Appendices
Carbon stocks and flows in native forests and harvested wood products in SE Australia
PNC285-1112

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Appendix 1. Emission factors for timber extracted from South East Asian tropical forests - supporting evidence in the determination of an emissions factor.

There are serious concerns over the rate of deforestation, C emissions and loss of biodiversity in Southeast Asia (SEA), where tropical forests comprise 60% of the forested area (FAO 2001). While in 1990 SEA had an estimated 268 million hectares (Mha) of forest cover, by 2010 this had dropped to 236 Mha (Stibig *et al* 2014), with an estimated net annual deforestation rate (2000-2010) ranging from 1.0- 1.45 Mha (Stibig *et al* 2014, FAO 2010). The Food and Agricultural Organisation (FAO) estimated SEA industrial roundwood production for 2013 to be 112 Mm^3 or approximately 6.5% of global production, with Indonesia alone producing approximately 3.5% of global pulp and paper production (FAOSTAT 2015). The value of wood product exports from Indonesia in 2013 was approximately US $4.2 billion (MOF 2014). SEA forests are an important economic and environmental resource for the local communities, the regions and the world; therefore understanding the drivers of deforestation and degradation is imperative in ensuring their survival.

Determining the C emissions caused by a particular industry is a challenging and complex task. Historically, estimations of land use change and deforestation have relied heavily on information provided by individual countries, which can be unreliable and problematic to use as explained by Wicke *et al* (2011) and FWI/GFW (2002). Estimations have also been made based on bookkeeping methods, which can use broad assumptions and generalised factors in their calculations (Harris *et al* 2012). The advent of satellite imagery and remote sensing data has improved the broad scale estimation of deforestation and forest degradation. Stibig *et al* (2014) estimated that 32 Mha of forest cover was lost from 1990-2010 in SEA (including Papua New Guinea (PNG) and the Solomon Islands), with 61% of this loss occurring in Indonesia alone. Margono *et al* (2014) reported that 15.79 Mha of forest cover was lost in Indonesia over 2000-2012. Miettinen *et al* (2011) reported a combined loss of 11 Mha for Indonesia and Malaysia for 2000-2010, whereas Abood *et al* (2014) reported a loss of 14.7 Mha for the same period for Indonesia alone. Thus while satellite imagery overcomes some of the shortcomings of other methods, it is not without its own limitations as inconsistencies in the definitions used when stratifying remotely sensed data and the use of different data sets can create differences in reported figures and make comparative analysis difficult.

Attempts have been made to link land use change and even quantitatively apportion it to major industries such as palm oil, pulp and timber. To date much of the industry specific research has focused on the palm oil industry. Carlson *et al* (2012) calculated net emissions of 0.4 Gt C from land converted to oil palm plantations in Kalimantan from 1990-2010, with peatland conversion accounting for 26% of the total. Wicke *et al* (2011) attempted to quantify land use change in Indonesia and Malaysia from 1975-2005, and in particular the role that palm oil has played. They estimated that forest cover decreased by 39 Mha from 1975 – 2005, while agricultural land increased by 10 Mha over this period, with palm oil accounting for approximately half of this expansion. Margono *et al* (2012) reported that 7.54 Mha of primary forest was lost in Sumatra from 1990-2010, driven by the establishment of palm oil and pulp plantations, with an additional 2.31 Mha degraded. Abood *et al* (2014) apportioned forest loss to multiple industries within Indonesia to the extent that it occurs within industrial concessions for the period 2000-2010 and found that deforestation within concessions accounted for 44.7% of total forest loss, with fibre plantation concessions accounting for

12.8%, logging concessions 12.5% and palm oil 11%, with the balance coming from mining (2.1%) and mixed concessions (6.3%).

There are however difficulties in directly attributing forest loss and degradation to a specific industry. Estimates from Abood *et al* (2014) are limited to the confines of concessions boundaries and therefore do not account for illegal forest loss outside of the concessions. Delays in plantation establishment can result in underestimation of an industries contribution (Abood *et al* 2014, Lawson *et al* 2014, Wicke *et al* 2011). Furthermore, the use of fire to clear lands often spread beyond the intended area, making industry apportioning difficult (Lawson *et al* 2014). This is further complicated by the common practice of acquiring plantation licences as a means to access timber with no intention of fulfilling the licence requirements of plantation establishment (Lawson *et al* 2014 & 2010, Obidzinski *et al* 2012, Wicke *et al* 2011, Persson *et al* 2014a). Lawson *et al* (2014) estimate that 65% of Malaysian and 75% of Indonesian tropical timber comes from lands that are converted to plantations or commercial agriculture. This raises perhaps the most challenging aspect in apportioning forest loss and emissions to a single industry - in most instances there is not a single driver of forest loss but more often there are multiple drivers. Margono *et al* (2014) found that 98% of the primary forest lost in Indonesia during 2000-2012 was in a degraded state prior to clearing typically having been logged. Degraded timber concessions are vulnerable to reclassification that allows legal deforestation and conversion to a plantation (FWI/GFW 2002). Wicke *et al* (2011) identified the "inter-linkages that exist between causes" as an impediment to definitively identifying the drivers and causes of forest cover loss. Elias (2011) discussed the inter-linkages and how the drivers for deforestation can become blurred when the income derived from the timber extracted through land clearance is necessary to finance the establishment of plantations. Agus *et al* (2013) surmised that "In almost all cases, all forms of agriculture and plantation forestry follow forest degradation, which presumably is initiated by logging and aggravated by wildfire".

A number of researchers have attempted to attribute land use change and its associated emissions to a commodity. Persson *et al* (2014b) developed a method for calculating a land use change C footprint for agricultural commodities and applied it to beef and soy from Brazil and palm oil from Indonesia. In a working paper for the Centre for Global Development, they applied this method to wood products for Indonesia, Malaysia and PNG and found that they emitted 8.5, 37 and 13 t CO_2 /t C in each product, respectively (Persson *et al* 2014a). Weighting these figures based on production quantity results in an average of 16.5 t CO_2 /t C in product.

Illegal logging adds further complexity when trying to derive an emissions factor for a single commodity. Timber volumes reported by governments in SEA only account for the legal movement of timber and even then in some instances these figures are considered inaccurate. The FAO attempts to account for this in their officially reported figures (FAO 2014), as too does Lawson *et al* (2010) through the use of "expert perceptions surveys" and wood balance estimates, although these alternate methods have their limitations. Lawson *et al* (2010) estimated that 40% of timber produced in Indonesia in 2006 was from illegal sources, a reduction from 80% in 2001 following a major crackdown by the government. The Environmental Investigation Agency (EIA) suggested that the officially reported export figures for Myanmar for the period 2001-2013 were only 23-52% of what was actually exported (EIA 2014). The use of Malaysia as a hub for illegal timber was reported by the EIA in 2007, as illegally sourced timber from Indonesia Papua was reportedly shipped to Sarawak or Sabah where it was stamped as Malaysian in origin (EIA 2008). Lawson *et al* (2010) discusses the role China and Vietnam play in the movement of illegal timber as they are both large processors of SEA timber and the amount of illegally sourced timber going via third party processing countries increased from 15 % in 2000 to 50 % in 2008. Analysing the data of individual SEA countries in isolation of each other can therefore portray a skewed image of the state of timber production within the region, as efforts by individual countries to combat illegal logging often creates a leakage effect (i.e. increased deforestation) into a neighbouring country. This phenomenon is evident in both Thailand and Vietnam where the Governments have placed very tight restrictions on harvest in their natural forests and while this has resulted in a reduction in the deforestation rates of these countries, it is strongly suspected that this has resulted in increased illegal logging in Laos and Cambodia (EIA 2008, Lawson 2010).

Method

Given the complexities and limitations discussed above in deriving an emissions factor for the timber extracted from native forests in SEA, we considered that a proportion of the timber extracted was directly attributable to deforestation and a proportion was responsible for forest degradation with a smaller proportion extracted sustainably. Based on that we created three harvest intensities; (i) low intensity harvest, (ii) high intensity harvest and (iii) deforestation. We calculated a weighted emissions factor for each harvest intensity based on the industrial sawlog volumes for each country for 2013 (see table 3.3 for the included countries). We then weighted the three harvest intensity emissions factors for SEA to derive a single factor.

i) Low intensity harvest

For the purpose of this study we defined low intensity harvest as harvesting which follows best practice. We assumed that as in Australia, best practice means that harvest is done with minimal disturbance and extraction rates and harvest rotations are at a sustainable level. On that basis, emissions from low intensity harvest in SEA would be the same as for Australia which include the fossil fuel emissions from harvesting, transport and processing. Therefore we used the same emission factor calculated for the Australian case studies here (0.06 t C / m^3).

ii) High intensity harvest

We define high intensity harvest as that which uses poor harvesting techniques and timber extraction levels which are unsustainable. Reduced Impact Logging (RIL), which is defined by Putz *et al* (2008a) as “intensively planned and carefully controlled timber harvesting conducted by trained workers in ways that minimize the deleterious impacts of logging,” was developed to improve harvesting techniques in native forests and has been the focus of much research. Much of the literature to date has focused on the economics, implementation, methodology and impact on biodiversity of RIL (Edwards *et al* 2012, Dennis *et al* 2008, Putz *et al* 2008a, Gustafsson *et al* 2007, Enters *et al* 2002, Davis *et al* 2000), with some studies including an assessment of the C implications. Smith *et al* (2002) modelled the difference between reduced impact logging (RIL) and “business as usual” operations combined with a higher harvest frequency (10-15 year interval) over 100 years, and found that “business as usual” resulted in an additional 20-25 % loss of total biomass above RIL. Based on a study in Sabah Malaysia, Pinard *et al* (1996) reported that areas under RIL retained 39 t C / ha (23% of AGB) more than conventionally logged (CL) areas. When compared on a cubic metre of timber extracted basis, the difference is much smaller with CL resulting in emissions of 0.5 t

C / m^3 and RIL 0.4 t C / m^3. Based on the same study area, Putz *et al* (2008b) reported that 30-36 t C / ha (18- 21 % of AGB) could be retained through RIL. Both these studies however do not include the effects of unnecessary forest clearance through poor planning of roads and log landings. Pearson *et al* (2014) reported a harvest emissions factor for Indonesia of 1.5 t C/ m^3 of extracted timber; this included emissions from logging infrastructure and covered a wide range of harvesting practices. Griscom *et al* (2014) compared the C emissions from Forest Stewardship Council (FSC) certified concessions and non-FSC concessions and found that overall there was no significant difference between the two. There were however differences when emissions from individual sources were analysed, particularly for skidding and haul road construction. The study concluded that even though FSC certification may have been granted, there is potentially a time lag and varying degrees to which best practice harvest techniques are implemented. Despite there being no overall difference in the results for FSC and non-FSC concessions, we used data from Griscom *et al* (2014) to derive a high intensity harvest emission factor, as the study was comprehensive in its coverage of harvest-induced emissions and provided recent and comparative data for the two management regimes.

FSC certification provides the forestry industry with a broad framework for "environmentally appropriate, socially beneficial, and economically viable management of the world's forests" (FSC 2014). Griscom *et al* (2014) calculated the C emitted as a result of harvest including damage to non-target trees, residues left on site, skid trails, dump sites and haul roads for both FSC certified concessions and non-FSC concessions in East Kalimantan Indonesia (Table 3.1). Due to the fact that there are fixed emissions (which primarily remain constant regardless of the amount of timber extracted such as haul road and log yard construction) as well as variable emissions (due to residue generation which will increase with increased extraction), economies of scale can produce somewhat perverse outcomes. Greater extraction rates can appear to be less C intensive when comparing volumes of extracted timber; in this instance the average emissions per cubic metre for FSC concessions was 1.6 t C compared to 1.3 t C for non-FSC concessions (Table 1). However on an area basis emissions from FSC concessions were 44 t C /ha compared to 54 t C / ha for non-FSC concessions (Table 1). Comparisons at this level may however mask highly destructive harvest practices. To overcome this, an emissions factor on a volume basis was calculated based on the differences between the two concession types. The difference in emissions of 10 t C / ha was divided by the difference in the harvest intensity of 13 m^3 / ha to give a non-FSC emissions factor that was 0.74 t C / m^3 higher than that of FSC concessions (Table 1). Applying this factor to SEA, we that high intensity harvest resulted in an emission factor of 34 t C / ha (0.9 t C / m^3) (Table 2), which equates to 26 % of above ground C stocks within SEA. This proportion is consistent with findings reported by Putz *et al* 2008b, Smith *et al* 2002 and Pinard *et al* 1996.

Table 1. Harvest intensity and emission factors for both FSC and non-FSC concessions in east Kalimantan, Indonesia (data from Griscom *et al* (2014)).

Concession		emissions assoc. with harvest t C/ha	extracted timber t C / ha	total emissions t / C / ha (inc. C in extracted timber)	harvest vol m^3 / ha	emissions t C / m^3
A	FSC	46	6	52	23	2.0
B	FSC	47	8	55	29	1.6
C	Non-FSC	50	9	59	31	1.6
D	Non-FSC	53	9	62	32	1.7
E	Non-FSC	38	10	48	36	1.1
F	FSC	40	11	51	40	1.0
G	Non-FSC	61	12	73	43	1.4
H	Non-FSC	46	17	63	58	0.8
I	Non-FSC	75	18	93	62	1.2
	Average					
	FSC	44	9	53	31	1.6
	NON-FSC	54	12	66	43	1.3
	Diff	**10**	**4**	**13**	**13**	**0.74**

iii) Deforestation

The deforestation emission factor was derived by dividing above ground C stocks for each country within SEA by a high extraction rate, on the basis that all commercially viable timber would be extracted. The calculated deforestation emissions factors ranged from 1170 kg C / m^3 - 2600 kg C / m^3, with a weighted average for the region of 2238 kg C / m^3 of timber extracted (Table 3.2). The weighting was based on the extracted native timber volumes for each country. There was considerable variation in published above ground C stock figures and extraction rates, with Indonesian ABG C stocks ranging from 124-265 t C / ha (Griscom *et al* 2014, Khun *et al* 2014, Pearson *et al* 2014, Harris *et al* 2012), and extraction rates on the Island of Borneo ranging between 23 - 75 m^3 / ha (Griscom *et al* 2014, Edwards et al 2012, Ruslandi *et al* 2011, Pinard *et al* 1996). Two key reasons for this variability include the fact that some of the SEA countries are comprised of a number of islands with differing forest types and species composition, and that mechanised commercial harvest across SEA has been used since the 1950's (Dykstra 2002), with many areas are undergoing a second rotation harvest (Ruslandi *et al* 2011). These forests however have a much lower C stock (Ruslandi *et al* 2011) than when they were first harvested, due to the short rotation time (average is 30 years); although it has been suggested that 10-15 years is a more common timeframe (Smith *et al* 2002). A more sustainable frequency of 60 years has been suggested (Putz *et al* 2012), with 100-150 years required for full recovery. Caution is required when sourcing C stock figures and timber extraction rates in SE Asia, as often the figure reported is the highest recorded figure for a country, which is not necessarily the average C stock or extraction rate across all forests within that country.

Table 2. Emission factors for SEA for each harvest intensity.

C emission factor t C / m^3	Low intensity harvest	High intensity harvest1	Deforestion1
	0.06	0.90	2.20

Note. [1]Includes fossil fuel emissions associated with harvesting, transport and processing (0.058 tC/m^3)

Net emissions factor

To calculate a net emissions factor, we accounted for the C sequestered either through native forest regeneration or land conversion following deforestation. For low intensity harvest, because it is assumed to be sustainable there is no C lost through harvesting, whereas for high intensity harvest there is a net loss of C through harvesting. For deforestation it was assumed that deforested land was converted to either plantations (palm oil, timber) or agricultural land (annual crops). Using a weighted average of land conversion across Indonesia and Malaysia, a sequestration rate of 27 t C / ha was calculated (Takeuchi 2012, Wicke *et al* 2011, Lasco 2002,). In Table 3 we report the calculated gross and net emission factors for each country and the weighted average for SEA for each harvest intensity. The C density used to convert the harvesting rates from cubic metres to C was 0.34 t C / m^3, as derived from the average of four commercial species (Table 4). An additional 23 kg C / m^3 was added to total emissions to account for international shipping (Ximenes and Brooks 2010).

Table 3. Weighted C emissions and C sequestration for Southeast Asia. Weighting is based on industrial sawlog volumes for 2013, excluding plantation timber (FAO 2015, Jürgensen 2014).

Country	Country weighting %	Gross C emissions [1] (t C / ha)			C sequestered (t C / ha)			Net C emissions (t C / ha)		
		Low	High	Def.	Low	High	Def.	Low	High	Def.
Brunei Darussalam	0.2	0.0	0.1	0.3	0.0	0.0	-0.1	0.0	0.1	0.2
Myanmar	5.9	0.6	2.4	7.3	-0.5	-0.5	-1.6	0.1	1.9	5.7
Indonesia	57.3	7.0	28.3	121.4	-6.0	-6.0	-15.5	1.0	22.3	106.0
Cambodia	0.4	0.0	0.2	0.5	0.0	0.0	-0.1	0.0	0.1	0.4
Lao PDR	1.8	0.2	0.8	3.3	-0.2	-0.2	-0.5	0.0	0.6	2.8
Malaysia	29.7	3.6	14.7	46.8	-3.1	-3.1	-8.0	0.5	11.6	38.7
Philippines	0.1	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.2
Thailand	1.4	0.1	0.6	1.3	-0.1	-0.1	-0.4	0.0	0.5	0.9
Viet Nam	2.9	0.3	1.2	3.4	-0.3	-0.3	-0.8	0.0	0.9	2.6
South East Asia	**100**	**11.9**	**48.3**	**184.5**	**-10.2**	**-10.2**	**-27.0**	**1.7**	**38.1**	**157.5**
South East Asia (tC/m^3)		**0.40**	**1.14**	**2.58**	**0.34**	**0.24**	**0.38**	**0.06**	**0.90**	**2.20**

Note. [1] Gross C emissions are the summation of the fossil fuel emissions associated with harvesting and the C in the extracted timber.

Table 4. Density of key SE Asia species assuming 50% C content (Brown 1997)

Species	Density (t / m^3)	C (t / m^3)
Tectona grandis (Teak)	0.75	0.38
Dipterocarpus sp. (Keruing)	0.60	0.30
Shorea sp. (Meranti)	0.70	0.35
Intsia sp.(Merbau/Kwila)	0.68	0.34
Average	**0.68**	**0.34**

Apportioning harvesting across the three harvest intensities.

Determining the origin of timber in SEA is difficult; for example information on the proportion of sawlog originating from plantations, which is readily available in other regions, is not officially recorded in most of SEA (Jurgensen *et al* 2014). So determining the proportion of sawlogs that have come from deforested lands, or through high intensity harvest practices is challenging. We derived an emission factor under two scenarios (Table 5 & 6), the first based on the general consensus that the majority of deforestation is preceded by degradation through selective harvesting (Margono *et al* 2012 & 2014, Agus *et al* 2013, Lawson et al 2014), and the second is based on Abood *et al's* (2014) apportioning of deforestation to logging concessions.

Scenario 1

Low Intensity Harvest
Calculations based on data from Ruslandi *et al* (2014) suggest that 4.4% of the sawlog harvested in Indonesia comes from FSC certified concessions. Recognising that there are other certification schemes such as Lembaga Ekolabel Indonesia and Pengelolaan Hutan Produksi Lestari (a new mandatory government-run program in Indonesia) and that harvesting at sustainable levels may occur outside of certification schemes, we conservatively apportioned 10% of sawlog production to low intensity harvest.

High Intensity Harvest
We use estimates from Lawson et al (2014) that an average of 70% (75% Indonesia, 65% Malaysia) of wood sourced from natural forests leads to forests being converted to either plantations or commercial agriculture, as the proportion of sawlog production under high intensity harvesting.

Deforestation
The proportion of sawlog production from deforestation is the balance for the three harvest intensities (20%).

Table 5. Calculated emissions under Scenario 1.

	Weighted net emissions t CO_2-e / t C in wood			
	Low intensity harvest	**High intensity harvest**	**Deforestation**	**Total emissions**
Sawlogs & Veneer logs	0.06	6.75	4.75	11.55

Scenario 2

Low Intensity Harvest
Calculations based on data from Ruslandi *et al* (2014) suggest that 4.4% of the sawlog harvested in Indonesia comes from FSC certified concessions. Recognising that there are other certification schemes such as Lembaga Ekolabel Indonesia and Pengelolaan Hutan Produksi Lestari (a new mandatory government run program in Indonesia) and that harvesting at sustainable levels may occur outside of certification schemes we apportioned 10% of sawlog production to low intensity harvest.

Deforestation
Using the conservative figures report by Abood *et al* (2014) of 12.5% of deforestation within Indonesia occurring within logging concessions (1.8 Mha during 2000-2010), the proportion of sawlog production directly attributable to deforestation ranges from 45-59 %. This is based on an extraction rate of 72 m^3 / ha, with the range covering the unknown proportion of plantation grown timber included in the FAO reported sawlog volumes. We conservatively applied 45% of sawlog production to deforestation.

High Intensity Harvest
The proportion of sawlog production from high intensity harvest is the balance for the three harvesting intensities (45%).

Table 6. Calculated emissions under Scenario 2

	Weighted net emissions t CO_2-e / t C in wood			
	Low intensity harvest	**High intensity harvest**	**Deforestation**	**Total emissions**
Sawlogs & Veneer logs	0.06	4.34	10.66	15.06

To date we have only found one other publication that has derived an emissions factor for timber extracted in SEA. Persson *et al's* (2014) approach was different to ours: based on Agus *et al's* (2013) remote sensing analysis, deforestation was proportioned between plantations (palm oil and pulp), other land use and wood products, with all land that was classified as cleared being attributed to the extraction of wood products. Emissions for 2009 were calculated based on an average above and below ground C stock of 238.7 (t C /ha), and apportioning some of the C emitted from plantation establishment to wood products to account for the prior degradation due to selective harvesting. Production quantities for the same year were used to derive an emission factor per unit of product. For the three SEA countries (Indonesia, Malaysia and PNG) included in their study they estimated that they emitted 8.5, 37 and 13 t CO_2 / t C in product respectively. Weighting these figures based on the production volumes for each country and excluding below ground biomass results in an average of 15 t CO_2 / t C in wood product, which is virtually the same figure as we derived under scenario 2.

There are limitations in all these approaches, most of which have already been discussed earlier in this appendix. As we have not included emissions from peatlands in our factors, which is in the range of 23 t C / ha/ yr for draining and 200 tC / ha for burning (Carlson *et al* 2013), we have used the higher of the two factors (15.06 t CO_2 / t C) in our calculations.

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Appendix 2. Preservative-treated wood

Different hazard levels use different preservatives, penetration patterns and retention levels (The Australian Timber Database 2015). There are four main types of preservatives used:

- Water borne preservatives – using water as the solvent; examples include Copper Chrome Arsenate (CCA), Alkaline Copper Quaternary (ACQ), and Copper Azole applied under pressure
- Light Organic Solvent borne preservatives (LOSP) – using a light organic solvent such as white spirit; examples include Tributyl tin naphthenate (TBTN), Tributyl tin oxide (TBTO), Copper naphthenate (CuN), and Propiconazole + Tebuconazole applied under pressure
- Envelope treatments – Treatments that penetrate to only a small extent ; examples include Synthetic pyrethroids dissolved in water or oil such as, Bifenthrin, Permethrin, and Imidacloprid that are either sprayed onto timber or applied by dipping
- Oil borne preservatives – using oil as the carrier; main example is Pigment Emulsified Creosote (PEC) applied under pressure.

There are six main levels of treatment and a number of sub-levels (Table 1). These are called hazard levels and relate to the hazard to which the timber is going to be exposed.

Table 1. Levels of Treatment - Hazard Levels

Hazard Level	Exposure	Specific service conditions	Biological hazard	Typical uses
H1	Inside, above ground	Completely protected from the weather and well ventilated and protected from termites	Lyctid Borer	Framing, flooring, furniture, interior joinery
H2	Inside, above ground	Protected from wetting, nil leaching	Borers and termites	Framing, flooring, etc., used in dry situations
H2S	Inside, above ground	Protected from wetting, Nil leaching	Borers and termites	LVL/Plywood (glue-line treatment) used in dry situations south of the Tropic of Capricorn only
H3A	Outside, above ground	Products predominantly in vertical exposed situations and intended to have the supplementary paint coat system that is regularly maintained	Moderate decay, borers and termites	Fascia, bargeboards, exterior cladding, window joinery, door joinery and non-laminated verandah posts
H4	Outside, in-ground contact	Subject to severe wetting and leaching	Severe decay, borers and termites	Fence posts, greenhouses, pergola posts (in-ground) and landscaping timbers
H5	Outside, in-ground contact, contact with or in fresh water	Subject to extreme wetting and leaching and/or where the critical use requires a higher degree of protection	Very severe decay, borers and termites	Retaining walls, piling, house stumps, building poles, cooling tower fill
H6	Marine waters	Subject to prolonged immersion in sea water	Marine wood borers and decay	Boat hulls, marine piles, jetty cross bracing

Minimum Preservative Retention in the Penetration Zone

The minimum preservative retention in the penetration zone represents the minimum amount of chemicals required to achieve the desired protection (Standards Australia 2012). Below (Table 2, 3 & 4) we include the retention values relevant for the HWP types included in our study:

Table 2. Framing - H2 & H2F – Softwood

H2 Hazard class	H2F Hazard Class (Envelope treatment)
• CCA (0.32%) • ACQ (0.35%) • Copper Azole (0.229%) • Boron (0.35%) • Permethrin (0.02%) • Bifenthrin (0.0047%)	• Permethrin (0.02%) • Bifenthrin (0.02%) • Imidacloprid (0.0078%)

Table 3. Decking / Cladding / Fencing – H3 – Softwood

H3 Hazard class
• CCA (0.38%) • ACQ (0.35%) • Copper Azole (0.229%) • LOSP – TBTN (0.08%) • LOSP – TBTO (0.16%) • LOSP – CuN (0.1%) • LOSP – Propiconazole + Tebuconazole (0.06%)

Table 4. Poles – H5 – Softwood

H5 Hazard class
• CCA (1.2%) • Creosote (13.0%) • Copper Azole (0.229%)

For round hardwood timber the standard penetration is a minimum 20 mm from the surface being the sapwood layer (Standards Australia 2012). In our calculations we added a loading factor (2x) to allow for some heartwood penetration (Martin Horwood, pers. comm.).

Timber Density

The assumed air-dry density for treated pine (including framing H2 & H2F, decking/cladding H3 and fencing H3 was 500 kg / m^3 (Bootle 1983). For hardwood poles (H5), a green density of 1136 kg / m^3 (as determined from this study) was used.

Emission footprint

Where possible, published figures on the emission intensity associated with the total active elements (TAE) used in the various preservative formulations was used (expressed as kg CO_2-e / kg TAE). For CCA, Boron and LOSP treatments the following factors were used (McCallum 2010).

- CCA = 4.71 kg CO2-e / kg TAE
- Boron = 4.54 kg CO2-e / kg TAE
- LOSP = 90.37 kg CO2-e / kg TAE

For ACQ, factors provided by Bolin and Smith (2010) were used. These include life cycle emissions associated with lumber production, treating, use, and disposal stages for US South-eastern species used for decking.

An emission factor for the use of creosote was derived from a life cycle assessment of creosote-treated wooden railroad crossties in the US (Bolin and Smith 2013). In this study information was provided on the fossil CO_2 emissions associated with the use of creosote (2.2 kg CO_2-e / kg of creosote used). It should be noted that only pigment emulsified creosote is allowed for use in Australia.

As emission factors for the H2F envelope preservatives (Permethrin, Bifenthrin, and Imidacloprid) were not found in the literature, the mean emission factor for CCA, ACQ and Boron was used.

References

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McCallum, D. (2010). Greenhouse gas emission factors for common timber treatment chemicals in New Zealand - copper chrome arsenate (CCA), boron and light organic solvent process (LOSP). Eco Balance Ltd, accessed 2 December 2014, http://maxa.maf.govt.nz/sff/about-projects/search/C09-034/ghg-chemicals.pdf

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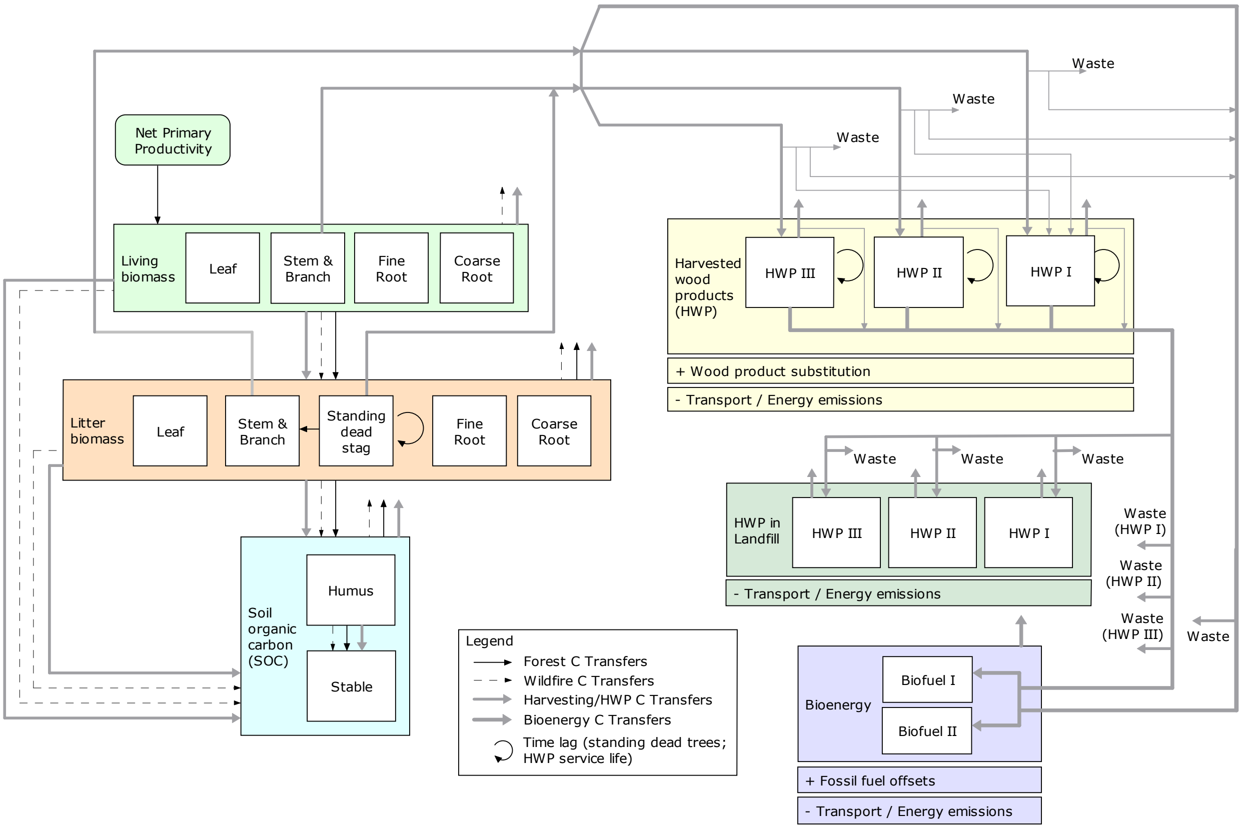
Appendix 3. ForestHWP Model description

Overview

A schematic of the model is shown in Figure 1.

Figure 1. Overview of the ForestHWP model.



Overall there are 19 state variables that represent the pools of C in the forest and HWP sub-systems. For the forest sub-system there are four living biomass pools (stem and branch - referred to hereafter simply as stem, leaf, fine root and coarse root); Five litter pools (leaf, stem, standing dead stag, fine root, coarse root) and two soil pools (humus and stable). For the HWP sub-system there are three in-service harvested wood products (designated I, II and III, and that can be calibrated to represent e.g. fast, medium and slow turnover product pools), three landfill pools corresponding to each of the HWP's and two bioenergy pools (I and II, that can be calibrated to represent e.g. residential and commercial bioenergy production). Because biomass for bioenergy usually has a short life before it is combusted, the size of these pool is often negligible, although the rate of consumption of wood for bioenergy could be high.

The dynamics of each state variable take the form:

$$\frac{dC_i}{dt} = \sum Gains - \sum Losses$$

Where C_i is the C stock of pool *i* (living biomass, litter, soil, HWP, landfill or bioenergy). Gains and losses for each pool are separated into continuous and event-driven or episodic. In ForestHWP episodic gains and lossess occur due to harvesting events or to natural disturbance (fire). Continuous gains and losses include growth, litterfall and decomposition, and are modelled as simple first-order exponential decay processes. A full description of the model equations is provided in the sections below.

1. Living biomass

1.1 LIVING BIOMASS FLUX COMPONENTS – CONTINUOUS GAINS

Gains to the living biomass pools occur via photosynthesis (via *NPP* – Net Primary Productivity), with the fraction of NPP allocated to the four living C pools defined by:

$$NPP\_to\_Leaf = a_t^L \cdot NPP_t$$

$$NPP\_to\_Stem = a_t^S \cdot NPP_t$$

$$NPP\_to\_FineRoot = a_t^{FR} \cdot NPP_t$$

$$NPP\_to\_CoarseRoot = a_t^{CR} \cdot NPP_t$$

Where allocations to leaf (a_t^L), stems and branches (a_t^S) and fine and coarse root (a_t^{FR} and a_t^{CR}), and Net primary Productivity (NPP_t, tC ha^{-1} yr^{-1}), are all functions of time to allow growth and allocation of photosynthate to respond dynamically to disturbance (fire, harvesting).

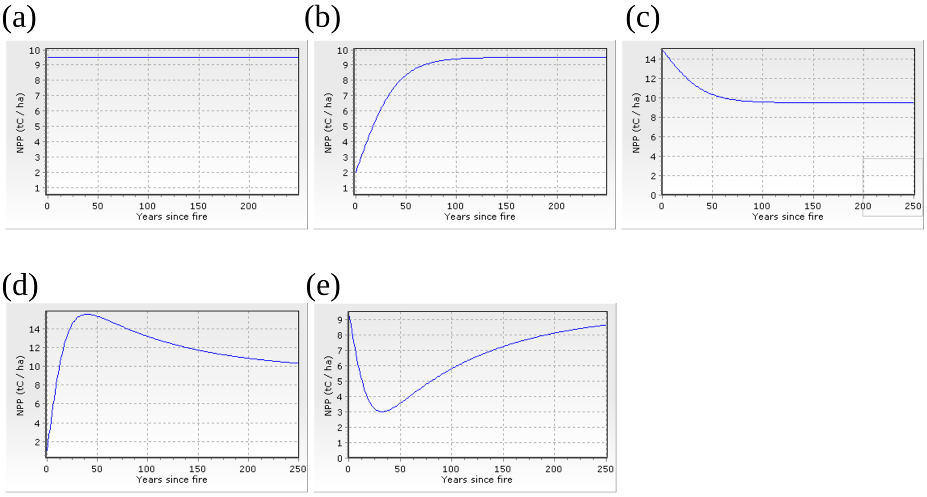
If a^i_t is the current allocation fraction for plant component *i* at time *t* , and $a^{i,M}$ is the allocation fraction for component *i* at forest maturity, then:

$$a_{t+1}^i = \frac{a_t^i \times R}{\left(1 + (R-1) \times a_t^i / a^{i,M}\right)}$$

Where the allocation fractions recover to mature forest values via a Sigmoidal function, with the rate of recovery governed by *R* (1.05 by default).

The dynamics for NPP are more complicated, with a functional response that can capture a wide range of behaviour, from no response following disturbance (Fig. 2a), through to monotonic recovery (Fig 2b, 2c) and the classic peaked response followed by gradual recovery to pre-disturbance levels (Fig 2d, 2e).

Figure 2. Range of post-disturbance NPP responses able to be simulated by the NPP-response function



The NPP function requires six parameters, with the ability to implement separate responses for i = fire, harvesting:

NPP_Mature The NPP of the forest at maturity (tC ha^{-1} yr^{-1}).

$NPP\_Peak\_Max_i$ Parameter controlling the post-disturbance NPP peak, for a maximum impact disturbance event.

$NPP\_Post\_Max_i$ The NPP immediately post disturbance (tC ha^{-1} yr^{-1}), for a maximum impact disturbance event.

$NPP\_InitialRate_i$ Parameter controlling initial NPP increase.

$NPP\_RecoveryRate_i$ Parameter controlling NPP decline as the forest matures.

t_D Time since disturbance (yrs).

For any given event, the magnitude of the response is linked to the magnitude of the perturbation to living biomass; i.e. minor disturbance to living C pools leads to a minor disruption to NPP, and *vice versa*. For any given disturbance event the actual peak- and post-NPP response parameters are given by:

$$NPP\_Peak_i = NPP\_Peak\_Max_i \times \left(C_{StemSS} - C_{Stem,t}\right) / C_{StemSS}$$
$$NPP\_Post_i = NPP\_Post\_Max_i \times \left(\left(NPP\_Mature - NPP\_Post\_Max_i\right) \times \left(C_{StemSS} - C_{Stem,t}\right) / C_{StemSS}\right)$$

Where $C_{Stem,t}$ is the current living stem biomass, and C_{StemSS} is the stem biomass at steady state, defined by:

$$C_{StemSS} = \frac{a^{S,M} \times NPP\_Mature}{\frac{1}{L_{Stem}} + SM}$$

, where SM is the rate of stem mortality, defined in Section 1.1 below.

The full NPP function is given by

$$NPP_t = (NPP\_Mature + NPP\_Peak_i - NPP\_Post_i) \times \left(\frac{2}{1 + e^{\left(\frac{-t_D}{NPP\_InitialRate_i}\right)}} - 1 \right) +$$

$$NPP\_Peak_i \times \left(e^{\left(\frac{-t_D}{NPP\_RecoveryRate_i}\right)} - 1 \right) + NPP\_Post_i$$

A flat-line response is achieved by setting *NPP_Peak* = 0 and *NPP_Post* = *NPP_mature* (Fig A2a). Monotonic recovery is specified by *NPP_Peak* = 0 and *NPP_Post* ≠ *NPP_mature* (Figs. A2b, A2c). A response of the form shown in Figs. A2d and A2e is obtained by setting *NPP_Peak* > 0 and *NPP_Peak* < 0, respectively.

1.2 LIVING BIOMASS FLUX COMPONENTS – CONTINUOUS LOSSES

The continuous losses from the living biomass pools are due to litterfall and other natural mortality

$$Leaf\_to\_LeafLit = \frac{C_{Leaf}}{L_{Leaf}}$$

$$Stem\_to\_StemLit = \frac{C_{Stem}}{L_{Stem}}$$

$$FRoot\_to\_FRootLit = \frac{C_{FineRoot}}{L_{FineRoot}}$$

$$CRoot\_to\_CRootLit = \frac{C_{CoarseRoot}}{L_{CoarseRoot}}$$

Where C_i are the current C stocks of the living pools (tC ha^{-1}), and L_i are the longevities of C in those pools (yr).
Standing dead stags are created continuously through natural mortality at an annual rate (in the range 0-1) given by parameter *SM*

$$Leaf\_to\_LeafLit\_Mortality = C_{Leaf} \times SM$$
$$FRoot\_to\_FRootLit\_Mortality = C_{FRoot} \times SM$$
$$Stem\_to\_StemStag\_Mortality = C_{Stem} \times SM$$
$$CRoot\_to\_CRootLit\_Mortality = C_{CRoot} \times SM$$

For the stem stag pool (i.e. above-ground parts of standing dead trees) the year of origin of each cohort is retained, to accommodate the lagged decay characteristics of this pool.
The equations for the change in the living C pools over continuous time are then given by:

$$\frac{dC_{Leaf}}{dt} = NPP\_to\_Leaf - Leaf\_to\_leafLit - Leaf\_to\_LeafLit\_Mortality$$

$$\frac{dC_{Stem}}{dt} = NPP\_to\_Stem - Stem\_to\_StemLit - Stem\_to\_StemStag\_Mortality$$

$$\frac{dC_{FineRoot}}{dt} = NPP\_to\_FRoot - FRoot\_to\_FRootLit - FRoot\_to\_FRoot\_Mortality$$

$$\frac{dC_{CoarseRoot}}{dt} = NPP\_to\_CRoot - CRoot\_to\_CRootLit - CRoot\_to\_CRootLit\_Mortality$$

1.3 LIVING BIOMASS FLUX COMPONENTS – EPISODIC LOSSES

Episodic events in the model include fire and harvesting. Fire and harvesting events occur at the end of the annual integration period, defined by the continuous equations above. The mean disturbance frequency through time and its CV for both harvesting and fire are specified independently. A CV of 0.0 imposes regular gaps between disturbance events. The time of the initial disturbance even is chosen at random in the period [0, $Freq_i$], where i = fire or harvesting. The next disturbance event year is calculated as:

$$Year\_of\_next\_disturbance_i = round\left(\left(NormRan \times \frac{CV_i}{100}\right) + Freq_i\right)$$

Where *NormRan* is a normal random deviate with mean 0 and s.d 1.0.

1.3.1 FIRE IMPACTS ON LIVING BIOMASS

During a fire event living biomass can be lost to litter (either ground litter, root litter or dead stags), or to the soil pool via the creation of humic material or more stable SOC fractions like char.

The total fractional loss in a fire event for pool i (where i = living leaf, living stem, living fine root or living coarse root) is given by F_i, and the proportion of that total loss that is transferred to the litter, humic or stable soil pools given by $F_{i,LIT}$, $F_{i,HUM}$ and $F_{i,SS}$ respectively. Combustion losses to the atmosphere are given by $F_{i,ATMOS}$. Living stems can also be converted into dead stags given by the proportion $F_{Stem,STAG.}$ For the living leaf and fine root pools $F_{i,LIT}$, $F_{i,HUM}$, $F_{i,SS}$ and $F_{i,ATMOS}$ must sum to 1.0; for the living Stem and coarse root pools $F_{i,LIT}$, $F_{i,HUM}$, $F_{i,SS}$, $F_{i,ATMOS}$ and $F_{i,STAG}$ must sum to 1.0. Given this, for component i = living leaf, stem and fine root:

$$Total\_i\_Lost\_Fire = C_{i,t} \times F_i$$

$$i\_to\_iLit\_Fire = Total\_i\_Lost\_Fire \times F_{i,LIT}$$

$$i\_to\_Humus\_Fire = Total\_i\_Lost\_Fire \times F_{i,HUM}$$

$$i\_to\_StableSoil\_Fire = Total\_i\_Lost\_Fire \times F_{i,SS}$$

$$i\_to\_Atmos\_Fire = Total\_i\_Lost\_Fire \times F_{i,ATMOS}$$

Additional fluxes associated with the conversion of stems/branch and coarse root to standing dead stag are given by the following:

$$Stem\_to\_StemStag\_Fire = Total\_Stem\_Lost\_Fire \times F_{Stem,StemStag}$$

For coarse roots the fluxes are

$$Total\_CRoot\_Lost\_Fire = C_{CRoot,t} \times F_{CRoot}$$
$$CRoot\_to\_CRootLit\_Fire = (Total\_CRoot\_Lost\_Fire \times F_{CRoot,LIT}) + (Total\_CRoot\_Lost\_Fire \times F_{CRoot,STAG})$$
$$CRoot\_to\_Humus\_Fire = Total\_CRoot\_Lost\_Fire \times F_{CRoot,HUM}$$
$$CRoot\_to\_StableSoil\_Fire = Total\_CRoot\_Lost\_Fire \times F_{CRoot,SS}$$
$$CRoot\_to\_Atmos\_Fire = Total\_CRoot\_Lost\_Fire \times F_{CRoot,ATMOS}$$

Living biomass emissions due to fire:

$$Living\_Emissions\_to\_Atmos\_Fire = Leaf\_to\_Atmos\_Fire + Stem\_to\_Atmos\_Fire + FRoot\_to\_Atmos\_Fire + CRoot\_to\_Atmos\_Fire$$

Changes to the living C pools in response to fire are given by:

$$C_{Leaf,t} = C_{Leaf,t} - Total\_leaf\_Lost\_fire$$
$$C_{Stem,t} = C_{Stem,t} - Total\_Stem\_Lost\_Fire$$
$$C_{FRoot,t} = C_{FRoot,t} - Total\_FRoot\_Lost\_Fire$$
$$C_{CRoot,t} = C_{CRoot,t} - Total\_CRoot\_Lost\_Fire$$

In addition to impacts on the C pools, fire can also affect NPP, and the NPP allocation parameters, with recovery dynamics described above. Fire impacts on the allocation parameters are given by:

$$a_t^L = a^L\_Fire$$
$$a_t^S = a^S\_Fire$$
$$a_t^{CR} = a^{CR}\_Fire$$
$$a_t^{FR} = a^{FR}\_Fire$$

Where a^i_Fire is the NPP allocation to living component *i* after fire, and sum to 1.0. The recovery of the allocation fractions post-fire follows the equation given in Section 1.1. Impacts on NPP are effected through the NPP response function, as described in Section 1.1

1.3.2 HARVESTING IMPACTS ON LIVING BIOMASS

During a harvesting event living biomass can be lost to litter, or to the soil pools via the creation of humic or stable material, or to one of four off-site product pools, comprising three Harvested Wood Product pools (HWPI, HWPII and HWPIII), and to one of two Bioenergy pools (BIOI, BIOII). Living biomass can also be directly combusted to the atmosphere due to harvesting operations, such as through the burning of slash. As with the stem stag pool, cohorts of each of the three HWP's harvested products are kept separate, to allow lagged decay (see section 1.3)

The total loss in a harvesting event for pool *i* (where *i* = living leaf, living stem or living fine and coarse root) is given by H_i , and the proportion of total loss that is transferred to the litter, humic or stable SOC pools given by $H_{i,LIT}$, $H_{i,HUM}$, and $H_{i,SS}$. Combustion losses to the atmosphere associated with harvesting operations are given by $H_{i,ATMOS}$. Transfers to the off-site product pools are given by $H_{Stem,HWPI}$, $H_{Stem,HWPII}$, $H_{Stem,HWPIII}$, and $H_{Stem,BIOI}$, $H_{Stem,BIOII}$ (leaves and roots are assumed not to be harvested into products). For the living Leaf and Root pools $H_{i,LIT}$, $H_{i,HUM}$, $H_{i,SS}$ and $H_{i,ATMOS}$ must sum to 1.0; for the living Stem pool $H_{Stem,LIT}$, $H_{Stem,HUM}$, $H_{Stem,SS}$, $H_{Stem,ATMOS,}$ $H_{Stem,HWPI,}$ $H_{Stem,HWPII}$ $H_{Stem,HWPIII}$ and $H_{Stem,BIOI}$, $H_{Stem,BIOII}$ must sum to 1.0. Given this, the following fluxes are defined for each component *i*:

$$Total\_i\_Lost\_Harvest = C_{i,t} \times H_i$$
$$i\_to\_iLit\_Harvest = Total\_i\_Lost\_Harvest \times H_{i,LIT}$$
$$i\_to\_Humus\_Harvest = Total\_i\_Lost\_Harvest \times H_{i,HUM}$$
$$i\_to\_StableSoil\_Harvest = Total\_i\_Lost\_Harvest \times H_{i,SS}$$
$$i\_to\_Atmos\_Harvest = Total\_i\_Lost\_Harvest \times H_{i,ATMOS}$$

Additional fluxes associated with the conversion of stems/branch to the harvested products are given by the following:

$$Stem\_to\_HWPI\_Harvest = Total\_Stem\_Lost\_Harvest \times H_{Stem,HWPI}$$
$$Stem\_to\_HWPII\_Harvest = Total\_Stem\_Lost\_Harvest \times H_{Stem,HWPII}$$
$$Stem\_to\_HWPIII\_Harvest = Total\_Stem\_Lost\_Harvest \times H_{Stem,HWPIII}$$
$$Stem\_to\_BioI\_Harvest = Total\_Stem\_Lost\_Harvest \times H_{Stem,BioI}$$
$$Stem\_to\_BioII\_Harvest = Total\_Stem\_Lost\_Harvest \times H_{Stem,BioII}$$

Living emissions due to harvest:

$$\begin{aligned} Living\_Emissions\_to\_Atmos\_Harvest = {} & Leaf\_to\_Atmos\_Harvest + \\ & Stem\_to\_Atmos\_Harvest + \\ & FRoot\_to\_Atmos\_Harvest + \\ & CRoot\_to\_Atmos\_Harvest \end{aligned}$$

Changes to the living C pools in response to harvest are given by:

$$C_{Leaf,t} = C_{Leaf,t} - Total\_Leaf\_Lost\_Harvest$$
$$C_{Stem,t} = C_{Stem,t} - Total\_Stem\_Lost\_Harvest$$
$$C_{FRoot,t} = C_{FRoot,t} - Total\_FRoot\_Lost\_Harvest$$
$$C_{CRoot,t} = C_{CRoot,t} - Total\_CRoot\_Lost\_Harvest$$

In addition to impacts on the C pools, harvesting can also affect NPP, and the NPP allocation parameters, with recovery dynamics described above. Harvest impacts on the allocation fluxes are given by:

$$a_t^L = a^L\_Harvest$$
$$a_t^S = a^S\_Harvest$$
$$a_t^{CR} = a^{CR}\_Harvest$$
$$a_t^{FR} = a^{FR}\_Harvest$$

Where a^i*_Harvest* is the NPP allocation to living component *i* after harvest, and sum to 1.0. The recovery of the allocation fractions post-harvest follows the equation given in Section 1.1. Impacts on NPP are effected through the NPP response function, as described in Section 1.1
When calculating the NPP and allocation responses, only the most recent disturbance is recognised, be that either fire or harvesting.

2. Litter

2.1 LITTER FLUX COMPONENTS – CONTINUOUS GAINS

Continuous gains to the litter pools were defined in the previous section.
$Leaf\_to\_LeafLit$, $Stem\_to\_StemLit$, $FRoot\_to\_FRootLit$, $CRoot\_to\_CRootLit$,
$Stem\_to\_StemStag\_Mortality$, $CRoot\_to\_CRootLit\_Mortality$,
$Leaf\_to\_LeafLit\_Mortality$, $FRoot\_to\_FRootLit\_Mortality$

2.2 LITTER FLUX COMPONENTS – CONTINUOUS LOSSES

The continuous loss fluxes are given by the following general equation, where L_i is the longevity of litter component *i* (yr), and H_i the fraction of lost litter that is incorporated into the SOC humus pool, and *i* = Leaf litter, stem litter, fine root litter, coarse root litter:

$$Total\_i\_Lost = \frac{C_i}{L_i}$$

$$i\_to\_Humus = Total\_i\_Lost \times H_{LeafLit}$$

$$i\_to\_Atmos = Total\_i\_Lost \times \left(1 - H_{LeafLit}\right)$$

Continuous litter emissions:

$$Litter\_Emissions\_to\_Atmos\_Decomp = LeafLit\_to\_Atmos + StemLit\_to\_Atmos + FRootLit\_to\_Atmos + CRootLit\_to\_Atmos$$

The transfer of standing dead stag stems to the stem litter pool is lagged to provide a period over which stags remain more or less intact, followed by an accelerated rate of loss corresponding to stags falling over and becoming more susceptible to decay. To achieve this, the age of each cohort (1..j) of stags is recorded as it enters the pool. At each timestep a Sigmoidal function is used to transfer stag stems to the stem litter pool.

The two parameters controlling this dynamic are $Stag\_Decay\_Longevity$, which controls the length of the delay of the stags falling over, and $Stag\_Decay\_Rate$, which controls the rate at which stags are incorporated into the stem litter pool. The total flux at a given time is given by the sum of the fluxes over *n* cohorts:

$$StemStag\_to\_StemLit = \sum_{j=1}^{n} \left(C_{StemStag,j,t} - \frac{C_{StemStag,j,i} \times \left(1 + e^{-Stag\_Decay\_Longevity}\right)}{1 + e^{Stag\_Decay\_Rate \times t_j - Stag\_Decay\_Longevity}} \right)$$

Where t_j is the age of the stag in cohort *j*, $C_{StemStag,j,t}$ is the current mass of the stag in cohort *j*, and $C_{StemStag,j,i}$ is the initial stem stag mass at death.

The equations for the change in the litter pools over continuous time are then given by:

$$\frac{dC_{LeafLit}}{dt} = Leaf\_to\_LeafLit + Leaf\_to\_LeafLit\_Mortality - Total\_LeafLit\_Lost$$

$$\frac{dC_{StemLit}}{dt} = Stem\_to\_StemLit + StemStag\_to\_StemLit - Total\_StemLit\_Lost$$

$$\frac{dC_{FRootLit}}{dt} = FRoot\_to\_FRootLit\_FRoot\_to\_FRoot\_Mortality - Total\_FRootLit\_Lost$$

$$\frac{dC_{CRootLit}}{dt} = CRoot\_to\_CRootLit + CRoot\_to\_CRootLit\_Mortality - Total\_CRootLit\_Lost$$

$$\frac{dC_{StemStag}}{dt} = Stem\_to\_StemStag\_Mortality - StemStag\_to\_StemLit$$

2.3 LITTER FLUX COMPONENTS – EPISODIC GAINS AND LOSSES

Impacts of episodic events on litter pools are similar to impacts on the living pools.

2.3.1 FIRE IMPACTS ON LITTER

The total episodic gains to the litter pools due to fire were defined above:

$Leaf\_to\_LeafLit\_Fire$, $Stem\_to\_StemLit\_Fire$, $FRoot\_to\_FRootLit\_Fire$, $CRoot\_to\_CRootLit\_Fire$, $Stem\_to\_StemStag\_Fire$.

During a fire event litter can be lost to the SOC pools (either humus or stable), or to the atmosphere. The total loss in a fire event for litter pool *i* (where *i* = leaf litter,stem litter, fine root litter or coarse root litter) is given by F_i, and the proportion of total loss that is transferred to the humic or stable soil pools given by $F_{i,HUM}$ and $F\_Lit_{i,SS}$ respectively. Combustion losses to the atmosphere are given by $F_{i,ATMOS}$. For all litter pools $F_{i,HUM}$, $F_{i,SS}$ and $F_{i,ATMOS}$ must sum to 1.0.
Losses from the litter C pools in response to fire are given by:

$$Total\_i\_Lost\_Fire = C_i \times F_i$$
$$i\_to\_Humus\_Fire = Total\_iLit\_Lost\_Fire \times F_{i,HUM}$$
$$i\_to\_StableSoil\_Fire = Total\_iLit\_Lost\_Fire \times F_{i,SS}$$
$$i\_to\_Atmos\_Fire = Total\_iLit\_Lost\_Fire \times F_{i,ATMOS}$$

In addition, stem stag mass can be lost to stem litter during fire, or can be combusted

$$Total\_StemStag\_Lost\_Fire = C_{StemStag} \times F_{StemStag}$$
$$StemStag\_to\_StemLit\_Fire = Total\_StemStag\_Lost\_Fire \times F_{StemStag,StemLit}$$
$$StemStag\_to\_Atmos\_Fire = Total\_StemStag\_Lost\_Fire \times F_{StemStag,ATMOS}$$

Litter emissions associated with fire

$$Litter\_Emissions\_to\_Atmos\_Fire = LeafLit\_to\_Atmos\_Fire + StemLit\_to\_Atmos\_Fire + FRootLit\_to\_Atmos\_Fire + CRootLit\_to\_Atmos\_Fire + StemStag\_to\_Atmos\_Fire$$

Changes to the litter pools in response to fire are given by:

$$C_{LeafLit,t} = C_{LeafLit,t} + Leaf\_to\_LeafLit\_Fire - Total\_LeafLit\_Lost\_Fire$$
$$C_{StemLit,t} = C_{StemLit,t} + Stem\_to\_StemLit\_Fire + StemStag\_to\_StemLit\_Fire - Total\_StemLit\_Lost\_Fire$$
$$C_{FRoot,t} = C_{FRoot,t} + FRoot\_to\_FRootLit\_Fire - Total\_FRootLit\_Lost\_Fire$$
$$C_{CRoot,t} = C_{CRoot,t} + CRoot\_to\_CRootLit\_Fire - Total\_CRootLit\_Lost\_Fire$$
$$C_{StemStag,t} = C_{StemStag,t} + Stem\_to\_StemStag\_Fire - Total\_StemStag\_Lost\_Fire$$

2.3.2 HARVESTING IMPACTS ON LITTER

The total episodic gains to the litter pools due to harvesting were defined above:

$Leaf\_to\_LeafLit\_Harvest$, $Stem\_to\_StemLit\_Harvest$, $FRoot\_to\_FRoot\_Harvest$, $CRoot\_to\_CRoot\_Harvest$

During a harvesting event litter can be lost to the SOC pools (either humus or stable), or to the atmosphere. In addition, stem litter can be removed to one of the harvest pools (though in most cases this would be to bioenergy)

The total loss in a harvest event for litter pool *i* (where *i* = leaf litter, stem litter, fine root litter, or coarse root litter) is given by H_i , and the proportion of total loss that is transferred to the humic or stable soil pools given by $H_{i,HUM}$ and $H_{i,SS}$ respectively. Combustion losses to the atmosphere for the leaf litter and root litter pools are given by $H_{i,ATMOS}$.

Given this, the following fluxes are defined for *i* = leaf litter, fine root litter, and coarse root litter:

$$Total\_i\_Lost\_Harvest = C_i \times H_i$$
$$i\_to\_Humus\_Harvest = Total\_iLit\_Lost\_Harvest \times H_{i,HUM}$$
$$i\_to\_StableSoil\_Harvest = Total\_iLit\_Lost\_Harvest \times H_{i,SS}$$
$$i\_to\_Atmos\_Harvest = Total\_iLit\_Lost\_Harvest \times H_{i,ATMOS}$$

Additional fluxes are associated with the conversion of stem/branch litter to the harvested products are given by the following:

$$Total\_StemLit\_Lost\_Harvest = C_{StemLit} \times H_{StemLit}$$
$$StemLit\_to\_Humus\_Harvest = Total\_StemLit\_Lost\_Harvest \times H_{StemLit,HUM}$$
$$StemLit\_to\_StableSoil\_Harvest = Total\_StemLit\_Lost\_Harvest \times H_{StemLit,SS}$$
$$StemLit\_to\_Atmos\_Harvest = Total\_StemLit\_Lost\_Harvest \times H_{StemLit,ATMOS}$$
$$StemLit\_to\_HWPI\_Harvest_t = Total\_StemLit\_Lost\_Harvest \times H_{StemLit,HWPI}$$
$$StemLit\_to\_HWPII\_Harvest_t = Total\_StemLit\_Lost\_Harvest \times H_{StemLit,HWPII}$$
$$StemLit\_to\_HWPIII\_Harvest_t = Total\_StemLit\_Lost\_Harvest \times H_{StemLit,HWPIII}$$
$$StemLit\_to\_BioI\_Harvest_t = Total\_StemLit\_Lost\_Harvest \times H_{StemLit,BioI}$$
$$StemLit\_to\_BioII\_Harvest_t = Total\_StemLit\_Lost\_Harvest \times H_{StemLit,BioII}$$

In addition, stem stag mass can be lost to stem litter and the atmosphere during harvest

$$Total\_StemStag\_Lost\_Harvest = C_{StemStag} \times H_{StemStag}$$
$$StemStag\_to\_StemLit\_Harvest = Total\_StemStag\_Lost\_Harvest \times H_{StemStag,StemLit}$$
$$StemStag\_to\_Atmos\_Harvest = Total\_StemStag\_Lost\_Harvest \times H_{StemStag,ATMOS}$$

And there is also option to harvest standing dead stags at a set number of years post-fire (1 year by default).

$$Total\_StemStag\_Lost\_Salvage = C_{StemStag} \times S_{StemStag}$$
$$StemStag\_to\_HWPI\_Salvage = Total\_StemStag\_Lost\_Salvage \times S_{StemStag,HWPI}$$
$$StemStag\_to\_HWPII\_Salvage = Total\_StemStag\_Lost\_Salvage \times S_{StemStag,HWPII}$$
$$StemStag\_to\_HWPIII\_Salvage = Total\_StemStag\_Lost\_Salvage \times S_{StemStag,HWPIII}$$
$$StemStag\_to\_BioI\_Salvage = Total\_StemStag\_Lost\_Salvage \times S_{StemStag,BioI}$$
$$StemStag\_to\_BioII\_Salvage = Total\_StemStag\_Lost\_Salvage \times S_{StemStag,BioII}$$

Litter emissions associated with harvest:

$$\begin{aligned} Litter\_Emissions\_to\_Atmos\_Harvest = {} & LeafLit\_to\_Atmos\_Harvest + \\ & StemLit\_to\_Atmos\_Harvest + \\ & FRootLit\_to\_Atmos\_Harvest + \\ & CRootLit\_to\_Atmos\_Harvest + \\ & StemStag\_to\_Atmos\_Harvest \end{aligned}$$

Changes to the litter C pools in response to harvest are given by:

$$C_{LeafLit,t} = C_{LeafLit,t} + Leaf\_to\_LeafLit\_Harvest - Total\_LeafLit\_Lost\_Harvest$$
$$\begin{aligned} C_{StemLit,t} = {} & C_{StemLit,t} + Stem\_to\_StemLit\_Harvest + StemStag\_to\_StemLit\_Harvest \\ & - Total\_StemLit\_Lost\_Harvest \end{aligned}$$
$$C_{FRootLit,t} = C_{FRootLit,t} + FRoot\_to\_FRootLit\_Harvest - Total\_FRootLit\_Lost\_Harvest$$
$$C_{CRootLit,t} = C_{CRootLit,t} + CRoot\_to\_CRootLit\_Harvest - Total\_CRootLit\_Lost\_Harvest$$
$$C_{StemStag,t} = C_{StemStag,t} - Total\_StemStag\_Lost\_Harvest - Total\_StemStag\_Lost\_Salvage$$

3. Soil

3.1 SOIL FLUX COMPONENTS – CONTINUOUS GAINS AND LOSSES

Continuous gains to the soil pools were defined in the previous section as:

$$LeafLit\_to\_Humus\ , StemLit\_to\_Humus\ ,\ FRoot\_to\_Humus\ , CRoot\_to\_Humus$$

The loss fluxes are given by the following, where L_i is the longevity of soil component i (yr), and H_{HUM} is the fraction of lost humus that is incorporated into the SOC stable pool:

$$Total\_Humus\_Lost = \frac{C_{Humus}}{L_{Humus}}$$

$$Humus\_to\_StableSoil = Total\_Humus\_Lost \times H_{HUM}$$

$$Humus\_to\_Atmos = Total\_Humus\_Lost \times (1 - H_{HUM})$$

$$StableSoil\_to\_Atmos = \frac{C_{Stable}}{L_{Stable}}$$

Continuous emissions from the soil

$$Soil\_Emissions\_to\_Atmos\_Decomp = Humus\_to\_Atmos + StableSoil\_to\_Atmos$$

The equations for the change in the soil pools over continuous time are given by:

$$\frac{dC_{Humus}}{dt} = LeafLit\_to\_Humus + StemLit\_to\_Humus + FRoot\_to\_Humus + CRoot\_to\_Humus - Total\_Humus\_Lost$$

$$\frac{dC_{Stable}}{dt} = Humus\_to\_StableSoil - StableSoil\_to\_Atmos$$

3.2 SOIL FLUX COMPONENTS – EPISODIC GAINS AND LOSSES

3.2.1 FIRE IMPACTS ON SOIL C

The total gains to the humus and stable SOC pools due to fire were defined in previous sections:

$Leaf\_to\_Humus\_Fire$, $Stem\_to\_Humus\_Fire$, $FRoot\_to\_Humus\_Fire$,
$CRoot\_to\_Humus\_Fire$, $FRootLit\_to\_Humus\_Fire$, $CRootLit\_to\_Humus\_Fire$,
$LeafLit\_to\_Humus\_Fire$, $StemLit\_to\_Humus\_Fire$
$Leaf\_to\_StableSoil\_Fire$, $Stem\_to\_StableSoil\_Fire$, $FRoot\_to\_StableSoil\_Fire$,
$CRoot\_to\_StableSoil\_Fire$, $FRootLit\_to\_StableSoil\_Fire$,
$CRootLit\_to\_StableSoil\_Fire$, $LeafLit\_to\_StableSoil\_Fire$,
$StemLit\_to\_StableSoil\_Fire$, $Humus\_to\_StableSoil\_Fire$

During a fire event SOC humus can be lost to the SOC stable pool or to the atmosphere, and SOC stable can be lost to the atmosphere.

The total loss in a fire event for SOC humus is given by F_{Humus}. The proportion of total humus loss that is transferred to the stable soil pool and atmosphere is given by $F_{Humus, SS}$ and $F_{Humus, ATMOS}$ respectively.

Losses from the SOC pools in response to fire are given by:

$$Total\_Humus\_Lost\_Fire = C_{Humus,t} \times F_{Humus}$$
$$Humus\_to\_StableSoil\_Fire = Total\_Humus\_lost\_Fire \times F_{Humus,,SS}$$
$$Humus\_to\_Atmos\_Fire = Total\_Humus\_lost\_Fire \times F_{Humus,,ATMOS}$$
$$Stable\_Lost\_Fire = C_{Stable,t} \times F_{SS}$$

Soil emissions associated with fire

$$Soil\_Emissions\_to\_Atmos\_Fire = Humus\_to\_Atmos\_Fire + Stable\_Lost\_Fire$$

Changes to the soil pools in response to fire are given by:

$$C_{Humus,t} = C_{Humus,t} + Leaf\_to\_Humus\_Fire + Stem\_to\_Humus\_Fire + FRoot\_to\_Humus\_Fire + CRoot\_to\_Humus\_Fire + FRootLit\_to\_Humus\_Fire + CRootLit\_to\_Humus\_Fire + LeafLit\_to\_Humus\_Fire + StemLit\_to\_Humus\_Fire - Total\_Humus\_Lost\_Fire$$
$$C_{Stable,t} = C_{Stable,t} + Leaf\_to\_StableSoil\_Fire + Stem\_to\_StableSoil\_Fire + FRoot\_to\_StableSoil\_Fire + CRoot\_to\_StableSoil\_Fire + FRootLit\_to\_StableSoil\_Fire + CRootLit\_to\_StableSoil\_Fire + LeafLit\_to\_StableSoil\_Fire + StemLit\_to\_StableSoil\_Fire - Stable\_Lost\_Fire$$

3.2.2 HARVESTING IMPACTS ON SOIL C

During a harvesting event SOC humus can be lost to the SOC stable pool or to the atmosphere, and SOC stable can be lost to the atmosphere.

The total gains to the humus and stable SOC pools due to harvest were defined previously:

$$Leaf\_to\_Humus\_Harvest, Stem\_to\_Humus\_Harvest, FRoot\_to\_Humus\_Harvest, CRoot\_to\_Humus\_Harvest, FRootLit\_to\_Humus\_Harvest, CRootLit\_to\_Humus\_Harvest, LeafLit\_to\_Humus\_Harvest, StemLit\_to\_Humus\_Harvest$$

$$Leaf\_to\_StableSoil\_Harvest, Stem\_to\_StableSoil\_Harvest, FRoot\_to\_StableSoil\_Harvest, CRoot\_to\_StableSoil\_Harvest, FRootLit\_to\_StableSoil\_Harvest, CRootLit\_to\_StableSoil\_Harvest, LeafLit\_to\_StableSoil\_Harvest, StemLit\_to\_StableSoil\_Harvest, Total\_StableSoil\_Lost\_Harvest$$

The total loss in a harvest event for SOC humus is given by H_{Humus}. The proportion of total humus loss that is transferred to the stable soil pool and atmosphere is given by $H_{Humus, SS}$ and $H_{Humus, ATMOS}$ respectively.

Losses from the SOC pools in response to fire are therefore given by:

$$Total\_Humus\_Lost\_Harvest = C_{Humus,t} \times H_{Humus}$$
$$Humus\_to\_StableSoil\_Harvest = Total\_Humus\_Lost\_Harvest \times H_{Humus,,SS}$$
$$Humus\_to\_Atmos\_Harvest = Total\_Humus\_Lost\_Harvest \times H_{Humus,,ATMOS}$$
$$Stable\_Lost\_Harvest = C_{Stable,t} \times H_{SS}$$

Soil emissions associated with fire

$$Soil\_Emissions\_to\_Atmos\_Harvest = Humus\_to\_Atmos\_Harvest + Stable\_Lost\_Harvest$$

Changes to the soil pools in response to Harvest are given by:

$$C_{Humus,t} = C_{Humus,t} + Leaf\_to\_Humus\_Harvest + Stem\_to\_Humus\_Harvest + FRoot\_to\_Humus\_Harvest + CRoot\_to\_Humus\_Harvest + FRootLit\_to\_Humus\_Harvest + CRootLit\_to\_Humus\_Harvest + LeafLit\_to\_Humus\_Harvest + StemLit\_to\_Humus\_Harvest - Total\_Humus\_Lost\_Harvest$$
$$C_{Stable,t} = C_{Stable,t} + Leaf\_to\_StableSoil\_Harvest + Stem\_to\_StableSoil\_Harvest + FRoot\_to\_StableSoil\_Harvest + CRoot\_to\_StableSoil\_Harvest + FRootLit\_to\_StableSoil\_Harvest + CRootLit\_to\_StableSoil\_Harvest + LeafLit\_to\_StableSoil\_Harvest + StemLit\_to\_StableSoil\_Harvest - Stable\_Lost\_Harvest$$

4. Harvested Wood Products (HWP)

4.1 EPISODIC GAINS TO HWP POOLS

Gains to the HWP pools only occur during episodic harvest events. The first step is the removal of material from the forest, and then to subtract from that any waste losses during processing, and any subsequent transfers from HWP II and III to HWP I (e.g. to allow the potential for processing waste to be transferred to a 'pulp' pool). In the equation below, *i* represents either I, II or III.

$$Total\_HWPi\_From\_Forest = Stem\_to\_HWPi\_Harvest + StemLit\_to\_HWPi\_Harvest + StemStag\_to\_HWPi\_Salvage$$

The proportion of the total HWP *i* is that is lost as waste during processing is given by $W_{Forest, HWPi}$. For HWP II and III the proportion of this waste that goes into the HWP I pool is $W_{HWPII, HWPI}$ and $W_{HWPIII, HWPI}$ respectively. Also, for each HWP pool, a proportion of the waste can be sent to bioenergy, given by $W_{HWPI\_Waste, BIOI}$, $W_{HWPII\_Waste, BIOI}$ and $W_{HWPIII\_Waste, BIOI}$, and $W_{HWPI\_Waste, BIOII}$, $W_{HWPII\_Waste, BIOII}$ and $W_{HWPIII\_Waste, BIOII}$.

The fluxes for HWP I are:

$$Total\_HWPI\_Waste = Total\_HWPI\_From\_Forest \times W_{Forest,HWPI}$$

$$HWPI\_Waste\_to\_BioI = Total\_HWPI\_From\_Forest \times W_{HWPI\_Waste,BioI}$$
$$HWPI\_Waste\_to\_BioII = Total\_HWPI\_From\_Forest \times W_{HWPI\_Waste,BioII}$$
$$HWPI\_Waste\_to\_Atmos = Total\_HWPI\_From\_Forest \times \left(1 - \left(W_{HWPI\_Waste,BioI} + W_{HWPI\_Waste,BioII}\right)\right)$$

The fluxes for HWP I and II (represented by *i*) are:

$$Total\_HWPi\_Waste = Total\_HWPi\_From\_Forest \times W_{Forest,HWPi}$$
$$HWPi\_Waste\_to\_HWPI = Total\_HWPi\_From\_Forest \times W_{iHWP,HWPI}$$
$$HWPi\_Waste\_to\_BioI = Total\_HWPi\_From\_Forest \times W_{HWPi\_Waste,BioI}$$
$$HWPi\_Waste\_to\_BioII = Total\_HWPi\_From\_Forest \times W_{HWPi\_Waste,BioII}$$
$$HWPi\_Waste\_to\_Atmos = Total\_HWPi\_From\_Forest \times \left(1 - \begin{pmatrix} W_{HWPi,HWPI} + W_{HWPi\_Waste,BioI} \\ + W_{HWPi\_Waste,BioII} \end{pmatrix}\right)$$

HWP waste emissions associated with processing

$$HWP\_Waste\_to\_Atmos = HWPI\_Waste\_to\_Atmos + HWPII\_Waste\_to\_Atmos + HWPIII\_Waste\_to\_Atmos$$

The net gain in the HWP pools is given by

$$C_{HWPI,t} = C_{HWPI,t} + Total\_HWPI\_From\_Forest + HWPII\_Waste\_to\_HWPI + HWPIII\_Waste\_to\_HWPI - Total\_HWPI\_Waste$$
$$C_{HWPII,t} = C_{HWPII,t} + Total\_HWPII\_From\_Forest - Total\_HWPII\_Waste$$
$$C_{HWPIII,t} = C_{HWPIII,t} + Total\_HWPIII\_From\_Forest - Total\_HWPIII\_Waste$$

Losses from the HWP pools occur both episodically, and continuously

4.2 EPISODIC LOSSES FROM HWP

Episodic losses from the HWP pools occur when cohort *j* of product *i* exceeds its service life, SL_i (yr), at which point all of that product is passed to either landfill, bioenergy, or is lost to the atmosphere. Parameter $EndLife_{i,\ Land}$ specifies the proportion of cohort *j* of product *i* that is lost to landfill; $EndLife_{i,\ Bioenergy}$ is the proportion moved to bioenergy, and the balance is lost to the atmosphere.
The fluxes are:

$Total\_End\_of\_Life\_HWPi = \sum_{j=1}^{n} Z \times C_{HWPi,j}$, where Z = 1 if age of cohort $j = S_{iHWP}$, 0 otherwise

$$End\_of\_Life\_HWPi\_to\_Landfill = Total\_End\_of\_Life\_HWPi \times Endlife_{HWPi,Land}$$
$$End\_of\_Life\_HWPi\_to\_BioI = Total\_End\_of\_Life\_HWPi \times Endlife_{HWPi,BioI}$$
$$End\_of\_Life\_HWPi\_to\_BioII = Total\_End\_of\_Life\_HWPi \times Endlife_{HWPi,BioII}$$
$$End\_of\_Life\_HWPi\_to\_Atmos = Total\_End\_of\_Life\_HWPi \times \left(1 - \begin{pmatrix} Endlife_{HWPi,land} + Endlife_{HWPi,BioI} \\ + Endlife_{HWPi,BioII} \end{pmatrix}\right)$$

HWP emissions associated with end of service life

$$HWP\_Emissions\_End\_of\_Life = End\_of\_Life\_HWPI\_to\_Atmos + End\_of\_Life\_HWPII\_to\_Atmos + End\_of\_Life\_HWPIII\_to\_Atmos$$

The loss in pools is given by

$$C_{HWPI,t} = C_{HWPI,t} - Total\_End\_of\_Life\_HWPI$$
$$C_{HWPII,t} = C_{HWPII,t} - Total\_End\_of\_Life\_HWPII$$
$$C_{HWPIII,t} = C_{HWPIII,t} - Total\_End\_of\_Life\_HWPIII$$

4.3 CONTINUOUS HWP LOSSES

Wood products in-service can 'decay' at a constant rate, given by L_i. The decay products can either be losses back to the atmosphere, or losses to landfill and bioenergy. Over all *n* cohorts the total losses are:

$$Total\_HWPi\_InLifeLoss = \sum_{j=1}^{n} \frac{C_{HWPi,j}}{L_{HWPi}}$$
$$InLifeLoss\_of\_HWPi\_to\_Landfill = Total\_HWPi\_Loss \times D_{HWPi,Land}$$
$$InLifeLoss\_of\_HWPi\_to\_BioI = Total\_HWPi\_Loss \times D_{HWPi,BioI}$$
$$InLifeLoss\_of\_HWPi\_to\_BioII = Total\_HWPi\_Loss \times D_{HWPi,BioII}$$
$$HWPi\_to\_Atmos\_InLifeLoss = Total\_HWPi\_InLifeLoss \times \left(1 - \left(D_{HWPi,land} + D_{HWPi,BioI} + D_{HWPi,BioII}\right)\right)$$

HWP emissions associated with in-service decay

$$HWP\_Emissions\_InLife = HWPI\_to\_Atmos\_InLifeLoss + HWPII\_to\_Atmos\_InLifeLoss + HWPIII\_to\_Atmos\_InLifeLoss$$

Continuous change in HWP due to decay

$$\frac{dC_{HWPI}}{dt} = -Total\_HWPI\_InLifeLoss$$
$$\frac{dC_{HWPII}}{dt} = -Total\_HWPII\_InLifeLoss$$
$$\frac{dC_{HWPIII}}{dt} = -Total\_HWPII\_InLifeLoss$$

5. Landfill

5.1 EPISODIC GAINS TO THE LANDFILL POOL

There are additional processing waste losses when moving end of service life HWP to landfill; these are given by $W_{i,\ Landfill}$. The total input to landfill, and associated waste losses, are given by:

$$Total\_Landfill\_From\_HWPi = End\_of\ \_life\_HWPi\_to\_Landfill + InLifeLoss\_of\ \_HWPi\_to\_Landfill$$

$$HWPi\_to\_Landfill\_Atmos = Total\_Landfill\_From\_iHWP \times W_{HWPi,Landfill}$$

Emissions associated with the processing of HWP to Landfill

$$HWP\_Emissions\_to\_Landfill = HWPI\_to\_Landfill\_Atmos + HWPII\_to\_Landfill\_Atmos + HWPIII\_to\_Landfill\_Atmos$$

Gains to landfill

$$C_{HWPI\_Landfill,t} = C_{HWPI\_Landfill,t} + Total\_Landfill\_From\_HWPI - HWPI\_to\_Landfill\_Atmos$$

$$C_{HWPII\_Landfill,t} = C_{HWPII\_Landfill,t} + Total\_Landfill\_From\_HWPII - HWPII\_to\_Landfill\_Atmos$$

$$C_{HWPIII\_Landfill,t} = C_{HWPIII\_Landfill,t} + Total\_Landfill\_From\_HWPIII - HWPIII\_to\_Landfill\_Atmos$$

5.2 CONTINUOUS GAINS AND LOSSES TO AND FROM THE LANDFILL POOL

Losses from landfill to the atmosphere occur continuously. The fluxes for HWP landfill component *i* are:

$$HWPi\_Landfill\_Decay = \frac{C_{HWPi\_Landfill}}{L_{HWPi\_Landfill}}$$

Emissions associated with landfill decay

$$Landfill\_Emissions\_Decay = HWPI\_Landfill\_Decay + HWPII\_Landfill\_Decay + HWPIII\_Landfill\_Decay$$

Continuous gains to landfill from HWP were given in Section 4.3. The net change in landfill is therefore

$$\frac{dC_{HWPI\_Landfill}}{dt} = InLifeLoss\_of\ \_HWPI\_to\_Landfill - HWPI\_Landfill\_Decay$$

$$\frac{dC_{HWPII\_Landfill}}{dt} = InLifeLoss\_of\ \_HWPII\_to\_Landfill - HWPII\_Landfill\_Decay$$

$$\frac{dC_{HWPIII\_Landfill}}{dt} = InLifeLoss\_of\ \_HWPIII\_to\_Landfill - HWPIII\_Landfill\_Decay$$

6. Bioenergy

6.1 EPISODIC GAINS TO THE BIOENERGY POOL

Gains to the Bioenergy pools only occur during harvest events, and from the HWP at end of service life. Associated with these gains is, however, the potential for loss via processing waste.

[DIRECTLY FROM THE FOREST]

$$Total\_BioI\_From\_Forest = Stem\_to\_BioI\_Harvest + StemLit\_to\_BioI\_Harvest + StemStag\_to\_BioI\_Salvage$$

$$BioI\_From\_Forest\_Waste = Total\_BioI\_From\_Forest \times W_{Forest,Bio}$$

$$Total\_BioII\_From\_Forest = Stem\_to\_BioII\_Harvest + StemLit\_to\_BioII\_Harvest + StemStag\_to\_BioII\_Salvage$$

$$BioII\_From\_Forest\_Waste = Total\_BioII\_From\_Forest \times W_{Forest,Bio}$$

[FROM HWP PROCESSING]

$$Total\_BioI\_From\_HWP\_Processing = HWPI\_Waste\_to\_BioI + HWPII\_Waste\_to\_BioI + HWPIII\_Waste\_to\_BioI$$

$$BioI\_From\_HWP\_Processing\_Waste = Total\_BioI\_From\_Processing \times W_{HWP\_processing,BioI}$$

$$Total\_BioII\_From\_HWP\_Processing = HWPI\_Waste\_to\_BioII + HWPII\_Waste\_to\_BioII + HWPIII\_Waste\_to\_BioII$$

$$BioII\_From\_HWP\_Processing\_Waste = Total\_BioII\_From\_Processing \times W_{HWP\_processing,BioII}$$

[FROM HWP END OF SERVICE LIFE]

$$Total\_BioI\_From\_EOL = End\_of\_Life\_HWPI\_to\_BioI + End\_of\_Life\_HWPII\_to\_BioI + End\_of\_Life\_HWPIII\_to\_BioI$$

$$BioI\_From\_EOL\_Processing\_Waste = Total\_BioI\_From\_EOL \times W_{HWP\_processing,BioI}$$

$$Total\_BioII\_From\_EOL = End\_of\_Life\_HWPI\_to\_BioII + End\_of\_Life\_HWPII\_to\_BioII + End\_of\_Life\_HWPIII\_to\_BioII$$

$$BioII\_From\_EOL\_Processing\_Waste = Total\_BioII\_From\_EOL \times W_{HWP\_processing,BioII}$$

Emissions associated with the processing of material for bioenergy

$$
\begin{aligned}
Bioenergy\_Emissions\_Waste = {} & BioI\_From\_Forest\_Waste + \\
& BioII\_From\_Forest\_Waste + \\
& BioI\_From\_HWP\_Processing\_Waste + \\
& BioII\_From\_HWP\_Processing\_Waste + \\
& BioI\_From\_EOL\_Processing\_Waste + \\
& BioII\_From\_EOL\_Processing\_Waste
\end{aligned}
$$

The net change in bioenergy is given by

$$
\begin{aligned}
C_{BioI,t} = C_{BioI,t} & + Total\_BioI\_From\_Forest + \\
& Total\_BioI\_From\_HWP\_Processing + \\
& Total\_BioI\_From\_EOL - \\
& BioI\_From\_Forest\_Waste - \\
& BioI\_From\_HWP\_Processing\_Waste - \\
& BioI\_From\_EOL\_Processing\_Waste \\
C_{BioII,t} = C_{BioII,t} & + Total\_BioII\_From\_Forest + \\
& Total\_BioII\_From\_HWP\_Processing + \\
& Total\_BioII\_From\_EOL - \\
& BioII\_From\_Forest\_Waste - \\
& BioII\_From\_HWP\_Processing\_Waste - \\
& BioII\_From\_EOL\_Processing\_Waste
\end{aligned}
$$

6.1.2 CONTINUOUS GAINS AND LOSSES TO AND FROM THE BIOENERGY POOL

Losses from the Bioenergy pool to the atmosphere occur continuously. The fluxes are:

$$
BioI\_Decay = \frac{C_{BioI}}{L_{BioI}}
$$

$$
BioII\_Decay = \frac{C_{BioII}}{L_{BioII}}
$$

Continuous gains to bioenergy were given in Section 4.3. The net change in landfill is therefore

$$
\begin{aligned}
\frac{dC_{BioI}}{dt} = {} & InLifeLoss\_of\_HWPI\_to\_BioI + InLifeLoss\_of\_HWPII\_to\_BioI + \\
& InLifeLoss\_of\_HWPIII\_to\_BioI - BioI\_Decay \\
\frac{dC_{BioII}}{dt} = {} & InLifeLoss\_of\_HWPI\_to\_BioII + InLifeLoss\_of\_HWPII\_to\_BioII + \\
& InLifeLoss\_of\_HWPIII\_to\_BioII
\end{aligned}
$$

7. Net Biome (system) Production

As this is a full system model, when averaged over the long term the internal transfers of C must conform to conservation of mass constraints. This implies that at long-term steady state:

Total_New_C_added = Total_C_emissions, where
Total_New_C_added = *NPP*, and Total_C_Emissions is the sum of all the terms in the light gray boxes

There are also additional emissions and sequestration that occur outside of the system boundary defined above. These are transport/energy emissions associated with harvesting and the processing of material for bioenergy and landfill, and offsets/credits associated with HWP substitution, and fossil fuel offsets associated with the combustion of wood for bioenergy.

8. HWP Substitution and Bioenergy Fossil Fuel Offsets

8.1 EPISODIC INCREMENTS TO HWP SUBSTITUTION

The parameters S_{HWPi} are the product substation factors, and describe the net benefit of the substitution of more energy costly materials by timber (units tC substituted / tC HWP created).

$$New\_HWPI\_Increment = Total\_HWPI\_From\_Forest + HWPII\_Waste\_to\_HWPI + HWPIII\_Waste\_to\_HWPI - Total\_HWPI\_Waste$$

$$New\_HWPII\_Increment = Total\_HWPII\_From\_Forest - Total\_HWPII\_Waste$$

$$New\_HWPIII\_Increment = Total\_HWPII\_From\_Forest - Total\_HWPIII\_Waste$$

$$C_{HWPI\_Sub} = C_{HWPI\_Sub} + \left(S_{HWPI} \times New\_HWPI\_Increment\right)$$

$$C_{HWPII\_Sub} = C_{HWPII\_Sub} + \left(S_{HWPII} \times New\_HWPII\_Increment\right)$$

$$C_{HWPIII\_Sub} = C_{HWPIII\_Sub} + \left(S_{HWPIII} \times New\_HWPIII\_Increment\right)$$

8.2 EPISODIC INCREMENTS TO BIOENERGY SUBSTITUTION

The parameter S_{Bioi} is the equivalent factor for quantifying bioenergy offsets (units tC offset / tC combusted)

$$\begin{aligned} New\_Bioi\_Increment = Total\_Bioi\_From\_Forest &+ \\ HWPI\_Waste\_to\_Bioi &+ \\ HWPII\_Waste\_to\_Bioi &+ \\ HWPIII\_Waste\_to\_Bioi &+ \\ End\_of\_Life\_HWPI\_to\_Bioi &+ \\ End\_of\_Life\_HWPII\_to\_Bioi &+ \\ End\_of\_Life\_HWPIII\_to\_Bioi & \end{aligned}$$

$$C_{BioI\_Sub} = C_{BioI\_Sub} + S_{BioI} \times New\_BioI\_Increment$$

$$C_{BioII\_Sub} = C_{BioII\_Sub} + S_{BioII} \times New\_BioII\_Increment$$

8.3 CONTINUOUS INCREMENTS TO HWP SUBSTITUTION

$$New\_Bioi\_Continuous = InLifeLoss\_of\_HWPI\_to\_Bioi + InLifeLoss\_of\_HWPII\_to\_Bioi + InLifeLoss\_of\_HWPIII\_to\_Bioi$$

$$\frac{dC_{BioI\_Sub}}{dt} = New\_BioI\_Continuous \times S_{BioI}$$

$$\frac{dC_{BioII\_Sub}}{dt} = New\_BioII\_Continuous \times S_{BioII}$$

9. Transport / Energy Emissions External to the System

Energy emissions associated with harvesting of forest C to HWP and bioenergy, and associated with the transfer of HWP to landfill and bioenergy, are given by E_i

9.1. EPISODIC ADDITIONS TO EMISSIONS

$$Total\_Forest\_to\_HWP = Total\_HWPI\_from\_Forest + Total\_HWPII\_from\_Forest + Total\_HWPIII\_from\_Forest$$

$$\begin{aligned} Total\_HWP\_to\_Bioenergy = {} & End\_of\_Life\_HWPI\_to\_BioI + \\ & End\_of\_Life\_HWPI\_to\_BioII + \\ & End\_of\_Life\_HWPII\_to\_BioI + \\ & End\_of\_Life\_HWPII\_to\_BioII + \\ & End\_of\_Life\_HWPIII\_to\_BioI + \\ & End\_of\_Life\_HWPIII\_to\_BioII + \\ & HWPI\_Waste\_to\_BioI + \\ & HWPI\_Waste\_to\_BioII + \\ & HWPII\_Waste\_to\_BioI + \\ & HWPII\_Waste\_to\_BioII + \\ & HWPIII\_Waste\_to\_BioI + \\ & HWPIII\_Waste\_to\_BioII \end{aligned}$$

$$Total\_HWP\_to\_Landfill = End\_of\_Life\_HWPI\_to\_Landfill + End\_of\_Life\_HWPII\_to\_Landfill + End\_of\_Life\_HWPIII\_to\_Landfill$$

$$
\begin{aligned}
Total\_Forest\_to\_Bioenergy = {} & Stem\_to\_BioI\_Harvest + \\
& Stem\_to\_BioII\_Harvest + \\
& Stemlit\_to\_BioI\_Harvest + \\
& Stemlit\_to\_BioII\_Harvest + \\
& HWPI\_Waste\_to\_BioI + \\
& HWPI\_Waste\_to\_BioII + \\
& HWPII\_Waste\_to\_BioI + \\
& HWPII\_Waste\_to\_BioII + \\
& HWPIII\_Waste\_to\_BioI + \\
& HWPIII\_Waste\_to\_BioII
\end{aligned}
$$

$$
\begin{aligned}
Total\_Transport/Energy\_Emissions = {} & (E_{Forest,HWP} \times Total\_Forest\_to\_HWP) + \\
& (E_{Forest,BIO} \times Total\_Forest\_to\_Bioenergy) + \\
& (E_{HWP,Landfill} \times Total\_HWP\_to\_Landfill) + \\
& (E_{HWP,BIO} \times Total\_HWP\_to\_Bioenergy)
\end{aligned}
$$

$$
\begin{aligned}
C_{TP\_Forest\_HWP} &= E_{Forest,HWP} \times Total\_Forest\_to\_HWP \\
C_{TP\_Forest\_Bio} &= E_{Forest,Bio} \times Total\_Forest\_to\_Bioenergy \\
C_{TP\_HWP\_Landfill} &= E_{HWP\_landfill} \times Total\_HWP\_to\_Landfill \\
C_{TP\_HWP\_Bio} &= E_{HWP,Bio} \times Total\_HWP\_to\_Bioenergy
\end{aligned}
$$

9.2. CONTUNUOUS ADDITIONS TO EMISSIONS

$$
\frac{dC_{TP\_HWP\_Bio}}{dt} = (New\_BioI\_Continuous + New\_BioII\_Continuous) \times E_{HWP,Bio}
$$

$$
\frac{dC_{TP\_HWP\_Landfill}}{dt} = \begin{pmatrix} InLifeLoss\_of\_HWPI\_to\_Landfill + \\ InLifeLoss\_of\_HWPII\_to\_Landfill + \\ InLifeLoss\_of\_HWPIII\_to\_Landfill \end{pmatrix} \times E_{HWP,Landfill}
$$

Appendix 4: Managing native forests for carbon storage and socio-economic benefits

Appendix 4.1. Summary of key modelling parameters

Industry value added values

National Parks & Reserves Value added	Far South Coast		North East	
	2005 *	2014	2005 ~	2014
Management Value Added Direct Effect ($s)	$3,255,000	$4,173,178	$8,609,000	$11,037,447
Visitor Expenditure Value Added Direct Effect ($s)	$14,070,000	$18,038,898	$52,784,000	$67,673,433
Total Value Added ($s)	**$17,325,000**	**$22,212,076**	**$61,393,000**	**$78,710,880**
Management Value Added Direct Effect ($s/ha)	$21.39	$27.42	$19.35	$24.80
Visitor Expenditure Value Added Direct Effect ($s/ha)	$92.45	$118.53	$118.62	$152.08
Total Value Added -Existing National Parks & Reserves ($s/ha)	**$113.83**	**$145.95**	**$137.96**	**$176.88**

Data source:

* Powell et al (2006)

`Gillespie Economics (2006)

Timber Industry Value Added	Eden RFA Region 2014	North East NSW RFA Region 2014
Timber Industry Value Added ($/yr)	$26,149,262	$253,800,758
Timber Industry Value added ($/gross ha/yr)	$159.45	$320.31

Data source:

ABARES (2015) AFWPS. 14. Industry value added in forest product industries

Visitation

Visitation relativities between Coastal National Parks and Coastal State Forests		
National Park Visitation by Year	Far South Coast	North Coast
2010	1,369,000	10,147,000
2012	1,025,000	9,246,000
2014	1,258,000	11,425,000
Total Visitation (Ave no./yr)	1,217,333	10,272,667
Total area of National Park & Reserves (ha)	461,771	1,415,182
Total Visitation (No./ha)	2.64	7.26
State forest visitation	Yabora & Bodalla	North Coast
Total Visitation (Ave no./yr)	13,000	1,030,800
Area of Coastal State forest (ha)	34,843	792,361
Total Visitation (No./ha)	0.37	1.30

Data source:

NPWS website visitation data

FCNSW visitation data for 2014 for selected sites

Employment

Employment	Bega LGA Jobs (No.)	Jobs (%)	North Coast Jobs (No.)	Jobs (%)
Direct employment - Timber industry	278	100%	3013.875	100%
Direct employment - Park Management	48			
Direct employment - Visitor Expenditure Share	246			
Total Direct Employment - National Parks & Reserves	294		1027	
Direct employment - reemployment of SF employee in NP mgt	13	4.8%	189	6.3%
Resident persons directly eligible for compensation (BAU)	265	95%	2824	

Data source:

ABARES (2011)

Unemployment Benefits	Bega LGA		North Coast	
	Unemployment Benefit ($/yr)	Unemployment Benefit ($/ha/yr)	Unemployment Benefit ($/yr)	Unemployment Benefit ($/ha/yr)
Commonwealth Unemployment Benefit (Ave/person/yr)	$13,499		$13,499	
Total Commonwealth Unemployment Benefit ($s/yr)	$3,573,973	$14.22	$38,128,098	$48.12

Year	1	2	3	4	5	6 to 20
Assumed proportion of residents receiving unemployment benefits (%) *	76%	53%	48%	36.5%	25.0%	25.0%
Assumed unemployment cost to Commonwealth - Eden ($/ha)	$10.81	$7.54	$6.83	$5.19	$3.56	$3.56
Assumed unemployment cost to Commonwealth - North Coast ($/ha)	$36.57	$25.50	$23.10	$17.56	$12.03	$12.03

Data source:

* Weller

Average change in carbon abatement over long term (65yrs) relative to BAU

Forest Management Scenarios		Eden	North Coast
		True Fate C	True Fate C
		tCO_2-e/ha/yr	tCO_2-e/ha/yr
1	Conservation	-0.74	1.28
2	30% forest residue to bioenergy	1.09	
3	50% forest residue to bioenergy		2.27
4	50% pulp to bioenergy	-1.69	
5	50% forest residue to pulp		5.94
6	100% pulp to bioenergy	-3.40	
7	EoL products and waste to bioenergy	0.52	1.50
8	Maximise product recovery	1.78	3.96
9	Maximising landfill	2.03	3.88
10	Maximise bioenergy	0.81	3.74
11	Increase product to poles		4.11

Appendix 4.2. Timber industry value-added

Industry value added figures for the Eden and North Coast sites were based on annual log production levels. The calculations to derive the industry value added figures were based on a top down approach using the latest available published data from ABARES.

The steps involved in the method were as follows:

- The national industry value added for forestry and forest products manufacturing was $7.359B, based on a three year annual average for 2011/12, 2012/13 and 2013/14 (ABARES (2015) AFWS Industry value added in forest product industries). This figure comprises forestry and logging ($1.122B), wood products manufacturing ($3.673B) and paper and paper products manufacturing ($2.564B).

- ABARES does not publish data for industry value added by State. This value was derived using forest and wood products statistics (also published by ABARES). Using the gross value of logs harvested by State (average for the years 2011/12, 2012/13 and 2013/14), it was assumed that NSW constituted 22% of the national value of *forestry and logging*, which equated to $247M per year. The NSW value added component of national *wood products manufacturing* was derived using sales and service income in forest product sales. Averaging the years 2011/12, 2012/13 and 2013/14, NSW constituted 32% of the national total which equated to $1.179B. The NSW value added component of *national paper and paper products manufacturing* value added was estimated at 37% or $943M based on sales and service income from paper and paper product sales. Combining these figures, the average industry value added for NSW was estimated at $2.369B.

- ABARES State log production values by log type were used to estimate the hardwood component of the NSW industry value figure. From these values it was estimated that hardwood comprises 33.8% of the value of *forestry and logging*, 31% of *wood products manufacturing* and 0% of *paper and paper products manufacturing*. From these figures the average value of the NSW hardwood industry for the years 2011/12, 2012/13 and 2013/14 was estimated at $444M.

- An annual average of 693,000m^3 of hardwood sawlog and 369,000m3 of hardwood pulpwood was produced within NSW over three financial years (2011/12, 2012/13 and 2013/14). In addition an estimated 62,000m^3 of hardwood sawlog was imported to NSW over the same three year period. This estimate was derived by converting imported hardwood products (e.g. rough sawn and dressed) into a green roundwood equivalent and multiplying by 32% to derive the NSW component. These calculations brought the total annual average sawlog consumed in NSW to 755,000 m^3. Source: Australian forest and wood products statistics: March and June Quarters 2015).

- Australia also imported manufactured wood products that were subject to varying degrees of further value-adding within New South Wales (e.g. hardboard, flooring and furniture). Calculating the value added component of these products was beyond the scope of this project. It was however considered important to provide an allowance for these imports to avoid an overestimation of the value of wood products grown and produced within New South Wales. A default allowance of 5% was assumed.

- Value adding of pulpwood in NSW is limited to *forestry and logging* and woodchipping. It was estimated from ABARES data that the value added of a m^3 of hardwood pulpwood is 13% of the value added of an average sawlog. The value added of NSW a domestically produced hardwood sawlog was calculated at \$526.31 per m^3 while the value added of domestically produced hardwood pulpwood was estimated at \$67.50 per m^3.

- *Cubic metre* value added figures were converted to *per hectare* values using the following arithmetic steps:
  i. Annual production levels of sawlog and pulpwood were averaged over three years (2011/12, 2012/13 and 2013/14) for each region. In the Eden Region, annual average production comprised of 24,700 m^3 of sawlog and 194,816 m^3 of pulpwood. Annual average (2011/12, 2012/13 and 2013/14) production figures for the entire north coast were used. The total annual average yield of north coast sawlogs, poles, piles and girders was 467,834m^3. The total annual average yield of pulpwood and miscellaneous timber sales was 112,138 m^3 over the same period.
  ii. Volumes of sawlog and pulpwood for each region were multiplied by the NSW hardwood value added rates (calculated above in \$s per m^3), to obtain a total value for each region.
  iii. To generate a per hectare value the total value added figure for each region was divided by the gross area of State forest for that region. In the Eden Region the area was 164,000 hectares. On the north coast the area was 792,361 hectares.

  The calculated value added figures were \$159.45/ha/yr for the Eden Region and \$320.31/ha/yr for the North Coast.

Appendix 4.3 Employment

- Employment figures used in this project were sourced from ABARES Australian Forest & Wood Product Statistics Socioeconomic Tables index, which were generated from the 2011 National Census. In particular:
  - ❖ Table 81 Employment and community contribution indicators, 2011 - Northern NSW region detail
  - ❖ Table 83 Employment and community contribution indicators, 2011 - South Coast NSW region detail

- Metropolitan forestry sector jobs dependant on Eden Region and North Coast Region hardwood resources were excluded from the analysis as they could not be easily separated from forestry sector jobs that were not dependant on these regions.

- Indirect jobs that were dependant on the forestry sector were also excluded on the basis that they were more difficult to estimate reliably. A1995 socio-economic study by State Forests of NSW was the last major study to examine indirect employment. It calculated a forestry sector multiplier of 1.53; however it may be argued that this figure may not accurately reflect the current market. It is acknowledged that the decision to exclude indirect jobs may have caused an underestimation of the cost of transition.

- For the Eden Region, forestry sector employment (n = 278) was based on the number of direct forestry sector jobs in the Bega Valley Local Government Area (LGA) in 2011. Eden forestry employees known to reside in Bombala were not counted. Their no. was considered equivalent to the forestry jobs in Bega LGA that are not directly associated with the forestry operations in Eden.

- For the North Coast the number of direct jobs in 2011 in the forestry sector was based on all Northern NSW LGAs except Inverell and Gunnedah (LGAs = 26, jobs no. =4230), less 25% to account for jobs dependent on forest resources other than State forest (n = 3172), less a further 5% to account for jobs dependent on State forest softwood plantation resources (n= 3014).

- ABAREs forestry sector data, groups employment into job categories. Under the transition scenario it was assumed that all jobs in the forestry support sector would be transferred to National Park. In Eden this constituted 4.8% of the jobs while on the North Coast it constituted 6.3% of the jobs.

Appendix 4.4 Structural adjustment costing assumptions

Under this decision the NSW government implemented a structural adjustment package that provided financial compensation to affected parties. Compensation was provided in accord with NSW Government (2010) worker assistance and business exit assistance guidelines and included the following components:

• Special Redundancy Payment (for all persons directly employed)	\$81,360 per person
• Training Allowance	Up to \$10,000
• Relocation Allocation	Up to \$20,000
• High quality log allocation holders	$\$250/m^3$
• Salvage quality log allocation holders	$\$170/m^3$
• Pulplog allocation holders	\$64/t
• Harvest & haul contractors	$\$64/\ m^3$ or t

For modelling purposes the same rates as applied in the Red Gum were assumed with four qualifications.

i. For training an average allowance of $5,000 was assumed
ii. For relocation an average allowance of $10,000 was assumed.
iii. Redundancy payments for Forestry Corporation employees were based on public sector voluntary redundancy rates. As the amount of each redundancy varied an average of $81,360 was assumed (i.e. the same payment rate as industry employees was applied).
iv. Persons assumed to be re-employed in forest management roles by the National Parks & Wildlife Service were ineligible for any payments. Note this contrary to what happened in the Red Gum.

Appendix 4.5. Reemployment assumptions for displaced timber industry workers

- Forest based tourism (ecotourism) jobs were not included in the analysis as there was no evidence to support a difference between State forests (BAU) and National Parks (Conservation scenario). All iconic forest areas on the North Coast and Eden with potential to support additional eco-tourism jobs (if promoted as National Park) are already under conservation management.

- The average value of an unemployment benefit was assumed to be $519.20 per fortnight or $13,499/year which is the same as the 2015 Newstart Allowance for single people.

- The number of jobs lost, and hence eligible for an unemployment benefit, under the transitioning scenario was calculated using the following key assumptions:
  - All persons working in forestry support services would obtain an equivalent new job in the NSW National Parks & Wildlife Service
  - There would be no change in the total number of visitors as the Forestry Corporation already promotes State forests as desirable visitor destinations.
  - Reemployment rates were based on the findings of Weller and Webber (1997) in Borland (1998), who examined the labour market outcomes of displaced Australian textile/footwear and clothing workers. They found that:
    - ❖ 24.2% were reemployed after 12 months
    - ❖ 47.1% were reemployed after 24 months
    - ❖ 51.8% were reemployed after 36 months
    - ❖ 25% of the displaced forestry opted out of the workforce completely*

  The findings of the textile/footwear and clothing workers study identified factors of socio-economic disadvantage which were common to the native forestry sector. The native forestry sector has an aging workforce, includes low average levels of formal educational qualifications and few alternative regional employment options.

*NSW Committee on Ageing (2001) The causes of early exit from the labour force are complex and appear to include a reluctance (amounting often to discrimination) among employers and employment agencies to recruit mature age people, the low average levels of formal educational qualifications among mature age people, lack of skills in new technology, work experience in declining industries, locational disadvantages, and disabilities and caring responsibilities that limit their employment options.

References for Appendix 4

ABARES (2015) Australian Forest & Wood Product Statistics. March and June Quarters 2015. Table 14 - Industry value added in forest product industries.

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