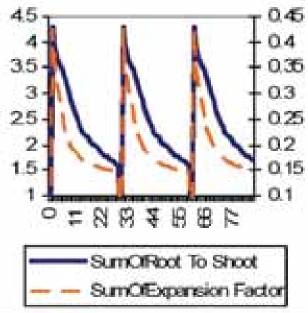


LookUp	Region(s)	Species	Density	CC% Leaf	CC% Twig	CC% Branch	CC% Sapwood	CC% Wood	CC% Bark	Regime Description
VicNSW891011 P.rad 1	Victoria and NSW	*Pinus radiata*	440	52	52	51	51	52	53	Average Sites - CF @ 30 years

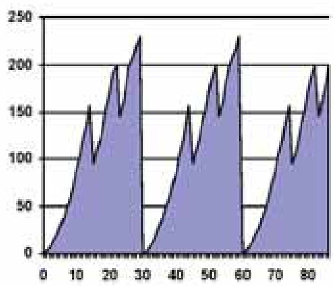


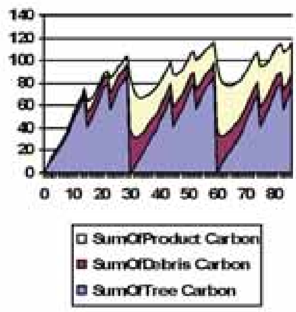


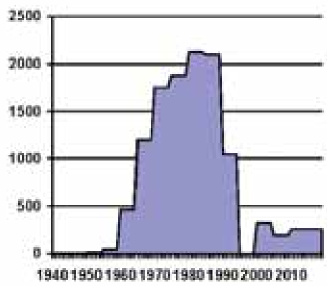


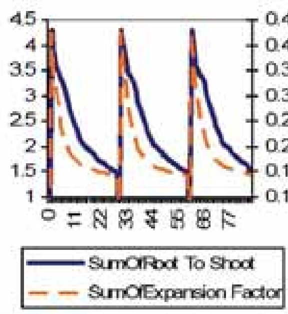


LookUp	Region(s)	Species	Density	CC% Leaf	CC% Twig	CC% Branch	CC% Sapwood	CC% Wood	CC% Bark	Regime Description
VicNSW6 P.rad 3	Murray Valley	*Pinus radiata*	440	52	52	51	51	52	53	Very Good Sites - 44% thinning @ 14 years, 31% @ 18, 27% @ 23, CF @ 30

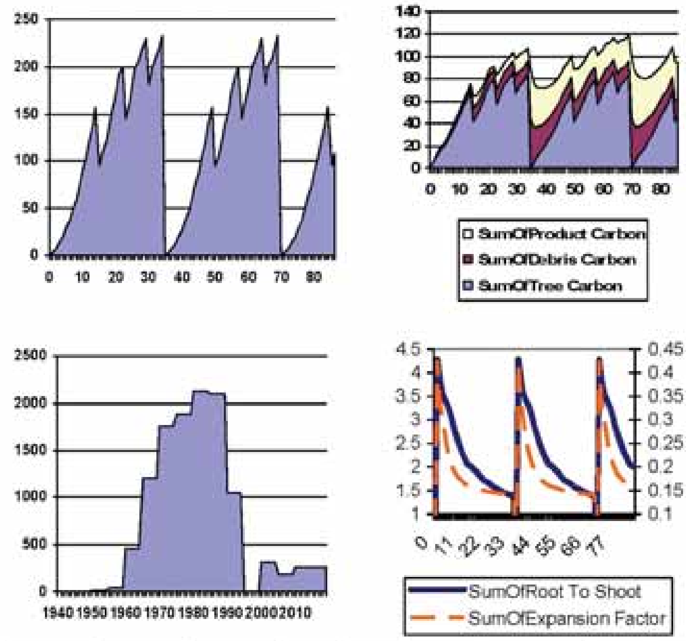




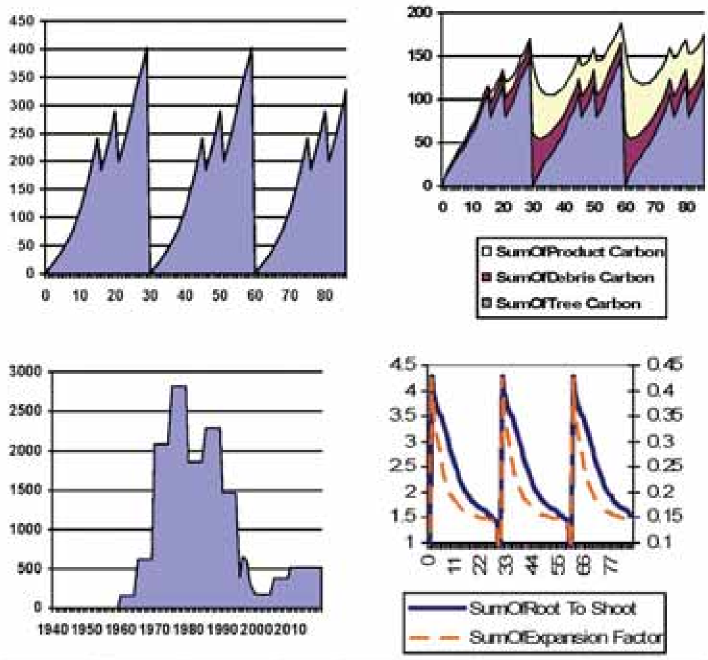




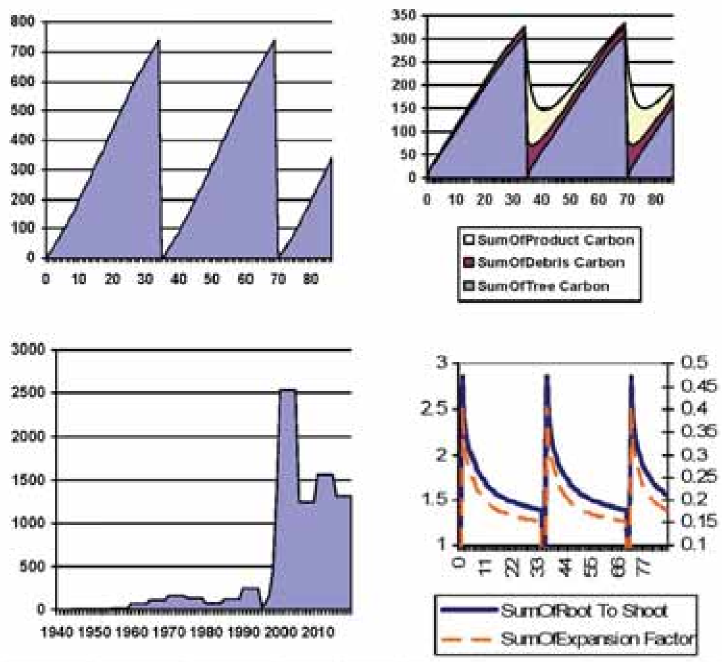
LookUp	Region(s)	Species	Density	CC% Leaf	CC% Twig	CC% Branch	CC% Sapwood	CC% Wood	CC% Bark	Regime Description
VicNSW6 P.rad 2	Murray Valley	*Pinus radiata*	440	52	52	51	51	52	53	Average Sites - 47% thinning @ 14 years, 35% @ 22, CF @ 30



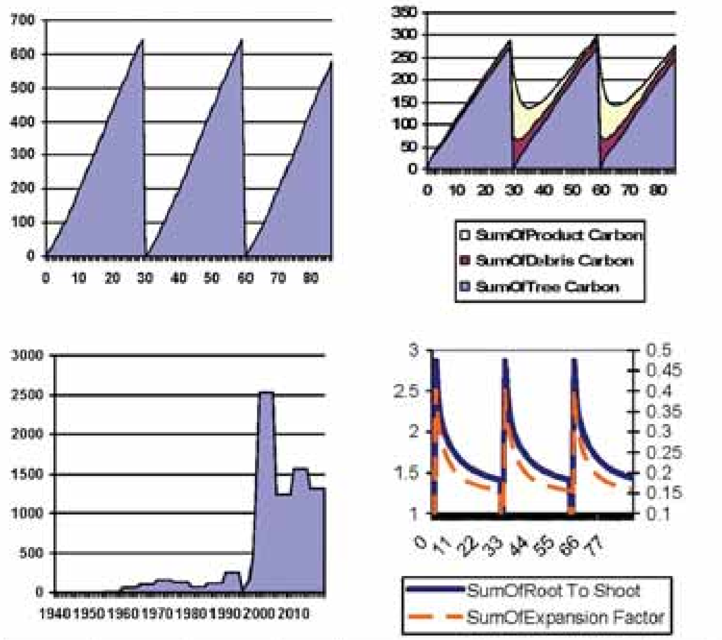
LookUp	Region(s)	Species	Density	CC% Leaf	CC% Twig	CC% Branch	CC% Sapwood	CC% Wood	CC% Bark	Regime Description
VicNSW6 P.rad 2	Murray Valley	*Pinus radiata*	440	52	52	51	51	52	53	Average Sites - 47% thinning @ 14 years, 35% @ 22, CF @ 30



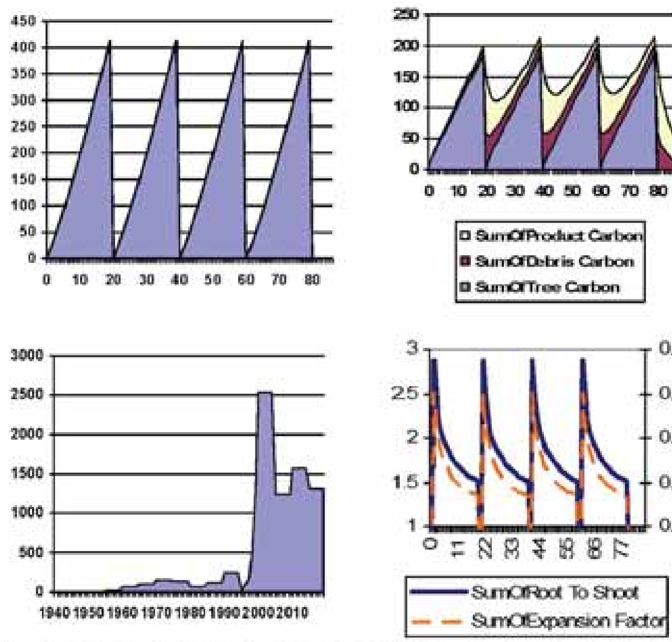
LookUp	Region(s)	Species	Density	CC% Leaf	CC% Twig	CC% Branch	CC% Sapwood	CC% Wood	CC% Bark	Regime Description
Vic7 P.rad 1	Victoria (Central Gippsland)	*Pinus radiata*	440	52	52	51	51	52	53	Average Sites - 33% thinning @ 15 years, 37% @ 20, CF @ 30



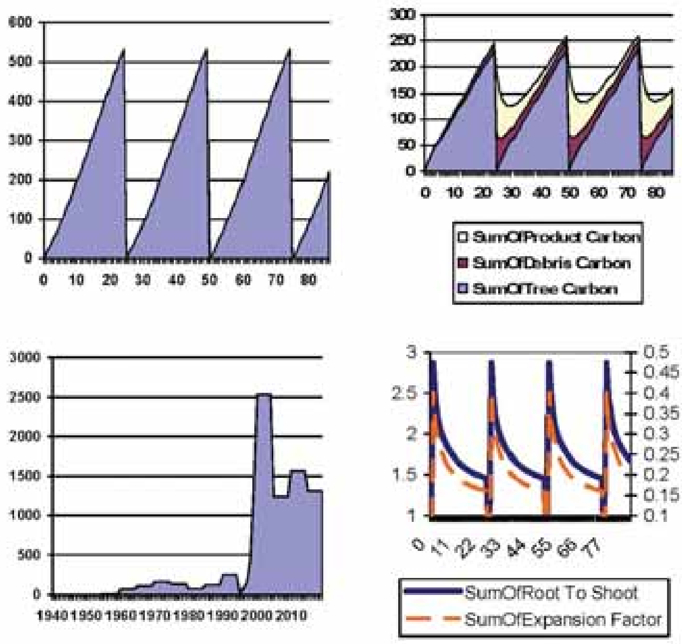
LookUp	Region(s)	Species	Density	CC% Leaf	CC% Twig	CC% Branch	CC% Sapwood	CC% Wood	CC% Bark	Regime Description
Vic7 Euc 4	Victoria (Central Gippsland)	Eucalyptus plantations	550	52	52	47	52	52	49	All Sites - CF @ 35



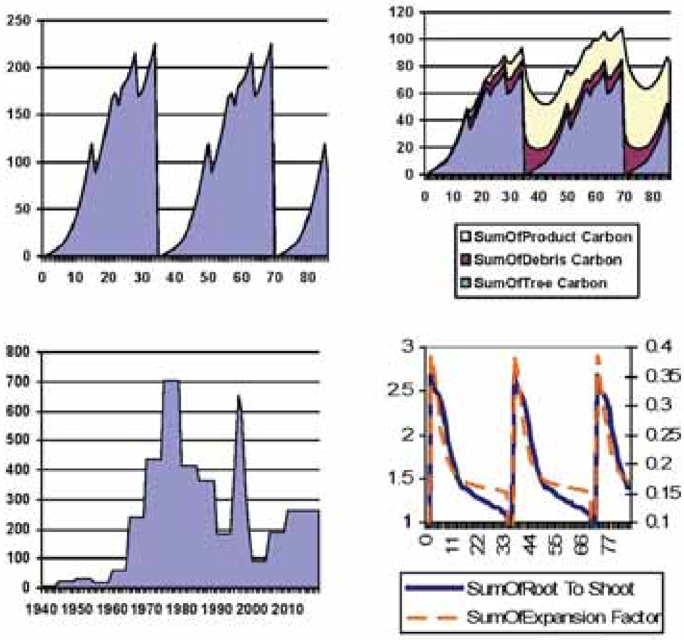
LookUp	Region(s)	Species	Density	CC% Leaf	CC% Twig	CC% Branch	CC% Sapwood	CC% Wood	CC% Bark	Regime Description
Vic7 Euc 3	Victoria (Central Gippsland)	Eucalyptus plantations	550	52	52	47	52	52	49	All Sites - CF @ 30



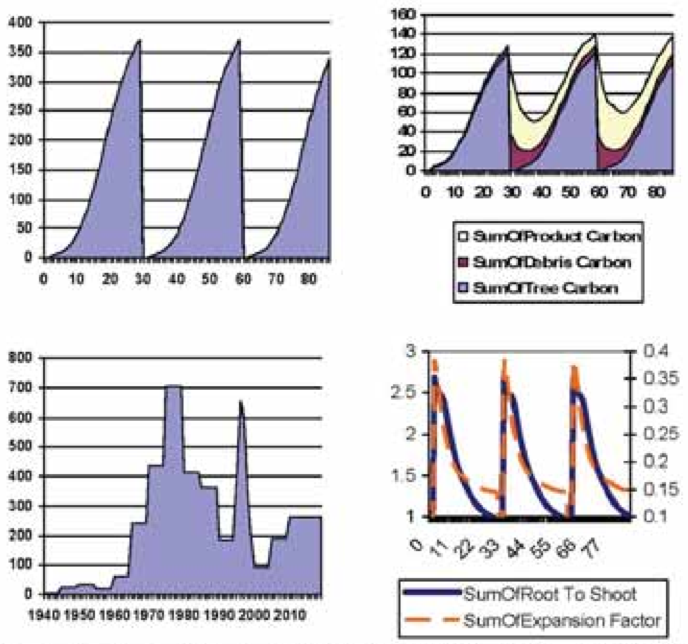
LookUp	Region(s)	Species	Density	CC% Leaf	CC% Twig	CC% Branch	CC% Sapwood	CC% Wood	CC% Bark	Regime Description
Vic7 Euc 2	Victoria (Central Gippsland)	Eucalyptus plantations	550	52	52	47	52	52	49	All Sites - CF @ 20



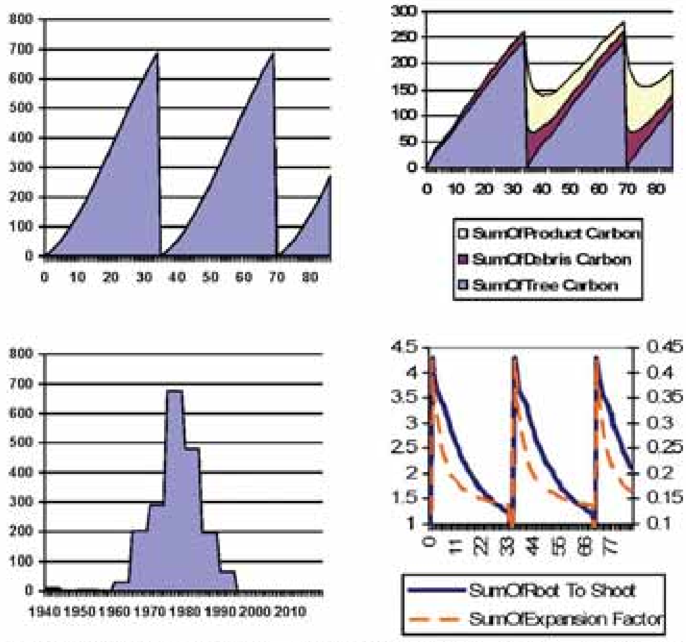
LookUp	Region(s)	Species	Density	CC% Leaf	CC% Twig	CC% Branch	CC% Sapwood	CC% Wood	CC% Bark	Regime Description
Vic7 Euc 1	Victoria (Central Gippsland)	Eucalyptus plantations	550	52	52	47	52	52	49	All Sites - CF @ 25



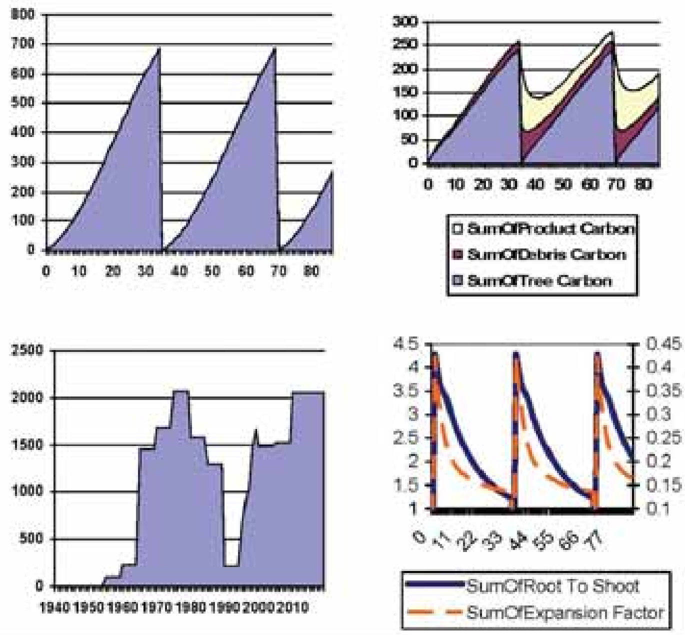
LookUp	Region(s)	Species	Density	CC% Leaf	CC% Twig	CC% Branch	CC% Sapwood	CC% Wood	CC% Bark	Regime Description
Vic5 P.rad 2	Victoria (Central)	*Pinus radiata*	440	52	52	51	51	52	53	Average Sites - CF @ 30



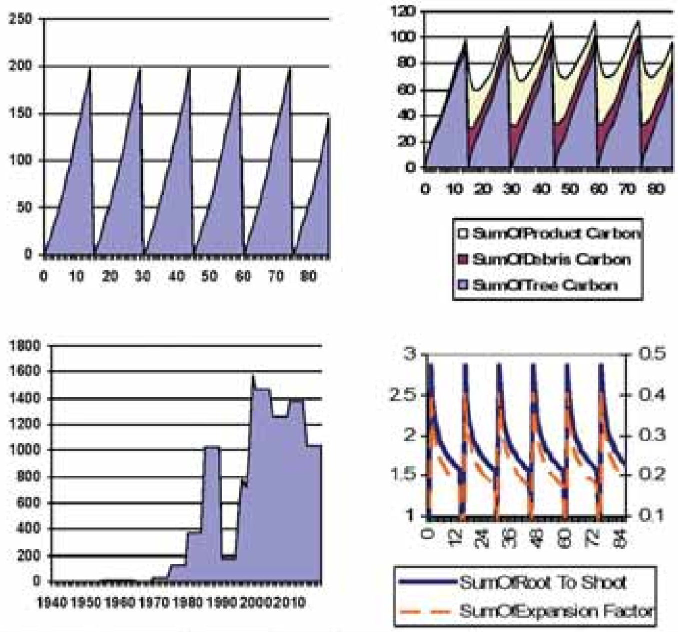
LookUp	Region(s)	Species	Density	CC% Leaf	CC% Twig	CC% Branch	CC% Sapwood	CC% Wood	CC% Bark	Regime Description
Vic5 P.rad 1	Victoria (Central)	*Pinus radiata*	440	52	52	51	51	52	53	Average Sites - 34% thinning @ 15 years, 18% @ 22, 24% @ 28, CF @ 35



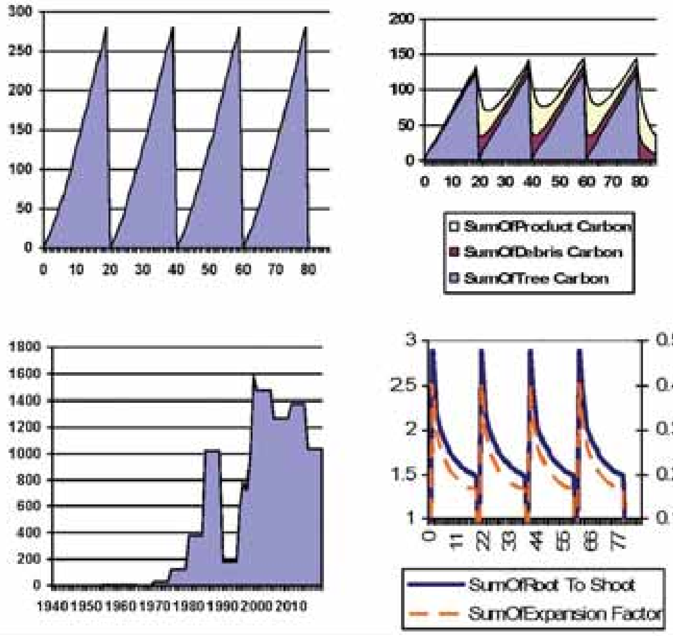
LookUp	Region(s)	Species	Density	CC% Leaf	CC% Twig	CC% Branch	CC% Sapwood	CC% Wood	CC% Bark	Regime Description
Tas2 Pinus 1	Tasmania	Pinus (other than radiata)	440	52	52	51	51	52	53	All Sites - CF @ 35



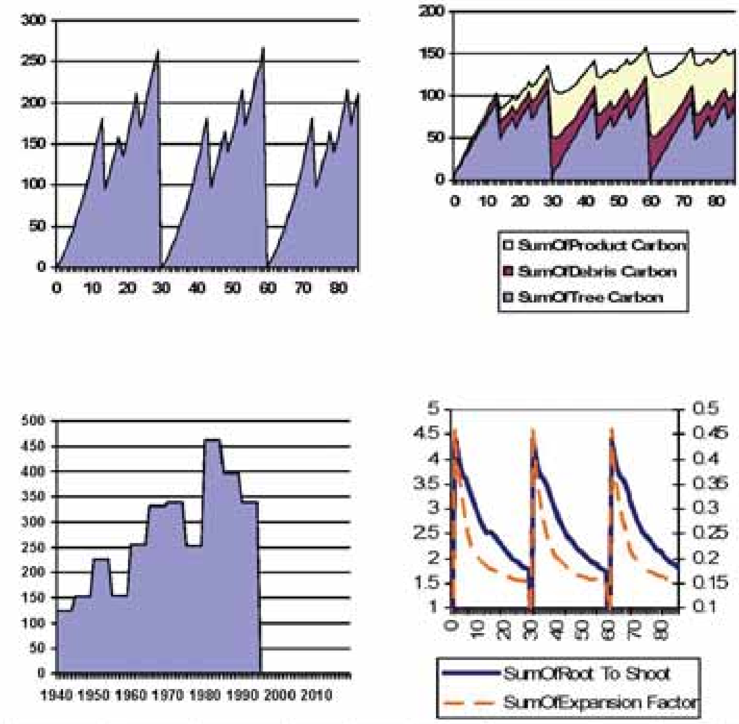
LookUp	Region(s)	Species	Density	CC% Leaf	CC% Twig	CC% Branch	CC% Sapwood	CC% Wood	CC% Bark	Regime Description
Tas2 P.rad 1	Tasmania	*Pinus radiata*	440	52	52	51	51	52	53	Average Sites - CF @ 35



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



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



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

Attachment 7.B2: Quality Assurance

CSIRO

Forestry and Forest Products

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30 November 2001

Mr Ian Carruthers
Senior Executive Manager
Greenhouse Policy Group
Australian Greenhouse Office
GPO Box 621
CANBERRA ACT 2601

Dear Ian

National Article 3.3 Model

I am pleased to be able to provide the following report of the review of the National Carbon Accounting System National Article 3.3 Model performed by a team of four scientists from CSIRO Forestry and Forest Products. The CSIRO team have not been directly involved in development of the CamFor model or its calibration for this particular application. However, CSIRO are very aware of the work that has supported it.

Based on some fundamental presumptions (such as the area statements and growth and yield estimates) the CSIRO team undertook a quality control/assurance review of the modelling framework, assumptions and results. During the review, future refinements of the models were agreed with the NCAS developers.

Findings:

1. Areas and Forest Types

The modelling was based upon some prescribed inputs that were not the subject of quality assurance. These were provided by the BRS and included:

1) Area statements and plantation expansion scenarios
2) Forest types, modified from the NPI
3) Average growth and yield forecasts for each of those forest types

The assignment of areas to forest types, and the entry of growth and yield data to the model, appears to be correct.

2. *Model Framework*

The CAMFor/CAMForEstate models are appropriate for this task. The alternative of using a processes-based modelling approach is considered premature, due to inadequate validation at the national scale. The capability for risk analysis, which is part of the model, is an important tool for analysing uncertainty.

3. *Density, Carbon Contents and Allocations*

Data for a range of tree characteristics have been drawn from a range of published sources and transferred to the models. Wood density is drawn from the NCAS Technical Report No. 18, Carbon Contents from NCAS Technical Reports 7 and 22, and expansion factors and root:shoot ratios from NCAS Technical Reports 5a, 5b and 17. The reports summarise the extent of readily available knowledge. This information has been summarised and correctly incorporated into CAMFor.

4. *Turnover Rates*

In this model application, rates of change were specified for :

(i) Turnover of tree components, and (ii) decomposition of wood products.

The turnover rates of tree components applied in the model provide realistic results. They should be revised to ensure more consistent model performance, but this is unlikely to have a major impact on forecasts of C sequestration.

The wood product decomposition rates are those derived from the NCAS Technical Reports 8 and 24, and whilst representing the state-of-knowledge in this area, are very uncertain. Getting better estimates is very important to improving future predictions.

5. *Model Results*

Model predictions are consistent with site level changes in carbon pools for the range of forest types examined.

6. *Transparency*

The model and data underpinning its calibration have been published in a range of NCAS reports, and peer-reviewed literature. Thus the assumptions can be readily reviewed, and feedback at several levels has been used to refine the model.

7. *Future Developments*

While the National Article 3.3 model represents good practice there are a range of areas where additional development would be beneficial.

1) Area Statements – a desirable objective would be to derive a plantation map from the NCAS satellite data. This will provide a more robust and spatial estimation of Kyoto-compliant forests. Projected rates of plantation establishment are the greatest source of uncertainty in estimating future carbon sequestration.

2) Growth and Yield –growth and yield curves should be progressively updated based on research and industry data so as to account for change in the plantation land base and management methods.

3) Forest Litter and Soils – while forests soils tend to stabilise around small net change in carbon stock in the medium to long term, the short term changes combined with highly skewed age class distributions have the potential to impact on the national account over the first Commitment period. Continued development of the NCAS capacity to operationalise a spatial soil carbon model should be pursued.

4) Data – the information used for model calibration, such as partitioning and turnover are the best available, but requires improvement. Further collection and synthesis of such data are required.

Yours sincerely

John Raison

John Raison
Chief Research Scientist

[1] Land Cover Change refers to a change in forested to non-forested (or vice-versa) vegetation cover.

[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.