[redacted]

Name:

Dailan Pugh

Which of the following best describes your situation?

Not for profit organisation

Are you responding on behalf of an organisation or industry body?

Yes

Who are you responding on behalf of?

North East Forest Alliance

What are the opportunities to reduce emissions and build carbon stores in agriculture and the land? What are the main barriers to action?

Stop logging public native forests and incentivize landowners to protect native forests

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How can we progress emission reduction efforts whilst also building resilience and adapting to climate change?

By proforestation you can increase carbon sequestration and storage, increase forest's resilience to climate heating, decrease fire threat, enhance populations of threatened species, and increase streamflows

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Are there initiatives or innovative programs underway that could be applied or expanded on at a national scale?

Following the lead of Victoria, Western Australia and south-east Queensland by immediately stopping logging of public native forests

How can the Australian Government bring together existing effort and new initiatives into one coordinated plan?

By getting rid of Regional Forest Agreements and applying the EPBC Act to all forest regions

What are the most important options to be further adopted or supported, looking in the short and the longer-term?

Immediately stopping logging of public native forests, and providing incentives to private landholders to protect native forests

What are the practical solutions to increase uptake?

Proforestation - the protection of native forests to allow degraded forests to regain their lost carbon

How do you see the agriculture and land sectors contributing over the medium and longer-term? What are the opportunities to deliver emission reductions in parallel with wider goals?

Protecting forests is climate action, while helping address our biodiversity crisis, increasing stream flows, increasing rural amenity, and diversifying regional economies through tourism.

How can the Australian Government better support agriculture and land sectors to:

a) drive innovation

b) build capacity

c) ensure the system enables emissions reductions

Proforestation, protecting public native forests and providing incentives to landholders to protect theirs

What new initiatives could the Australian Government design that would support emissions reduction and carbon storage in agriculture and land and help ensure a productive, profitable, resilient and sustainable future for the sectors?

Proforestation, protecting public native forests and providing incentives to landholders to protect theirs. Identifying landscape scale corridors and encouraging rehabilitation of native vegetation and revegetation of gaps with locally endemic native species

A consistent and trusted approach for assessing and reporting emissions is often raised as a barrier to reducing emissions. Is there a role for the Australian Government in addressing this concern, and how can producers and land managers be supported?

Better satellite monitoring of terrestrial carbon storage in real time, for assessing changes over time and identifying where illegal clearing is occurring

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What skills, knowledge and capabilities do you think producers and land managers need to implement change? What information and data would help them make decisions about emissions reductions and sustainable land management in the short and longer-term?

The values and benefits of protecting and rehabilitating native vegetation

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Do you have any additional views or feedback that you would like to include in your response?

See submission

Is your response confidential?

No

Do you agree to your response being published on our website?

Yes

I have read and understood the privacy notice and consent to the collection, use and disclosure of my personal information as outlined in the privacy notice.

Yes

Confirm that you have read and understand this declaration.

Yes

North East Forest Alliance Submission to: Agriculture, land and emissions, Discussion paper

Dailan Pugh, December 2023

It is noted that the plan will focus on the emissions that come directly from activities on the land (known as scope 1 emissions), though this is too narrow a focus as it is essential it focusses on carbon storage and sequestration as a primary focus, particularly in relation to forestry. This is acknowledged in the statement that increasing carbon stored in the land is an important part of stabilising global temperatures, and that emissions and sequestration associated with the management of land, are accounted for under the land use, land use change, and forestry (LULUCF) sector of the NGA.

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.

This submission seeks to address the discussion paper request for views on advancing the opportunities to reduce emissions:

1. What are the most important options to be further adopted or supported, looking in the short and the longer-term?
2. What are the practical solutions to increase uptake?

Table 1 Carbon storage technologies and practices identifies

- Planting and seeding native trees for carbon storage and other benefits
- Managing land to allow native forest to regenerate

As you note more frequent and extreme weather events, together with changing seasonal conditions, are putting pressure on landscape health, which means that the carbon sequestration potential of native vegetation will continue to deteriorate and there is an increasing risk that native vegetation will deteriorate into net carbon sources. This emphasises the need for urgent action both to increase the CO_2 sequestration of native forests and to restore their health and vitality to beter cope with the challenges ahead.

While planting trees and allowing cleared land to regenerate will help in the long term, given the urgency of the situation, the most effective urgent action we can take is to stop logging public native forests, incentivise the protection of private forests, and allow them to begin re-capturing their lost carbon. Water availability is also recognised as an issue, while new plantings can reduce water yields for decades, in existing forests water yields increase with forest maturity, providing the double benefit of increasing both carbon storage and water yields.

Trees are our life support system, amongst the many benefits and services they provide us is their crucial role in the carbon cycle. Through the process of photosynthesis they use sunlight to process carbon dioxide from the air and water from the ground into carbohydrates for energy and structure.

In this process they remove carbon dioxide from the air, store carbon in their wood and provide us with oxygen to breathe.

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). With terrestrial ecosystems currently removing an amount of atmospheric carbon equal to one-third of what humans emit from burning fossil fuels (Moomaw *et. al.* 2019).

IEA identify that global CO_2 emissions from energy combustion and industrial processes reached their highest ever annual level in 2021 of 36.3 billion metric tonnes. Worldwide forests absorb 15.6 billion metric tonnes of CO_2 per year from the atmosphere, though through clearing, logging and other disturbances they also emit 8.1 billion metric tonnes of carbon dioxide (Harris *et. al.* 2021). It is clear that we depend on forests to remove the carbon we emit to avoid runaway climate heating.

It is well recognised that natural climate solutions are essential to draw down enough atmospheric CO_2 to give us a chance of limiting global heating to less than 1.5ºC, or even 2ºC (Sohngen and Sedjo 2004, Wardell-Johnson *et. al.* 2011, Keith *et. al.* 2015, Griscom *et. al.* 2017, Houghton and Nassikas 2018, Fargione *et. al.* 2018, IPCC 2018, Moomaw *et. al.* 2019, Goldestein *et. al.* 2020). Griscom *et. al.* (2017) consider that "*Forest pathways offer over two thirds of cost-effective NCS mitigation needed to hold warming to below 2ºC and about half of low-cost mitigation opportunities pathway*".

While ambitious reforestation and plantation projects have been launched, many have failed and all suffer from the problem of the lag between when they are conceptualised to when they begin sequestering significant volumes of atmospheric carbon (if ever). As observed by Moomaw *et. al.* (2019) "*newly planted forests require many decades to a century before they sequester carbon dioxide rapidly*". We cannot remove sufficient carbon by growing young trees during the critical next decade.

By comparison there are millions of hectares of existing native forests that have had their carbon stocks depleted by past logging, that still have substantial carbon stocks, and which can immediately begin to regain their lost carbon. Many scientists have attested to the significant role that protecting degraded forests (sometimes termed proforestation) can have in reducing atmospheric carbon on a global scale with the urgency required (Mackey *et. al.* 2008, Houghton and Nassikas 2018, Moomaw *et. al.* 2019, Mackey *et. al.* 2022). As stated by Moomaw *et. al.* (2019):

> *Proforestation serves the greatest public good by maximizing co-benefits such as nature-based biological carbon sequestration and unparalleled ecosystem services such as biodiversity enhancement, water and air quality, flood and erosion control, public health benefits, low impact recreation and scenic beauty.*
>
> *… 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.*

In 2018–19, NSW emitted around 141 million tonnes carbon dioxide equivalent (CO_2-e), which was partially offset by trees having the net effect of reducing total emissions by 5 million tonnes (3%) due to photosynthesis. The 2021 NSW State of the Environment Report considers the land use, land-use change and forestry (LULUCF) sector is currently considered a carbon 'sink' as it stores more carbon than it emits and thus reduces the state's emissions by 3%, while noting "*the sequestration by 'forest remaining forest' has halved*" since 2005, with "*a decline in the forest sink by around 14%*" relative to 2005, and warning that without further action the land sink is estimated to peak in 2022 as the "*forest land sink decreases*" (EPA 2021). Such statements are indicative of the value of forests as carbon sinks, their fragility, and the necessity of accounting for them in an open and transparent manner in carbon accounts (Mackey *et. al.* 2022).

Aside from permanent clearing, logging is by far the biggest threat to terrestrial carbon stores. Cutting down and bulldozing trees releases their stored carbon, with at best a small fraction stored in timber products with a life of a few decades. Within our logged forests the volumes of carbon stored have been halved and continue to decline as retained old trees die out, logging intensifies and return times become more frequent.

There have been a number of assessments of the carbon benefits of protecting public native forests in south-east Australia (Mackey *et. al.* 2008, Dean *et. al.* 2012, Perkins and Macintosh 2013, Keith *et. al.* 2014b, Macintosh *et. al.* 2015, Keith *et. al.* 2015). For their assessment of 14.5 million ha of eucalypt forests in south-eastern Australia, Mackey *et. al.* (2008) found that:

> *… 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.*

While all sorts of methodologies, parameters and offsets have been variously applied, the conclusions have been that it is in our best interests to stop logging public native forests. Recently Frontier Economics (2021) found stopping logging of public native forests in southern NSW would produce a net economic benefit to the state of approximately $60 million, while also reducing net greenhouse gas emissions by almost 1 million tonnes per year over the period 2022-2041, compared to logging.

It is particularly important at this crucial time in our climate crisis to recognise that we need to protect forests to get the rapid reductions in atmospheric carbon we need. As part of their review of national greenhouse gas inventories, Mackey *et. al.* (2022) found:

> *… the State of Tasmania delivered negative emissions due to a change in forest management—a large and rapid drop in native forest logging—resulting in a mitigation benefit of ~22 Mt CO_2-e yr^{-1} over the reported period 2011/12–2018/19. This is the kind of outcome required globally to meet the Paris Agreement temperature goal. All CO_2 emissions from, and atmospheric removals into, forest ecosystem carbon stocks now matter and should be counted and credited to achieve the deep and rapid cuts in emissions needed over the coming decades.*

Logging and clearing compound the impacts of climate heating in other ways. Clearing forests increases regional temperatures and reduces rainfalls, thereby increasing fire risk, which is worsened by fragmentation and edge effects. Logging forests dries and heats the microclimate, promotes flammable understorey vegetation, changes fuel arrays and increases the loss of water through transpiration to make forests more vulnerable to burning.

It is also relevant to consider that forests subject to logging are being progressively degraded, with the EPA (2021) identifying that State Forests have been reduced to only 30% of their original ecological carrying capacity for native species, while national parks have 63% of their original ecological carrying capacity remaining.

There is abundant evidence that numerous animal species prefer larger trees for increased resources, such as browse and nectar, and that many are dependent upon the hollows provided by the oldest trees. Hatanaka *et. al.* (2011) sought to measure the direct relationship between carbon and birds in Victorian forests aged from less than 5 years old to mature stands more than 100 years old, finding

> *Mature forest stands had the highest number of bird species, abundance and biomass, and the most distinctive bird assemblages compared with regrowth forest sites ... On average, there were 72% more species per stand in mature stands than in older regrowth (41–60 years). There also were 72% more individuals and a huge increase in bird biomass (176%).*

A significant part of the solution to the extinction and climate crises is to protect native forests from clearing and logging to avoid emissions and allow them to regain their carbon carrying capacity. This will provide immediate results as growing trees take up and store ever increasing volumes of carbon as they age. This will also increase water yields to streams. We can take immediate and meaningful action on climate heating just by stopping logging of public native forests and offering incentives to private landholders to protect theirs.

1. Proforestation

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 2º 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

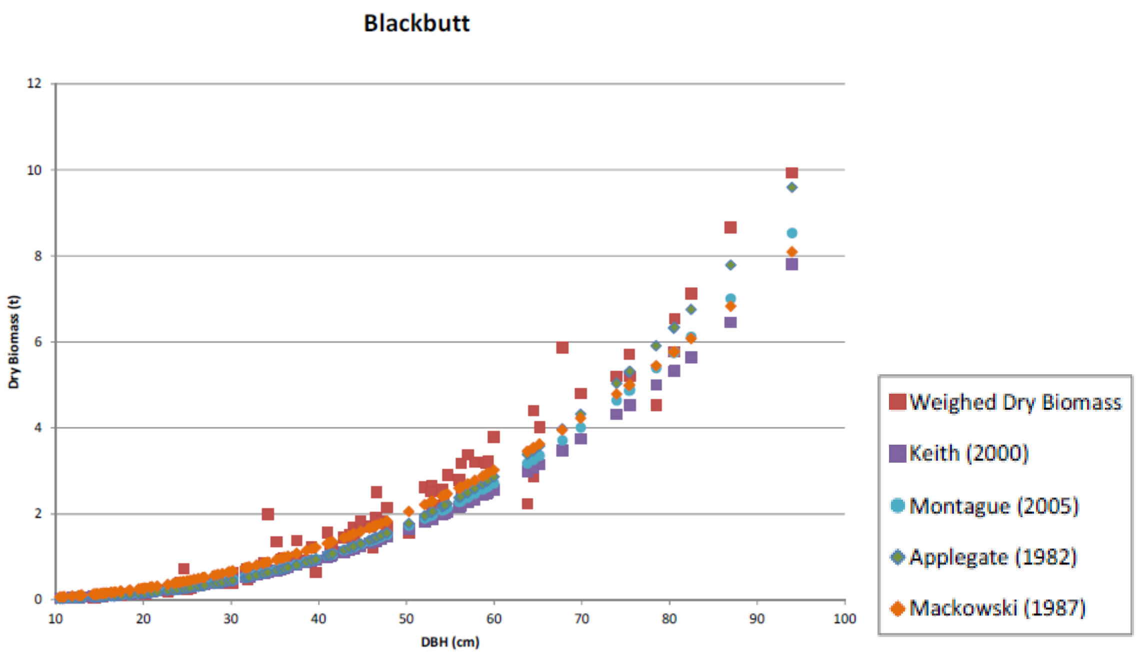
> *The present paper shows that old-growth forests are usually carbon sinks. Because old-growth forests steadily accumulate carbon for centuries, they contain vast quantities of it. They will lose much of this carbon to the atmosphere if they are disturbed, so carbon-accounting rules for forests should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

2. Forest's carbon storage.

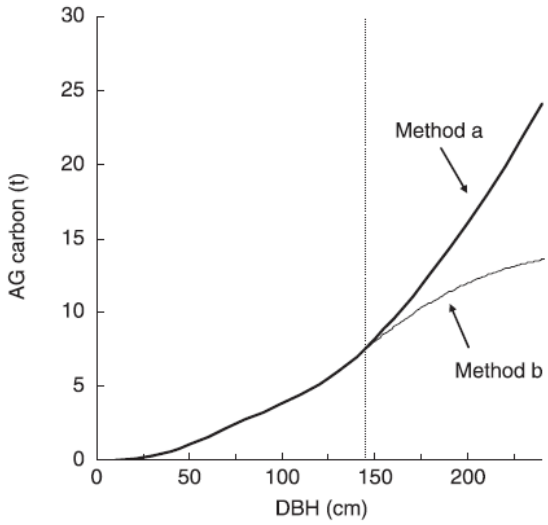
Native forests play a crucial role in the storage of carbon and the sequestration of carbon dioxide from the atmosphere, with oldgrowth forests maximising carbon storage while still continuing to sequester carbon.

As trees grow their biomass increases exponentially, sequestering ever increasing volumes of carbon and storing it in their trunks, branches and roots. As their leaves and branches decompose on the forest floor, some of the carbon returns to the atmosphere and some is stored in the soil. Underground, trees share carbon with mycorrhiza, spreading it through the soil, while both decaying mycorrhiza and roots enrich soil carbon and return some to the atmosphere. Tree's role in storing carbon can continue for decades after they die, as dead trees can take decades to collapse and downed logs decades to decompose.

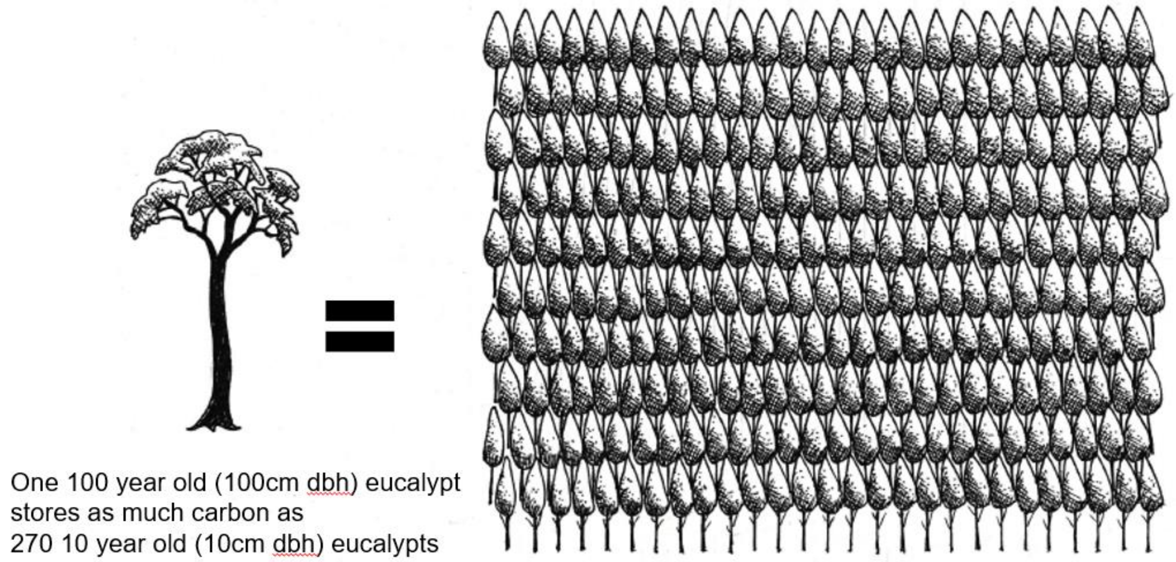


As trees grow their carbon storage increases exponentially. Figure 1.40. from Ximenes *et al.* (2016) showing the relationship for Blackbutt between DBH (diameter at breast height) and dry above ground biomass (tonnes), from their direct weighing compared to various biomass equations developed by other studies. Each tonne of dry biomass is equivalent to around half a tonne of carbon.

As trees age they sequester more carbon, with the volumes they store increasing exponentially, and along with this their annual rate of carbon sequestration. Far from being static carbon reservoirs, the biggest trees have also been found to sequester the most carbon (Zhou *et. al.* 2006, Sillett *et.al* 2010, Stephenson *et. al* 2014), with Stephenson *et. al* (2014) observing "*at the extreme, a single big tree can add the same amount of carbon to the forest within a year as is contained in an entire mid-sized tree".* For most trees once they reach old age internal decay can begin as they are hollowed out from within by termites and fungi. As very old trees shed branches, or loose canopy in storms, their rate of sequestration can decline.



Above-ground biomass/carbon relationship to tree diameter at breast height. From Roxburgh *et.al.* (2006). Method A assumes minimal internal tree decomposition. Method B allows for internal decay.



For example, a 10cm diameter (dbhob) Spotted Gum may have a biomass of 21kg, a 30cm diameter tree a biomass of 300 kg, a 100 cm diameter tree a biomass of 5,700 kg, and a 150 cm diameter tree a biomass of 15,200 kg (though in the older trees internal decay may begin reducing heart wood). With allowance for possibly 39% water content, and half the dry wood being carbon, a 100 cm diameter Spotted Gum may store 1.7 tonnes of carbon, with this increasing to a 150 cm diameter tree storing 4.6 tonnes of carbon. In carbon storage terms a 100cm diameter (100 year old) Spotted Gum will store the equivalent to 270x10 cm (10 year old) diameter trees, while a 150 cm diameter (say 200 year old) tree could store the equivalent of 724x10cm diameter trees.

Old growth forests are the most significant carbon storehouses, with most carbon stored in the oldest and biggest trees (Roxburgh *et.al.* 2006, Zhou *et. al.* 2006, Mackey *et. al.* 2008, Sillett *et.al* 2010, Dean *et. al.* 2012, Stephenson *et. al* 2014, Keith *et. al.* 2014b, Moomaw *et. al.* 2019). For many decades the prevalent myth was that forests over 100 years old stop accumulating carbon, based on the premise that as forests age the decrease in the volume of photosynthetic leaves relative to respiring sapwood results in a decline in net ecosystem production (NEP). This myth has been demonstrated to be wrong by numerous studies that have proven that forests continue to sequester carbon as they age (Harmon *et. al.* 1990, Carey *et. al.* 2001, Chen *et. al.* 2004, Falk *et. al.* 2004, Roxburgh *et.al.* 2006, Mackey *et. al.* 2008, Luyssaert *et. al.* 2008, Dean *et. al.* 2012, Keith *et. al.* 2014b, Curtis and Gough 2018), though the rate of sequestration may decline in some of the oldest forests (Carey *et. al.* 2001, Luyssaert *et. al.* 2008, Curtis and Gough 2018).

Luyssaert *et. al.* (2008) found "*Consistent with earlier studies, biomass continues to increase for centuries irrespective of whether forests are boreal or temperate*", speculating:

> *… when high above-ground biomass is reached, individual trees are lost because of lightning, insects, fungal attacks of the heartwood by wood-decomposers, or trees becoming unstable in strong wind because the roots can no longer anchor them. If oldgrowth forests reach high above-ground biomass and lose individuals owing to competition or small-scale disturbances, there is generally new recruitment or an abundant second canopy layer waiting in the shade of the upper canopy to take over and maintain productivity.*
>
> *Although tree mortality is a relatively rapid event (instantaneous to several years long), decomposition of tree stems can take decades. Therefore, the CO_2 release from the decomposition of dead wood adds to the atmospheric carbon pool over decades, whereas natural regeneration or in-growth occurs on a much shorter timescale. Thus, old-growth forest stands with tree losses do not necessarily become carbon sources, as has been observed in even-aged plantations (that is, where trees are all of the same age).*

It is also evident that structurally complex forests are more effective at sequestering carbon than simplistic monocultures, for example Gough *et. al.* (2019) found that "*Forests that were more structurally complex, had higher vegetation-area indices, or were more diverse absorbed more light and used light more efficiently to power biomass production, but these relationships were most strongly tied to structural complexity*".

Forests also sequester carbon in slowly decomposing organic matter in litter and soil. (Zhou *et. al.* 2006, Luyssaert *et. al.* 2008). Moomaw *et. al.* (2019) consider the sequestering of carbon in soil another key factor in the storage of carbon in oldgrowth forests:

> *Intact forests also may sequester half or more of their carbon as organic soil carbon or in standing and fallen trees that eventually decay and add to soil carbon (Keith et al., 2009). Some forests continue to sequester additional soil organic carbon (Zhou et al, 2006) and older forests bind soil organic matter more tightly than younger ones (Lacroix et al., 2016).*

Curtis and Gough (2018) concluded "*new observations, ecological theory and our emerging biological understanding of temperate forest ecosystems point to sustained* [Net Ecosystem Productivity] *in aging temperate deciduous forests*", and thus carbon uptake. They consider:

> *... the conservation of these aging forests into late stages of ecosystem development is likely to result in nominal reductions in the land carbon sink, whilst maintaining an immense store of terrestrial carbon, and restoring the many ecosystem services afforded by the resurgence of biologically and physically complex forest ecosystems in eastern North America.*

Australia bases its carbon accountancy upon the Federal Government's FullCAM (Full Carbon Accounting Model) which assumes a maximum upper limit to biomass accumulation for any location based on potential site productivity, for NSW forests with a canopy cover >50% it identifies the upper limit of above ground dry matter of 210 to 287±9 t DM ha^{-1} (Roxburgh et. al. 2017). Though this conservative estimation may grossly under-estimate the potential for ongoing accumulation of carbon in oldgrowth forests subject to infrequent natural disturbances, particularly on higher productivity sites.

Carbon Carrying Capacity is a useful baseline to use for assessing changes in carbon storage due to past logging, though should also only be considered an indicative benchmark rather than a true representation of carbon capacity,

3. The Effects of Logging on Carbon

The older and bigger a tree gets the more carbon it sequesters, storing it in living and dead wood, as well as soil organic matter. Natural forests are generally multi-aged forests, dominated by giant old trees, but with a succession of age classes resulting from trees succumbing to old age or past disturbances. Such forests can be considered to have reached their Carbon Carrying Capacity. They are the benchmark for assessing changes against.

Logging trees releases their stored carbon as the wood decomposes. Most of the tree is left in the forest as leaves, bark, branches, defective trunks, stump and roots, much of which rots or burns quickly and releases its carbon, while the larger wood may take many decades to decompose. Of the wood in the logs removed most ends up as sawdust in milling, as offcuts or as short-lived products, with the balance of the carbon being stored in various products (mostly flooring, poles, girders, fencing) for possibly decades.

Regrowth forests (less than 15-30 years old) may be carbon sources due to lower leaf areas resulting in reduced sequestration and higher respiration from the residual carbon in soils and woody debris (Chen *et. al.* 2004, Luyssaert *et. al.* 2008).

Past logging has reduced the size of forest trees, basically halving the forest's biomass and carbon storage. Each logging operation releases more carbon which it takes the forest decades to recover, never being allowed to recover their Carbon Carrying Capacity.

Natural higher-productivity eucalypt forests are generally multi-aged, dominated by large trees many centuries old, with a range of smaller trees resulting from past disturbance events such as high intensity wildfires and tree-falls. Logging fundamentally changes the structure of forests by removing most of the large old trees, in the past often supplemented by the culling of old trees under Timber Stand Improvement. Logging also increases mortality of retained trees (NSW Scientific Committee 2007, NRC (2021). NRC (2021) noting "*there is evidence that trees retained on logged sites have higher rates of mortality and collapse than trees in comparable unlogged sites".*

Logging reduces the age classes of trees in forests, particularly the old giant trees, and thus their carbon storage. It is obvious that by removing the largest trees that logging dramatically reduces the carbon stored in forests. on average, production forests are considered to have lost 40-60% of their carbon stores (Harmon *et. al.* 1990, Roxburgh *et.al.* 2006, Mackey *et. al.* 2008, Wardell-Johnson *et. al.* 2011, Dean *et. al.* 2012, Keith *et. al.* 2014b, Keith *et. al.* 2015, Noormets *et. al.* 2015). Carbon stocks are maintained at these low levels by repeat harvesting events, never allowed to regain their natural carbon carrying capacity. Mackey *et. al.* (2008) note:

> *The majority of biomass carbon in natural forests resides in the woody biomass of large old trees. Commercial logging changes the age structure of forests so that the average age of trees is much younger. The result is a significant (more than 40 per cent) reduction in the long-term average standing stock of biomass carbon compared with an unlogged forest.*

This suppression of carbon storage is illustrated Keith *et. al.* (2014b):

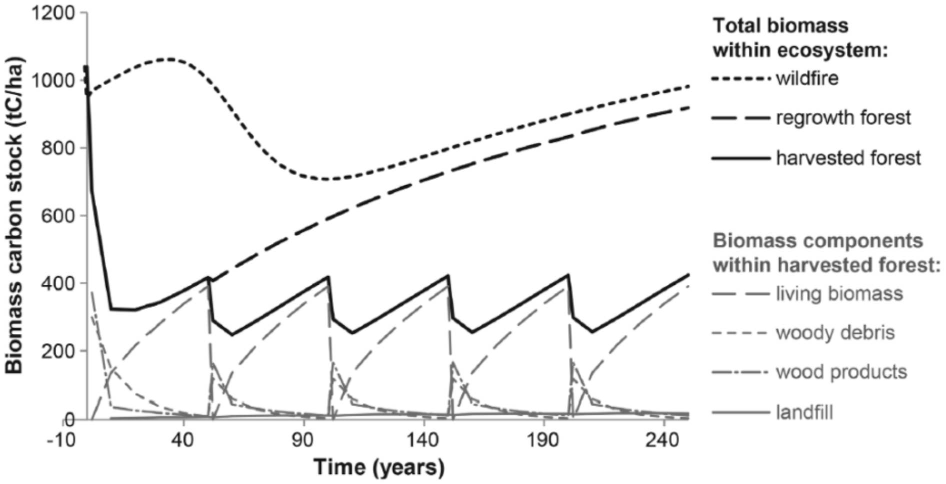


Fig. 10. from Keith *et. al.* (2014b): Changes in total biomass carbon stock of the ecosystem over time under three scenarios (shown as black lines) from an initial stock of a native forest: (1) wildfire that occurred at time 0 years and then the forest regenerated and dead biomass decomposed over time, (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

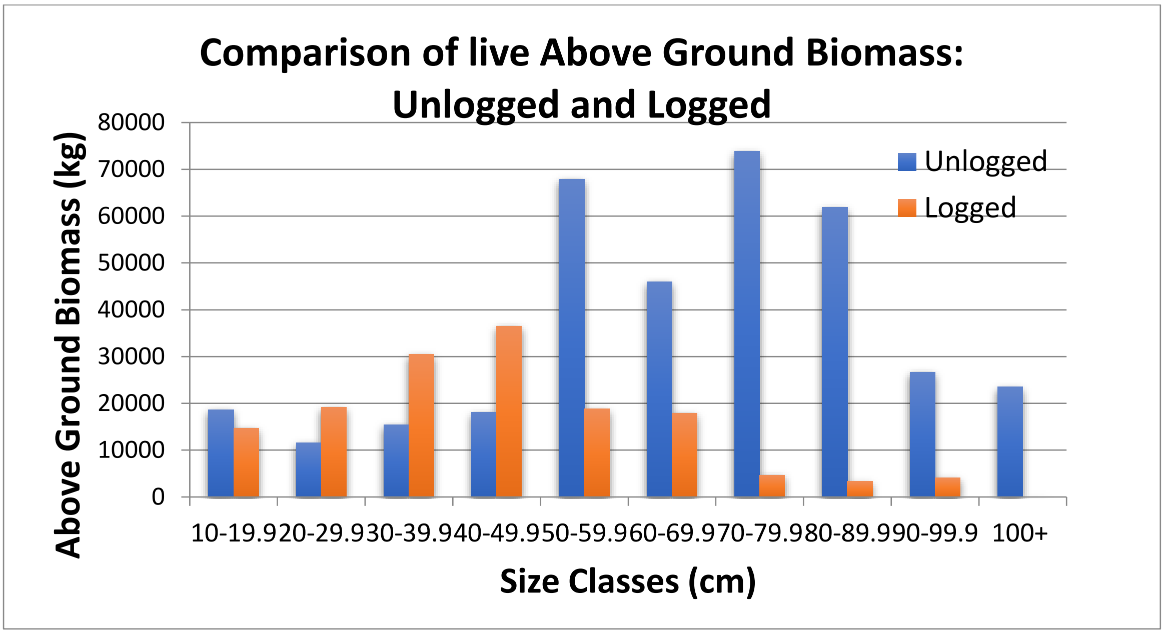
It needs to be recognised that there is a sequestration hiatus following the establishment of regeneration or plantations. Forests regenerating after logging may be net sources of carbon for several decades, due to the limited photosynthesis of the low leaf area of seedlings being overwhelmed by the respiration from decomposition of residual coarse woody debris, litter and soil organic matter (Chen *et. al.* 2004, Luyssaert *et. al.* 2008). A variety of studies have found logging to cause long-term reductions in soil carbon (Rab 1994, James and Harrison 2016, Dean *et. al.* 2017, Bowd *et. al.* 2019), though some claim there is insufficient evidence to determine whether logging significantly reduces soil carbon (England *et. al.* 2014)

This effect has also been documented for eucalypt plantations in north-east NSW where the overall biomass growth may not off-set establishment losses for 5-20 years (Turner and Lambert 2000, Turner *et. al.* 2005), with loss of soil carbon found to continue for over a decade following establishment before slowly recovering (Turner and Lambert 2000, Polgase *et. al.* 2000, Turner *et. al.* 2005). In already depleted soils, Zhang *et. al.* (2018) found that soil carbon (down to a metre) increased significantly with stand age, comprising the majority of ecosystem carbon.

3.1. How much can carbon storage be reduced.

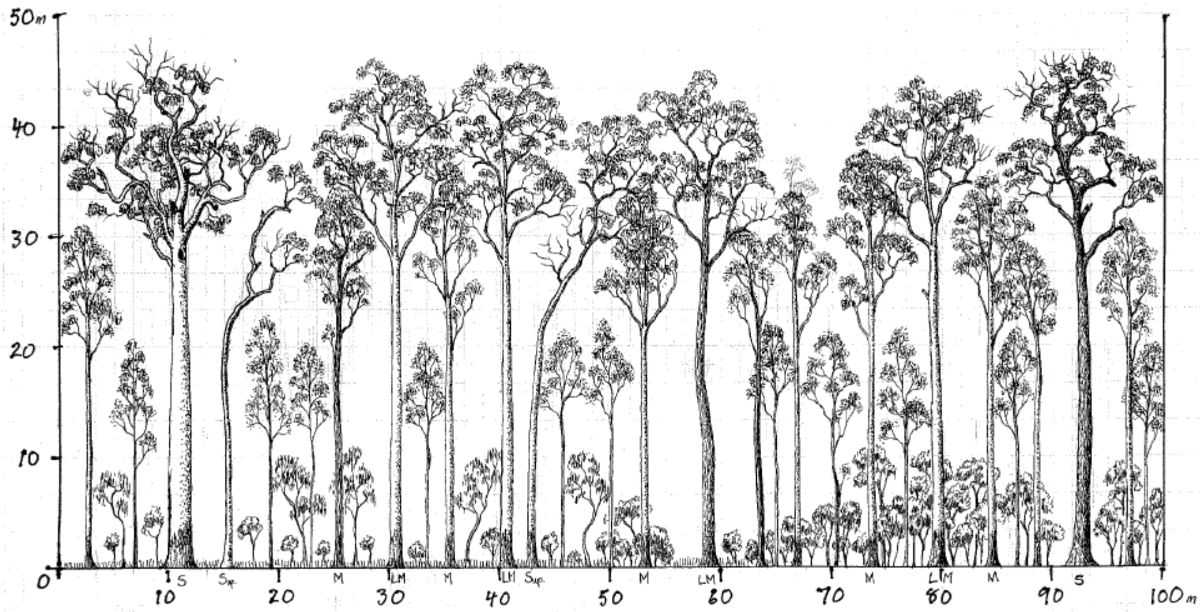
In north-east NSW forests in the North Coast Intensive Zone are allowed to be clearfelled, resulting in nearly all of the carbon stored in vegetation removed, along with a significant proportion of soil carbon (which is to some extent offset by inputs from burnt biomass). Selective logging in the balance of logging areas is allowed to reduce the above ground biomass stored in a natural forest by 60-80%, though with regrowth the average carbon storage is taken to be 40-60% of a natural forest.

NEFA (Pugh 2020) assessed the Above Gound Biomass of apparently unlogged and logged (generally over 20 years ago) Spotted Gum forests south of Casino, finding a reduction in basal area from 40.7 m^2 per hectare down to 20.2 m^2, primarily attributable to past logging. There had been an overall loss of 59% of live above ground biomass from these forests, which increased to 65% of biomass for trees above 30 cm dbh, and to 84% of biomass for trees above 50 cm dbh.



Comparison of Above Ground Biomass of logged and unlogged plots in Spotted Gum forest showing the dramatic reduction in the biomass of larger trees (from Pugh 2020)

The 2018 CIFOA logging rules allow for increased logging intensity, and therefore a further reduction in carbon storage. The CIFOA establishes 3 zones where logging intensity is limited by basal area retention; a 140,000ha North Coast Intensive Zone with no minimum basal area, a coastal "regrowth" zone with a requirement for retention of a minimum basal area of 10m^2 ha and an escarpment "non-regrowth" zone with a minimum basal area of 12m^2 ha.



Indicative immediate effect of logging on the structure of a natural forest resulting from a single logging event with application of the current CIFOA rules. Based on a 100m x 20m transect (0.2ha)

Ximenes *et al.* (2016) assessed live above ground biomass of what they considered older forests with no management history, though likely past logging, for Silvertop Ash on the south coast identifying a basal area of 49m^2/ha, and for Blackbutt 39m^2/ha. Similarly Ximenes *et al.* (2004) measured biomass in 3 "representative" south coast Spotted Gum forests on low, moderate and high site qualities which they claimed to be "*close to, or at, maximum carbon carrying capacity*" (though all had been logged in the late 1970s), finding low site quality Spotted Gum had a basal area of 29.3 m^2/ha, medium site quality Spotted Gum 33.6 m^2/ha, and high site quality Spotted Gum 42.9 m^2/ha.

The "wet sclerophyll" forest types, dominated by species such as Brush Box, Tallowwood, Sydney Blue Gum and Flooded Gum are far more productive and do have far higher maximum upper limits to biomass accumulation than those assessed.

If Ximenes *et al.* (2004, 2016) sites are taken to be representative low to moderate site-quality natural forest within the coastal "regrowth" zone where the CIFOA now prescribes retention of a minimum of 10m^2 ha, which if applied to his sites represent potential basal area reductions of 66% to 80%. Outside the intensive zone this represents the maximum carbon reduction allowed in such site quality forests.

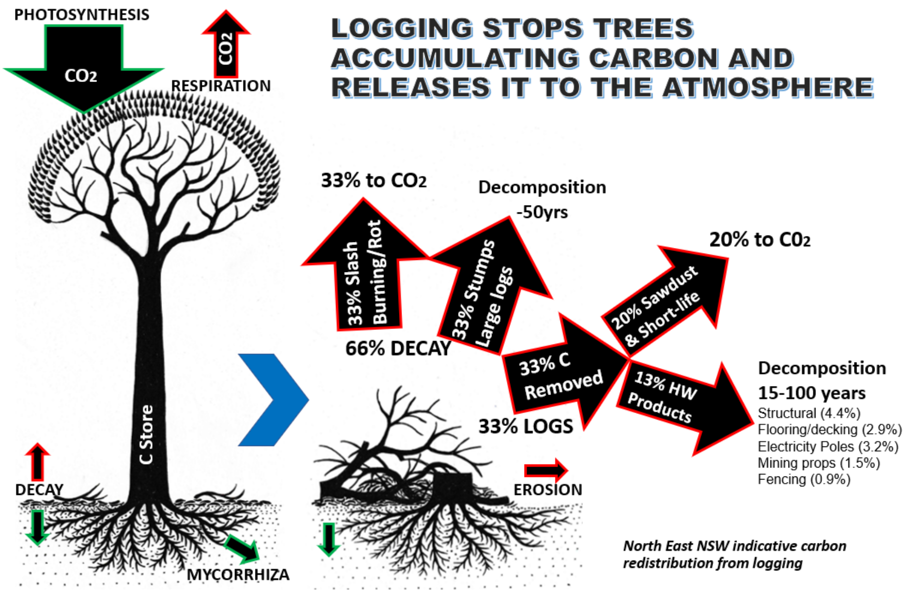
3.2. How much tree carbon does logging release?

It is clear that following logging that the majority of a tree, being the leaves, branches, defective trunks, bark, stump and roots are left in the forest to decompose, with some burning or decomposing rapidly to release their carbon, while the larger residues, such as stumps and larger branches, may take decades to decompose and release their carbon. Of the timber removed from the forest, most ends up as sawdust or in short-lived products, which rapidly release their carbon, with only a small proportion ending up stored for decades in relatively long-lived products. Once its usefulness is finished, a small proportion may end up in landfill, where decay may be extremely slow due to the anaerobic conditions.

With the currently limited pulpwood market in north-east NSW, the indications are that of each tree felled:

- **66.5% of its biomass is left in the forest, where around half will rot or burn rapidly releasing its carbon to the atmosphere and half (logs, stumps) slowly releasing its carbon over decades due to decay.**
- **33.5% of its biomass may be removed in log form, with 20.7% of the tree carbon rapidly released from short-lived residues and hardwood products, and 12.8% ending up in longer lived hardwood timber products (at best) with various carbon retention times of 15 years to over 100 years (where buried in landfill).**

Indicative fate of Logged Forest Carbon in north-east NSW



In regions with large pulpwood industries the majority of the logs removed from the forests are likely to be woodchipped and thus release their carbon quickly, with as little as 4-6% of the logged trees ending up in sawn products (ie Keith *et. al.* 2014). Export woodchipping from north-east NSW was stopped in 2013, and pulpwood currently comprises less than 5% of the logs removed from native forests.

The only relevant sampling assessments located for north-east NSW were 2 in blackbutt forests on the mid north coast undertaken by Ximenes *et al.* (2016). These are very small samples from which to extrapolate across a million hectares of public forests, particularly as Ximenes *et al.* (2016) only accept one 500m^2 site as being representative.

Ximenes *et al.* (2016) assessed above ground biomass (AGB) in old blackbutt dominated forest and advanced regrowth blackbutt forests in north-east NSW by clearfelling 500m^2 plots. These identified that the old forest had 169% more live (tree) Above Ground Biomass (AGB) than the regrowth stand, which was offset to an extent by the 354% increase in Coarse Woody Debris (CWD) in the regrowth stand, which was attributed to unmerchantable logs remaining from the original forest felled in earlier logging and ringbarking.

	Basal Area (m^2/ha)	Total live green AGB (t/ha)	Dead trees (t/ha)	CWD (t/ha)	Litter (t/ha)	Total AGB (t/ha)

Old forest	39	674.8	5.4	48.1	21.9	750.2
Regrowth	25	399.0	19.8	170.4	23.4	612.6

Above Ground Biomass (AGB), including Coarse Woody Debris (CWD), identified on cleafelled plots by Ximenes *et al.* (2016).

Ximenes *et al.* (2016) exclude the below ground portion of trees from their calculations, by only accounting for AGB. This provides an incomplete picture of the fate of carbon. As tree roots represent around 25% of the biomass of a tree, their inclusion increases the volumes of live green biomass to around 843.5 t/ha for the old forest and 498.8 t/ha for the regrowth stand. Live tree biomass thus accounts for 70-92% of a forest's carbon storage, without accounting for the significant contribution of soil carbon.

Ximenes *et al.* (2016) weighed the trees to further identify the distribution of biomass within the logged trees, expressed in dry tonnes per hectare, identifying that on the old blackbutt forest site some 78% of the above ground biomass was left on site (bark, crown, stump and other) with 22% removed as logs, and on the regrowth site 52% was left on site with 48% removed in logs.

	Bark		Crown		Stump		Other		Logs		TOTAL
	t/ha	%	t/ha	%	t/ha	%	t/ha	%	t/ha	%	t/ha
Old forest	34	8	148	35	11	3	134	32	91	22	418
Regrowth	17	7	35	14	12	5	71	27	123	48	258

Live Above Ground Biomass (AGB), converted into dry biomass in tonnes per hectare, on cleafelled plots differentiated into tree parts left on site (bark, crown, stump and other) and removed in log form, as identified by Ximenes *et al.* (2016). The 'Other' residues includes non- commercial species, dead and small trees as well as parts of the stem that had no commercial value due to damage during felling, decay or a reflection of the current market for that region. 'Other' is a lot higher for blackbutt than other types with pulpwood markets, ie averaging only 7% for silvertop ash.

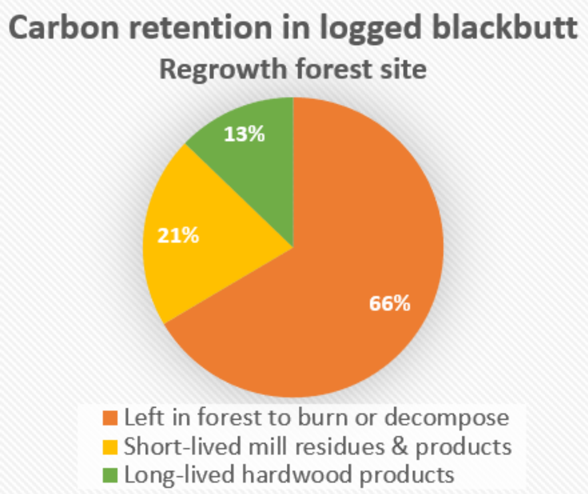
Leaves, bark and small branches and rootlets will rapidly decompose, releasing their carbon in the process, though stumps, sections of trunks, large branches, and large roots will decompose more slowly. In dry environments standing dead trees and other Coarse Woody Debris (CWD) may remain for decades, with longevity dependent on species and temperature (Woldendorp *et. al*. 2002, Mackensen *et. al.* 2011, Keith *et. al.* 2014b). Keith *et. al.* (2014b) assume that half the logging debris will have a life of around 50 years. Mackensen *et. al.* (2011) found:

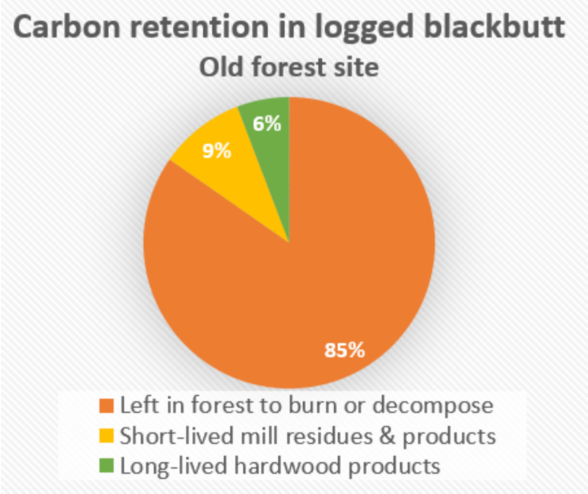
> *In total, 184 values for lifetimes (t0.95) of CWD were calculated from studies available in the literature. In 57% of all cases, the calculated lifetime (t0.95) is longer than 40 years (Fig. 4). The median of this distribution is at 49 years and the mean is 92 years.*

For this assessment it is assumed that half the biomass left on site will be burnt or decay within 3 years and half will progressively decay or burn over 60 years.

The figures of Ximenes *et al.* (2016) for dry tonnes per hectare were adapted to take into account root biomass retained on site, giving total volumes of tree biomass as 522.5t/ha for the old forest site and 322.5 t/ha for the regrowth site. In addition the adjustment applied by Ximenes *et al.* (2016) to removed log products from the regrowth blackbutt site to reflect more realistic "*adjusted regional average production*" resulted in a decline in logs deemed to be removed from 123 t/ha down to 108 t/ha (33.5%). The application of this ratio to the old blackbutt site reduced the logs deemed to be removed from 91 t/ha down to 80 t/ha (15.3%).

Ximenes *et al.* (2016) assume that 50% of the dry biomass is carbon. They identify the yield from the 108 t/ha (33.5%) removed from the regrowth blackbutt site as 66.8 t/ha (20.7% of tree carbon) of short-lived residues and hardwood products that will rapidly release their carbon, and 41.2 t/ha (12.8%) as longer lived hardwood products: structural (4.4%) flooring/decking (2.9%) electricity poles (3.2%), mining props (1.5%), and fencing (0.9%). For the old blackbutt site this would indicate that applying this ratio would result in 9.5% of tree carbon rapidly being released and 5.8% being held in relatively long-lived products.





Understandably Forestry Corporation and Ximenes *et al.* (2016) prefer the statistics for the regrowth (production) blackbutt stand and adopt this as being more representative of north-east NSW. While this is an extremely small sample, it has similarly been adopted for this review, though it needs to be recognised (as shown by the old forest site) that the proportion of biomass converted into long-lived products is likely to be far less on average, and thus this is a conservative assumption. Ximenes *et al.* (2016) note:

> *The data from the FCNSW for the mid-north coast covered a broad geographical area and suggests that the study "production" site yielded a slightly higher proportion of high quality logs than the average blackbutt forest in that region.*

The amount of carbon released by logging is to some extent offset by long term storage of carbon in products.

Of the timber removed from the forest, according to Ximenes *et al.* (2016) 61.8% will end up as short-lived mill residues and products, and 38.2% as relatively long-lived hardwood products, this is just 12.8% of tree biomass. Of the hardwood products, over half can be expected to be in exposed situations conducive to decay (decking, poles, mining props and fencing) and thus have a lifespan of 15 to 40 years, with the balance (flooring, some structural timber) expected to have a lifetime equivalent to the building it is used in.

The National Electrical and Communications Association identifies "*Australian Standards indicate a life expectancy of up to 40 years above ground and 25 years below ground for hardwood poles. … If your customers' poles are hardwood, it is recommended that they replace all those that have been in service for more than 25 years*". They take this further by recommending that should power poles need replacement that they "*should use new steel poles … in preference to wood poles*". Hardwood fencing has a reduced life expectancy of 15 to 30 years (when concreted in), with treated pine recommended for longer life.

In Australia, the average life of a brick home is 88 years and a timber home is 58 years (Snow and Prasad 2011), though some can last longer, while typical big box retail stores may only last 30-40 years.

After its useful life is over, a portion of the timber product may end up in landfill, where very low rates of decomposition are reported because of the anaerobic conditions. Keith *et. al.* (2014) consider the proportion of the initial forest carbon stock that remains in long-term storage in landfill is less than 3%.

Based on this, it is reasonable to assume that of the 12.8% (at best) of tree biomass made into long-life timber products, some 7% will retain its carbon for 15-30 years, 3% will last 60-90 years and 2.8% over 100 years.

3.2.1. How much forest carbon does logging release in north-east NSW each year?

Some 400,000 m^3 per annum of logs are allowed to be removed from north-east NSW's public native forests each year, with allowance for forest residues this equates to 413,732 tonnes (t/yr) of carbon per annum, with the potential to generate 1.52 million tonnes of CO_2.

Stopping logging of north-east NSW's public forests will avoid 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 realised over decades as logs left in the forest decay and wood used in buildings reach the end of its useful life.

Development of a biomass market for electricity generation will increase the removal of live trees, while increasing the removal of logs from the forest and wood from landfill that would otherwise decompose slowly, and rapidly release significantly more CO_2.

Logging has profound impacts on forest carbon storage by cutting and removing carbon stored in tree trunks, while converting carbon in leaves, branches, bark, tree bases and roots into detritus where it rots or burns. Logging kills trees that have been accumulating carbon in their wood for decades or centuries and releases their carbon.

As previously identified, some two thirds of this carbon will remain in the forest as roots, stumps, offcuts, branches, bark and leaves, with around half of this carbon rapidly released and half over decades. At best, an average of 38.2% of the carbon removed may end up being stored in timber products for some decades, with the rest being sawdust or short-lived products. Thus the volume of logs removed each year can be used to estimate the volume of carbon rapidly oxidised to form CO2, and the volume slowly oxidised over decades.

There are significant additional emissions during logging from disturbed and eroded soils, and from the fuel used during logging and transport. These have not been considered in this basic assessment. There are also additional emissions from wildfires, and while their intensity, and thus carbon release, is increased by logging these are considered to be landscape scale impacts.

The Forestry Corporation North Coast Biomaterial Reports are only available up to 2019, with the reports identifying an annual average of 9,655 ha logged for a yield of 396,818 m^3 of logs over the 5 years 2015-19. This varies from an average derived from log sale figures (Forestry Corporation pers. comm.) over the same period of 408,564 m^3 per annum. Given the disruptions to log supplies since the 2019 fires, including from floods, these pre-fire averages are considered reasonable indicators of intended future yields given that Wood Supply Agreements have been extended until 2028. Removals will significantly increase if the Forestry Corporation are successful in developing a biomass market.

For the purpose of this assessment a figure of 400,000 m^3 per annum for removals from north-east NSW's public forests is adopted. This is converted into tonnes using the multiplier of 110% (NSW EPA 2017), and then to dry weight using the 0.63 multiplier for blackbutt of Ximenes *et al.* (2016), giving and annual yield in log form of 277,200 tonnes of dry biomass from State forests in north-east NSW, of which 171,310 tonnes (61.8%) can be expected to release its carbon within a few years and 105,890 tonnes (38.2%) can be expected to end up stored in timber products for 15-100 years.

Annual yields of wood from north-east NSW's public forests:

Year	Area (ha)	High Quality Products (m^3)	Low Quality Products (m^3)	Pulpwood (m^3)	Other (firewood, fencing etc) (m^3)	TOTAL
2015	10,604	209,384	159,945	15,132	11,537	395,998
2016	10,943	217,616	148,919	16,680	13,224	396,439
2017	9,521	231,350	132,191	21,187	11,142	395,871
2018	9,249	221,565	133,371	22,197	12,860	389,994
2019	7,960	224,137	140,955	20,341	20,355	405,788
Average	9,655	220,810	143,076	19,107	13,824	396,818

Source: Forestry Corporation North Coast Biomaterial Reports. Note that data obtained from Forestry Corporation for the same period gives averages of 224,769 m^3 of high quality products and a total of 408,563 m^3.

Based on Ximenes *et al.* (2016) some 66.5% of the trees logged can be expected to remain in the forest as residues, meaning for the removal of 277,200 tonnes of dry biomass, 550,263 tonnes of dry biomass will be left in the forest, increasing the total generation of biomass from logging to 827,463 tonnes per annum. Some 50% of this can be assumed to be carbon, totalling 413,732 tonnes (t/yr) of carbon per annum.

In most southern forests the majority of the timber removed from the forests is for woodchips or pulplogs, meaning most of their carbon is relatively quickly released to the atmosphere as CO_2. This is not currently the situation in north-east NSW as export woodchipping was stopped in 2013, and pulpwood currently comprises less than 5% of the logs removed from native forests. Ximenes *et al.* (2016) note:

> *The ratio of pulp logs to sawlogs (on a C basis) was 70/30 for silvertop ash, and 64/36 for mountain ash. There was no difference between the commercial log recoveries for blackbutt and for silvertop ash (59%) – however if there was a pulp market in the mid-North coat of NSW, the production log recoveries for blackbutt would have been considerably higher.*

One of the scenarios considered by Ximenes *et al.* (2016) was "*50% of forest residues left on site utilised for pulp*", which would predominantly be comprised of the relatively long-lived Coarse Woody Debris and trees which otherwise wouldn't be logged. Currently only some 20,000 m^3/yr is removed from north-east NSW as pulpwood, though DPI (2017) identify that 399,958 tonnes (247,974 tonnes dry biomass) per annum are potentially available from public native forests for biomass. The removal of this material, intended to be for burning to generate electricity, would significantly increase short-term CO_2 impacts.

Based on past logging (without an increase in pulpwood), of the 413,732 t/yr of carbon likely to be converted by logging from storage in living biomass to dead biomass per annum in north-east NSW's public forests, 275,132 t/yr will be left in the forest as residues where half will quickly release its carbon as CO_2, and of the 138,600 t/yr of carbon removed as logs some 85,655 t/yr can be expected to be quickly released as CO_2. This 223,221 t/yr of quick release carbon reacts with oxygen to form 819,220 t of CO_2. The balance of 137,566 t/yr of carbon in CWD forest residues and 53,945 t/yr in longer-lived wood products will ultimately be converted to an additional 699,175 t of CO_2, though over a timeframe of 15 to 100+ years.

It is important to recognise that carbon from trees logged 30, 60 and a hundred years ago that was temporarily stored in logs or wood products is still being released today, creating ongoing legacy emissions. As logging volumes have decreased, these legacy emissions are proportionally higher than those released today.

3.3. 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, encompassing 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 and have carbon sequestration potential.

Commonwealth of Australia (2019) give NSW emissions in 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.

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] (t C)	Carbon Sequestration Potential (t C)	Carbon Dioxide Sequestration Potential[3] ($t\ CO_2$)	Annual Sequestration potential[4] ($t\ CO_2$)	% 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.

3.4. 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).*

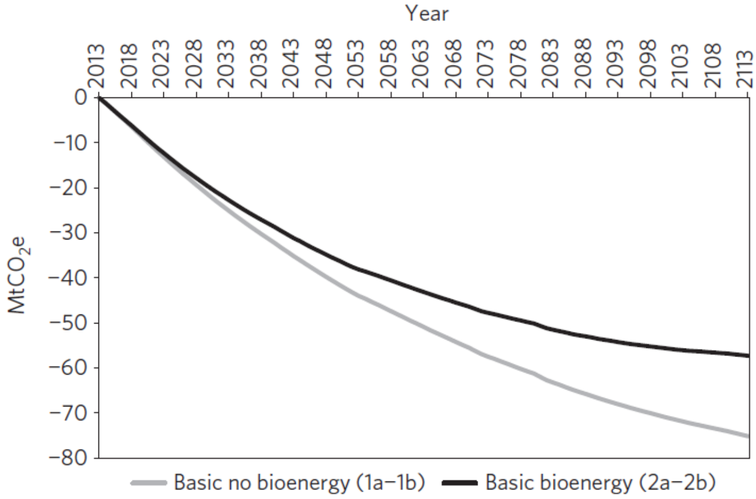


Fig 1 from Macintosh *et. al.* (2015). Basic scenarios—difference between the sustainable use reference case and the conservation scenario as cumulative net GHG emissions. Net emissions were calculated as the net flux difference (emissions less removals) between the sustainable use reference case and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

Forest age	Biomass carbon stock (tC/ha)			
	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).

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

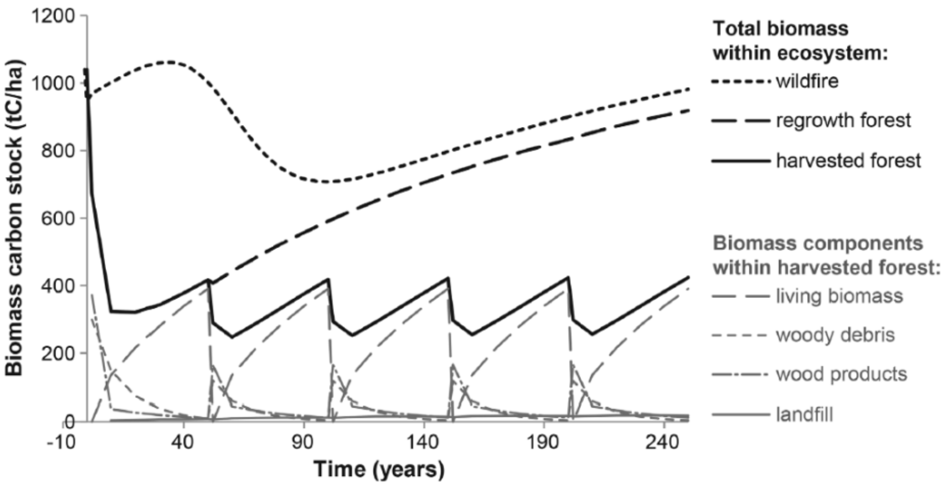


Fig. 10. from Keith *et. al.* (2014b): Changes in total biomass carbon stock of the ecosystem over time under three scenarios (shown as black lines) from an initial stock of a native forest: (1) wildfire that occurred at time 0 years and then the forest regenerated and dead biomass decomposed over time, (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*".

4. Plantings do not Provide Immediate Carbon Benefits.

The establishment of plantations involves significant soil disturbance and consequently the loss of soil organic carbon. It can take one or more decades for soils to recover the lost carbon. This means that it can take 5-10 years before biomass in plantations result in a net increase in carbon storage, even when established on cleared land.

From their review of plantations in eastern Australia, Turner *et. al.* (2005) found that plantations may reduce soil carbon for the whole rotation (up to 30 years), with overall biomass growth often not off-setting establishment losses for 5-10 years

> *... after establishment, there are reduced inputs of carbon into the soil from prior vegetation or rapidly growing weeds, together with accelerated decomposition of soil organic matter as a result of disturbance, and this leads to a net loss of soil organic carbon. In some systems this loss of soil organic carbon is not balanced by carbon biomass sequestration until 5–10 years after establishment and on some sites, a reduction in soil organic carbon may remain until the end of the rotation. ... There was a general pattern of reduced carbon in surface soil immediately after plantation establishment and with time this extended deeper into the soil profile. The actual quantities varied greatly depending on the soil type. The decline was primarily a result of losses of labile carbon and was greater when the previous land use had essentially been native vegetation or highly improved pastures as opposed to regrowth woodland, or native pasture, or degraded land. In the absence of further disturbance, soil organic carbon can accumulate to pre-establishment levels but many short rotation plantations are terminated prior to this being attained.*

From their review of Australian studies Polgase *et. al.* (2000) found

> *For soil in the <10 cm or < 30 cm layers, there were significant effects of stand age on C change. Soil C generally decreased during the first 10 years (particularly the first five years) of afforestation followed by a slower rate of recovery and accumulation.*

For north-east NSW Polgase *et. al.* (2000) found

> There is a decline in C in the surface 10 or 50 cm for about 15 years after plantation establishment and then a general levelling out. The initial decline in soil C was 10%-12% yr^{-1} during the first two years after afforestation. Twenty-five years after afforestation, change in soil C was only –1.13 to –1.18 % yr^{-1}.

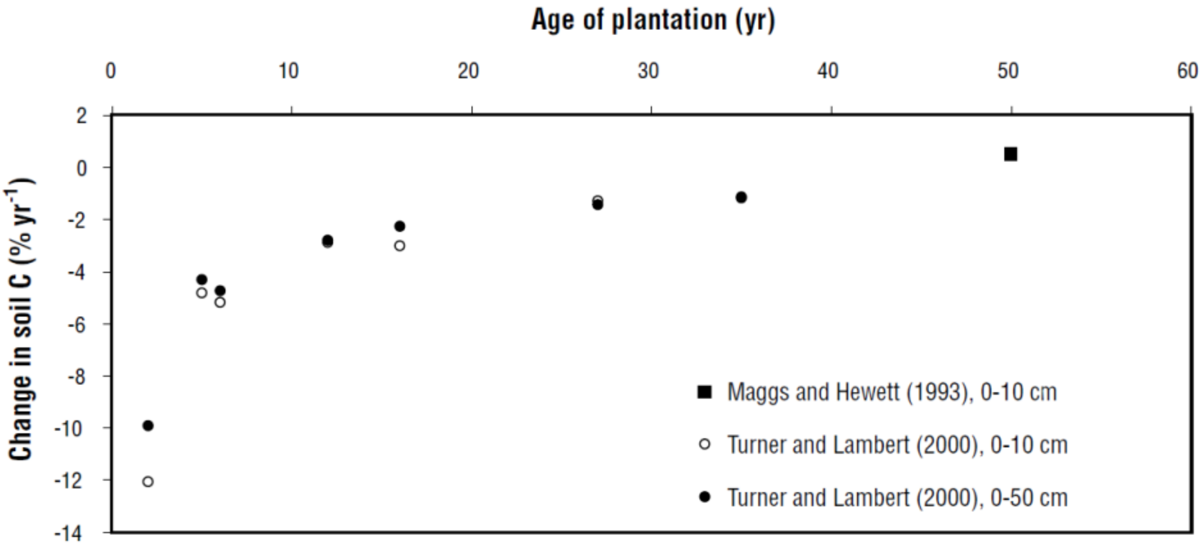


Figure 12.2. from Polgase *et. al.* (2000) Change in soil C in 0-10 cm or 0-50 cm layer under 2- to 50-year-old forest on ex-pasture land in the subtropical climatic regions of Queensland and the north coast of New South Wales.

Polgase *et. al.* (2000) consider that the "*losses in soil C*" by Turner and Lambert (2000) "*were by far the largest recorded in any of the studies reviewed*" and thus should be "*treated with caution*", summarising them as:

> *The paper by Turner and Lambert (2000) used a chronosequence approach to estimate change in soil C following afforestation. The calculated decrease (0-50 cm) during the first two years was about 3,900 g m^{-2} (1,900 g m^{-2} yr^{-1}) for P. radiata plantations and 8,400 g m^{-2} (4,200 g m^{-2} yr^{-1}) for the E. grandis chronosequence. Turner and Lambert (2000) further state that it may take 10-20 years before losses from soil C are offset by accumulation in biomass.*

From their comparison of 26 year old eucalypt reforestation with agricultural sites in Western Australia, Harper *et. al.* (2012) found that soil organic carbon up to 0.3 m depth ranged between 33 and 55 Mg ha^{-1}, "*with no statistically significant differences between tree species and adjacent farmland*".

5. The Struggling Forests

Trees are increasing sickening and dying as the result of increasing droughts and heatwaves generated by global warming. This is not just a threat to forest ecosystems, it is also a threat to future timber supplies. This problem is aggravated by a variety of stressors on tree health, including logging, grazing and weed invasion. As evidenced by the increasing severity of droughts, heatwaves, and wildfires we are perilously close to a cascading series of feedbacks that cause the irreversible decline of forest ecosystems and the release of vast quantities of carbon stored in forest vegetation and soils into the atmosphere, making them into carbon sources rather than sinks. As shown by the 2019-20 fires we don't have any time to waste.

There is no time to waste in turning this around as forests are already succumbing to climate change and reducing their ability to take up the carbon we emit. The increasing frequency of wildfires is accelerating the degradation of forests, as evidenced by the burning of 35% of north-east NSW's rainforests in the 2019-20 fires. If forests are turned from carbon sinks into carbon sources we have no chance of averting the unfolding climate catastrophe. We must act now while forests still have the ability to assist the transition.

The consequences of increasing temperatures and more erratic rainfall due to climate change are more frequent droughts and extreme temperatures. Steffen et.al. (2015) identify that by 2070 Sydney's average number of hot days (>35^{o}) will increase from 3.4 to somewhere between 4.5-12 days per annum. As identified by Fensham *et. al* (2009)

> *A doubling in the frequency of severe droughts has been predicted under future climate scenarios. The physiological effect of drought on trees may well be enhanced by rising temperatures, ... Enhanced drought conditions will intensify tree-death which is likely to be a symptom of global climate change.*

Allen *et. al.* (2008) note *"studies compiled here suggest that at least some of the world's forested ecosystems already may be responding to climate change and raise concern that forests may become increasingly vulnerable to higher background tree mortality rates and die-off in response to future warming and drought",*

Episodes of widespread tree mortality in response to drought and/or heat stress have been observed across the globe in the past few decades. As noted by Anderegg et. al. (2016):

> *... the principal cause of drought induced tree death has been found to be the failure of a plant's vascular water transport system through embolism caused by air bubbles during high xylem tensions caused by low soil moisture and/or high atmospheric evaporative demand during drought, though there are numerous other contributing influences*

Griscom *et. al.* (2017) warn "*Unchecked climate change could reverse terrestrial carbon sinks by midcentury and erode the long-term climate benefits of NCS. Thus, climate change puts terrestrial carbon stocks (2.3 exagrams) at risk*", noting:

> *Delaying implementation of the 20 natural pathways presented here would increase the costs to society for both mitigation and adaptation, while degrading the capacity of natural systems to mitigate climate change and provide other ecosystem services. Regreening the planet through conservation, restoration, and improved land management is a necessary step for our transition to a carbon neutral global economy and a stable climate.*

Bastin *et. al.* (2019)'s assessment is that forests are coming under increasing stress due to climate heating, with tropical forests most at risk of being lost by 2050:

> *our model highlights the high probability of consistent declines of tropical rainforests with high tree cover. Because the average tree cover in the expanding boreal region (30 to 40%) is lower than that in declining tropical regions (90 to 100%), our global evaluation suggests that the potential global canopy cover will decrease under future climate scenarios ... leads to a global loss of 223 Mha of potential canopy cover by 2050,*

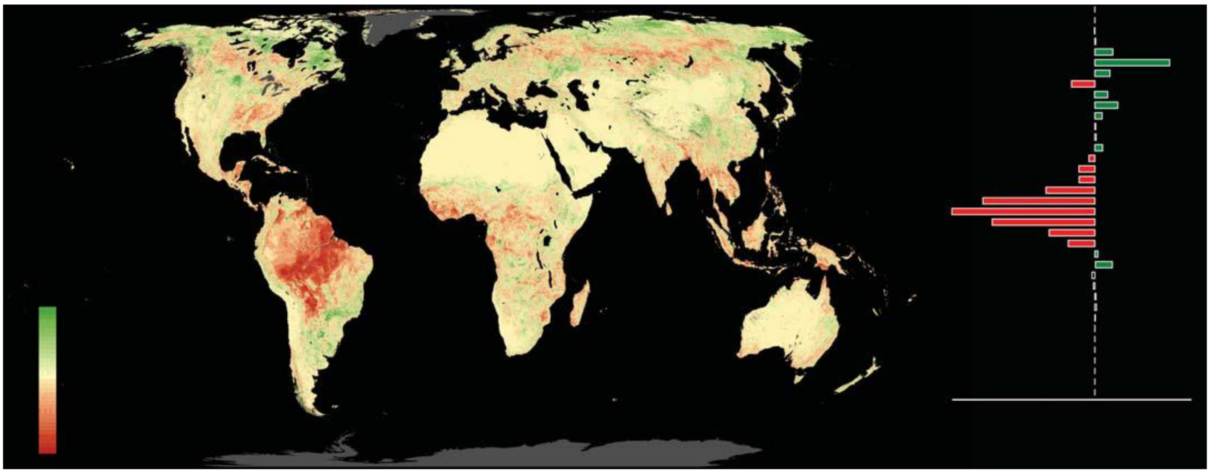


Fig. 3 from Bastin et. al. (2019): Risk assessment of future changes in potential tree cover. (A) Illustration of expected losses in potential tree cover by 2050, under the "business as usual" climate change scenario (RCP 8.5), ... (B) Quantitative numbers of potential gain and loss are illustrated by bins of 5° along a latitudinal gradient.

Tree dieback has been recognised in the New England area since the mid 1800's (Lynch *et. al.* 2018), though it achieved widespread notoriety during the 1970s and 1980s. This dieback has been attributed to a multitude of factors including clearing, fungi, grazing, native animals (e.g. koalas, possums, territorial birds), climatic changes, land degradation, parasitic plants, and repeated defoliation by insects.

Ross and Brack (2015) assessed 'Monaro dieback' as affecting 2,000 km^2, with almost all Ribbon Gum (*E. viminalis)* within that area either dead or severely affected. The problem dated back to 2005. Ribbon Gum is the dominant species in the region, and the only one badly affected, yet they considered that at the then rate "*it seems inevitable that E. viminalis will disappear entirely from the Monaro region*".

Lynch et. al. (2018) identify that in the ACT region there has been severe dieback of Blakely's Red gum (*Eucalyptus blakelyi*) dating back to 2004, with an additional 7 eucalypt species affected in recent years.

Australia's forests and woodlands are strongly influenced by large climatic variability and recurring droughts. Extreme droughts can cause widespread tree death in agricultural lands, woodlands and forests (Fensham and Fairfax 2007, Fensham *et. al* 2009, Mitchell *et.al.* 2014, Ross and Brack 2015). Mitchell *et.al.* (2014) identify that a wide range of studies have implicated temperature increases as amplifying moisture deficit, heat stress, and the impacts of biotic agents on tree species.

Within trees hydraulic failure (desiccation of water conducting tissues within the plant) and carbon starvation (depletion of available carbohydrates and failure to maintain defences against biotic agents) have been singled out as causes of tree death (Mitchell *et.al.* 2013, 2014). Mitchell *et.al.* (2014) found that periods of heat stress during droughts were likely to have been pivotal in initiating tree death. Species have been found to have differing susceptibilities (Calvert 2001, Fensham and Fairfax 2007, Mitchell *et.al.* 2013, Ross and Brack 2015, Lynch *et. al.* 2018). Fensham *et. al* (2009) also found trees at higher densities more vulnerable. In some cases, a drought event may simply be the coup-de-grace for a weakened stand of trees.

Mitchell *et.al.* (2014) consider their findings suggests that "*regardless of regional climatic differences, tree populations among many species in Australian ecosystems tolerate at least 98% of the climatic conditions they experience and become vulnerable to drought stress events beyond this common climatic threshold*", noting "*the likelihood of drought events crossing these thresholds and inducing mortality will increase significantly under future climate scenarios for many forest and woodland ecosystems globally*".

Interactions of drought effects with biotic agents and their feedbacks can also significantly change the demographic patterns of tree mortality (Anderegg et. al. 2016). Droughts can increase attacks by a variety of insects. Keith et. al. (2012) found the "*combined impact of drought stress and insect damage resulted in markedly reduced growth (45–80%) and higher mortality of trees (5–60%)*", concluding "*Drought conditions result in (1) weather conditions that break the synchronisation of insects with parasites and predators resulting in insect outbreaks, (2) moisture stress that predisposes trees to attack by insects, and (3) moisture stress that restricts leaf regeneration after damage*". Marsh and Adams (1995) found that chronic insect infestations and periodic insect outbreaks may be supported by high concentrations of nitrogenous solutes in sap and foliage, especially epicormic foliage, which in turn may be a response to drought.

Lambert (2015) observe:

> *Epicormic leaves of eucalypts following sessions of defoliation have been observed to contain high levels of nitrogen, particularly nitrogenous solutes such as proline, compared to mature leaves (Marsh and Adams 1995). Foliage nitrogen levels are also high during periods of drought when nitrogen soil availability increases. Xylem sap taken from dying trees contained a higher level of nitrogen than that taken from healthy trees (Marsh and Adams 1995). The increased uptake of nitrogen has been related to increases in herbivory, eventually leading to tree decline (Landsberg et al. 1990, Granger et al. 1994).*

Mitchell *et.al.* (2014) warn:

> *Changes in the frequency of extreme drought under the scenario presented here and elsewhere ... may also reduce vegetation resilience through time if a complete recovery of plant vasculature, carbohydrate status and defensive mechanisms is not realized in the intervening years between drought events. A small number of predicted droughts fell outside the margins of the observed record and are perhaps indicative of "mega-drought" conditions, characterized by higher intensities and longer durations than have ever been observed in the historic record ... If realized, these climate events may generate unprecedented, extensive die-off that could induce long-term shifts in vegetation structure and function.*

An American study found forests are shifting to communities that can cope with greater average water stress as well as more variability in water stress, primarily through the death of less hardy tree species (Trugman *et. al.* 2020)

6. Valuing Forest's Water Yields

All runoff from forests now has an economic value, though the value varies with downstream uses, with runoff feeding into urban water supplies being of the highest value. Stopping logging and allowing forests to mature will increase water yields over time as the forest's structure regrows, and thus stopping logging is of direct economic benefit to downstream water users. While the relative value of forest runoff will vary depending on its usage, it is apparent that in most instances it will be of higher economic benefit to maximise water

yields by not logging forests. This value will escalate as climate change gathers momentum and dry periods become more frequent and severe.

Forests are key components of the earth's water cycle. Forests do not just respond to rainfall, they actively generate their own. They recycle water from the soil back into the atmosphere by transpiration, create the updrafts that facilitate condensation as the warm air rises and cools, create pressure gradients that draw moist air in from afar, and, just to be sure, release the atmospheric particles which are the nuclei around which raindrops form.

Forests have been described as 'biotic pumps' driving regional rainfall because their high rates of transpiration return large volumes of moisture to the atmosphere and suck in moisture laden air from afar.

While most of our rain originates from evaporation of the oceans, it is estimated that 40% of the rain that falls on land comes from evaporation from the land and, most importantly, from transpiration by vegetation. Recycled water vapour becomes increasingly important for inland rainfall.

Having created and attracted the water vapour, the plants then make it rain. Plants emit volatile organic compounds (VOCs), such as plant scents and the blue haze characteristic of eucalypt forests. They play an important role in communication between plants, and messages from plants to animals, and also between plants and moisture-laden air. They oxidise in the air to form the cloud condensation nuclei around which waterdrops form.

The transpiration of vegetation also results in evaporative cooling whereby the surface heat is transferred to the atmosphere in water vapour. The resultant clouds also help shade and cool the surface.

Forests store water in their tissues, in the soil amongst their roots and in the protected microclimate beneath their canopies, releasing it over time to the atmosphere by evapotranspiration and to streams through the groundwater system. Forests are a vital component of our hydrological cycle and due to their roles in attracting and recycling rainfall, reducing temperatures and regulating runoff they provide immense economic benefits to human societies. Their importance will become increasingly significant as climate change results in more erratic rainfalls and intense dry periods.

Of the rain that falls upon a forested catchment some is evaporated directly from leaf and ground surfaces and part may be redirected by surface flows directly into streams. Except in intense rainfall events, the majority can be expected to infiltrate the soil where it is used for transpiration by plants, with the excess contributing to groundwater seepage into streams or possibly seeping deep down to aquifers. In a natural forest situation most of the streamflow response to rainfall is provided by the groundwater system.

The eWater CRC notes:

> *All plants evaporate water through their leaves. This water is extracted from the soil root zone, and the rate of evaporation depends on the weather, the available soil moisture, and the total area of leaves in the vegetation (trees and understorey). There are differences between various forest types, but basically different forests have evolved to make optimum use of the available rainfall to ensure their survival. Streamflow in drier periods is the "left-over rainfall" that passes beyond the root zone and exudes into the stream from boggy areas and the water table next to the stream. In storms, water runoff also occurs where the rainfall*

is intense enough to exceed the capacity of the soil to absorb it, or where the soil is already saturated. This runoff results in rapid increases in streamflow, or floods during major storms.

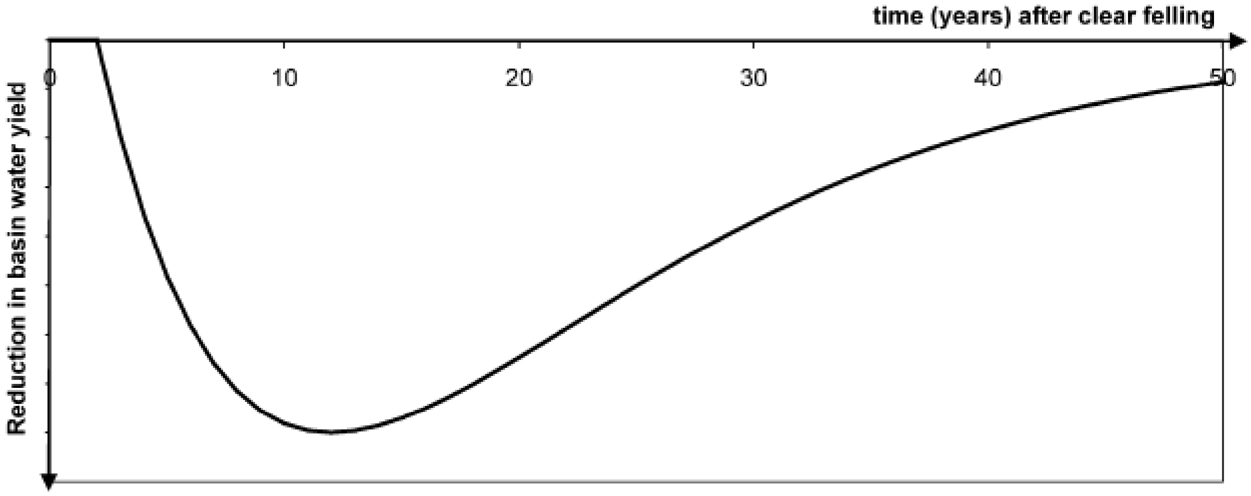
For example, during an average year at a south eastern Australian catchment where the annual rainfall is 1000 mm, the forest canopy may intercept and evaporate 150 mm of the rainfall before it reaches the ground. The forest may consume a further 750 mm by plant transpiration, leaving only 100 mm to appear as streamflow (this is equivalent to a water yield of 1 megalitre per hectare). Of this 100 mm, 80 mm may occur as short-term runoff during storms, while the remaining 20 mm occurs as sustained dry-weather flow or "baseflow".

Dargavel *et. al* (1995) note:

Streamflow is the residue of rainfall after allowing for evaporation from vegetation, changes in soil storage from year to year and deep drainage to aquifers. Forest management operations can interfere with these processes by:

- *changing the type of vegetative cover on a catchment. Experimental results show that these changes can affect evapotranspiration and therefore streamflow;*
- *changing the soil properties. The ability of the soil to both absorb and store moisture infiltration can affect the proportion of rainfall delivered. Forest operations which compact the soil can reduce both infiltration and storage capacities.*

The most significant relationship between water yields and vegetation is that related to forest age. The basic relationship between water yields and eucalypt forest age was established by studies of regrowth Mountain Ash forests following wildfires in Victoria. Kuczera (1985, cited in Vertessy *et. al*. 1998) developed an idealised curve describing the relationship between mean annual streamflow and forest age for mountain ash forest. This shows that after burning and regeneration the mean annual runoff reduces rapidly by more than 50% after which runoff slowly increases along with forest age, taking some 150 years to fully recover.



Kuczera (1985) Curve, reduction and recovery of water yields following loss of overstorey.

Tree water use has been found to be primarily related to sapwood extent, with the thickness of sapwood, and the basal area of sapwood declining as forests age, even though overall basal area increases (Dunn and Connor 1994, Roberts *et al.* 2001, Macfarlane and Silberstein 2009, Buckley *et.al.* 2012, Benyon *et. al.* 2017).

Dunn and Connor (1994) made diurnal measurements of sap velocity in 50-, 90-, 150- and 230-year-old mountain ash (*Eucalyptus regnans* F. Muell.) forests in the North Maroondah catchment finding "*The measurements have shown a significant decrease in overstorey water use with age. At the extreme, measured daily water use of the mature forest is 56% smaller than that of the regrowth forest.",* concluding:

> *There was a significant decline with age in the overstory sapwood conducting area of these forests. In order of increasing age, the values were 6.7, 6.1, 4.2 and 4.0 m^{-2} ha^{-1}, respectively. ... Annual water use decreased with forest age from 679 mm for the 50-year-old stand to 296 mm for the 230-year-old stand. ... The annual water use of the intermediate-aged stands was 610 and 365 mm for the 90- and 150-year-old stands, respectively.*

Roberts *et al.* (2001) studied water use of different aged stands of *Eucalyptus sieberi* (Silvertop Ash) within Yambulla State Forest, with an average annual rainfall of 900 mm per year, finding:

> *Stand sapwood area declined with age from 11 m^2 ha^{-1} in the 14 year old forest, to 6.5 m^2 ha^{-1} in the 45 year old forest, to 3.1 m^2 ha^{-1} in the 160 year old forest. LAI was 3.6, 4.0, and 3.4 for the 14, 45, and 160 year old plots, respectively. Because of the difference in sapwood area, plot transpiration declined with age from 2.2 mm per day in 14 year old forest, 1.4 mm per day in 45 year old forest, to 0.8 mm per day in 160 year old forest.*

Macfarlane and Silberstein (2009) assessed the water use related characteristics of regrowth and old-growth forest in the high (1200 mm $year^{-1}$) rainfall zone of jarrah forest in Western Australia, finding (SAI sapwood area index):

> *The old-growth stands had more basal area but less canopy cover, less leaf area and thinner sapwood. ...SAI of the regrowth forest at Dwellingup (7.0 m^2 ha^{-1}) was nearly double that of the old growth 3.7 m^2 ha^{-1}),..*
>
> *... At the old-growth site, daily transpiration rose from 0.4 mm day^{-1} in winter to 0.8 mm day^{-1} in spring-summer. In contrast, at the regrowth site transpiration increased from 0.8 mm day^{-1} in winter to 1.7 mm day^{-1} in spring-summer. Annual water use by the overstorey trees was estimated to be ~200 mm $year^{-1}$ for the oldgrowth stand and ~420 mm $year^{-1}$ at the regrowth stand, which is 17% and 35% of annual rainfall, respectively.*

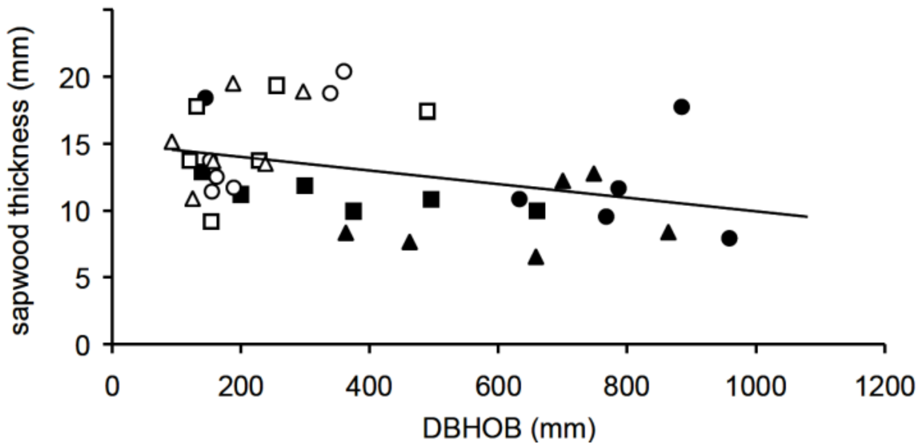


Figure 5 from Macfarlane and Silberstein (2009) sapwood thickness versus tree diameter (measured at breast height over bark, DBHOB) at the old-growth (closed symbols) and regrowth (open symbols) study sites.

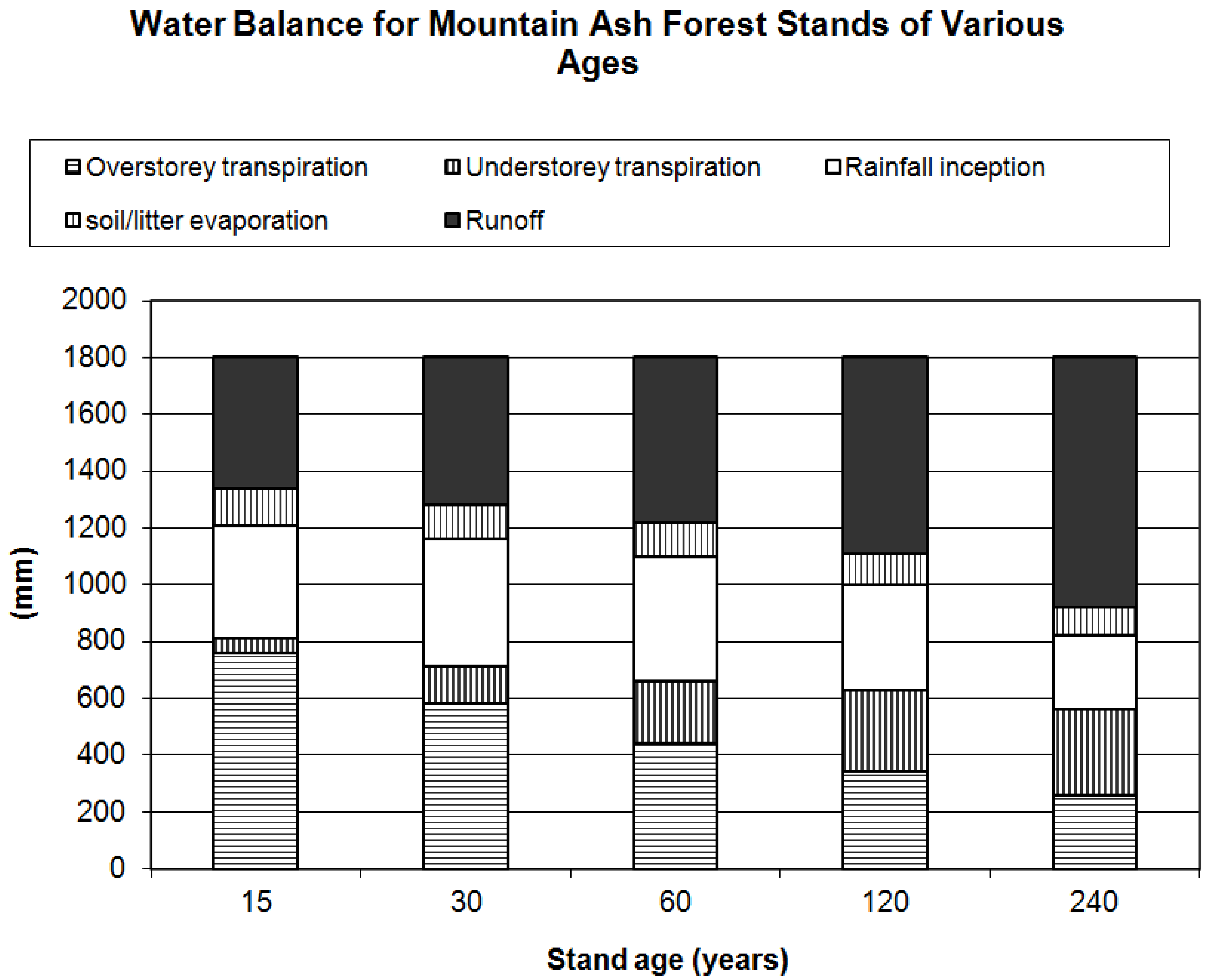
For 'actual evapotranspiration' (E_a) Benyon *et. al.* (2017) identify:

... in even-aged eucalypt forests in south-eastern Australia, catchment mean overstorey sapwood area index (SAI), estimated from a relationship between stand mean sapwood thickness and tree density (trees ha^{-1}), applied to repeated measurements of tree density and mean tree diameter over several decades, was strongly correlated with catchment mean annual E_a, estimated as annual precipitation minus annual streamflow (Benyon et al., 2015).

From their study of Mountain Ash forests, Benyon *et. al.* (2017) concluded (E_a actual evapotranspiration, SAI sapwood area index):

In non-water-limited eucalypt forests, overstorey sapwood area index is strongly correlated with annual overstorey transpiration and total evapotranspiration. Interception loss from the overstorey is also positively correlated with overstorey SAI. ... Variation in SAI explained almost 90% of the between-plot variation in annual E_a across three separate studies in non-water-limited eucalypt forests. Our results support the use of measured spatial and temporal variations in SAI for mapping mean annual E_a (Jaskierniak et al., 2015b) and for modelling longterm streamflows in ungauged catchments (Jaskierniak et al.,2016).

Vertessy *et. al.* (1998) have attempted to quantify the different components of rainfall lost by evapo-transpiration, identifying them as: interception by the forest canopy and then evaporated back into the atmosphere; evaporation from leaf litter and soil surfaces; transpiration by overstorey vegetation; and transpiration by understorey vegetation. All of these have been measured as declining with increasing forest maturity, with the exception of understorey transpiration which becomes more important as transpiration from the emergent eucalypts declines.



Water balance for Mountain Ash forest stands of various ages, assuming annual rainfall of 1800 mm (from Vertessy et. al. 1998)

The generalised pattern following heavy and extensive logging of an oldgrowth forest is for there to be an initial increase in runoff from disturbed areas peaking after 1 or 2 years and persisting for a few years. Water yields then begin to decline below that of the oldgrowth as the regrowth uses more water. Water yields are likely to reach a minimum after 2 or 3 decades before slowly increasing towards pre-logging levels in line with forest maturity.

For Mountain Ash forest in Victoria, a mean annual rainfall of 1,800 mm/yr has been found to generate a mean annual runoff from oldgrowth Mountain Ash forest of about 1,200 mm/yr (Kuzcera 1987, Vertessy *et. al.* 1998). After burning and regeneration the mean annual runoff reduces rapidly by more than 50% to 580 mm/yr by age 27 years, after which runoff slowly increases along with forest age, taking some 150 years to fully recover (Kuzcera 1987). Following clearfelling of a forest there may or may not be an initial increase in water yields for a relatively limited period. Thereafter water yields usually decline relatively rapidly in relation to growth indices of the regrowth, after some decades maximum transpiration of the regrowth is reached and water yields begin to recover with increasing forest maturity.

In the Barrington Tops area Cornish (1993) found that *"water yield decline exceeded 250 mm in the sixth year after logging in the catchment with the highest stocking of regeneration and the highest* *regrowth basal area".* This represents a major reduction given that the mean runoff pre-logging was only 362 mm (38-678 mm) and that only 61% of its catchment was logged.

Cornish and Vertessy (2001) report that the yields kept declining:

> *Water yields in a regrowth eucalypt forest were found to increase initially and then to decline below pre-treatment levels during the 16-year period which followed the logging of a moist old-growth eucalypt forest in Eastern Australia. ... Yield reductions of up to a maximum 600 mm per year in logged and regenerated areas were in accord with water yield reductions observed in Mountain Ash (Eucalyptus regnans F.J. Muell.) regeneration in Victoria. This study therefore represents the first confirmation of these Maroondah Mountain Ash results in another forest type that has also undergone eucalypt-to-eucalypt succession. Baseflow analysis indicated that baseflow and stormflow both increased after logging, with stormflow increases dominant in catchments with shallower soils. The lower runoff observed when the regenerating forest was aged 13–16 years was principally a consequence of lower baseflow.*

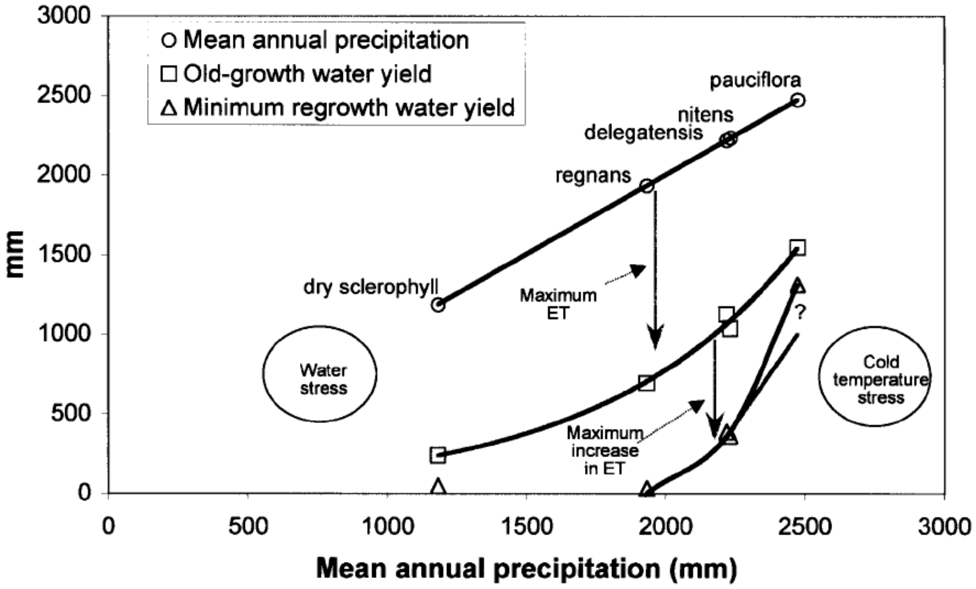
Cornish and Vertessy (2001) elaborate:

> *This analysis indicates that (in common with the results of many previous studies, e.g. Bosch and Hewlett, 1982) canopy removal increased water yield substantially. Mean increases here were frequently significant while the regrowth trees were less than 3 years old. As the trees increased in age water use increased, but mean water use was not significantly different from the pre-treatment forest between ages 3 and 12. Water yields then declined further between ages 13 and 16 years, resulting in mean reductions being statistically significant in all but one catchment.*

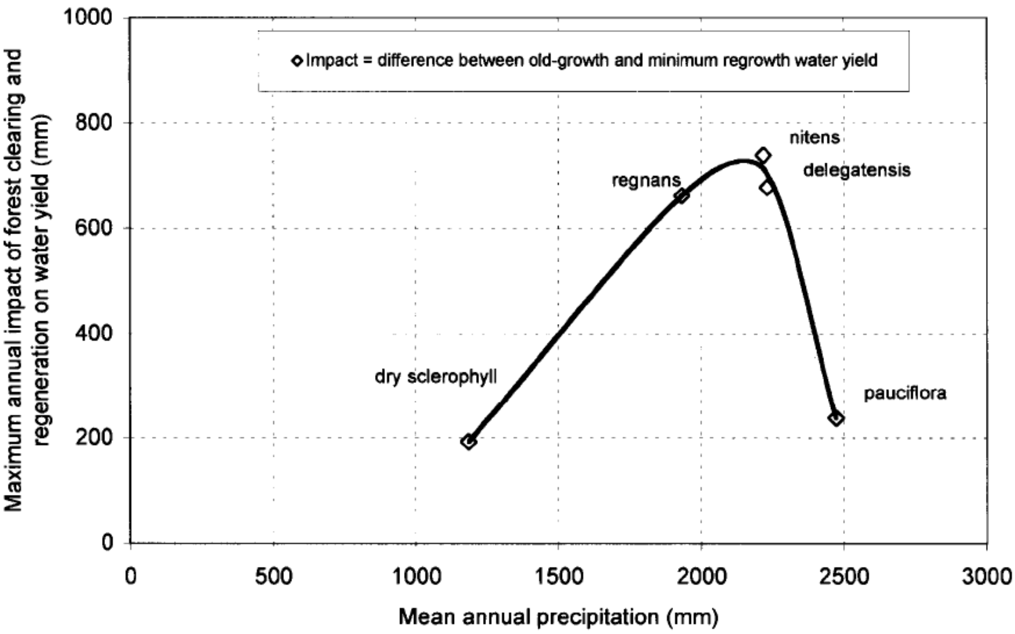
Vertessy (1999) notes that "*the maximum decrease in annual streamflow is over 60 mm per 10% of forest area treated, which is similar to the maximum reductions noted for Victorian mountain ash forests*".

The process of increasing water use by regrowth is relatively well understood and has been found to apply across forests, though localised impacts are complicated by varying vegetation types and conditions within a catchment, the depth of soils, rainfall and a multitude of environmental variables, and the compounding effects of events over time.

For example Peel *et. al.* (2000) undertook modelling in the Maroondah and Thomson catchments to identify the variations in water yield depressions according to forest types and rainfall.



Summary of simulated impacts of forest clearing and regeneration on water yield, showing the relationship between species, precipitation, and water yields. From Peel *et. al.* (2000)



Relationship between species, precipitation and maximum impact of regeneration on water yields. From Peel *et. al.* (2000)

The effects of yield reductions are most pronounced in dry periods as the vegetation utilises proportionately more of the rainfall. As identified by Peel *et. al.* (2000) for dry sclerophyll forests, it is likely that there are prolonged periods where the regrowth is utilising most of the rainfall, leaving little for runoff into streams.

It is during dry periods, which are becoming more frequent and extreme with climate heating, that runoff is of the most value. Forests, particularly oldgrowth, are increasingly important during such periods due to their ability to hold and slowly release water. NSW Office of Water (2010) caution:

> *Many of the coastal unregulated rivers within NSW have extreme competition for water during dry periods. In-stream values can be stressed during these low flow periods, wildlife*

becomes concentrated in particular locations and water quality can deteriorate through eutrophication.

After leaving the forests there are a variety of calls upon the water released into streams and aquifers from irrigation, industry and fisheries. The Water Management Act 2000 requires water sharing plans to:

- *Allocate water between all water users and the environment*
- *Improve river health*
- *Provide security for water users*
- *Meet the needs of regional communities*
- *Enable water trading.*

Water Sharing Plans in NSW allow the trade of allocation water. As a tradeable commodity water has an economic value, though this is highly variable depending on availability and competition for available supplies. Wilks Water identify prices as high as $6000 to $6,400 per ML from 15 November 2019 to 8 May 2020 in Victoria's Murray-Goulburn, though these drop to $600-900 per ML in other areas. In 2020 the NSW Government made available 51,269 ML of Groundwater across 11 Water Sharing plans with minimum bid prices as low as $500/ML.

The value of water in a catchment is far higher if used for potable drinking water. For example Rous County Council is currently going through a process of examining options to supplement the regional water supply. Hydrosphere Consulting 2020 identify the cost of the cheapest option, building a second dam on Rocky Creek, for augmenting regional water supplies as having a NPV of $15,000 (2020 $, 40 years @ 5%) per ML secure yield

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