Submission
No 7

# INQUIRY INTO 2024 ANNUAL REPORT OF THE NET ZERO COMMISSION

**Organisation:** North East Forest Alliance Inc

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# Submission to inquiry into 2024 Annual Report of the Net Zero Commission.

Dailan Pugh, North East Forest Alliance Inc., February 2025

The Net Zero Commission's 2024 Annual Report recognizes the importance of the land sector, and particularly forests, in contributing to NSW reducing its net greenhouse gas emissions:

- Carbon stored in the land sector has been a large contributor to NSW's progress in reducing its net greenhouse gas emissions.
- Unlike other sectors, the land sector has the capacity to absorb emissions and store carbon, and release carbon at considerable scales.
- Land management strategies that maintain forest and soil carbon stocks will help retain today's levels of land-based carbon storage and position the land sector to maximise its contribution to the achievement of the state's emission reduction targets.
- Carbon storage in the sector stems predominantly from reforestation activity and carbon stock change in existing forests

Regrettably it fails to consider the role of logging in increasing emissions and the ability of degraded forests to sequester and store ever increasing volumes of carbon in their wood and soils if allowed to recover their natural carbon carrying capacity.

Stopping logging and protecting forests will contribute significantly to helping NSW meet its emission targets by avoiding the emissions associated with killing trees and disturbing soils during logging, and increasing carbon sequestration and storage as the forests recover from past running down of their carbon stores.

**Rapidly increasing atmospheric $CO_2$ is causing climate heating, which is an existential threat to our future and quality of life. As temperatures rise, and droughts and wildfires increase in frequency and extent, it is a growing threat to the health and survival of numerous other species and is causing ecosystem collapse. We rely upon forests for numerous ecosystem services, including sequestering $CO_2$ from the atmosphere and storing it out of harm's way in their wood and soils. While we release large quantities of $CO_2$ by clearing and logging forests, the existential threat is that if forest ecosystems collapse and become net emitters of $CO_2$ then our ability to limit the extremes of climate heating will be lost. Given the developing climate crisis we urgently need to reduce our emissions of $CO_2$, particularly from fossil fuels, and allow forests to increase their sequestration of $CO_2$, which can be achieved by stopping logging them. It is important to recognise that plantations will take over a decade to begin sequestering and many more decades before they start sequestering significant volumes, whereas if protected existing degraded forests can begin sequestering meaningful volumes immediately. This assessment is that logging of public forests in north east NSW releases over one million tonnes of $CO_2$ each year, and that by stopping logging the recovering forests will be able to sequester over two million tonnes of $CO_2$ per annum. Protecting existing forests and allowing them to regain their lost carbon is part of the solution to climate heating.**

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 soils, 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). We depend upon forests to remove the carbon we emit to avoid runaway climate heating.

It is imperative that the world decarbonizes as quickly as possible as we progress towards net zero emissions. It is recognized that even if all feasible steps are taken to reduce carbon emissions there will still be residual emissions that need to be offset by measures to remove and store atmospheric carbon. It is well recognised that natural climate solutions are essential to draw down enough atmospheric CO2 to give us a chance of limiting global heating to less than 1.5°C, or even 2°C (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 2°C 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.

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, Mo *et al.* 2023). 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.*

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. Protecting forests enables them to regain their lost carbon and is an important contribution to mitigating the worst impacts of climate heating.

**Summary of principal issues discussed**

**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 continuing to sequester carbon. The volume of carbon stored in logged forests has been more than halved. Stopping logging will enable forests to regain their lost carbon and make a significant contribution to meeting our climate targets. This assessment indicates that stopping logging of native state forests in north-east NSW could sequester in the order of an additional 2 million tonnes of $CO_2$ per annum over the next hundred years, though another assessment put this as 0.45 million tonnes per annum over 65 years. While there is a need for an accurate assessment, it is apparent that recovering forests can sequester significant volumes of $CO_2$ and thereby help redress climate heating. It is essential that logging stop to allow forests to reduce the impacts of climate heating by removing $CO_2$ from the atmosphere, and recover their integrity to better withstand future disasters.**

**Following logging that most 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, based on the limited data available 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).**

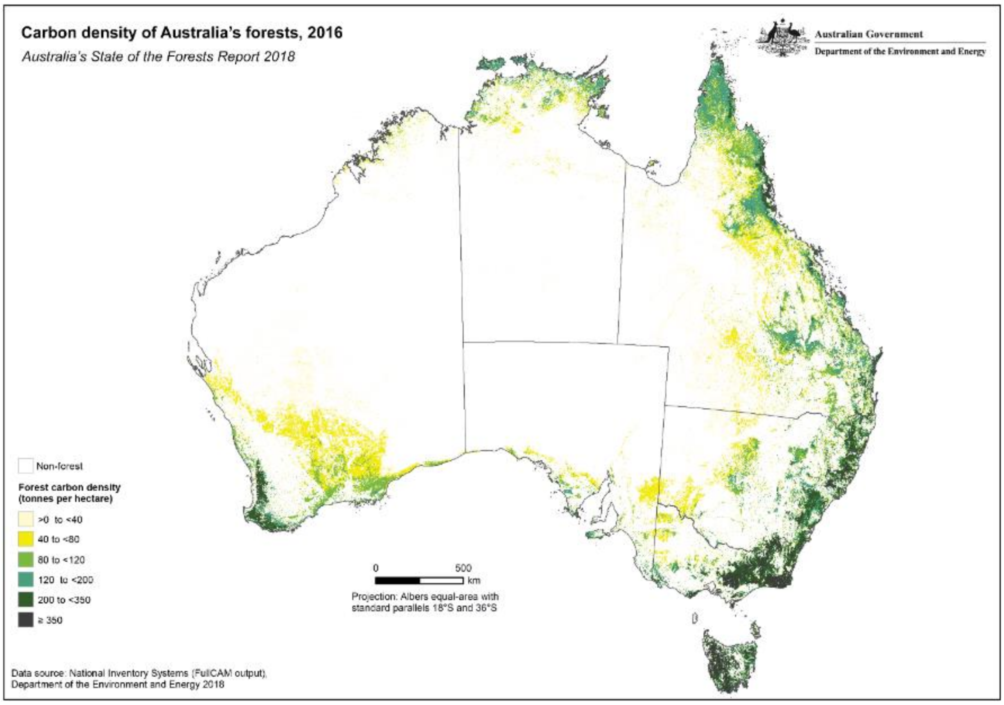
**Based on conservative assumptions, current logging of State Forests in north east NSW results in the release of over a million tonnes of $CO_2$ per annum, which is an ongoing process with carbon temporarily stored in products and logs over previous decades also progressively releasing its stored carbon. It is important to recognize**

**that if the Forestry Corporation's claims for sustainable yields are ever realized this could nearly double.**

**Trees are increasing sickening and dying as the result of increasing droughts and heatwaves generated by global warming. 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. We urgently need to stop degrading forests and begin rehabilitating them to restore their resilience to climate changes, and enable them to continue their essential role in removing our carbon from the atmosphere and mitigating the worst impacts of climate heating for their and our futures.**

## 1.1. CO2 sequestration potential

**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 continuing to sequester carbon. The volume of carbon stored in logged forests has been more than halved. Stopping logging will enable forests to regain their lost carbon and make a significant contribution to meeting our climate targets. This assessment indicates that stopping logging of native state forests in north-east NSW could sequester in the order of an additional 2 million tonnes of $CO_2$ per annum over the next hundred years, though another assessment put this as 0.45 million tonnes per annum over 65 years. While there is a need for an accurate assessment, it is apparent that recovering forests can sequester significant volumes of $CO_2$ and thereby help redress climate heating. It is essential that logging stop to allow forests to reduce the impacts of climate heating by removing $CO_2$ from the atmosphere, and recover their integrity to better withstand future disasters.**




ABARES (2018) map of forest carbon density, showing the importance of north-east NSW.

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.

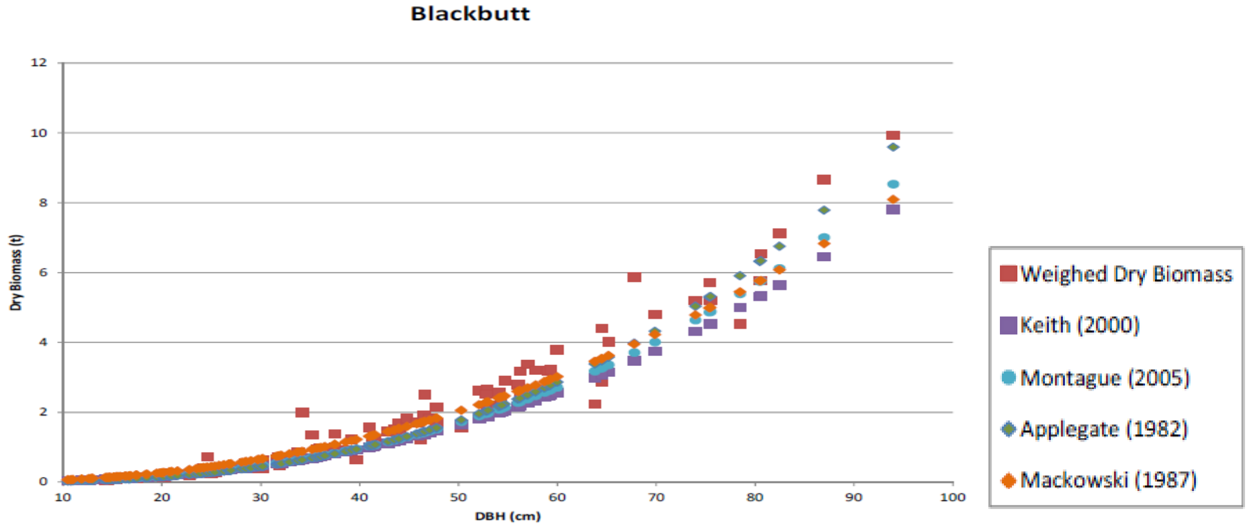
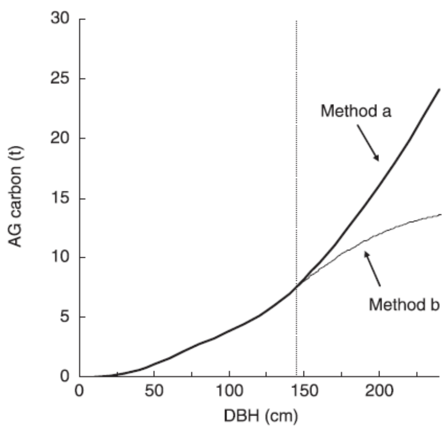


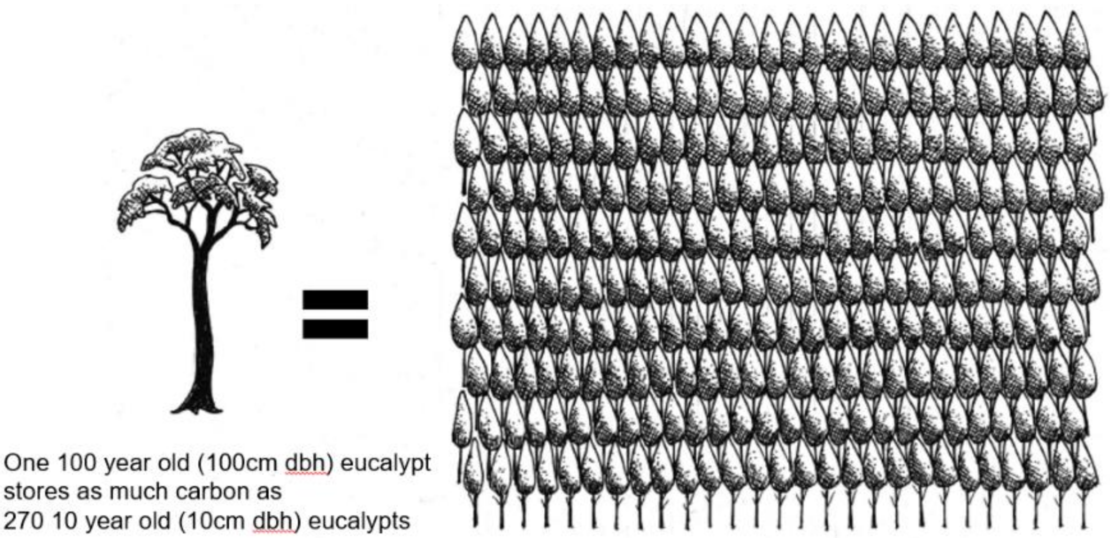

**Figure 1.40. from Ximenes *et al.* (2016) showing the relationship for Blackbutt between DBH (diameter at breast height) and dry above ground biomass (tonnes), from their direct weighing compared to various biomass equations developed by other studies. Each tonne of dry biomass is equivalent to around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




| Diameter (dbh) | Biomass | Carbon |
|---|---|---|
| 10cm | 21 kg | <0.01 tonnes |
| 30 cm | 300 kg | 0.1 tonnes |
| 100 cm | 5,700 | 1.7 tonnes |
| 150 cm | 15,200 | 4.6 tonnes |

Oldgrowth forests provide the baseline of how much carbon forests can contain under natural disturbance regimes; they represent a forest's **Carbon Carrying Capacity**. One method of identifying how much carbon a degraded forest can sequester is to compare its **current carbon storage** to the Carbon Carrying Capacity of the original oldgrowth forest likely to have occurred on the site. The difference between the two is a forest's **carbon sequestration potential**, indicating the volume of $CO_2$ a forest is capable of sequestering from the atmosphere if allowed to grow old in peace (Roxburgh *et.al.* 2006, Mackey *et. al.* 2008).

Carbon Carrying Capacity will vary with forest ecosystems, species composition, and site productivity. Even then oldgrowth forests have been found to continue sequestering and accumulating carbon indefinitely (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), so at best an indicative baseline Carbon Carrying Capacity is identified.

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*

Mackey *et. al.* (2008) assessed the Carbon Carrying Capacity for intact natural eucalypt forests of south-eastern Australia (which included north-east NSW) as an average of about 640 t C ha$^{-1}$, with 44% in soils, 45% in living biomass, and 11% in dead biomass.

**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 |
|---|---|---|---|---|
| **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.

Keith *et. al.* (2015) identified the maximum carbon stock for forests in aboveground living biomass on the south coast as 130-250 tCha$^{-1}$ and in Mountain Ash forests as 775 tCha$^{-1}$. With allowance for 25% of the biomass to be below ground, for south coast forests this translates as 162.5-312.5 tCha-$^{1}$ – an average of 237.5 tCha$^{-1}$.

Additional information on Carbon Carrying Capacity is provided by Ximenes *et al.*'s (2004, 2016) measurements of above ground biomass (AGB) at 5x0.5 ha sites in NSW, that were chosen as representative of older forests with no management history (though all appeared to have had some logging) and 2x0.5 ha sites chosen as representative of older logged forest. Ximenes *et al.*'s (2016) assessments were limited to above ground biomass, including dead biomass, so did not consider tree roots or soils. It is emphasised that as well as the small samples, these do not account for the wet sclerophyll types found in north-east NSW, dominated by species such as flooded gum, tallowwood, blue gum and brush box, which have far higher biomasses.

Ximenes *et al.*'s (2016) measurements of above ground biomass in "representative" stands of previously logged Silvertop Ash and Blackbutt (which had matured sufficiently for relogging), provide an indication of minimum biomass reductions in older logged stands:

| Sites | Total live green AGB (t / ha) | Dead trees (t / ha) | CWD (t / ha) | Litter (t/ha) | Total AGB (t / ha) |
|---|---|---|---|---|---|
| Silvertop ash conservation | 786.2 | 6.9 | 63.0 | 14.5 | 870.6 |
| Silvertop ash production | 320.8 | 28.0 | 85.2 | 14.6 | 448.6 |
| Blackbutt conservation | 674.8 | 5.4 | 48.1 | 21.9 | 750.2 |
| Blackbutt production | 399.0 | 19.8 | 170.4 | 23.4 | 612.6 |

**Table 1.3. from Ximenes *et al.* (2016), Above ground biomass as measured for each site as fresh weight**

Total carbon in living vegetation includes both above ground biomass (trunks, branches and leaves) and below ground biomass (roots). For conversion purposes, water may comprise 30-40% of the biomass of a tree, roots around 25% of the above ground biomass, and the dry weight of trees is taken to be comprised of 50% carbon.

For comparison Ximenes *et al.*'s (2016) assessed dry above ground biomass was converted to account for below ground biomass (x1.25), with 50% of the dry weight taken to be carbon. For Silvertop Stringybark forests on the NSW south-coast, this gives 128 tC/ha for the production forest and 298 tC/ha for the older forests, a loss of 170 tC/ha (57%). For Blackbutt forests on the north coast, this gives 161 tC/ha for the production forest and 261 tC/ha for the older forests, a loss of 100 tC/ha (38%), though the older forest had a low density of large trees and the "*"production" site yielded a slightly higher proportion of high quality logs than the average blackbutt forest"*, meaning they likely understate the average carbon loss.

For the older forests Ximenes *et al.*'s (2016) results give a carbon content of 261-298 tC/ha in live biomass, with an average of 279.5 tC/ha, which is considered relatively low because the stands are likely below Carbon Carrying Capacity and are not representative of the more productive wet-sclerophyll types. The average carbon reduction live biomass in logged forests is 100-170 tC/ha, with an average loss of 130 tC/ha (46%). It is emphasized that current logging is more intense.

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). The dry Above Ground Biomass was 220.2, 287 and 397.3 tonnes ha. For the low, moderate and high site qualities respectively. These are equivalent to a total (including below ground biomass) carbon content of 138, 179 and 248 $tCha^{-1}$ in live biomass – an average of 188 $tCha^{-1}$.

The Federal Government's FullCAM (Full Carbon Accounting Model) is applied at the national scale for land sector greenhouse gas emissions accounting. It includes a value for the 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). This is equivalent to a maximum (including below-ground) carbon accumulation of 131 to 179 $tCha^{-1}$, which are significantly below measured values, and thus bring into question the accuracy of FullCAM.

These are significantly less than the 289 tC/ha derived by Mackey *et. al.* (2008) for live biomass, the Keith *et. al.* (2015) south coast average of 237.5 $tCha^{-1}$, the derived Ximenes *et al.* (2016) average of 279.5 $tCha^{-1}$ and even the Ximenes *et al.* (2004) average for Spotted Gum of188 $tCha^{-1}$.

It is considered that for the purpose of this review it is reasonable to assume an average Carbon Carrying Capacity of 250 $tC/ha^{-1}$ for natural forests in north-east NSW (which is conservative as it does not account for productive wet sclerophyll forests). Thus, it is considered reasonable to assume that if logged forests have retained an average of 50% of their original carbon (which is unlikely with current logging intensities), they would have a *carbon sequestration potential* of 125 $tC/ha^{-1}$. This is the volume of carbon that has been lost by past logging. Each tonne of carbon produces 3.67 tonnes of carbon dioxide when oxidized. Applying the multiplier of 3.67, this is equivalent to a *carbon dioxide sequestration potential* 459 $tCO^2/ha^{-1}$.

This is a simplistic and indicative assessment of sequestration potential, and likely to be conservative, though can be applied to indicate the magnitude of $CO_2$ that can be sequestered by forests recovering from logging in north east NSW.

There have been several 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.*

There are 1,153,217 ha of State Forests identified in north-east NSW outside claimed plantations (FMZ 5 and 6). It is claimed that around 50% of State Forests are available for logging, which equates as 577,000 hectares of native forest in north-east NSW. Application of the indicative carbon dioxide sequestration potential 459 $tCO^2/ha^{-1}$ gives a total potential to sequester in the order of a total of 265 million tonnes of $CO_2$ if logging of State Forests in north east NSW was stopped and the logged forests are allowed to regain their lost carbon over time.

The key question is the rate of carbon sequestration. In Australian forests Roxburgh et.al. (2006) found that following logging "*Model simulations predicted the recovery of an average site to take 53 years to reach 75% carrying capacity, and 152 years to reach 90% carrying capacity*". Carbon accounting is based on a 100 year timeframe, so it can be expected that some 87% of the adopted carbon carrying capacity of 250 tC/ha could be restored if loggable forests were protected, which, assuming a current carbon volume of 125t C/ha, is an additional 92.5 tC/ha that could be regained over 100 years, or 0.93 tC/ha per annum. This converts into the sequestration of 3.4 tonnes of $CO_2$ per hectare per annum over 100 years, which across 577,000 hectares of native forest in north-east NSW is in the order of 2 million tonnes of $CO_2$ per annum.

This is substantially different to the 0.45 million tonnes of carbon (which is assumed to refer to $CO_2$) annually applied by Blueprint Institute (2023), Their figure is attributed to "*a 2016 FWPA study*", which used "*life cycle assessments… including the influence of carbon leakage*" over a 65 year period, though as it is not fully cited it was not able to be assessed to review the different methodology used.

It is feasible to more accurately identify north-east NSW's forest's current carbon storage, carbon carrying capacity, and thus carbon sequestration potential, by using LiDAR mapping. Griffith University is currently analysing LiDAR mapping to identify forest structure down to individual trees across the Northern Rivers, being the Tweed, Richmond and Clarence River catchments. This mapping is being extended to include the proposed Great Koala National Park, and now that the methodological issues have been resolved, can be readily extended to include the balance of north-east NSW.

Existing LiDAR data can be analysed to identify standing tree carbon for each forest ecosystem across the landscape. Representative old stands can be assessed to quantify carbon carrying capacity for each ecosystem. Being spatial data, the current carbon storage for each ecosystem in the loggable areas of State Forests can be quantified, and their carbon sequestration potential accurately identified.

Forestry Corporation growth plots provide plots to ground truth and refine the LiDAR mapping, as well as quantifying the potential annual rate at which carbon can be sequestered by the recovering forests.

## 1.2. CO2 released by logging

**Following logging that most 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, based on the limited data available 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).**

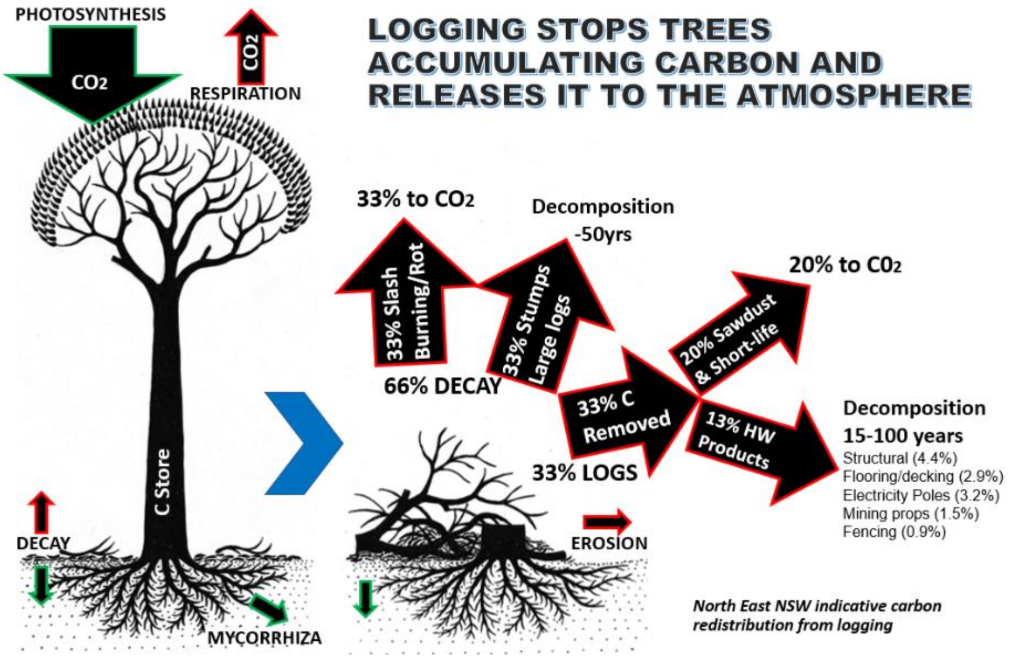
**Based on conservative assumptions, current logging of State Forests in north east NSW results in the release of over a million tonnes of $CO_2$ per annum, which is an ongoing process with carbon temporarily stored in products and logs over previous decades also progressively releasing its stored carbon. It is important to recognize that if the Forestry Corporation's claims for sustainable yields are ever realized this could nearly double.**

Sanger (2023) assessed that native forest logging in NSW releases 3.6 million tonnes of carbon (CO2e) per year, which is equivalent to the annual emissions of 840,000 cars. She considered that by 2050 76 million tonnes of carbon can be prevented from entering the atmosphere if forests are protected rather than logged, which could provide $2.7 billion worth of climate benefit to the community.

In regions with large pulpwood industries most 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 (i.e. Keith *et. al.* 2014). Export woodchipping from north-east NSW was stopped in 2013, though has since increased (mostly from plantations), with pulpwood currently comprising 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.

## Indicative fate of Logged Forest Carbon in north-east NSW




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 |

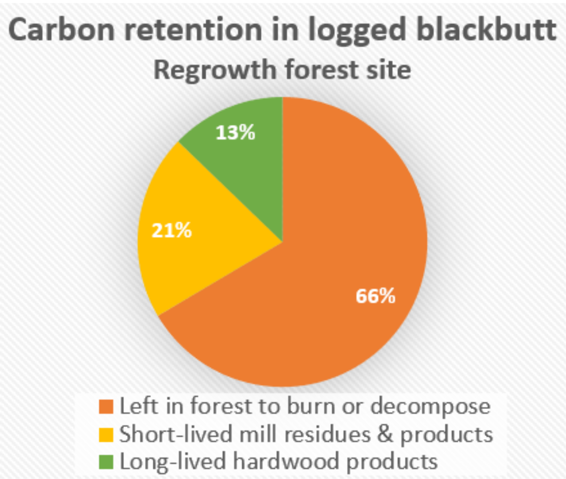
Live Above Ground Biomass (AGB), converted into dry biomass in tonnes per hectare, on cleafelled plots differentiated into tree parts left on site (bark, crown, stump and other) and removed in log form, as identified by Ximenes *et al.* (2016). The 'Other' residues include non- commercial species, dead 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, i.e. averaging only 7% for silvertop ash.

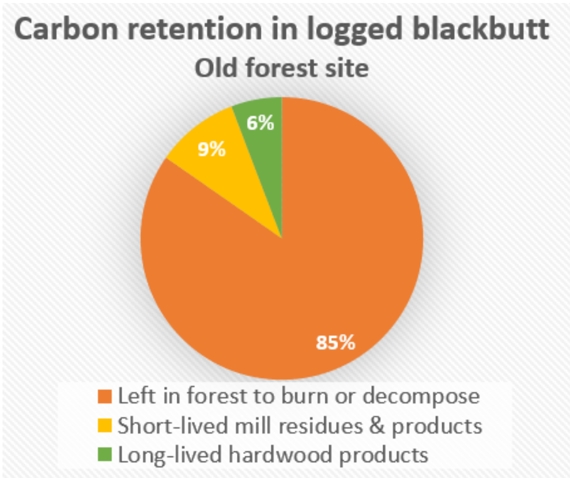
Leaves, bark and small branches and rootlets will rapidly decompose, releasing their carbon in the process, though stumps, sections of trunks, large branches, and large roots will decompose more slowly. In dry environments standing dead trees and other Coarse Woody Debris (CWD) may remain for decades, 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) estimates of the fate of carbon in logged forests.**

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.

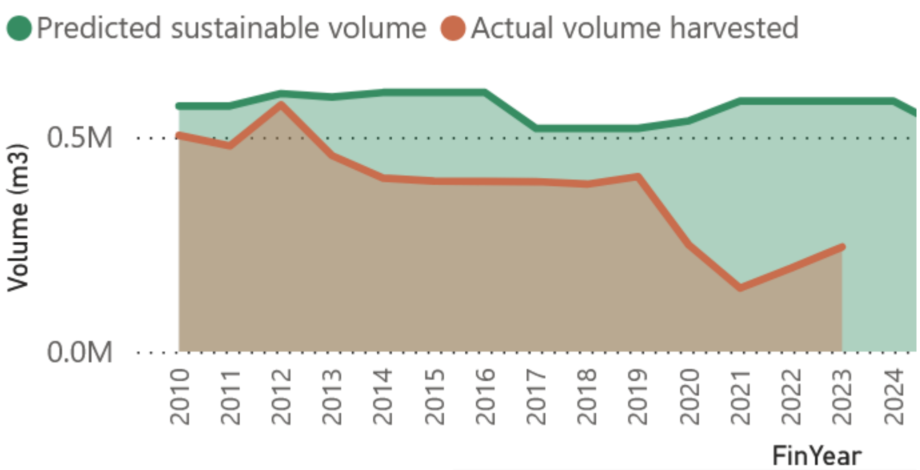
After its useful life is over, a portion of the timber product may end up in landfill, where very low rates of decomposition are reported because of the anaerobic conditions. Keith *et. al.* (2014) consider the proportion of the initial forest carbon stock that remains in long-term storage in landfill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

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 long-lived 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. 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.

Forestry Corporation's 2023 Sustainability report identifies the volumes attained from north coast hardwood forests in 2022/23 as 243,629 m3, with an annual average over the past 9 years (since the 2014 buyback) of 313,346 $m^3$. This includes the significant reduction in 2019/20 due to the wildfires.

| | Volume Harvested $m^3$ |
|---|---|
| 2022/23 | 243629 |
| 2021/22 | 194066 |
| 2020/21 | 147668 |
| 2019/20 | 247771 |
| 2018/19 | 407600 |
| 2017/18 | 389993 |
| 2016/17 | 395878 |
| 2015/16 | 396445 |
| 2014/15 | 397068 |
| TOTAL | 2820118 |
| Annual Average | 313346 |

The report shows yields to be declining and significantly below estimates of sustainable yields. The decline started after 2012 with retirements and purchases of quotas, with another significant drop after the 2019 wildfires, and some recovery in 2023. So, the average yields for the past 9 years are less than what can be expected under a business as usual scenario.




**Graph from Forestry Corporation's 2023 Sustainability Report identifying the volumes attained from north coast hardwood forests, note the significant drop below "predicted sustainable volume" since 2012, and the further decline since the 2019 wildfires.**

For 2023 the Sustainability Report, identifies the total yield from native forests on the north coast (including joint ventures) as 243,629m$^3$, with 94,427m$^3$ large HQ sawlogs, 39,302m$^3$ small HQ sawlogs, 71,249m$^3$ low quality logs and pulp/other 38,650m$^3$. The report identifies a sustainable yield of all products as 583,810 m$^3$.

Over the nine years 2014/15 to 2022/23 the average annual volume of products removed was 313,346 m$^3$. Using the conversions of 35% of the wood being water, and 50% of dry wood being carbon, this represents 101,837 tonnes of carbon. Based on 66.5% of the biomass being left in the forest this would represent 202,135 tonnes of carbon left in the forest each year, where it can be expected that half will be burnt or decay within 3 years and half will progressively decay or burn over 60 years. Based on Ximenes *et al.* (2016), of the carbon removed, 62,935 tonnes (61.8%) will end up as short-lived mill residues and products, and 38,901 tonnes (38.2%) as relatively long-lived hardwood products. Of the 12.8% (at best) of total forest carbon made into long-life timber products, some 21,278 tonnes (7%) of carbon will be released over 15-30 years, 9,119 tonnes (3%) of carbon will be released over 60-90 years and 8,511 tonnes (2.8%) of carbon may remain sequestered for over 100 years.

In summary, based on conservative assumptions and with conversion into $CO_2$ (using a multiplier of 3.67), current logging of State Forests in north east NSW results in the release of over 1,116,000 tonnes of $CO_2$ per annum, with just 5.8% of the forests' sequestered carbon (equivalent to 64,702 tonnes of $CO_2$) expected to end up in forest products lasting more than 60 years. So, in total, each year logging of State forests in north-east NSW releases over a million tonnes of $CO_2$ per annum, which is an ongoing process with carbon temporarily stored in products and logs over previous decades also progressively releasing its stored carbon. It is important to recognize that if the Forestry Corporation's claims for sustainable yields are ever realized this could nearly double.

## 1.3. Plantations have a delayed carbon benefit

**The establishment of plantations or regrowth 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 over a decade before biomass in plantations or regrowth result in a net increase in carbon storage. Sequestration will increase as the trees age.**

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).

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.*

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. 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 % $yr^{-1}$.

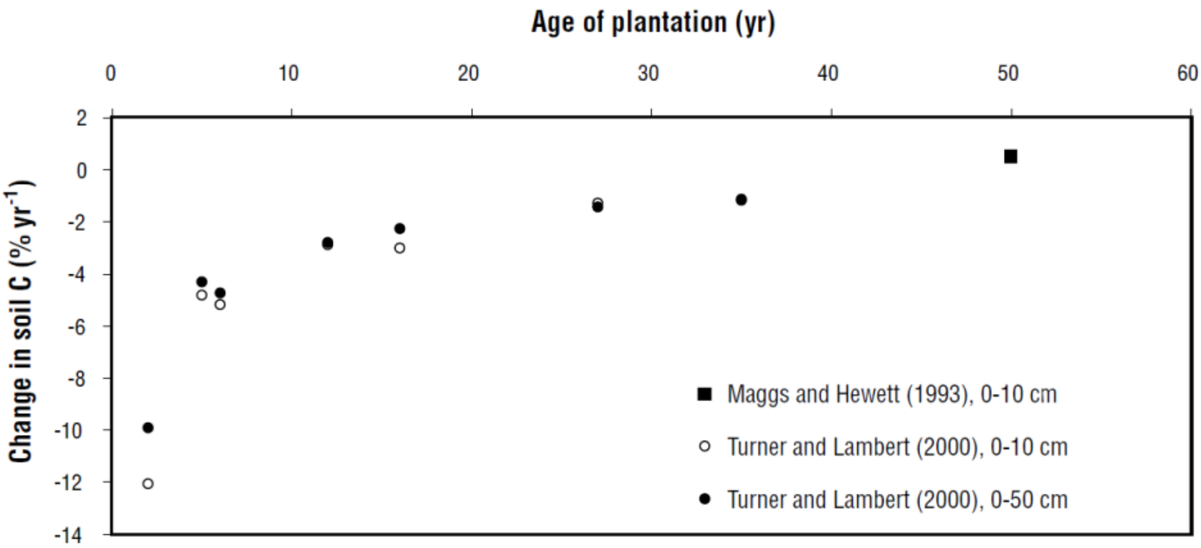



**Figure 12.2. from Polgase *et. al.* (2000) Change in soil C in 0-10 cm or 0-50 cm layer under 2- to 50-year-old forest on ex-pasture land in the subtropical climatic regions of Queensland and the north coast of New South Wales.**

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*".

## 1.4. The growing risk of ecosystem collapse and degradation

**Trees are increasing sickening and dying as the result of increasing droughts and heatwaves generated by global warming. 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. We urgently need to stop degrading forests and begin rehabilitating them to restore their resilience to climate changes, and enable them to continue their essential role in removing our carbon from the atmosphere and mitigating the worst impacts of climate heating for their and our futures.**

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°) 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,*

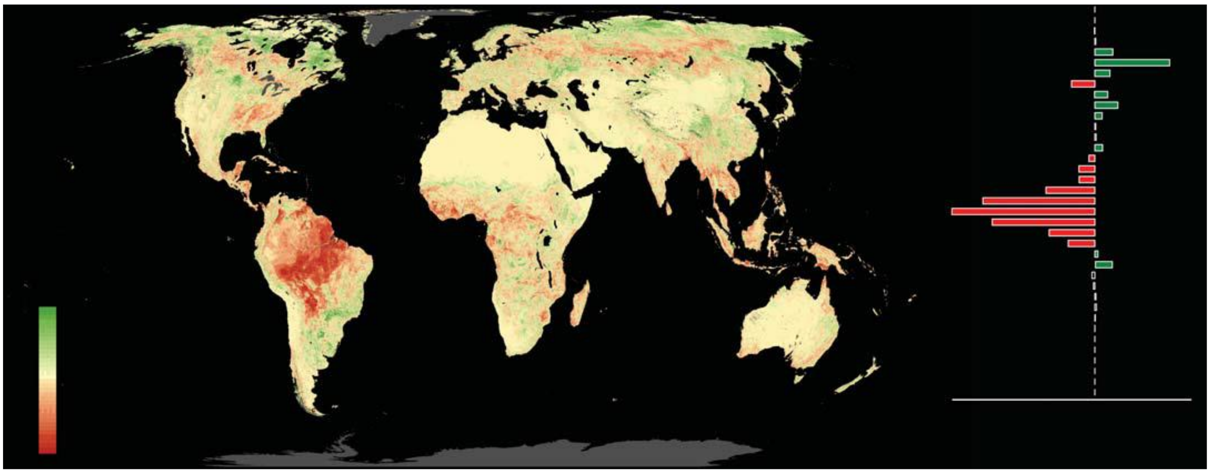


**Fig. 3 from Bastin et. al. (2019): Risk assessment of future changes in potential tree cover. (A) Illustration of expected losses in potential tree cover by 2050, under the "business as usual" climate change scenario (RCP 8.5), ... (B) Quantitative numbers of potential gain and loss are illustrated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

# References

Allen G.D. *et. al.* (2010) A global overview of drought and heat-induced tree mortality reveals emerging climate change risks for forests. Adaptation of Forests and Forest Management to Changing Climate — Selected papers from the conference on “Adaptation of Forests and Forest Management to Changing Climate with Emphasis on Forest Health: A Review of Science, Policies and Practices”, Umeå, Sweden, August 25-28, 2008.Forest Ecology and Management, Volume 259, Issue 4, 5 February 2010, Pages 660–684.

Anderegg, W.R., Klein, T., Bartlett, M., Sack, L., Pellegrini, A.F., Choat, B. and Jansen, S., 2016. Meta-analysis reveals that hydraulic traits explain cross-species patterns of drought-induced tree mortality across the globe. *Proceedings of the National Academy of Sciences*, *113*(18), pp.5024-5029.

Bastin, J.F., Finegold, Y., Garcia, C., Mollicone, D., Rezende, M., Routh, D., Zohner, C.M. and Crowther, T.W., 2019. The global tree restoration potential. *Science*, *365*(6448), pp.76-79.

Blueprint Institute (2023) Branching out, Exploring Alternate Land Use Options for the Native Forests of New South Wales. Calvert 2001

Carey, E.V., Sala, A., Keane, R. and Callaway, R.M., 2001. Are old forests underestimated as global carbon sinks?. *Global Change Biology*, *7*(4), pp.339-344.

Chen, J., Ustin, S.L., Suchanek, T.H., Bond, B.J., Brosofske, K.D. and Falk, M., 2004. Net ecosystem exchanges of carbon, water, and energy in young and old-growth Douglas-fir forests. *Ecosystems*, *7*(5), pp.534-544.

Curtis, P.S. and Gough, C.M., 2018. Forest aging, disturbance and the carbon cycle. *New Phytologist*, *219*(4), pp.1188-1193.

Dean, C., Wardell-Johnson, G.W. and Kirkpatrick, J.B., 2012. Are there any circumstances in which logging primary wet-eucalypt forest will not add to the global carbon burden?. *Agricultural and Forest Meteorology*, *161*, pp.156-169.

Falk, M., Suchanek, T.H., Ustin, S.L., Chen, J., Park, Y.S., Winner, W.E., Thomas, S.C., Hsiao, T.C., Shaw, R.H., King, T.S. and Pyles, R.D., 2004. Carbon dioxide exchange between an old-growth forest and the atmosphere. *Ecosystems*, *7*(5), pp.513-524.

Fargione, J.E., Bassett, S., Boucher, T., Bridgham, S.D., Conant, R.T., Cook-Patton, S.C., Ellis, P.W., Falcucci, A., Fourqurean, J.W., Gopalakrishna, T. and Gu, H., 2018. Natural climate solutions for the United States. *Science advances*, *4*(11), p.eaat1869.

Fensham, R. J.; Fairfax, R. J. (2007) Drought-related tree death of savanna eucalypts: Species susceptibility, soil conditions and root architecture. *Journal of Vegetation Science 18: 71-80.*

Fensham, R. J.; Fairfax, R. J.; and Ward, D.P. (2009) Drought-induced tree death in savanna, Global Change Biology Volume 15, Issue 2, 2009, 380-387Mitchell *et.al.* 2013.

Goldstein, A., Turner, W.R., Spawn, S.A. *et al.* (2020) Protecting irrecoverable carbon in Earth's ecosystems. *Nat. Clim. Chang.* (2020). https://doi.org/10.1038/s41558-020-0738-8

Griscom, B.W., Adams, J., Ellis, P.W., Houghton, R.A., Lomax, G., Miteva, D.A., Schlesinger, W.H., Shoch, D., Siikamäki, J.V., Smith, P. and Woodbury, P., 2017. Natural climate solutions. *Proceedings of the National Academy of Sciences*, *114*(44), pp.11645-11650.

Harmon, M E Ferrell, W. K; and Franklin, J. F (1990) Effects on Carbon Storage of Conversion of Old-Growth Forests to Young Forests. *Science;* Feb 9, 247, 4943 pp699-702.

Harper, R.J., Okom, A.E.A., Stilwell, A.T., Tibbett, M., Dean, C., George, S.J., Sochacki, S.J., Mitchell, C.D., Mann, S.S. and Dods, K., 2012. Reforesting degraded agricultural landscapes with Eucalypts: Effects on carbon storage and soil fertility after 26 years. *Agriculture, Ecosystems & Environment*, *163*, pp.3-13.

Harris, N.L., Gibbs, D.A., Baccini, A. *et al.* (2021) Global maps of twenty-first century forest carbon fluxes. *Nat. Clim. Chang.* **11,** 234–240. https://doi.org/10.1038/s41558-020-00976-6

Houghton, R.A. and Nassikas, A.A., 2018. Negative emissions from stopping deforestation and forest degradation, globally. *Global change biology*, *24*(1), pp.350-359.Hubbard, R. K.; Newton, G. L.; and Hill, G. M., (2004) "Water Quality and the Grazing Animal". *Publications from USDA-ARS / UNL Faculty.* Paper 274. http://digitalcommons.unl.edu/usdaarsfacpub/274

IPCC (2018) GLOBAL WARMING OF 1.5 °C, an IPCC special report on the impacts of global warming of 1.5 °C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty. Summary for Policymakers.

Keith H, Lindenmayer D, Macintosh A, Mackey B (2015) Under What Circumstances Do Wood Products from Native Forests Benefit Climate Change Mitigation? PLoS ONE 10(10): e0139640. doi:10.1371/journal.pone.0139640

Keith, H., Lindenmayer, D.B., Mackey, B.G., Blair, D., Carter, L., McBurney, L., Okada, S. and Konishi-Nagano, T., 2014b. Accounting for biomass carbon stock change due to wildfire in temperate forest landscapes in Australia. *PloS one*, *9*(9).

Keith, H., Lindenmayer, D., Mackey, B., Blair, D., Carter, L., McBurney, L., Okada, S. and Konishi-Nagano, T., 2014. Managing temperate forests for carbon storage: impacts of logging versus forest protection on carbon stocks. *Ecosphere*, *5*(6), pp.1-34.Kovács *et. al.* (2017)

Keith, H, Van Gorsel, E, Jacobsen, K.L and Cleugh, H.A. 2012 Dynamics of carbon exchange in a *Eucalyptus* forest in response to interacting disturbance factors. Agricultural and Forest Meteorology Volume 153, Pages 67–81

Luyssaert, S., Schulze, E.D., Börner, A., Knohl, A., Hessenmöller, D., Law, B.E., Ciais, P. and J. (2008) Old-growth forests as global carbon sinks. *Nature* 455, 213-215

Lynch, A.J.J., Botha, J., Johnston, L., Peden, L., Seddon, J. and Corrigan, T., 2018. Managing a complex problem: Blakely's Red Gum dieback in the ACT. *Restore, Regenerate, Revegetate*, p.51.

Macintosh, A., Keith, H. and Lindenmayer, D., 2015. Rethinking forest carbon assessments to account for policy institutions. *Nature Climate Change*, *5*(10), pp.946-949.

Macintosh, A et. al (2024) Australian human-induced native forest regeneration carbon offset projects have limited impact on changes in woody vegetation cover and carbon removals. Communications Earth & Environment | (2024) 5:149.

Mackey, B., Keith, H., Berry, S.L. and Lindenmayer, D.B. (2008) Green carbon: the role of natural forests in carbon storage. Part 1, A green carbon account of Australia's south-eastern Eucalypt forest, and policy implications. ANU E Press

Mackey, B., Moomaw, W., Lindenmayer, D. and Keith, H. (2022) Net carbon accounting and reporting are a barrier to understanding the mitigation value of forest protection in developed countries. *Environ. Res. Lett.* **17** 054028.

Marsh, N. R., and M. A. Adams. 1995. Decline of Eucalyptus tereticornis near Bairnsdale, Victoria: insect herbivory and nitrogen fractions in sap and foliage. Australian Journal of Botany **43**:39-50.

Mitchell, P.J., O"Grady, A.P., Tissue, D.T., White, D.A. Ottensschlaeger, M.L. and Pinkard, E.A. (2013) Drought response strategies define the relative contributions of hydraulic dysfunction and carbohydrate depletion during tree mortality. New Phytol.;197(3):862-72. doi: 10.1111/nph.12064.

Mitchell, P.J., O"Grady, A.P., Hayes, K.R. and Pinkard, E.A. (2014) Exposure of trees to drought induced die-off is defined by a common climatic threshold across different vegetation types. Ecol Evol.4(7): 1088–1101

Mo, L., Zohner, C.M., Reich, P.B., Liang, J., De Miguel, S., Nabuurs, G.J., Renner, S.S., van den Hoogen, J., Araza, A., Herold, M. and Mirzagholi, L., 2023. Integrated global assessment of the natural forest carbon potential. *Nature*, *624*(7990), pp.92-101.

Moomaw, W.R., Masino, S.A. and Faison, E.K., 2019. Intact Forests in the United States: Proforestation Mitigates Climate Change and Serves the Greatest Good. *Frontiers in Forests and Global Change*, *2*, p.27.

Perkins, F. and Mackintosh, A. (2013) Logging or carbon credits, Comparing the financial returns from forest-based activities in NSW's Southern Forestry Region. Australia Institute, Tech Brief 23. ISSN 1836-9014

Polglase, P.J., Paul, K.I., Khanna, P.K., Nyakuengama, J.G., O'Connell, A.M., Grove, T.S. and Battaglia, M. (2000). Change in soil carbon following afforestation or reforestation. CSIRO Forestry and Forest Products, National Carbon Accounting System, Technical Report No. 20, October 2000.

Ross, C. and Brack, C. (2015) *Eucalyptus viminalis* dieback in the Monaro region, NSW. J. Aust. Forestry 78:4,

Roxburgh, S. H., Wood, S.W., Mackey, B.J., Woldendorp, G., and Gibbons, P. (2006) Assessing the carbon sequestration potential of managed forests: a case study from temperate Australia. *Journal of Applied Ecology* (2006) 43, 1149–1159. doi: 10.1111/j.1365-2664.2006.01221.x

Roxburgh, S., Karunaratne, S., Paul, K., Lucas, R., Armston, J. and Sun, J., 2017. A revised above-ground maximum biomass layer for Australia's national carbon accounting system. Prepared for the Department of the Environment. CSIRO.

Sanger, J. (2023) NSW Forest Carbon, An Effective Climate Change Solution. The Trees Project.

Snow, M., & Prasad, D. (2011). Climate Change Adaptation for Building Designers: An Introduction. *Environment Design Guide*, 1–11. http://www.jstor.org/stable/26150792

Stephenson, N.L., Das, A.J., Condit, R., Russo, S.E., Baker, P.J., Beckman, N.G., Coomes, D.A., Lines, E.R., Morris, W.K., Rüger, N. and Alvarez, E., 2014. Rate of tree carbon accumulation increases continuously with tree size. *Nature*, *507*(7490), pp.90-93.

Trugman, A.T., Anderegg, L.D.L., Shaw, J.D., Anderegg, W.R.L. (2020) Trait velocities reveal that mortality has driven widespread coordinated shifts in forest hydraulic trait composition. PNAS https://doi.org/10.1073/pnas.1917521117

Turner, J., Lambert, M.J. and Johnson, D.W., 2005. Experience with patterns of change in soil carbon resulting from forest plantation establishment in eastern Australia. *Forest Ecology and Management*, *220*(1-3), pp.259-269.

Wardell-Johnson GW, Keppel G, Sander J (2011) Climate change impacts on the terrestrial biodiversity and carbon stocks of Oceania. Pacific Conservation Biology 17: 220–240.

Woldendorp, G. & Keenan, Rodney & Ryan, M.. (2002). Coarse Woody Debris in Australian Forest Ecosystems. A Report for the National Greenhouse Strategy, Module 6.6 (Criteria and Indicators of Sustainable Forest Management), Commonwealth of Australia.

Ximenes F, Gardner WD, Marchant JF 2004. Total biomass measurement and recovery of biomass in log products in spotted gum (Corymbia maculata) forests of SE NSW. NCAS Technical Report No. 47, Australian Greenhouse Office.

Ximenes, F., Bi, H., Cameron, N., Coburn, R., Maclean, M., Matthew, D.S., Roxburgh, S., Ryan, M., Williams, J. and Ken, B., 2016. Carbon stocks and flows in native forests and harvested wood products in SE Australia. *Project No: PNC285-1112*.

Zhang, H., Duan, H., Song, M. *et al.* (2018) The dynamics of carbon accumulation in *Eucalyptus* and *Acacia* plantations in the Pearl River delta region. *Annals of Forest Science* **75,** 40. https://doi.org/10.1007/s13595-018-0717-7

Zhou, G., Liu, S., Li, Z., Zhang, D., Tang, X., Zhou, C., Yan, J. and Mo, J. (2006) Old-Growth Forests Can Accumulate Carbon in Soils. *Science,* Vol. 314 no. 5804 p. 1417. *DOI:* 10.1126/science.1130168