Submission
No 79

INQUIRY INTO CLIMATE CHANGE (NET ZERO FUTURE) BILL 2023

Organisation: North East Forest Alliance Inc

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North East Forest Alliance Submission to: Climate Change (Net Zero Future) Bill 2023

Dailan Pugh, North East Forest Alliance Inc, October 2023

It is good to see NSW legislating to cutting greenhouse gas emissions by at least 50% by 2030 and reaching net zero by 2050, and establishing a Net Zero Commission. The trouble is that its not enough and is not happening fast enough. Climate heating is already wreaking havoc on our environment and communities, as exemplified by the 2019/20 fires and 2022 floods. The Great Barrier Reef is teetering on the brink of extinction, over a third of north-east NSWs World Heritage rainforests were burnt in fires of unprecedented extent and intensity, millions of trees are dying in droughts and numerous species being eliminated from extensive lands as their temperature thresholds are being exceeded. There can be no doubt that we are in the midst of a climate and extinction crisis that demands urgent and meaningful action.

It is not enough just to manage emissions. We need to immediately increase the removal of carbon from the atmosphere. Forests already remove a third of our emissions each year, though their ability to fulfil this service is being increasingly compromised as forests continue to be cleared and logged, while suffering from increasing fires, droughts and pest outbreaks. There is now a real danger that many forests will stop performing their vital role as carbon sinks and become carbon sources, ruining our chances of limiting climate heating even with some distant goal of net zero.

It is clear that we need to urgently start restoring the integrity of forests, and stop logging them and increasing their vulnerability to droughts and fires. If we increase their sequestration of CO2 they have the ability to make a vital and immediate difference to NSW's carbon accounts.

Native forest logging in New South Wales emits around 3.6 million tonnes of carbon each year, equivalent to the annual emissions of 840,000 cars. In north-east NSW, when a tree is logged around two thirds is left in the forest (roots, stumps, tree heads), with larger logs taking decades to decompose. Of that removed most ends up as sawdust or short-lived products, with at best 12.8% ending up in longer lived hardwood timber products with various carbon retention times of 15 years to over 100 years (where buried in landfill). The removal of some 400,000 m^3/annum of logs from north-east NSW's public forests results in the quick emission of 820,000 tonnes of CO_2 per annum from tree biomass, and the creation of legacy emissions of 700,000 tonnes of CO_2 per annum that will be released over decades as logs left in the forest decay and wood used in buildings reach the end of its useful life**.** Legacy emissions from the past continue.

Avoided emissions is one benefit of stopping logging, the greatest benefit comes from allowing regenerating forests to recover their lost carbon from the atmosphere. The carbon stored in logged forests has more than halved, with repeated logging keeping it below this level. Just by stopping logging the growing trees can slowly regain their lost carbon, a single 100 year old tree (100 cm diameter) can store as much carbon as 270x10 year old trees (10 cm diameter). The bigger they get, the more carbon they sequester and store, with a 150 cm diameter tree storing as much carbon as 724x10cm diameter trees. Allowing degraded forests to regain their carbon carrying capacity is one of the most important immediate climate actions we can take.

For the 502,200ha of loggable State Forests in north-east NSW (north from the Hunter River) the application various estimates of the carbon sequestration potential of logged forests indicate the ability of recovering State forests to sequester in the order of 3.2 to 8.6 million tonnes of CO2 per annum. While accurate figures are warranted, it is apparent that if logging of State forests in north-east NSW is stopped, the recovering forests can immediately begin sequestering a significant volume of CO_2 and make a significant and necessary contribution to NSW's carbon accounts. Which would be significantly enhanced if landholders were paid stewardship payments for the volumes of carbon their forests store.

Saving forests is climate action. The need to protect them is urgent.

The carbon sequestration value of stopping logging.

Vast areas of remnant native forests have had their carbon storage in trees, logs, litter and soils dramatically reduced by logging and ringbarking, with their carbon released into the atmosphere to add to the growing problem of global heating. The degraded carbon stores in logged forests now represent an opportunity to remove significant volumes of carbon from the atmosphere and store it back in the recovering forest. Significant emissions can also be avoided by ceasing logging and the continuing running down of forest carbon stores.

Using the forests to generate carbon credits will generate greater aggregate net benefits to the community than logging. The avoidance of emissions by retaining trees, and their ongoing carbon sequestration, provides a higher benefit to the people of NSW than logging them. Protecting forests is an essential part of the solution to climate change and generates the greatest economic benefit to the people of NSW.

Loss of carbon from deforestation and degradation has contributed 35% of the accumulated anthropogenic carbon dioxide concentration in the atmosphere, and annually is around 10% of global anthropogenic emissions (Keith et. al. 2015). In Australia, an estimated 44% of the carbon stock in temperate forests has been released due to deforestation (Wardell-Johnson *et. al.* 2011), with stocks further reduced by around 50% in logged forests (Mackey *et. al.* 2008, Moomaw *et. al.* 2019).

The Intergovernmental Panel on Climate Change (IPCC 2018), identifies that to limit global heating to 1.5ºC or even 2ºC the world needs to slow global emissions immediately and reach net zero carbon dioxide (CO_2) emissions by around 2050. Even then we need to remove copious quantities of carbon from the atmosphere. The IPCC (2018) identify:

> *All pathways that limit global warming to 1.5°C with limited or no overshoot project the use of carbon dioxide removal (CDR) on the order of 100–1000 $GtCO_2$ over the 21st century. CDR would be used to compensate for residual emissions and, in most cases, achieve net negative emissions to return global warming to 1.5°C following a peak (high confidence).*
> *...*
> *Model pathways that limit global warming to 1.5°C with no or limited overshoot project the conversion of 0.5–8 million km^2 of pasture and 0–5 million km^2 of non-pasture agricultural land for food and feed crops into 1–7 million km^2 for energy crops and a 1 million km^2 reduction to 10 million km^2 increase in forests by 2050 relative to 2010 (medium confidence). Land use transitions of similar magnitude can be observed in modelled 2°C pathways (medium confidence).*

Goldestein *et. al.* (2020) warn:

> *Given that emissions have not slowed since 2017, as of 2020, this carbon budget will be spent in approximately eight years at current emissions rates. Staying within this carbon budget will require a rapid phase-out of fossil fuels in all sectors as well as maintenance and enhancement of carbon stocks in natural ecosystems, all pursued urgently and in parallel.*

With the urgent need to sequester carbon from the atmosphere we should be managing our forests as carbon sinks. As Mackey *et. al.* (2008) conclude;

> *The remaining intact natural forests constitute a significant standing stock of carbon that should be protected from carbon-emitting land-use activities. There is substantial potential for carbon sequestration in forest areas that have been logged commercially, if allowed to regrow undisturbed by further intensive human landuse activities*

Vast areas of remnant native forests have had their carbon storage in trees, logs, litter and soils dramatically reduced by logging and ringbarking, with their carbon released into the atmosphere to add to the growing problem of global heating. The degraded carbon stores in logged forests now represent an opportunity to remove significant volumes of carbon from the atmosphere and store it

back in the recovering forest. Significant emissions can also be avoided by ceasing logging and the continuing running down of forest carbon stores.

Allowing forests to recover and regain their lost carbon is termed proforestation. It is a significant and essential part of the measures needed to limit global warming to 1.5 ^{o} or 2^{o} C. There are vast areas of forest in various states of degradation and regrowth that have the potential to rapidly increase their carbon sequestration and storage just by stopping cutting them down. Moomaw *et. al.* (2019) note:

In sum, proforestation provides the most effective solution to dual global crises – climate change and biodiversity loss. It is the only practical, rapid, economical and effective means for atmospheric carbon dioxide removal among the multiple options that have been proposed because it removes more atmospheric carbon dioxide in the immediate future and continues to sequester it into the long-term future. Proforestation will increase biodiversity of species that are dependent on older and larger trees and intact forests and provide numerous additional and important ecosystem services (Lutz et al., 2018). Proforestation is a very low-cost option for increasing carbon sequestration that does not require additional land beyond what is already forested and provides new forest related jobs and opportunities along with a wide array of quantifiable ecosystem services, including human health.

The big advantage of proforestation is that there is no waiting, the forests are already growing and absorbing more carbon as they age, we just need to let them do their thing and we can start the process of reducing atmospheric carbon. But we need to start now. As identified by Keith *et. al.* (2014b):

> *Avoiding emissions from forest degradation and allowing logged forests to regrow naturally are important activities for climate change mitigation. The former prevents further increases, and the latter helps reduce atmospheric concentrations of carbon dioxide. This kind of rapid response over the next few decades is important to allow time for technological advances in renewable energy sources that will hopefully eliminate the need for fossil fuel use (Houghton 2012).*

Houghton and Nassikas (2018) assessed the potential to take up the equivalent of 47% of global CO_2 emissions just by stopping clearing and degrading native vegetation, identifying "*the current gross carbon sink in forests recovering from harvests and abandoned agriculture to be -4.4 PgC/year, globally. The sink represents the potential for negative emissions if positive emissions from deforestation and wood harvest were eliminated*".

Houghton and Nassikas (2018) conclude that:

> *... negative emissions are possible because ecosystems are below their natural carbon densities as a result of past land use. That is, potential negative emissions are directly coupled to past positive emissions. There is nothing magical about these negative emissions. They simply restore carbon lost previously. The corollaries of this conclusion are (i) that negative emissions will diminish as forests recover to their undisturbed state (negative emissions will only work for a few decades) and (ii) that much of that recovery will have occurred before 2100, according to these simulations.*

Sohngen and Sedjo (2004) consider:

> *If incentives are provided to increase the stock of carbon, land owners may shift their management regimes from providing timber outputs to providing carbon sequestration. Some of the adjustments can occur relatively quickly, for example, by holding trees longer than the economically optimal rotation age, or stopping deforestation. Other adjustments, however, may occur over longer time periods, such as replanting agricultural land to trees.*

One means of payment for carbon sequestration is based on the 'rental concept' where "*carbon temporarily stored can be paid while it is stored, with no payments accruing when it is no longer stored*" (Sohngen and Sedjo 2004). Though Sohngen and Sedjo (2004) propose a variation where a price for a ton of abatement is paid in the year in which it occurs and a tax is paid in the year in which the emission occurs, considering "*The price of a ton of carbon sequestered or the tax on carbon emitted in any given year is the marginal cost of energy abatement*".

From their economic assessment in the United States Lubowski *et. al.* (2006) considered various levels of subsidy/tax payments, finding "*When a $100 per acre subsidy/tax is introduced, forest area almost doubles during the simulation period, from 405 to 754 million acres*", and concluding:

> *... if emission reductions in the United States on the scale proposed under the Kyoto Protocol were to be achieved entirely through domestic actions (forest-based sequestration and/or energy-based abatement activities) and with the type of policy incentive considered in this paper, our analysis implies that 33% to 44% of the reductions could be met cost-effectively through forest-based sequestration.*

It is relevant that Lubowski *et. al.* (2006) found "*lower marginal costs of carbon sequestration when timber harvesting is prohibited on lands enrolled in the carbon sequestration program. Marginal costs fall because the additional present value costs of enrolling lands on which harvesting is prohibited are more than outweighed by the additional present value carbon sequestered*", and because the restrictions on harvesting increase timber prices creating incentives for other landholders to retain their forests.

Luyssaert *et. al.* (2008) identify that one of the failings of the Kyoto Protocol is that only anthropogenic effects on ecosystems are considered, resulting in the perversion that "*15% of the global forest surface, which is currently not being considered for offsetting increasing atmospheric CO_2 concentrations, is responsible for at least 10% of the global NEP*". Considering that

> *The present paper shows that old-growth forests are usually carbon sinks. Because old-growth forests steadily accumulate carbon for centuries, they contain vast quantities of it. They will lose much of this carbon to the atmosphere if they are disturbed, so carbon-accounting rules for forests should give credit for leaving old-growth forest intact.*

Moomaw *et. al.* (2019) consider "*Private forest land owners might be compensated to practice proforestation, for sequestering carbon and providing associated co-benefits by letting their forests continue to grow*".

North East NSW's Carbon Sequestration Benefits

Roxburgh *et.al.* (2006) and Mackey *et. al.* (2008) advocate an approach to assessing the carbon stocks of native forests based on the Carbon Carrying Capacity of oldgrowth forest. Mackey *et. al.* (2008) consider that for reliable carbon accounts two kinds of baseline are needed;

> *1) the current stock of carbon stored in forests; and*
> *2) the natural carbon carrying capacity of a forest (the amount of carbon that can be stored in a forest in the absence of human land-use activity). The difference between the two is called the carbon sequestration potential—*
>
> > *the maximum amount of carbon that can be stored if a forest is allowed to grow given prevailing climatic conditions and natural disturbance regimes*

Oldgrowth forests thus provide the baseline of how much carbon remnant forests used to contain before the European invasion and the past 230 years of accelerating degradation. The difference between original carbon volumes and current volumes, is the volume that degraded remnant forests are capable of recovering from the atmosphere if allowed to grow old in peace. Mackey *et. al.* (2008) consider:

> *Once estimates of the carbon carrying capacity for a landscape have been derived, it is possible to calculate a forest's future carbon sequestration potential. This is the difference between a landscape's current carbon stock (under current land management) and the carbon carrying capacity (the maximum carbon stock when undisturbed by humans).*

Average Carbon Carrying Capacity of the Eucalypt Forests of South-eastern Australia. (from Mackey *et. al.* 2008)

Carbon component	Soil	Living biomass	Total biomass	Total carbon
Total carbon stock for the region (Mt C)	4,060	4,191	5,220	9,280
Carbon stock ha^{-1} ($t\ C\ ha^{-1}$)	280 (161)	289 (226)	360 (277)	640 (383)

Carbon stock per hectare is represented as a mean and standard deviation (in parentheses), which represents the variation in modelled estimates across the region. The study region covers an area of 14.5 million ha.

Proforestation has the potential to take-up and store a significant proportion of NSW's annual carbon emissions. The Commonwealth of Australia (2019) give NSW emissions for 2016/17 as 131.5 million tonnes $CO_{2\text{-}e}$ (carbon dioxide equivalent) with stationary energy (which generates heat and electricity) the largest contributing sector. NSW's emissions represent 25% of Australia's total emissions.

To obtain an indication of the carbon sequestration potential of proforestation of north-east NSW's forests the methodology of Mackey *et. al.* (2008) was applied. This makes it clear that allowing north-east NSW's forests to recover from past logging can make a significant contribution to redressing NSW's CO_2 emissions.

The North-east NSW RFA regions, north from the Hunter River, total 8.5 million ha, of which 1,472,000 hectares is national parks and nature reserves and 838,000 hectares is State Forests. Some 278,000 ha of State Forests is classed as FMZ 1, 2 and 3A and taken to be informal reserves. native forests in various stages of degradation, with 127,000 hectares of plantations. Around half the national parks and the informal reserves were protected either as an outcome of the Regional Forest Agreement process in 1998 or the Forest Icon decision in 2003, so significant parts had previously been logged.

Oldgrowth forests best approximates those forests that have not been significantly affected by logging or other disturbances such as intense wildfire, though many of these areas survived as oldgrowth because they are steep and low productivity forests (i.e. with relatively low carbon volumes). The last assessment of oldgrowth forests was for the Regional Forest Agreements, so can only be considered current as at around 1997. This identifies 1.3 million hectares of old growth forest in that part of the North East RFA region north from the Hunter River. There has been no assessment of how much of the 462,000 ha of rainforest identified in the RFA is oldgrowth,

North East NSW (CRA Regions - north from Hunter River) broad forest structure as mapped at 1998 according to current tenure, note that growth-stage mapping was primarily limited to eucalypt and Brush Box dominated forests and excluded rainforest, melaleuca forests and non-forest communities.

GROWSTAGE	National Park (ha)	State Forest Informal Reserve (ha)	State Forest General Logging (ha)	Other tenures (ha)	**TOTALS (ha)**
Rainforest	263,504	81,491	2,862	114,227	462,084
Candidate Old Growth	720,120	120,347	49,674	419,075	1,309,216
Other Forests	348,306	61,298	452,516	1,508,017	2,370,136
TOTALS	1,331,930	263,136	505,052	2,041,318	4,141,436

Based on the CRA data from 20 years ago, around 2.3 million ha (64%) of remnant eucalypt forests had then been logged (or otherwise degraded) and had significantly reduced carbon storage below original carrying capacity. Since then it can be expected that most of the oldgrowth forest in the general logging area on State Forests has been logged, along with significant areas of oldgrowth forest on private lands, though it also needs to be considered that a large proportion of oldgrowth remaining at that time had survived because it was low-productivity forest on poor soils and steep slopes.

Based on environmental and cultural heritage data generated by the NSW Office of Environment & Heritage for the *Biodiversity Conservation Act 2016* and the *Local land Services Act 2013,* DPI (2018) identify old growth forest as a regulatory constraint covering 139,542ha of private land in the north-east NSW RFA area, which is considerably less than mapped in 1998. It is assumed that some of this difference is because of changes in thresholds for mapping and protecting old growth forests on private lands, and because of logging since 1998.

DPI (2018) identify the total area native forests in private ownership in the whole of the North East RFA regions (which is a larger area than the figures cited above) as 2.8 million ha of native forests, with the union of all regulatory exclusion categories (including oldgrowth) covering 734,992 ha, or 25.6%, of the total area of private native forest on the NSW north coast. Application of this constraint to the above growth stage data for "other" lands suggests that over 1,500,000 ha of degraded private forests are available for logging have carbon sequestration potential.

Commonwealth of Australia (2019) give NSW emissions in 2016/17 as 131.5 million tonnes CO_{2-e} (carbon dioxide equivalent) with stationary energy (which generates heat and electricity) the largest contributing sector. NSW's emissions represent 25% of Australia's total emissions.

Based on the carbon carrying capacity data provided in Mackey *et. al.* (2008), proforestation has the potential to take-up and store a significant proportion of NSW's annual carbon emissions. Previously logged and otherwise disturbed forests incorporated into north-east NSW's existing formal and informal reserves decades ago are likely currently taking up the equivalent of 3.6% of NSW's annual CO_2 emissions. If logging of north-east NSW's State Forests were stopped tomorrow they would immediately begin sequestering in the order of 6.5% of NSW annual emissions, and by stopping logging there would be additional benefits in avoided emissions. Given the urgency of the climate emergency the phase-out needs to start immediately.

Area of degraded eucalypt and Brush Box Forest with carbon sequestration potential in north east NSW, note this is only indicative though shows the magnitude of benefits that will accrue over time from protecting forests.

	Areas of degraded forests	Total Carbon Carrying Capacity[1] (t C)	Current Carbon Stock[2]	Carbon Sequestration Potential	Carbon Dioxide Sequestration Potential[3]	Annual Sequestration potential[4]	% of NSW Annual Emissions[5]
Protected, National parks and informal reserves	409,600	262144000	191365120	70778880	2597584906	4727605	3.6
Loggable State Forests	502,200	321408000	192844800	128563200	471826944	8587250	6.5
Loggable Private Lands	1,500,000	960000000	576000000	384000000	1409280000	25648896	19.5
TOTALS	2,411,800	1543552000	926131200	617420800	2265934336	41240005	29.6

1. An average of 640 t per ha is taken as the potential Carbon Carrying Capacity
2. Assumed that Carbon Carrying Capacity in degraded forests has been reduced by 40% (Mackey *et. al.* 2008), except in reserve areas which were protected at various times, particularly over the period 1982 until 2003, with the majority being protected in 1998, to account for the time since protection it was assumed for this exercise that they had already regained a third of their lost carrying capacity resulting in a current deficit of 27% of capacity.
3. Application of conversion factor of 3.67 for tonnes of carbon to tonnes of carbon dioxide equivalent
4. Conversion factor of 0.0182 t CO_2 yr^{-1} (for 100 years) to identify annual avoided emissions (Mackey *et. al.* 2008)
5. Based on NSW emissions in 2016/17 of 131.5 million tonnes CO_2-e (carbon dioxide equivalent) (Commonwealth of Australia 2019).

The biggest gains in sequestration, up to some19.5% of NSW's annual emissions, would come from assisting private landholders in north-east NSW to protect their forests. It is recommended that to encourage landholders to manage their forests for carbon sequestration and storage, whether in soils or vegetation, those storing above average volumes of carbon should receive annual payments proportional to the volume stored at that time and the ecosystem benefits (i.e. threatened species habitat) it provides. This will recompense landholders for providing a public benefit and be an incentive for increasing storage.

For NEFA's proposed Sandy Creek Koala Park (south of Casino in the Richmond Valley) we assessed current biomass and carbon stocks by measuring 75 plots in logged forests on 10 transects, and the proforestation carbon carrying potential from 12 plots on two transects in similar unlogged forests'. For these medium site quality Spotted Gum forests we identified that past logging had reduced live biomass (above and below ground) from 454 tonnes/ha down to 190 tonnes/ha, a reduction of 265 tonnes/ha. This represents 132 tonnes of carbon per hectare and is the volumes recoverable over time if the forest was left to mature.

	Aboveground biomass		Belowground biomass		Total biomass	
	Biomass (t/ha)	Carbon (tC/ha)	Biomass (t/ha)	Carbon (tC/ha)	Biomass (t/ha)	Carbon (tC/ha)
Unlogged	363	182	91	45	454	227
Logged	152	76	38	19	190	95
Reduction	211	106	53	26	265	132

Estimates of biomass and carbon volumes per hectare within the logged forests of the proposed Sandy Creek Koala Park, compared to an unlogged control site in Banyabba State Forest. Note that this excludes dead standing trees and logs, so is an under-estimation.

NEFA also applied annual growth rates derived from south-east Queensland to NEFA's plot data to identify indicative carbon sequestration volumes per hectare if the forests were allowed to grow for 30 years. This gave a carbon sequestration rate of 1.75 tonnes per hectare per annum over 30 years, totalling 52.6 tonnes of carbon per hectare by 2050.

	Aboveground biomass		**Belowground biomass**		**Total biomass**	
	Biomass (t/ha)	Carbon (tC/ha)	Biomass (t/ha)	Carbon (tC/ha)	Biomass (t/ha)	Carbon (tC/ha)
Current	151.6	75.8	37.9	19.0	189.5	94.8
Increase by 2050	84.3	42.2	21.1	10.5	105.4	52.6
Average annual increase	2.81	1.41	0.70	0.35	3.51	1.75

Estimates of Carbon sequestration potential from application of growth rates derived from Ngugi *et. al.* (2015) to plot data for the proposed Sandy Creek Koala Park (dead standing trees and logs omitted)

This provides an indication of the carbon sequestration potential of medium site quality Spotted Gum forest that has been subject to repeated logging operations in the past, if protected from further logging. Sequestering 1.75 tC/ha a year is equivalent to 6.42 tonnes of CO_2/ha per annum, or 193 tonnes of CO_2/ha by 2050. The total recoverable over 100 years is 484 tonnes of CO2/ha.

The starting point of the degraded forest is 95 tC/ha of living biomass, which is equivalent to 349 tonnes of CO_2/ha. If a landholder agrees to permanently protect this (in an environmental zone or by covenant), or if it is already protected, it should also be recognized as part of a protected carbon bank and a proportion of its carbon value paid to the landholder on a regular basis.

It needs to be recognised that Spotted Gum forests grow slowly compared to many other forest types, so these figures represent the lower bounds of those achievable. This estimate for Spotted Gum of 6.42 tonnes of CO_2/ha per annum is significantly less than the 17.1 tonnes of CO_2/ha per annum derived from Mackey *et. al.* (2008). There could be a variety of reasons for these differences, particularly the relatively small size and volumes of trees left in these forests and lower growth rates, such that it is considered that the sequestration volumes identified by Mackey *et. al.* (2008) could be obtained in more productive forest types. Thus for illustrative purposes a range of potential carbon sequestration of 6.4 – 17.1 tonnes of CO_2/ha per annum is assumed for logged over forests in north-east NSW.

For the 502,200ha of loggable State Forests in north-east NSW the application of these variations indicate the ability of recovering State forests to sequester in the order of 3.2 to 8.6 million tonnes of

CO_2 per annum. While accurate figures are warranted, it is apparent that if logging of State forests in north-east NSW is stopped, the recovering forests can immediately begin sequestering a significant volume of CO_2 and make a significant contribution to NSW's carbon accounts. Which would be significantly enhanced if landholders were paid stewardship payments for the volumes of carbon their forests store.

Other Australian Assessments of Carbon Benefits of Protecting Forests

There have been a variety of Australian studies undertaken on the costs and benefits of managing forests for carbon sequestration that consistently find that the greatest net benefit comes from stopping logging.

For their assessment of existing and potential carbon stocks in south-east Australia, including north-east NSW, Mackey *et. al.* (2008) found;

> *Our analyses showed that the stock of carbon for intact natural forests in south-eastern Australia was about 640 t C ha^{-1} of total carbon (biomass plus soil, with a standard deviation of 383), with 360 t C ha^{-1} of biomass carbon (living plus dead biomass, with a standard deviation of 277).*
>
> *...*
>
> *The highest biomass carbon stocks (more than 1500 t C ha^{-1}) are in the mountain ash (Eucalyptus regnans) forest in the Central Highlands of Victoria*
>
> *...*
>
> *Using our figures, the total stock of carbon that can be stored in the 14.5 million ha of eucalypt forest in our study region is 9.3 Gt, if it is undisturbed by intensive human land-use activity and allowed to reach its natural carbon carrying capacity ... Note that while our model estimates the average total carbon stock of natural eucalypt forests at 640 t C ha^{-1}, real site values range up to 2500 t C ha^{-1}. This range reflects the natural variability found across landscapes in the environmental conditions and disturbance regimes that affect forest growth.*

Average Carbon Carrying Capacity of the Eucalypt Forests of South-eastern Australia. (from Mackey *et. al.* 2008)

Carbon component	Soil	Living biomass	Total biomass	Total carbon
Total carbon stock for the region (Mt C)	4060	4191	5220	9280
Carbon stock ha^{-1} (t C ha^{-1})	280 (161)	289 (226)	360 (277)	640 (383)

Carbon stock per hectare is represented as a mean and standard deviation (in parentheses), which represents the variation in modelled estimates across the region. The study region covers an area of 14.5 million ha.

Oldgrowth forests thus provide the baseline of how much carbon remnant forests used to contain before the European invasion and the past 230 years of accelerating degradation. The difference between original carbon volumes and current volumes, is the volume that degraded remnant forests are capable of recovering from the atmosphere if allowed to grow old in peace. Mackey *et. al.* (2008) consider:

> *Once estimates of the carbon carrying capacity for a landscape have been derived, it is possible to calculate a forest's future carbon sequestration potential. This is the difference between a landscape's current carbon stock (under current land management) and the carbon carrying capacity (the maximum carbon stock when undisturbed by humans).*

From their assessment Mackey *et. al.* (2008) concluded:

> *The carbon carrying capacity of the 14.5 million ha of eucalypt forest in our study area is about 9 Gt C (equivalent to 33 Gt CO_2). About 44 per cent of the area has not been logged and can be considered at carbon carrying capacity, which represents about 4 Gt C (equivalent to 14.5 Gt CO_2). About 56 per cent of the area has been logged, which means these forests are substantially below their carbon carrying capacity of 5 Gt C. If it is assumed that logged forest is, on average, 40 per cent below carbon carrying capacity (Roxburgh et al. 2006), the current carbon stock is 3 Gt C (equivalent to 11 Gt CO_2). The total current carbon stock of the 14.5 million ha is 7 Gt C (equivalent to 25.5 Gt CO_2). If logging in native eucalypt forests was halted, the carbon stored in the intact forests would be protected and the degraded forests would be able to regrow their carbon stocks to their natural carbon carrying capacity. Based on the assumptions above, the carbon sequestration potential of the logged forest area is 2 Gt C (equivalent to 7.5 Gt CO_2).*

The other key attribute is the rate at which carbon is sequestered by vegetation, which governs how quickly the carbon can be removed from the atmosphere. Mackey *et. al.* (2008) note:

> *Gross primary productivity (GPP) is the annual rate of carbon uptake by photosynthesis. Net primary productivity (NPP) is the annual rate of carbon accumulation in plant tissues after deducting the loss of carbon dioxide by autotrophic (plant) respiration (Ra). This carbon is used for production of new biomass components—leaves, branches, stems, fine roots and coarse roots—which increments the carbon stock in living plants. Mortality and the turnover time of carbon in these components vary from weeks (for fine roots), months or years (for leaves, bark and twigs) to centuries (for woody stem tissues). Mortality produces the dead biomass components that provide the input of carbon to the litter layer and soil through decomposition. ...*
>
> *The proportion of carbon uptake used for biomass production is represented by the ratio of NPP:GPP.*
>
> *...*
>
> *Our analyses (Table 1) showed that the stock of carbon for intact natural forests in our study area is about 640 t C ha_{-1} and the average NPP of natural forests is 12 t C ha^{-1} yr^{-1} (with a standard deviation of 1.8). In terms of global biomes, Australian forests are classified as temperate forests. The IPCC default values for temperate forests are a carbon stock of 217 t C ha^{-1} and an NPP of 7 t C ha^{-1} yr^{-1}.*

For their assessment of south-east Australia, Mackey *et. al.* (2008) adopted the conversion that every 1 t CO_2 stored (for 55 year) is equivalent to 0.0182 t CO_2 yr^{-1} (for 100 years) of avoided emissions, finding that:

> *Our analysis shows that in the 14.5 million ha of eucalypt forests in south-eastern Australia, the effect of retaining the current carbon stock (equivalent to 25.5 Gt CO_2 (carbon dioxide)) is equivalent to avoided emissions of 460 Mt CO_2 yr^{--1} for the next 100 years. Allowing logged forests to realize their sequestration potential to store 7.5 Gt CO_2 is equivalent to avoiding emissions of 136 Mt CO_2 yr^{--1} for the next 100 years. This is equal to 24 per cent of the 2005 Australian net greenhouse gas emissions across all sectors; which were 559 Mt CO_2 in that year.*

In Tasmanian wet-eucalypt forests Dean *et. al.* 2012 found:

> *Over the last two decades, the majority of forest C destined for short- or long-term emission (LTE, i.e. over several centuries and multiple harvests) was from clearfelling the higher-biomass wet-eucalypt forests on public land. ... The first cycle of conversion of primary-forests contributed 43(±5)% to the LTE, and the LTE constituted ~50% of the primary-forest C stock. Whether the first logging of even-aged primary-forests was prior to or after maturity, the LTEs were equivalent, although short-term emissions (STEs) were ~2× higher from old-growth.*

Tables 3a and b from Dean *et. al.* 2012:

Table 3a
Comparison of [long-term average] C stocks and changes for Site-1 (even-aged *E. regnans*, mixed-forest) with an ensuing sequence of 80-yr harvesting cycles.

	Primary-forest C (long-term average) (Mg ha^{-1})	Harvesting cycle (long-term average) (Mg ha^{-1})	Δ (Mg ha^{-1})	Δ (%)
Total-C	1246	595	−651	−52%
Biomass	549	150	−399	−72%
SOC	627	326	−301	−48%
Necromass (forest debris)	67	45	−22	−33%
Wood-products	0	70	70	–

Half-lives: SOC 550 years, sawlog 40 years, pulpwood 2 years (including mill residues).

Table 3b
Comparison of [long-term average] C stocks and changes for Site-2 (uneven-aged, wet-sclerophyll) with an ensuing sequence of 15-yr plantation harvesting cycles.

	Primary-forest (long-term average) (Mg ha^{-1})	Harvesting cycle (long-term average) (Mg ha^{-1})	Δ (Mg ha^{-1})	Δ (%)
Total-C	127	37	−90	−71%
Biomass	121	17	−104	−86%
Necromass (forest debris)	2.4	2.2	−0.2	−9%
Wood-products	0	18	18	–

Total does not include SOC. Half-lives: pulpwood 1.73 years, fibreboard 9.55 years, mill residue 0.2 years.

Perkins and Macintosh (2013) undertook an economic analysis to compare the net financial benefits from harvesting NSW's Southern Forest Region's (SFR's) native forests with those produced by conserving the forests and generating carbon credits, finding that *"using the forests to generate carbon credits will generate greater aggregate net benefits than harvesting".* They note:

> *The analysis in this paper suggests that, in the absence of a rebound in relevant wood product prices (especially the export woodchip price), continued harvesting in the SFR is likely to generate substantial aggregate net losses over the next 20 years. In the core harvest scenario (H1), the combined net financial benefits generated by the Forestry Corporation of NSW and the SFR's private hardwood processors over the period 2014-2033 were estimated at between -$40 million and -$77 million. These losses would be borne by the Forestry Corporation of NSW and SEFE; the sawmills are projected to produce a small positive net financial benefit over the projection period. This is mainly because the Forestry Corporation of NSW and SEFE's operations subsidise SFR hardwood sawmilling.*
>
> *Stopping harvesting and using the native forests of the SFR to generate carbon credits offers a viable alternative to commercial forestry. In the core no-harvest scenario (CC1, method 1), it was estimated that the New South Wales government could earn 33.8 million ACCUs over the period 2014-2033 (an average of 1.7 million per year). The net financial benefits that could be generated through the sale of these credits (accounting for transaction and management costs) were estimated at $222 million. The Australian government would also receive the benefit of 12.8 million residual FM credits from the cessation of harvesting in the SFR over the period 2014-2033. However, if the New South Wales government receives ACCUs, the financial benefits to the Australian government are likely to be relatively small as lost company tax revenues associated with ceasing harvesting would largely cancel out the financial benefits received from the residual FM credits.*
>
> *Overall, the analysis supports two general conclusions:*
>
> - *under current and likely future market conditions, the harvesting and processing of native logs in the SFR is likely to generate substantial losses; and*
> - *the aggregate net financial benefits are likely to be significantly higher if commercial harvesting is stopped and the native forests of the SFR are used to generate carbon credits.*

Macintosh *et. al.* (2015) conducted life-cycle assessments of Green House Gasses (GHG) in the NSW Southern Forestry Region (SFR), a commercial public native forest estate covering almost 430,000 ha, comparing ongoing logging and woodchipping (sustainable use) with stopping logging (conservation), finding:

> *The results of the basic scenarios suggest conservation will produce significantly better GHG outcomes than sustainable use over the projection period, with cumulative abatement of 57-75Mt of CO2-equivalent emissions (MtCO2e; Fig. 1). The greater emissions from the*

sustainable use scenario are attributable to the high proportion of biomass left on the forest floor after harvesting and the low percentage of roundwood assigned to long-lived wood products.

...

With the scope of inquiry confined to impacts on national net emissions, conservation of the SFR generated 79-85MtCO2e of cumulative abatement over the projection period relative to the sustainable use reference case, 10-21MtCO2e above the equivalent results from the basic scenarios (Fig. 3).

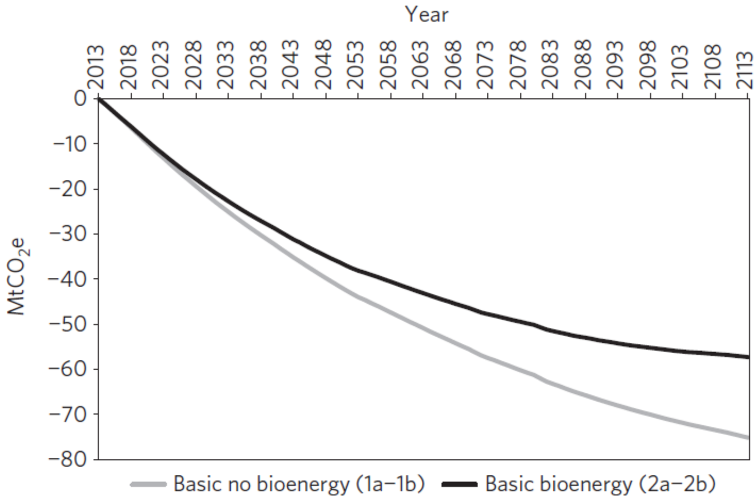

Fig 1 from Macintosh *et. al.* (2015). Basic scenarios—difference between the sustainable use reference case and the conservation scenario as cumulative net GHG emissions. Net emissions were calculated as the net flux difference (emissions less removals) between the sustainable use reference case and the conservation scenario. Negative net emissions occur when net emissions in the conservation scenario are less than those in the sustainable use reference case (abatement).

Macintosh *et. al.* (2015) considered a variety of timber substitution scenarios, assuming if harvesting ceased in the SFR, most of the substitutes for the foregone sawnwood products are likely to be imported or derived from domestic plantations, with Japan likely obtaining equivalent woodchips from eucalypt plantations in Vietnam. They found that if sawnwood timber substitution comes from Australian or New Zealand plantations then there was still a net benefit from a conservation outcome, though if substitution comes from Indonesian rainforests the sustainable use scenario had a net carbon benefit.

Keith *et. al.* (2014b) assessed the effects of logging on Mountain Ash forests in Victoria, demonstrating:

... that the total biomass carbon stock in logged forest was 55% of the stock in old growth forest. Total biomass included above- and below ground, living and dead. ... Reduction in carbon stock in logged forest was due to 66% of the initial biomass being made into products with short lifetimes (,3 years), and to the lower average age of logged forest (,50 years compared with .100 years in old growth forest). Only 4% of the initial carbon stock in the native forest was converted to sawn timber products with lifetimes of 30–90 years.

...

Only the sawn timber products and dead and downed woody debris remaining on-site had mean residence times in the order of decades

...

We estimated that continued logging under current plans represented a loss of 5.56 Tg C over 5 years in the area logged (824 km^2), compared with a potential gain of 5.18–6.05 TgC over 5 years by allowing continued growth across the montane ash forest region (2326 km^2)

...

As a logging system averaged spatially across the landscape with areas at different times since logging, the average carbon stock was 37% of the initial stock. The maximum carbon *stock at age 50 years was 44% of the initial stock. After a single logging event, accumulation of carbon took 250 years to regain the initial stock.*

Table 2 from Keith *et. al.* (2014b): Current carbon stock in living and dead biomass components for different age classes of montane ash forest (mean ± SE; n = 6).

	Biomass carbon stock (tC/ha)			
Forest age	Living trees	Standing dead trees	Woody debris† + litter	Total
1983 regrowth	293 ± 43	34 ± 8	78 ± 15	405 ± 33
1939 regrowth	426 ± 64	89 ± 31	88 ± 25	603 ± 74
Old growth	930 ± 41	41 ± 25	65 ± 9	1039 ± 44

† Woody debris refers to dead and downed woody debris.

Table 4. from Keith *et. al.* (2014b): Projected biomass carbon stocks in the montane ash forest study area (2326 km^2) estimated from the current carbon stock (CCS) in 2010; predictions for +20 years (2030), +50 years (2060), +100 years (2110) and +150 years (2160); and the carbon carrying capacity (CCC).

	Total biomass carbon stock (Mt C)‡					
Carbon accumulation method†	CCS	2030	2060	2110	2160	CCC
Eq. 1	113	133	162	196	221	204
Eq. 2	113	130	152	177	194	204

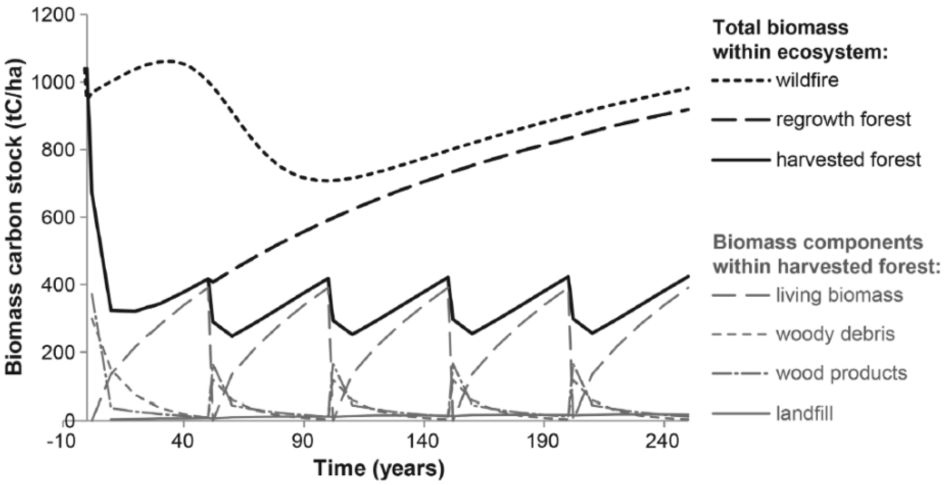

Fig. 10. from Keith *et. al.* (2014b): Changes in total biomass carbon stock of the ecosystem over time under three scenarios (shown as black lines) from an initial stock of a native forest: (1) wildfire that occurred at time 0 years and then the forest regenerated and dead biomass decomposed over time, (2) regrowth forest after logging once and regeneration, and (3) harvested forest under a regime of repeated logging rotations consisting of clearcutting and slash burning on a 50 year cycle

Keith *et. al.* (2014b) consider that older forests can have even greater carbon stocks:

> *Maximum carbon stock of living biomass occurs in old growth forests, such as our research sites dominated by approximately 250-year-old trees. However, old growth forests of* E.regnans *and other eucalypts can have maximum ages up to 400–500 years (Gilbert 1959, Ogden 1978, Wellington and Noble 1985, Banks 1993, Looby 2007, Wood et al. 2010), and so the maximum stock could be higher than our site values (Stephenson et al. 2014). Defining this asymptote is hampered by limited data for old forests.*

For south-east NSW and East Gippsland, Keith *et. al.* (2015) assessed "*two contrasting management scenarios: (i) harvested native forests, with options for accounting for the carbon storage in regrowth forest biomass, wood and paper products, landfill, and the carbon benefits of bioenergy substituted for fossil fuel energy, and (ii) conserved native forests, accounting for carbon storage in forest biomass, with options for accounting for substitution by non-native wood products.*" They "*demonstrated that changing native forest management from commercial harvesting to conservation can make an important contribution to climate change mitigation*", finding "*stopping harvesting results in an immediate and substantial reduction in net emissions*", and "*that the* *greatest mitigation benefit from native forest management, over the critical decades within the next 50 years, is achieved by protecting existing native forests*".

	Conservation forest			Harvested forest
	20 yrs	50 yrs	100 yrs	constant over time
Forest biomass	139	158	170	116
Products	-2.4	-6.0	-12.1	3.3
Landfill				6.5
Total	136.6	152.0	157.9	125.8
Difference due to scenarios (conservation—harvested)	10.8	26.2	32.1	
Difference due to sensitivity of parameter values	6.4	13.0	25.8	

Table 4 from Keith *et. al.* (2015). Change in carbon stocks (tC ha^{-1}) over the 20, 50 and 100 year simulation periods for scenarios of conservation forest with product substitution compared with harvested forest plus products and landfill in NSW South coast forest. The difference in carbon stock due to scenarios is compared with the sum of the differences due to parameter values.

	Conservation forest			Harvested forest
	20 yrs	50 yrs	100 yrs	constant over time
Forest biomass	444	566	719	340
Products	-7.0	-16.9	-33.5	9.2
Landfill				22.5
Total	437	549	685	372
Difference due to scenarios (conservation—harvested)	65	177	313	
Difference due to sensitivity of parameter values	10.6	21.7	35.0	

Table 5 from Keith *et. al.* (2015). Change in carbon stocks (tC ha^{-1}) over the 20, 50 and 100 year simulation periods for scenarios of conservation forest with product substitution compared with harvested forest plus products and landfill in Mountain Ash forest. The difference in carbon stock due to scenarios is compared with the sum of the differences due to parameter values.

Keith *et. al.* (2015) also considered the effects of a wildfire, recognising that they affect the carbon stocks of native forests, but "*result in relatively small fluctuations due to emissions, with the carbon stock regained within a decade through regeneration*", noting "*the biomass carbon stocks in conserved native forests on a landscape basis can be considered as a stable stock with the value fluctuating in response to natural disturbances around a long term mean. Additionally, evidence from the 2009 wildfire in the Mountain Ash forest showed that protected old-growth forests were less likely to burn at high severity*".

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