THE AUSTRALIAN NATIONAL UNIVERSITY

Potential carbon credits from reducing native forest harvesting in Australia

Andrew Macintosh

CCLP Working Paper Series 2011/1

ANU Centre for Climate Law and Policy

Sponsored by

BAKER & McKENZIE

About the ANU Centre for Climate Law and Policy

The ANU Centre for Climate Law and Policy (CCLP) is part of the ANU College of Law. It was established in 2007 with the objective of providing a focal point for law and policy research related to climate change. The CCLP also runs courses in climate law and provides consulting services. Additional details of the CCLP can be found on its website: http://law.anu.edu.au/CCLP/.

The CCLP gratefully acknowledges the support of its founding sponsor, Baker & McKenzie.

CCLP Working Paper Series

The CCLP Working Paper Series provides a forum for the presentation of initial findings from CCLP research projects. The publications are intended to facilitate the exchange of information on climate law and policy issues. Through this process, the CCLP hopes to improve its final research outputs.

CCLP Working Paper Series 2011/1 corresponding author:

Andrew Macintosh
Ph: 61 2 6125 3832
Email: macintosha@law.anu.edu.au

1. Introduction

Australia has undertaken to reduce its greenhouse gas emissions by between 5%-25% on 2000 levels by 2020. To meet the 5% target, it has been estimated that Australia will need to reduce its emissions by an additional 152 million tonnes (Mt) of carbon dioxide equivalents (CO_2-e) in 2020 (DOT, 2011).[1] Due to the magnitude of the abatement task, there is considerable public interest in identifying cost-effective ways of reducing emissions that may not be captured by the Australian Government's proposed carbon pricing scheme (Australian Government, 2011a). The Opposition Liberal-National Party Coalition has also promised to repeal the carbon pricing scheme if it wins office at the next election and pursue emissions reductions through a 'direct action' policy (LPA and NPA, 2010). The success of this policy will hinge on the ability of the Opposition to identify the cheapest and most politically palatable sources of abatement. One of these is potentially reducing native forest harvesting.

Over the past decade, the Australian forestry industry has experienced considerable structural change. A rapid increase in plantations has coincided with a contraction in the size of the native forest sector. Between 2001 and 2010, plantation roundwood removals rose by 39%, increasing from 13.4 million m^3 yr^{-1} to 18.6 million m^3 yr^{-1} (ABARES, 2011a; 2011b). Over the same period, native forest removals fell by 41%, from 11.1 million m^3 yr^{-1} to 6.5 million m^3 yr^{-1}. Native forests now account for only 26% of total Australian roundwood removals, down from 60% in the early 1990s (ABARES, 2011a; 2011b). Although native forests are now responsible for only a minority of wood production, the harvesting of these areas is highly contentious. For 40 years, there has been a heated debate about the impact of native forest harvesting on the biodiversity, heritage and other values associated with these areas, and repeated calls for harvesting to be reduced or excluded entirely (Ajani, 2007). Changing community attitudes towards native forests have been reflected, at least in part, in government policy, with an estimated 5.5 million hectares (M ha) of new forest reserves created between 1990 and 2009 (MPIG, 2008; Australian Government, 2011b; 2011c). Concerns about climate change have heightened the interest in reducing native forest harvesting, with many groups and individuals now calling for it to be wound down to preserve native forest carbon stocks (Roxburgh et al., 2006; Ajani, 2008; Mackey et al., 2008; Ajani, 2011).

The object of this paper is to evaluate the credits that Australia could generate over the period 2013-2020 by reducing native forest harvesting. It is assumed for these purposes that, under the international accounting rules for the period 2013-2020 forest management (FM) is accounted for using a 'reference level' (or baseline-and-credit) system. Under this system, FM credits will be determined on the basis of the extent to which net FM emissions deviate from a pre-set reference level, which ideally would be a projection of net emissions over the period 2013-2020 assuming no policy change from December 2009. It is also assumed that Australia is able to partially or wholly exclude emissions from wildfires (the proposed 'force majeure' rule) and that, due to this, it opts to account for FM over the period 2013-2020 (Macintosh, 2011).

[1] This abatement task estimate assumes there is a carbon pricing scheme and that 7 Mt CO_2-e of Carbon Farming Initiative credits are sold into the domestic scheme in 2020. If the Carbon Farming Initiative credits are excluded, the abatement task estimate is 159 Mt CO_2-e in 2020 (DOT, 2011).

On this basis of these assumptions, this paper provides estimates of the credits that could be generated under the proposed new FM accounting regime by reducing native forest harvesting. Section 2 provides details of the method used to estimate the potential credits. Section 3 presents and discusses the results and section 4 provides a conclusion.

2. Method

To assess the magnitude of the credits that could arise from reduced native forest harvesting, four scenarios were devised:

- a reference case (FM-NFR scenario), where harvesting in native forests over the period 2010-2020 was assumed to equal the mean from the period 2002-2009;
- the FM-NF30 scenario, where harvesting in native forests was assumed to remain at 2010 levels over the period 2010-2020, some 30% below the mean from 2002-2009;
- the FM-NF50 scenario, where harvesting was assumed to fall to 50% below the mean from 2002-2009; and
- the FM-NFNH scenario, where harvesting in native forests was assume to cease.

2.1 The FM-NFR scenario

The FM-NFR scenario was based on FM reference level submission made by the Australian Government in accordance with the Cancun Agreements (Australian Government, 2011b). Here, the FM-NFR scenario was confined to a projection of net emissions from multiple use public forests and Tasmanian private native forests. Private native forests in other jurisdictions were excluded due to a lack of reliable data on the forest types and silviculture practices used in these areas.

The carbon (C) pools included in the FM-NFR scenario were live above- and below-ground biomass, debris and harvested wood products (HWP). The soil C pool was assumed to be stable, providing no net emissions or removals over the projection period (2010-2020).

Consistent with the Australian Government’s FM reference level, the calculation of the reference level was done in two parts:

- C stock changes in the live biomass and debris pools; and
- C stock changes in the HWP pool.

C stock changes in the live biomass and debris pools

In the Australian Government’s FM reference level, the projected C stock changes in these pools were modelled using the non-spatially explicit Tier 2 capabilities of *FullCAM* (Richards and Evans, 2004; Richards and Brack, 2004; Brack et al., 2006;

Australian Government, 2011b; 2011c). Within the model, the forest area (multiple use public forests and Tasmanian private native forests) was divided into six broad forest types (rainforest, tall dense eucalypt forest, medium dense eucalypt forest, medium sparse eucalypt forest, cypress pine forest and other forest), ten silvicultural systems and eight age classes, producing 73 forest type/silviculture/age class combinations. The C stock changes were modelled on the basis of the estimated area in each forest type/silviculture/age class combination using assumed forest type growth, turnover and decomposition rates. Harvest slash emissions over the period 2010-2020 were calculated using the forest type/silviculture/age class combinations and an assumption that the national harvest rate would equal the mean from the period 2002-2009.

To devise the FM-NFR scenario, a modified version of the approach adopted by the Australian Government was used.

- The scenario was devised using the Tier 2 capabilities of *FullCAM* (version 3.30.1).

- The *FullCAM* representative plot file data used to calculate net emissions from 'Harvested Native Forests' in Australia's *National Inventory Report 2009* were obtained from the Australian Government (Australian Government, 2011b; 2011c). These representative plot files cover the same 73 forest type/silviculture/age class combinations used to devise Australia's FM reference level.

- The representative plot files obtained from the Government were modified slightly by adjusting the above-ground biomass yield increment rates to ensure greater consistency with the rates noted in the *National Inventory Report 2009*. Details of these yield increment rates are provided in Appendix A.

- Of the 73 representative plot files, harvesting occurred in 55 of them over the period 2002-2009. To project harvest-related emissions over the period 2010-2020 in the FM-NFR scenario, the mean harvest rate in the 55 representative plot files subject to harvest over the period 2002-2009 was used (i.e. harvesting was assumed to occur on the same plot types, employing the same harvest techniques as occurred over the period 2002-2009). This provided a total annual harvest rate of 103,237 ha^{-1} yr^{-1} for the projection period. Details of the representative plot types and assumed annual harvest rate in each plot type are provided in Appendix B.

- The representative plots subject to harvest over the period 2010-2020 were assumed to form part of a single estate and the C stock changes on the estate were modelled using an estate simulation start date of 1960 and an end date of 2020.

- C stock changes on plots not subject to harvest over the period 2010-2020 under this reference case were not modelled as they remain the same in all scenarios, thereby cancelling each other out under the FM reference level accounting system.

- The impacts of wildfires were excluded from all scenarios.

Details of the key parameters used in *FullCAM* in the FM-NFR and mitigation scenarios are provided in Appendix A.

C stock changes in the HWP pool

In the Australian Government's FM reference level, projected C stock changes in the HWP pool were estimated using the harvested wood products model that is used for the purposes of Australia's *National Inventory Reports* (Richards et al., 2007; Australian Government, 2011b; 2011c). When used for the purpose of *National Inventory Reports*, the model estimates C stocks and flows from all wood products in Australia, regardless of their origin. The model was adjusted for the purposes of the FM reference level to exclude imports and include exports to ensure consistency with the proposed accounting framework. Adjustments were also made to the decay rate assumptions. For all domestically produced and consumed wood products, the standard decay rates in the model were used. With exports, the model was used to classify exported products into decay class pools but losses from the pools were determined in accordance with the default decay rates set out in the 'Revised proposal by the Chair, Draft decision -/CMP.6 (Land use, land-use change and forestry)'.[2]

In estimating HWP emissions in its FM reference level and the *National Inventory Reports*, the Australian Government does not use the roundwood removal estimates generated by *FullCAM*. Separate Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES) wood production data are used for this purpose. For the FM reference level, the Government assumed that annual wood production and the proportion of production allocated to end-use categories remain stable at 2008 levels throughout the projection period (Australian Government, 2011b).

To devise the FM-NFR scenario, the IPCC first-order decay function for harvested wood products was used,[3] assuming half lives of 2 years for paper, 25 years for wood panels and 35 years for sawn wood and a base year of 1990 (consistent with the default option in the 'Revised proposal by the Chair, Draft decision -/CMP.6 (Land use, land-use change and forestry)').[4] It was necessary to use this Tier 1 method because the Australian Government's harvested wood products model was not available. As in the Australian Government's FM reference level, in the FM-NFR scenario, it was assumed that wood production from native forests remains constant at 2008 levels from 2008-2020. The wood product data for the period 1990-2008 were obtained from ABARES (ABARES, 2011a; 2011b; 2011c), the Food and Agriculture Organization of the United Nation's FAOSTAT database (FAO, 2011) and Australia's *National Inventory Report 2009* (Australian Government, 2011c).

2.2 Mitigation scenarios

The approach used to devise the FM-NFR scenario was replicated for the FM-NF30, FM-NF50, and FM-NFNH scenarios, only with adjusted harvest and wood production projections. To estimate the C stock changes in the live biomass and debris pools, the 55 representative harvest plot files used in the FM-NFR scenario were replicated and the harvest events removed. This provided 110 representative plot files for the FM-NF30 and FM-NF50 scenarios (55 harvest plots and 55 no harvest plots), and 55 for

[2] FCCC/KP/AWG/2010/18/Add.1.
[3] Eggleston et al. (2006), Vol 4, Chpt 12, Equation 12.1 (p 12.11).
[4] FCCC/KP/AWG/2010/18/Add.1.

the FM-NFNH scenario (zero harvest plots and 55 no harvest plots). The area allocated to each representative harvest plot was reduced on a pro-rate basis to account for the assumed reduction in native forest harvesting; by 30% in the FM-NF30 scenario and 50% in the FM-NF50 scenario. The areas deducted from each representative harvest plot were then added to the corresponding no harvest plot (details of the plot types and assumed annual harvest rate in each plot type under the FM-NF50 scenario are provided in Appendix C for illustration). In the FM-NFNH scenario, the areas allocated to the representative harvest plots in the FM-NFR scenario were transferred to the corresponding no harvest plots. To project C stock changes in the HWP pool, the wood product estimates from the FM-NFR scenario were reduced on a pro-rata basis (by 30% in the FM-NF30 scenario, 50% in the FM-NF50 scenario and 100% in the FM-NFNH scenario).

2.3 Sensitivity analysis

There is a significant degree of uncertainty associated with the models and data used to devise Australia's FM reference level (and estimate net emissions from Harvested Native Forests in Australia's *National Inventory Reports*). *FullCAM* was originally designed to estimate C stock changes due to reforestation and deforestation. It was then recalibrated to cover managed native forests. While considerable effort has gone into ensuring the accuracy of the model, there is a marked lack of data on C stocks and fluxes in native forests. There are also data gaps concerning the age-class distribution of these forests and the silviculture practices used in them (MPIG, 2008; Australian Government, 2011b; 2011c). Due to this, the Government's estimates of emissions and removals from native forests are subject to a significant margin of error.

As the method used here is a replica of that used by the Australian Government, it embodies all of the same uncertainties. To account for this, basic sensitivity analysis was undertaken by modifying two of the key parameters in *FullCAM*: the above-ground live biomass yield increment rates and the age-class distribution of the forests subject to harvest.

The margin of error associated with the above-ground live biomass yield increment rates was assumed to be ±25%. To account for this range, replica representative plot files were created with +25% and -25% yield increments. The FM-NFR, FM-NF30, FM-NF50, and FM-NFNH scenarios were then re-run to test how the lower and higher yield increments affected the credit outcomes.

In relation to the uncertainties associated with the age-class distribution of the forests, the estate simulation start date was adjusted ±10 years. In the base case scenario, the estate simulation start date was 1960, meaning that in the sensitivity analysis model runs start dates of 1950 and 1970 were used.

3. Results and discussion

3.1 Base case

The net emissions from native forests subject to harvest under the FM-NFR, FM-NF30, FM-NF50, and FM-NFNH scenarios are shown in Figure 1. The average annual credits generated by reducing native forest harvesting under the three mitigation scenarios over the period 2013-2020 are shown in Table 1.

Figure 1 Carbon stock change (live biomass, debris, harvested wood product pools) in reference and mitigation scenarios, Mt CO_2-e yr^{-1}, 2011-2020

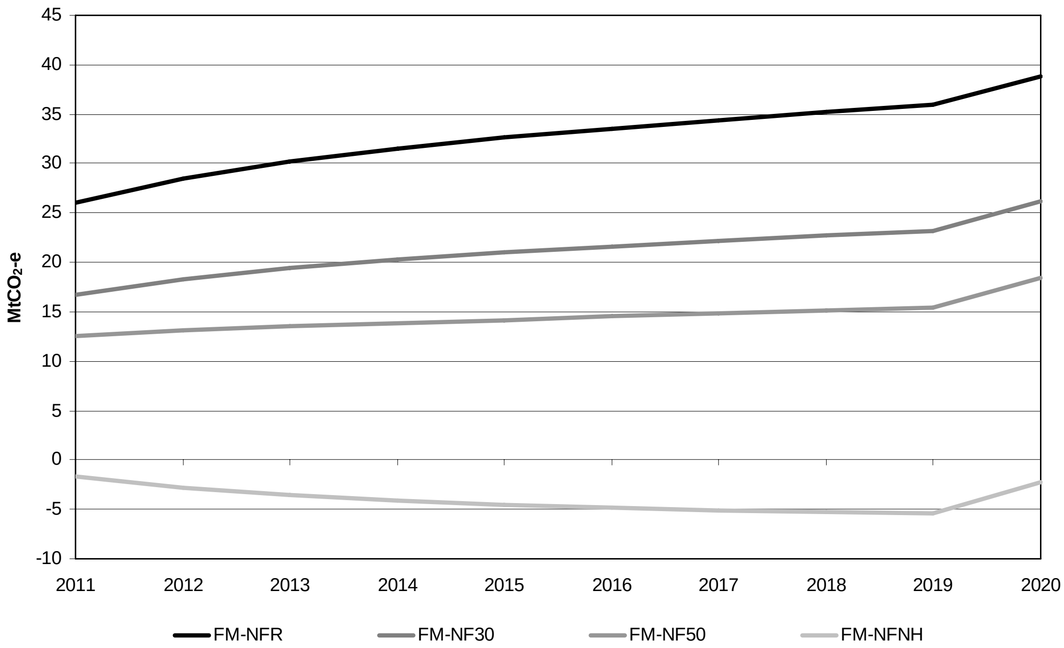


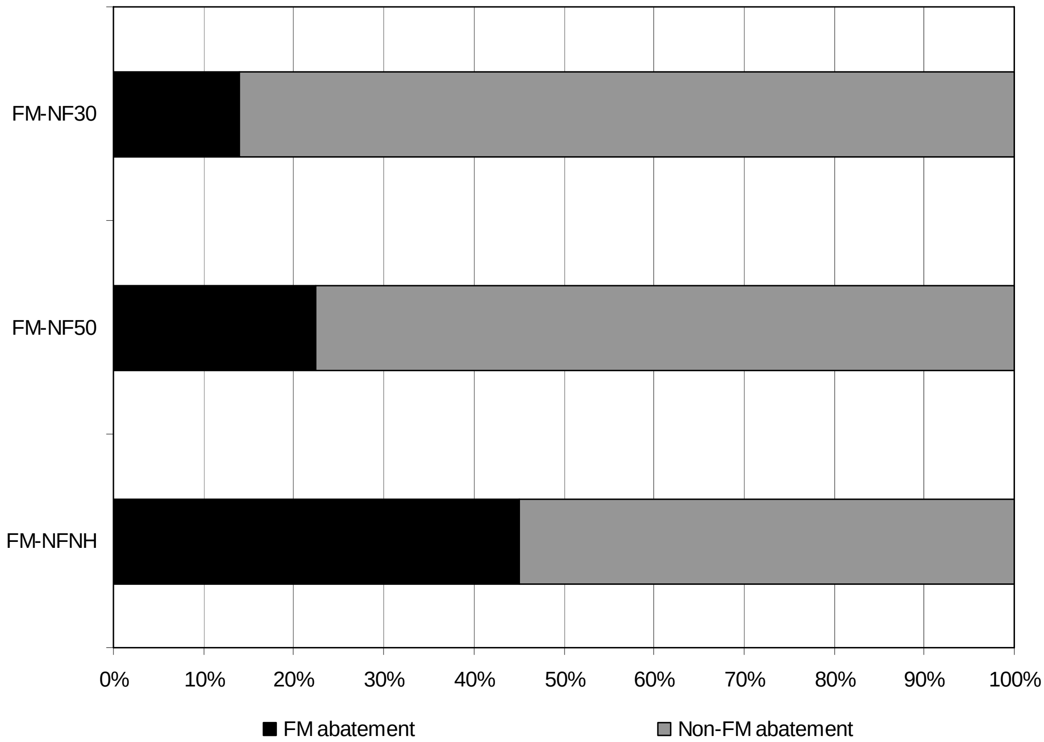
Table 1 Mean annual credits from reduced native forest harvesting, 2013-2020

Scenario	Average annual credits (Mt CO_2-e yr^{-1}) over the period 2013-2020
FM-NF30	11.94
FM-NF50	19.06
FM-NFNH	38.40

These results suggest that reducing the harvesting of native forests could generate a substantial quantity of credits. Keeping native forest harvesting at 2010 levels throughout the projection period would generate an average of 12 Mt CO_2-e yr^{-1} of credits, or 14% of Australia's cumulative abatement task (681 Mt CO_2-e) for the period 2013-2020 with a 5% mitigation target (Figure 2) (DOT, 2011). Reducing native forest harvesting to 50% below the 2002-2009 mean would generate 19 Mt CO_2-e yr^{-1} of credits, 22% of Australia's cumulative abatement task. Stopping native forest harvesting altogether would yield 38 Mt CO_2-e yr^{-1} of credits, almost half (45%) of the 2013-2020 abatement task.

While theoretical abatement potential from reducing native forest harvesting is large, the critical policy question is whether it is the most cost-effective way of achieving Australia's mitigation target. Answering this question is beyond the scope of this paper. Further research is required to evaluate the abatement cost of reducing native forest harvesting, a task that should include consideration of the 'co-benefits' of forest conservation (e.g. biodiversity, hydrological and cultural heritage benefits).

Figure 2 Theoretical abatement from reduced native forest harvesting as a percentage of Australia's cumulative abatement task for the period 2013-2020 with a 5% mitigation target



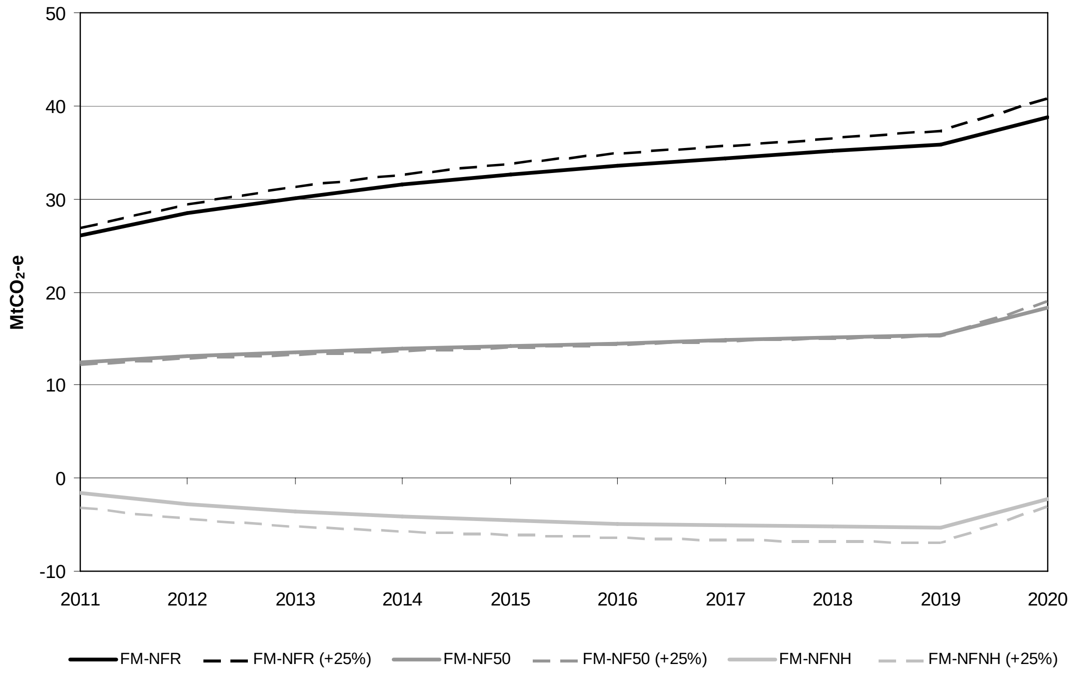
Source: DOT (2011), Australian Government (2011c), author estimates.

3.2 Lower and higher yield increment rates

Higher live biomass growth rates will generally result in higher onsite biomass. Where plots are harvested, this produces higher harvest emissions, all things being equal. In an estate that has high biomass growth rates and a mix of harvest and non-harvest plots, the increased harvest emissions produced by the high growth rates are likely to be partially offset by increased biomass growth on non-harvest plots. These trends are demonstrated in the results from the sensitivity analysis scenarios with modified above-ground biomass yield increment rates.

Figure 3 shows the results under the FM-NFR, FM-NF50 and FM-NFNH scenarios, both with the base case yield increment rates and +25% rates. In the FM-NFR scenario, emissions are higher with the higher yield increments. In the FM-NFNH scenario, there are fewer removals in the base case than with the higher yield increment rates. Under the FM-NF50 scenario, the higher increments make little difference due to the offsetting effects of higher emissions and higher growth.

Figure 3 Carbon stock change (live biomass, debris, harvested wood product pools) in FM-NFR, FM-NF50 and FM-NFNH scenarios, with base case and +25% above-ground live biomass yield increment rates, Mt CO_2-e yr^{-1}, 2011-2020



The net effect of the lower (-25%) and higher (+25%) yield increment rates on the credits generated by reducing native forest harvesting are shown in Table 2.

Table 2 Estimated credits from reduced native forest harvesting, with base case, -25% and +25% above-ground live biomass yield increment rates

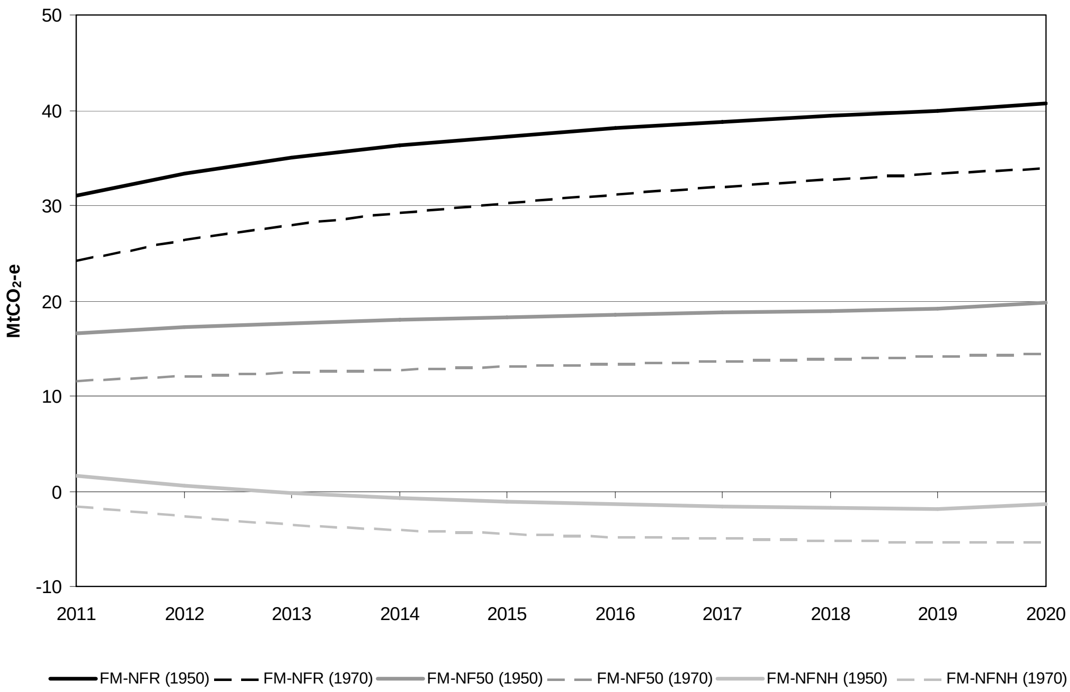
Scenario	Average annual credits (Mt CO_2-e yr^{-1}) over the period 2013-2020
FM-NF30 (-25%)	11.09
FM-NF30*	11.94
FM-NF30 (+25%)	12.79
FM-NF50 (-25%)	17.64
FM-NF50*	19.06
FM-NF50 (+25%)	20.48
FM-NFNH (-25%)	35.56
FM-NFNH*	38.40
FM-NFNH (+25%)	41.25

* Base case.

3.3 Younger and older forests subject to harvest

The effect of changing the age-class distribution of the forests is effectively the same as altering the biomass yields. All things being equal, younger forests contain less biomass and have higher biomass growth rates than older ones. Therefore, if the forest estate is younger than expected, the emissions from harvest will be less and *vice versa*. This is shown in Figure 3, which contains the outputs from the FM-NFR, FM-NF50 and FM-NFNH scenarios with estate simulation start dates of 1950 and 1970. In the FM-NFR and FM-NF50 scenarios, net emissions are lower when the estate simulation commences in 1970 (younger estate) than when it commences in 1950 (older estate). In the FM-NFNH scenarios, the effect of the higher biomass growth rates is evident; removals are larger in the 1970 estate than in the 1950 estate.

Figure 4 Carbon stock change (live biomass, debris, harvested wood product pools) in FM-NFR, FM-NF50 and FM-NFNH scenarios, with 1950 and 1970 estate simulation start dates, Mt CO_2-e yr^{-1}, 2011-2020



The net effects of the modified estate simulation start dates on the credits generated by reducing native forest harvesting are shown in Table 3.

Table 3 Estimated credits from reduced native forest harvesting, with 1950, 1960 (base case) and 1970 estate simulation start dates

Scenario	Average annual credits (Mt CO_2-e yr^{-1}) over the period 2013-2020
FM-NF30 (1950)	12.25
FM-NF30 (1960)*	11.94
FM-NF30 (1970)	11.23
FM-NF50 (1950)	19.57
FM-NF50 (1960)*	19.06
FM-NF50 (1970)	17.88
FM-NFNH (1950)	39.44
FM-NFNH (1960)*	38.40
FM-NFNH (1970)	36.04

* Base case.

3.4 Combined results

Table 4 shows the results from the FM-NFR, FM-NF30, FM-NF50, and FM-NFNH scenarios, with the sensitivity analysis scenarios providing the margin of error. The low range estimates were derived using a 1970 estate simulation start date and above-ground live biomass yield increment rates that are 25% below the base case. The high range estimates were derived using a 1950 estate simulation start date and biomass yield increment rates that are 25% above the base case.

Table 4 Estimated potential credits from reduced harvesting in native forests

Scenario	Average annual credits (Mt CO_2-e yr^{-1}) over the period 2013-2020
FM-NF30	11.94* (10.56 – 13.18)
FM-NF50	19.06* (16.75 – 21.12)
FM-NFNH	38.40* (33.79 – 42.54)

* Base case.

3.5 Reality check of the results

To test the robustness of the methods used to generate these results, and by extension those employed by the Australian Government in reporting on C fluxes from native forests, the modelled representative native eucalypt forest plots (i.e. tall dense eucalypt forest, medium dense eucalypt forest and medium sparse eucalypt forest) were run with *FullCAM* until they reached an old growth (or senescent) state (assumed to be 200 years). This was taken to represent the ‘carbon carrying capacity’ of the plots; or the mass of carbon they are able to store without human disturbance

(Mackey et al., 2008). To estimate the carbon carrying capacity of Australia's eucalypt forests that are, or have been, subject to harvest, these modified representative old growth plots were allocated across the 'Harvested Native Forest' estate in accordance with the forest area data reported in the *National Inventory Report 2009* (Australian Government, 2011c). To evaluate how the carbon carrying capacity of the derived eucalypt forest estate compares to real world data, the results from Mackey et al. (2008) were used. Table 5 contains the comparison.

Table 5 Carbon carrying capacity of biomass pools in native eucalypt forests that are, or have been, subject to harvest, Australian Government vs. Mackey et al. (2008)

	Estate area (M ha)	Live biomass	Debris	Total biomass
***National Inventory Report* eucalypt forest plots**				
Total C stock (Mt C)	12.0	3281	903	4184
Mean C stock ha^{-1} (t C ha^{-1})	NA	274	75	350
Mackey et al. (2008) *Green Carbon* Report				
Total C stock (Mt C)	14.5	4191	1029	5220
Mean C stock ha^{-1} (t C ha^{-1})	NA	289	71	360
% diff. in mean C stock ha^{-1}	**NA**	**5%**	**-6%**	**3%**

Source: Australian Government (2011b; 2011c); Mackey et al. (2008).

The Mackey et al. (2008) study calculated the carbon carrying capacity of eucalypt forests in south-eastern Australia, covering a study area of 14.5 M ha. The eucalypt forest estate generated here includes eucalyptus forests in other jurisdictions, most notably Western Australia, and it is smaller than the study area from Mackey et al. (2008) (12.0 M ha). Notwithstanding these differences, the results are remarkably similar, with the Mackey et al. (2008) estimates of the mean carrying capacity of the live biomass and debris pools being 5% above and 6% below the equivalent estimates derived from the Australian Government's plot files. The difference in the estimates of total mean biomass carrying capacity is a mere 3%. The closeness of these estimates provides increased confidence in the results of this study and the methods used by the Australian Government to estimate C stocks and fluxes in native eucalypt forests. It should be emphasised, however, that uncertainty remains about a number of key issues, including general C dynamics in native forests, the characteristics of the forests that are subject to harvest, and the silviculture practices that are employed in these and other areas.

4. Conclusion

The object of this paper was to estimate the credits that could be generated under the proposed new FM accounting regime by reducing native forest harvesting. This was undertaken using the methods employed by the Australian Government to set its proposed FM reference level. The exception is in relation to harvested wood products, where a Tier 1 method was used because of the unavailability of the Government's model.

The results suggest that Australia could generate an average of 12 Mt CO_2-e yr^{-1} (±1 Mt CO_2-e yr^{-1}) of credits over the period 2013-2020 by keeping native forest harvesting at 2010 levels, some 30% below the mean from 2002 to 2009. Reducing native forest harvesting to 50% below the 2002-2009 mean would generate 19 Mt CO_2-e yr^{-1} (±2 Mt CO_2-e yr^{-1}) of credits between 2013-2020, while stopping it altogether would produce 38 CO_2-e yr^{-1} (±4 Mt CO_2-e yr^{-1}). FM credits of this magnitude would constitute a significant proportion of Australia's abatement task to 2020. For example, the credits generated under the FM-NF30 scenario constitute 14% of Australia's estimated cumulative abatement task (681 Mt CO_2-e) for the period 2013-2020 with a 5% mitigation target. The credits generated under the FM-NFNH scenario, where there is no harvesting of native forests, represent almost half (45%) of the 2013-2020 abatement task.

These results are subject to three important caveats. First, there is a significant degree of uncertainty associated with the models and data that have been relied on in this study. Particular attention should be drawn to the estimated net harvested wood product emissions, where the default Tier 1 method was used. The Australian Government's harvested wood products model could generate different results, most likely reducing the credits generated by reducing native forest harvesting.

Second, in estimating the credits that could be generated by reducing native forest harvesting, the study excluded harvest emissions associated with private native forestry outside of Tasmania. Between 2002 and 2009, average annual roundwood removals from these areas were 880,448 m^3 yr^{-1} (ABARES, 2011c). The inclusion of the emissions associated with these log removals would increase the credits available from reducing native forest harvesting.

Third, this study has looked at the theoretical abatement potential from reducing native forest harvesting. This does not imply that reducing native forest harvesting is necessarily a cost-effective way of achieving Australia's mitigation target. Further research is required to evaluate this issue.

Appendix A Key parameters used in FM-R, FM-NF30, FM-NF50, FM-NFNH

Table A1 Above-ground biomass yield increment rates dmt ha^{-1} yr^{-1}

Forest type	Est. 1-10 yrs	Juvenile 11-30 yrs	Immature 31-100 yrs	Mature 101-200 yrs	Senescent >200 yrs
Tall dense eucalypt forest (TDEF)	12.658	8.668	4.383	1.455	0
Medium dense eucalypt forest (MDEF)	8.377	5.532	1.956	0.356	0
Medium sparse eucalypt forest (MSEF)	0.475	0.475	0.475	0.475	0
Cypress pine forest (CPF)	0.494	0.494	0.494	0.494	0

Table A2 Partitioning of biomass to tree components

Forest type	Fraction of biomass allocated to					
	Stems	Branch	Bark	Leaves	Coarse roots	Fine roots
TDEF	0.55	0.12	0.10	0.03	0.17	0.03
MDEF	0.50	0.15	0.12	0.03	0.17	0.03
MSEF	0.47	0.15	0.12	0.03	0.20	0.03
CPF	0.47	0.15	0.12	0.03	0.20	0.03

Table A3 Carbon fraction of biomass

Tree component	% C
Stem	52
Branch	47
Bark	49
Leave	52
Coarse roots	49
Fine roots	46

Table A4 Turnover percentages

Tree component	Turnover % yr^{-1}
Stem	No turnover
Branch	5
Bark	7
Leave	50
Coarse roots	10
Fine roots	85

Table A5 Partitioning of turnover between decomposable and resistant debris pools

Tree component	Decomposable %	Resistant %
Stem	10	90
Branch	15	85
Bark	10	90
Leave	70	30
Coarse roots	55	45
Fine roots	70	30

Table A6 Decomposition rates for debris pool

Debris component	Breakdown % yr^{-1}	
	Decomposable	Resistant
Deadwood	4.5	4.5
Bark litter	50	50
Leaf litter	80	80
Coarse dead roots	40	10
Fine dead roots	100	100

Table A7 Initial tree conditions dmt ha^{-1}

Forest type	Age-class	Stems	Branch	Bark	Leaves	Coarse roots	Fine roots
TDEF	31-100	209.7	45.7	38.1	11.4	64.8	11.4
TDEF	101-200	421.4	92.0	76.6	23.0	130.3	23.0
TDEF	>200	517.7	113.0	94.1	28.2	160.0	28.2
TDEF	Unknown	239.9	52.3	43.6	13.1	74.2	13.1
MDEF	31-100	124.9	37.5	30.0	7.5	42.5	7.5
MDEF	101-200	214.7	64.4	51.5	12.9	73.0	12.9
MDEF	>200	240.6	72.2	57.7	14.4	81.8	14.4
MDEF	Unknown & 3 aged	139.7	41.9	33.5	8.4	47.5	8.4
MSEF	Unknown & 3 aged	11.7	3.7	3.0	0.75	5.0	0.7
MSEF	>200	58.3	18.6	14.9	3.7	24.8	3.7
CPF	Unknown & 3 aged	12.2	3.9	3.1	0.8	5.2	0.8

Table A8 Initial debris conditions t C ha^{-1}

Forest type	**TDEF**		**TDEF**		**TDEF**		**TDEF**	
Age-class	**31-100**		**101-200**		**>200**		**Unknown**	
Decomposable (D) & Resistant (R)	**D**	**R**	**D**	**R**	**D**	**R**	**D**	**R**
Deadwood	5.19	29.39	8.05	45.63	11.13	63.04	5.14	29.13
Bark litter	0.26	2.38	0.55	4.94	0.68	6.12	0.31	2.79
Leaf litter	1.36	0.58	2.77	1.19	3.41	1.46	1.57	0.67
Coarse dead roots	2.21	7.61	4.65	17.14	5.77	22.20	2.62	9.12
Fine dead roots	0.38	0.16	0.77	0.33	0.95	0.41	0.44	0.19
Forest type	**MDEF**		**MDEF**		**MDEF**		**MDEF**	
Age-class	**31-100**		**101-200**		**>200**		**Unknown & 3 aged**	
Decomposable (D) & Resistant (R)	**D**	**R**	**D**	**R**	**D**	**R**	**D**	**R**
Deadwood	3.75	21.24	5.81	32.9	7.24	41.03	3.89	22.02
Bark litter	0.21	1.87	0.37	3.33	0.42	3.76	0.24	2.16
Leaf litter	0.89	0.38	1.55	0.66	1.74	0.75	1.01	0.43
Coarse dead roots	1.45	4.88	2.61	9.74	2.96	11.44	1.69	5.90
Fine dead roots	0.25	0.11	0.43	0.19	0.48	0.21	0.28	0.12
Forest type	**MSEF**		**MSEF**		**CPF**			
Age-class	**Unknown & 3 aged**		**>200**		**Unknown & 3 aged**			
Decomposable (D) & Resistant (R)	**D**	**R**	**D**	**R**	**D**	**R**		
Deadwood	0.51	2.87	1.71	9.71	0.53	3.00		
Bark litter	0.02	0.19	0.11	0.97	0.02	0.20		
Leaf litter	0.09	0.04	0.45	0.19	0.09	0.04		
Coarse dead roots	0.17	0.59	0.89	3.35	0.18	0.62		
Fine dead roots	0.03	0.01	0.12	0.05	0.01	0.01		

Appendix B FM-R plot types and assumed annual harvest rates

Plot file*	Area (ha)	Plot file*	Area (ha)
Cypress pine PH NPW	6279	MDEF unknown age PH NPW	3482
MDEF 31-100 CF NPW	52	MDEF unknown age PH PW TAS	10555
MDEF 31-100 CF PW	463	MDEF unknown age PH PW WA NSW	15893
MDEF 31-100 PH NPW	290	MDEF unknown age PH PW WA	1467
MDEF 31-100 PH PW TAS	880	MSEF PH NPW	8748
MDEF 31-100 PH PW WA NSW	1324	MSEF senescent PH NPW	2187
MDEF 31-100 PH PW WA	122	TDEF 31-100 CF NPW	91
MDEF 31-100_non_com_thin	4839	TDEF 31-100 CF PW	820
MDEF mature CF NPW	103	TDEF 31-100 PH NPW NSW	255
MDEF mature CF PW	926	TDEF 31-100 PH PW NSW	613
MDEF mature PH NPW	580	TDEF 31-100 PH PW VIC	235
MDEF mature PH PW TAS	1759	TDEF 31-100 PH PW WA	54
MDEF mature PH PW WA NSW	2649	TDEF mature CF NPW	46
MDEF mature PH PW WA	245	TDEF mature CF PW	410
MDEF senescent CF NPW	52	TDEF mature PH NPW NSW	127
MDEF senescent CF PW	463	TDEF mature PH PW NSW	306
MDEF senescent PH NPW	290	TDEF mature PH PW WA	27
MDEF senescent PH PW TAS	880	TDEF senescent CF NPW	46
MDEF senescent PH PW WA NSW	1324	TDEF senescent CF PW	410
MDEF senescent PH PW WA	122	TDEF senescent PH NPW NSW	127
MDEF three aged CF NPW	206	TDEF senescent PH PW NSW	306
MDEF three aged CF PW	1853	TDEF senescent PH PW WA	27
MDEF three aged PH NPW	1161	TDEF unknown age CF NPW	729
MDEF three aged PH PW TAS	3518	TDEF unknown age CF PW	6564
MDEF three aged PH PW WA NSW	5298	TDEF unknown age PH NPW NSW	2037
MDEF three aged PH PW WA	489	TDEF unknown age PH PW NSW	4903
MDEF unknown age CF NPW	618	TDEF unknown age PH PW WA	430
MDEF unknown age CF PW	5558	**Total**	**103,237**

* Plot descriptions: forest type, age-class, partial harvest (PH) or clearfell (CF), pulpwood (PW) or no pulpwood (NPW), and state (if applicable).

Appendix C FM-NF50 plot types and assumed annual harvest rates

Plot file	Area (ha)	Plot file	Area (ha)
Cypress pine PH NPW	3139	MDEF unknown age CF PW	2779
MDEF 31-100 CF NPW	26	MDEF unknown age PH NPW	1741
MDEF 31-100 CF PW	232	MDEF unknown age PH PW TAS	5277
MDEF 31-100 PH NPW	145	MDEF unknown age PH PW WA NSW	7946
MDEF 31-100 PH PW TAS	440	MDEF unknown age PH PW WA	734
MDEF 31-100 PH PW WA NSW	662	MSEF PH NPW	4374
MDEF 31-100 PH PW WA	61	MSEF senescent PH NPW	1094
MDEF 31-100_non_com_thin	2419	TDEF 31-100 CF NPW	46
MDEF mature CF NPW	51	TDEF 31-100 CF PW	410
MDEF mature CF PW	463	TDEF 31-100 PH NPW NSW	127
MDEF mature PH NPW	290	TDEF 31-100 PH PW NSW	306
MDEF mature PH PW TAS	880	TDEF 31-100 PH PW VIC	117
MDEF mature PH PW WA NSW	1324	TDEF 31-100 PH PW WA	27
MDEF mature PH PW WA	122	TDEF mature CF NPW	23
MDEF senescent CF NPW	26	TDEF mature CF PW	205
MDEF senescent CF PW	232	TDEF mature PH NPW NSW	64
MDEF senescent PH NPW	145	TDEF mature PH PW NSW	153
MDEF senescent PH PW TAS	440	TDEF mature PH PW WA	13
MDEF senescent PH PW WA NSW	662	TDEF senescent CF NPW	23
MDEF senescent PH PW WA	61	TDEF senescent CF PW	205
MDEF three aged CF NPW	103	TDEF senescent PH NPW NSW	64
MDEF three aged CF PW	926	TDEF senescent PH PW NSW	153
MDEF three aged PH NPW	580	TDEF senescent PH PW WA	13
MDEF three aged PH PW TAS	1759	TDEF unknown age CF NPW	365
MDEF three aged PH PW WA NSW	2649	TDEF unknown age CF PW	3282
MDEF three aged PH PW WA	245	TDEF unknown age PH NPW NSW	1019
MDEF unknown age CF NPW	309	TDEF unknown age PH PW NSW	2452

TDEF unknown age PH PW WA	215	MDEF unknown age CF PW NH	2779
Cypress pine PH NPW NH	3139	MDEF unknown age PH NPW NH	1741
MDEF 31-100 CF NPW NH	26	MDEF unknown age PH PW TAS NH	5277
MDEF 31-100 CF PW NH	232	MDEF unknown age PH PW WA NSW NH	7946
MDEF 31-100 PH NPW NH	145	MDEF unknown age PH PW WA NH	734
MDEF 31-100 PH PW TAS NH	440	MSEF PH NPW NH	4374
MDEF 31-100 PH PW WA NSW NH	662	MSEF senescent PH NPW NH	1094
MDEF 31-100 PH PW WA NH	61	TDEF 31-100 CF NPW NH	46
MDEF 31-100_non_com_thin NH	2419	TDEF 31-100 CF PW NH	410
MDEF mature CF NPW NH	51	TDEF 31-100 PH NPW NSW NH	127
MDEF mature CF PW NH	463	TDEF 31-100 PH PW NSW NH	306
MDEF mature PH NPW NH	290	TDEF 31-100 PH PW VIC NH	117
MDEF mature PH PW TAS NH	880	TDEF 31-100 PH PW WA NH	27
MDEF mature PH PW WA NSW NH	1324	TDEF mature CF NPW NH	23
MDEF mature PH PW WA NH	122	TDEF mature CF PW NH	205
MDEF senescent CF NPW NH	26	TDEF mature PH NPW NSW NH	64
MDEF senescent CF PW NH	232	TDEF mature PH PW NSW NH	153
MDEF senescent PH NPW NH	145	TDEF mature PH PW WA NH	13
MDEF senescent PH PW TAS NH	440	TDEF senescent CF NPW NH	23
MDEF senescent PH PW WA NSW NH	662	TDEF senescent CF PW NH	205
MDEF senescent PH PW WA NH	61	TDEF senescent PH NPW NSW NH	64
MDEF three aged CF NPW NH	103	TDEF senescent PH PW NSW NH	153
MDEF three aged CF PW NH	926	TDEF senescent PH PW WA NH	13
MDEF three aged PH NPW NH	580	TDEF unknown age CF NPW NH	365
MDEF three aged PH PW TAS NH	1759	TDEF unknown age CF PW NH	3282
MDEF three aged PH PW WA NSW NH	2649	TDEF unknown age PH NPW NSW NH	1019
MDEF three aged PH PW WA NH	245	TDEF unknown age PH PW NSW NH	2452
MDEF unknown age CF NPW NH	309	TDEF unknown age PH PW WA NH	215

* Plot descriptions: Same as in Appendix B, only NH indicates the file is a ‘no harvest’ file (the corresponding harvest file has the same plot name without NH).

References

Ajani J (2007). *The Forest Wars*. Melbourne University Press, Melbourne.

Ajani J (2008). Australia's Transition from Native Forests to Plantations: The Implications for Woodchips, Pulpmills, Tax Breaks and Climate Change. *Agenda* 15(3), 21-38.

Ajani J (2011). *Australia's Wood and Wood Products Industry Situation and Outlook – Working Paper*. Australian National University Fenner School of Environment and Society, Canberra.

Australian Bureau of Agricultural and Resource Economics and Sciences (2011a). *Australian Forest and Wood Products Statistics*. Australian Government, Canberra.

Australian Bureau of Agricultural and Resource Economics and Sciences (2011b). *Australian Commodity Statistics 2010*. Australian Government, Canberra.

Australian Bureau of Agricultural and Resource Economics and Sciences (2011c). *Australian Private Native Forestry Roundwood Removals – unpublished data*. Australian Government, Canberra.

Australian Government (2011a). Securing a Clean Energy Future: The Australian Government's Climate Change Plan. Australian Government, Canberra.

Australian Government (2011b). *Submission to the SBI and SBSTA: Forest Management Reference Level Submission*. UNFCCC Secretariat, Bonn, Germany.

Australian Government (2011c). *National Inventory Report 2009*. Australian Government, Canberra.

Brack C, Richards G, Waterworth R (2006). Integrated and comprehensive emissions estimation for greenhouse gases. *Sustain. Sci.* 1, 91-106.

Department of Treasury (DOT) (2011). *Strong Growth, Low Pollution: Modelling a Carbon Price*. Australian Government, Canberra.

Eggleston S, Buendia L, Miwa K, Ngara T, Tanabe K (Eds.) (2006). *2006 IPCC Guidelines for National Greenhouse Gas Inventories*. Institute for Global Environmental Strategies, Japan.

Food and Agriculture Organization (FAO) (2011). *FAOSTAT database*. http://www.fao.org/forestry/databases/29420/en/ (27 July 2011).

Liberal Party of Australia (LPA) and National Party of Australia (NPA) (2010). *The Coalition's Direct Action Plan: Environment & Climate Change*. LPA and NPA, Canberra.

Macintosh A (2011). LULUCF in the post-2012 regime: fixing the problems of the past? *Climate Policy* (in press).

Mackey B, Keith H, Berry S, Lindenmayer D (2008). *Green Carbon: The Role of Natural Forests in Carbon Storage*. ANU E-Press, Canberra.

Montreal Process Implementation Group (MPIG) (2008). *Australia's State of the Forests Report: Five-yearly Report 2008*. Australian Government, Canberra.

Richards G, Borough C, Evans D, Reddin A, Ximenes F, Gardner D (2007). Developing a carbon stocks and flows model for Australian wood products. *Australian Forestry* 70(2), 108-119.

Richards G, Brack C (2004). A modelled carbon account for Australia's post-1990 plantation estate. *Australian Forestry* 67(4), 289-300.

Richards G, Evans D (2004). Development of a carbon accounting model (FullCAM vers. 1.0) for the Australian continent. *Australian Forestry* 67(4), 277-283.

Roxburgh S, Wood S, Mackey B, Woldendorp G, Gibbons P (2006). Assessing the carbon sequestration potential of managed forests: a case study from temperate Australia. *Journal of Applied Ecology* 43, 1149-1159.

[This page has intentionally been left blank]

ANU Centre for Climate Law and Policy
ANU College of Law
The Australian National University
Canberra ACT 0200
Ph: 61 2 6125 3832

http://law.anu.edu.au/CCLP/