Submission to NSW Independent Bushfire Inquiry

Dailan Pugh, for North East Forest Alliance, April 2020

Six months later: Much of the heavily burnt stands in Ellangowan State Forest are not going to recover,

Consideration against the NSW Independent Bushfire Inquiry's terms of reference:

1. **The causes of, and factors contributing to, the frequency, intensity, timing and location of, bushfires in NSW in the 2019-20 bushfire season, including consideration of any role of weather, drought, climate change, fuel loads and human activity.**

6. [to make recommendations on] **hazard reduction, zoning, and any appropriate use of indigenous practices.**

2019 was Australia's hottest, driest year on record and 2018-2019 was southeast Australia's driest two-year period on record. It is apparent the principle exasperating factors affecting the severity and extent of the 2019-20 bushfires in north-east NSW were the record drought and temperatures in the preceding months. There can be no doubt the extent and severity of the fires were due to climate heating. Though there are numerous underlying factors contributing to the dryness, structure, and composition of the vegetation, and thus the nature and extent of the fires.

Fire initiated by lightning has been a factor driving evolution and adaptation of Australian biota for millions of years, long before people arrived. There can be no doubt that people, and their use of fire for a variety of purposes, changed the extent and frequency of fire in parts of the landscape, and thus contributed to subsequent environmental changes. What is not clear is the significance of these contributions.

It appears that people first arrived on the Australian continent around 50,000 years ago. The first people used landscape fire to clear passageways, aid hunting, create green pick to concentrate prey and promote growth of food plants. It is apparent that their use of fire would have been tailored to regional and ecosystem differences, and specific management goals, as well as having to adapt between years and over time to changing climates.

Within a few thousand years of arrival, Aboriginal burning regimes in Monsoon forests may have facilitated a decline in rainforests, expansion of grassy woodlands, the elimination of the megafauna, and increasing aridity as the Monsoon rainfalls retreated from central Australia. Human induced changes in fire regimes due to 'firestick farming' have been attributed by some as a principal causative factor of the changes, though equally the changes have been attributed to climate changes.

The conclusion from long term charcoal and pollen analyses up until European arrival, is that the dominant influence on fire since Aboriginal settlement has been the variable climate, as vegetation and fire events apparently varied primarily in response to climate regardless of human presence (see Section 1).

The evidence reviewed herein indicates that before the European invasion the wetter forests of north-east NSW are likely to have had fire regimes measured in centuries, and for drier forests one measured in multiple decades. There were evidently long fire-free periods. It appears that some areas may have had significantly increased fire frequencies due to Aboriginal burning (at least over the past 5,000 years), though these were likely discrete areas. (see Section 1.1.)

What is apparent from charcoal records across Australia is that the frequency of fire increased dramatically with settlement by Europeans, before declining slightly more recently since the adoption of fire suppression policies. (see Section 1.1.)

Many of the proponents for increased burning who cite Aboriginal 'firestick' farming don't seem to be advocating replicating the burning regimes actually practiced, with all the nuances about seasons, patch size, frequency, exclusions etc (i.e. Bird *et. al.* 2008), but rather a free-for-all where people can burn at will. People who are advocating a return to the good old days are primarily calling for a return of the record European burning of a few decades ago, not to the Aboriginal burning regimes of hundreds or thousands of years ago.

Frequent patch burning is being advocated as the traditional Aboriginal cultural burning regime for east coast forests, despite the lack of evidence that Aborigines applied a frequent burning regime in north-east NSW (Sections 1 and 1.1.). The importation of Aboriginal burning regimes from Monsoon woodlands on Cape York to temperate forests in NSW without recognition that they are very different environments and ecosystems with very different fire histories cannot be considered 'culturally' appropriate.

If we want to emulate the burning that occurred in north-east NSW during pre-European times then we need to retain most forests free of fire for decades or centuries. This is considered a worthwhile goal, though regrettably it is likely unattainable in many areas due to human demands, the degraded nature of the vegetation, the drying of regional climates due to land clearing and the increasing frequency of extreme climatic events due to climate heating. Never-the-less a return to natural fire frequencies should be pursued where possible through both fire suppression in remote areas and allowing occasional wildfires to run their course.

The evidence is that frequent landscape burning is a relatively recent cultural construct of European invaders in north-east NSW's forests, particularly to facilitate cattle grazing, there is no evidence it was a cultural practice of Aboriginal people before then.

Changes to forest's flammability since European settlement have been profound. What is most apparent is that the extent, structure and species composition of forests have been dramatically altered. Large areas of forests and woodlands have been cleared, while increased burning, logging and stock grazing have significantly altered forest's species composition, structure and microclimates. Introduced grasses and weeds (notably lantana) provide novel fuel sources.

It is a very different environment and climate from what existed 230 years ago and fire behaves differently in this altered landscape. Changes initiated by human activity since European invasion include:

1. Displacement of Aboriginal fire management by European fire regimes, resulting in dramatic increases in the frequency and intensities of fires, thereby altering the nature and structure of vegetation, and increasing its flammability (see Section 1.1.).
2. Extensive land clearing resulting in fragmented forests, and regional increases in temperatures and reduced rainfall, thereby amplifying climatic extremes and increasing landscape flammability (see Section 5.1.) .

3. Altering forest structure through logging, by removing most older trees, while increasing younger age classes with more contiguous canopies, increasing transpiration and water demand, along with flammability (see Section 2).
4. Livestock increasing and changing grazing pressure, changing the structure and species composition of forest understories, eating tree seedlings, compacting soils, promoting weeds, degrading wetlands and eroding stream banks, thereby affecting vegetation structure and flammability (see Section 3).
5. Introduction of exotic grasses and weeds that have changed the structure and flammability of vegetation (see Section 3.4, 4.2.2.)

Clearing has significantly altered the climate by reducing evapotranspiration and surface roughness, thereby reducing regional rainfalls and increasing temperatures. These changes are being compounded by climate heating which is increasing temperatures and intensifying droughts. The result of these impacts is a significant increase in the frequency and longevity of extreme fire weather.

Whatever the fire regime was 230 years ago, it is unlikely to be appropriate or successful in current forests with such wide expanses significantly altered by recent use and a heating climate. A high priority has to be to stop degrading forests and restore their natural resilience to burning. An over-riding intent has to maintain viable populations of the numerous species whose populations have been decimated by the consequences of past land management.

Since European settlement people have built permanent houses and infrastructure throughout forested landscapes, changing the emphasis of burning to protecting widely dispersed and expensive assets. It is recognised that frequent control, fuel reduction and/or patch burning are necessary tools for fire management in our changing world, though they have to be applied judiciously to maximise direct protection of assets while minimising environmental impacts.

Relevant recommendations: R1.1., R1.2., R1.3., R2.1., R3.1.

2. The preparation and planning... for bushfires in NSW, including current laws, practices and strategies ...

5 [to make recommendations on] **Preparation and planning for future bushfire threats and risks.**

7. [to make recommendations on] **Appropriate action to adapt to future bushfire risks to communities and ecosystems.**

Due to climate heating bushfires are becoming more frequent and intense. As evidenced in 2019-20, droughts and heatwaves are drying forests out and making them more flammable. The fires were of unprecedented extent burning through 2.4 million hectares of north-east NSW, and unprecedented intensity as evidenced by the burning of 35% of rainforest. The situation is dire and urgent action is needed to stop further climatic deterioration and increase the resilience of forests.

As noted by the Climate Council (Hughes *et. al.* 2020) report Summer of Crisis regarding the 2019-20 fires:

> *Climate change has fuelled the extreme weather we have seen this summer. The severity and frequency of these extreme weather events – bushfires and smoke, heatwaves, floods,*

> *hailstorms and drought – will continue to increase in coming decades, with commensurate increases in costs, due to the greenhouse gas emissions that we have already emitted, and continue to emit. If we fail to take strong action to rapidly phase out coal, oil and gas as part of a global effort, the impacts of climate change, including worsening extreme weather, will continue to escalate.*

Though it is not just an issue of reducing emissions. The Intergovernmental Panel on Climate Change (IPCC 2018) identifies we need to start reducing emissions immediately and reach net zero carbon dioxide (CO_2) emissions by around 2050, though even then we need trees to remove copious quantities of carbon from the atmosphere (Section 5.2).

If there is a genuine intent to limit the increasing frequency and intensity of wildfires then climate heating must be stopped and the role of forests in achieving this recognised. Clearing of native vegetation must cease, right now. Stoping logging of public native forests is a logical next step as the regenerating forests will store ever increasing volumes of carbon as they age and fulfil the essential role of reducing atmospheric carbon. For the medium term regeneration and reforestation is needed to expand the draw-down of atmospheric carbon. Rewarding landholders for the volumes of carbon they store in soils and trees will provide a needed incentive.

There are three principal *natural solutions* for dealing with the flammability of forests and the risks of future fires:

1. Restoring the environmental services provided by native forests.

   Forests play a key role in regional climates and thus landscape wetness and flammability. The clearing of forests decreases regional rainfalls and increases temperatures, and the conversion of older forests to regrowth dries forests and decreases streamflows. We need our forests more than ever, not just because of their intrinsic worth and beauty, but for the ecosystem services they provide us, such as generating rainfall, cooling the land, calming winds, regulating streamflows, and capturing and storing the carbon we emit (Section 5.1.).

   Land-clearing needs to be stopped to limit ongoing rainfall declines, temperature increases and wind intensification. Regrowth forests need to be allowed to mature to reduce water demand as they age, thereby making forests moister and increasing streamflows. Forest regeneration and reforestation needs to be encouraged to help counteract rainfall declines and temperature increases due to climate change, though account needs to be made of the effects on streamflows. (Section 5.1.)

2. Restoring the natural resilience of native forests to burning.

   Burning promotes species more tolerant of burning, thereby increasing the flammability of forests. Logging makes forests more vulnerable to wildfires and increases their flammability by drying them, increasing fuel loads, promoting more flammable species, and changing forest structure. This includes increasing the risks of canopy fires by reducing canopy height, increasing tree density and increasing fuel connectivity from the ground into the canopy. (see Section 2). Grazing degrades vegetation and can promote more flammable vegetation (see Section 3). Weeds (such as lantana) change understorey structure and increase the flammability of forests, at its worst lantana has initiated dieback of tens of thousands of hectares of forests and greatly increased both their flammability and vulnerability to fire (see Sections 3.4 and 4.2.2.)

Logging of native forests has to stop to reduce their increasing flammability, and to allow them to recover their natural structure and inherent resilience to weed invasion and burning (Section 2). As a matter of urgency widespread control of Lantana and other weeds needs to be undertaken throughout burnt forests, focusing on bad weed infestations, rainforest ecotones and areas of Bell Miner Associated Dieback. Time is of the essence if the fire's elimination of most lantana is to be capitalised on (see Section 4.2.2.). To allow recovery such areas must have logging excluded

3. Adopting natural solutions to draw-down atmospheric carbon and help redress climate change

It is urgent that atmospheric carbon be reduced as soon as possible. There are various estimates that natural carbon solutions can contribute 21-37% of cost-effective CO_2 mitigation needed, with proforestation (protecting existing vegetation) and reforestation (regenerating or planting new vegetation) providing the most benefit. (Section 5.2.)

Proforestation provides the most immediate carbon sequestration benefits as the trees are already growing and will sequester increasing volumes of carbon as they age (Section 5.2.1.). 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 each year, in addition to avoiding emissions. Even larger sequestration gains could be made if landholders were encouraged to manage their forests for carbon sequestration and storage by annual payments for volumes stored. (Section 5.2.1.3.)

There is a need to account for the loss of soil carbon from logging and too frequent burning. Maintaining and restoring soil carbon is one of the benefits of stopping logging (Section 5.2.2.).

There is a lag in benefits with planting trees, even on cleared land, because of soil carbon losses during establishment and an initial slow rate of carbon accumulation. Plantings are needed now to meet increased sequestration needs by 2050. If the intent is to manage plantings for short rotation timber crops then they are of marginal benefit. (Section 5.2.3.)

Mixed species regeneration and plantings are the most efficient and effective for capturing and storing atmospheric carbon, and local indigenous species provide the greatest biodiversity benefits. Though to maximise benefits they need to be established for the long-term and appropriately protected. Rather than commercial plantations, the Government needs to encourage and support native forest regeneration and reforestation as an urgent priority to achieve the needed additional long-term carbon sequestration. (Section 5.2.3.)

Relevant recommendations: R5.1. R5.2, R5.3, R5.4, R5.5. R5.6., R5.7., R5.8., R5.9.

3. Responses to bushfires, particularly measures to control the spread of the fires and to protect life, property and the environment,

7. [make recommendations on] **Appropriate action to adapt to future bushfire risks to communities and ecosystems**

8. [make recommendations on] **Emergency responses to bushfires**

The 2019-20 fires were of an unprecedented scale and intensity, burning over half the native vegetation and over half the public lands in north-east NSW. Within the fire grounds it was so dry that fires burnt through riparian vegetation and 35% of rainforests, the usual refuges for many species. It is likely that over 350 million mammals, birds, reptiles and frogs were killed in north-east NSW. Numerous hollow-bearing trees have been lost, already depleted nectar resources set back for years and most large logs incinerated. This has had a massive impact on the region's exceptional biodiversity (see Section 4).

The first response should have been to rescue animals from burnt areas (i.e. burnt koalas) and assist survivors with food and water, the second to undertake surveys in habitat of those worst affected to assess the status of affected populations before allowing clearing or logging to further degrade habitat. A moratorium of further degrading activities until the consequences are known is still required.

The NSW Government's response to the environmental consequences of the 2019-2020 wildfires has been woefully inadequate, both during and after the fires. For example, NEFA had been documenting an important Koala population on State Forests south of Casino, part of the Banyabba population (Section 4.1.1.). Virtually the whole of the 7,000 ha area we had been assessing was burnt out on the night of 8 October 2019. As it was a fireground we were refused access, though when the Government refused to do anything to assess the impacts on Koalas we searched for survivors in the vain hope the Government would then do something. They refused any meaningful assistance to the Banyabba Koalas despite being shown by us where survivors were. By then the area we were assessing was safe, though because of continuing burning on other fronts a long way away, the whole fireground remained closed unnecessarily. NEFA was thus unable to mount a concerted rescue mission with community volunteers. NEFA maintained water supplies to one colony and monitored their response to the fires, collecting invaluable data on fire impacts in the process. The fireground remained closed to public access up until we completed our work in mid-January 2020. By then NEFA assessed that 90% of the Koalas in the fire grounds had been lost, many during the 3 months of drought following the fire.

Despite the significance of parts of this population being verified by the EPA (2016) no effort was made to rescue injured Koalas or support survivors (aside for 6 water stations that went dry). The EPA and Environment Minister refused NEFA's requests for them to reassess the systematic survey sites they had done in 2015 (EPA 2016) to independently quantify impacts. Hundreds of Koalas were likely killed, many deaths could have been avoided and the survivors assisted had the Government done something (Section 4.1.1.). The Government should have been the first responders. If nothing else, if the RFS had of lifted the Section 44 declaration from <u>that part</u> of the fireground where the Koalas were as soon as it was safe then the community could have stepped up to save and support the Koalas. Other Section 44 declarations over less extensive areas were lifted as soon as the fires were declared out, even if there was another fire nearby.

Overall, at the Banyabba ARKS population level, 83% of 71,000 ha of 'likely' Koala habitat burnt, with it likely that 75% of Koalas were killed. Any habitat that is capable of supporting breeding females is of exceptional importance to the recovery of the Banyabba population. To add insult to injury, on the 3 March 2020 the EPA approved logging of burnt Koala habitat in 19 compartments in 3 State Forests in the Banyabba population (Section 4.1.2), despite admitting the logging rules (IFOA) were "*not designed to moderate the environmental risks associated with harvesting in landscapes that have been so extensively and severely impacted by fire*". There was only an untested token addition specifically aimed at mitigating impacts on Koalas. The EPA did not bother to undertake a desk-top assessment of the individual compartments, assess the effects of the fires on the Banyabba population, nor undertake ground based assessments, before issuing their new conditions. Their approval was reckless, and could jeopardise the survival of this population.

Another example of recklessness was the decision to log the only unburnt patch of occupied habitat of the Endangered Hastings River Mouse left in Styx River State Forest (Section 4.1.3). The NSW Government identified that 82% of all recorded locations of the Endangered Hastings River Mouse were burnt, and the Commonwealth identified it as one of 113 species nationally in most *'urgent need of emergency action over the coming weeks and months*', recommending *'protecting unburnt areas within or adjacent to recently burnt ground that provide refuges*' as '*essential*'. Undaunted the Forestry Corporation and the Environment Protection Authority ignored the advice, despite 95% of the habitat around Hastings River Mouse locations being burnt, including most of the logging exclusions, they focussed logging into the only known area of unburnt occupied habitat left. With the species survival at stake this was a grossly irresponsible act.

Rainforests descended from the rainforests of Gondwana, 70 million years ago, and are responsible for maintaining most of our biodiversity. The burning of a third of northern NSW's ancient and irreplaceable rainforests in the 2019-20 fires should be a major wakeup (Section 4.2.1.). Rainforests are particularly vulnerable to fire. their burning is akin to the bleaching of coral reefs. As it becomes more frequent the rainforests will retreat and the more sensitive plants will be lost, and the rainforests will dry and become more flammable. There are actions that can be taken to increase rainforest's resilience, particularly protecting and restoring buffers around them, though until we stop global heating burning will become more frequent and intense, eroding the extent, viability, and biodiversity of our relictual rainforests, along with our future.

The only silver lining to the fires (and drought) has been the widespread death of lantana (Section 4.2.2.). Whole ecosystems were in collapse because of its proliferation. This opportunity to stop its resurgence must be capitalised on if we want to increase the resilience of wet sclerophyll forests and rainforests at minimal cost. Getting rid of it will reduce the flammability of our degraded forests.

See Recommendations R4.1, R4.2, R4.3, R4.4, R4.5, R4.6, R4.7, R4.8, R4.9, R4.10, R4.11, R4.12, R4.13, R4.14, R4.15, R4.16, R4.17, R4.18, R4.19, R4.20, R4.21.

Summary and Recommendations

1: Pre-European Fire regimes

Aborigines have inhabited Australia for over 50,000 years, through major climatic upheavals. Fire was definitely a management tool they used for various purposes, though how they applied fire at a landscape scale is debated (Section 1).

Before their arrival fires were ignited by lightning and had a significant effect on vegetation. Many studies suggest the new arrivals did not significantly change fire regimes beyond what would be expected to result from climatic changes, though some attribute Aboriginal burning to have played a role in the retreat of Monsoonal rainforests, expansion of savanna woodlands, extinction of the megafauna, and the increasing aridity of central Australia as the rainforests and Monsoon rainfalls retreated.

Soon after the arrival of Aborigines the monsoon forests underwent profound changes with an increase in fire frequency, decline in rainforests, expansion of grassy woodlands, the elimination of the megafauna, and increasing aridity as the Monsoon rainfalls retreated from central Australia (Section 1). There is debate about cause and effect: did Aboriginal burning change the vegetation and cause the retreat of the monsoon rains and extinction of the megafauna, or did the retreat of the monsoon rains increase burning, change the vegetation and cause the extinction of the megafauna? What is apparent is that in an era of climate change the increased burning promoted grassy woodlands at the expense of rainforests and shrubby forests and thereby profoundly changed the environment. Is this a process that we should now emulate in east coast forests?

It is thought that Aboriginal burning likely played a discernible role in large areas of savanna woodlands in northern Australia though not elsewhere. Bradstock *et. al.* 2012 identify:

> *Although temperate forests and tropical savannas share a eucalypt-dominated overstorey, their fire regimes are inherently different owing to contrasts in climate and fuel availability (Bradstock 2010). These fundamental differences appear to substantially affect the efficacy of prescribed burning*

There is no evidence of high frequency landscape burning of forests in north-east NSW before the European invasion. Rather they indicate infrequent occurrence of fire, with long periods fire free. The tablelands were rarely burnt, the wetter forests likely had fire frequencies measured in centuries, and the coastal forests likely had fire frequencies measured in multiple decades. Other ecosystems, such as heaths, may have burnt more frequently.

It is likely that there were discrete areas subject to higher frequencies associated with larger Aboriginal settlements, particularly with population increases over the past 5,000 years.

The charcoal data does clearly show that across Australia, including north-east NSW, there was a significant increase in fire frequency and intensity in concert with European settlement (Section 1.1.). There has been a marked decline in places since fire suppression policies in the 1950's, but burning remains well above pre-European frequencies. The practice of regular burning of grazing lands, with frequencies of 1-5 years, continues, particularly on the tablelands and escarpment country of north-east NSW (see section 3.2).

R1.1. Calls to emulate Aboriginal 'cultural' burns seem more aimed at maintaining the burning regimes initiated by European graziers. There needs to be an honest and factual consideration of pre-European burning regimes to inform current management given the evidence that north-east NSW's forests were not subject to a frequent landscape burning regime until after European occupation.

R1.2. The evidence is that in north-east NSW landscape fires in pre-European times occurred with a frequency measured in centuries in wetter forests and multiple-decades in drier forests. It is recommended that attempts should be made to emulate pre-European fire regimes where feasible.

R1.3. It needs to be recognised that increased fire frequencies, grazing, logging and weed invasion since the European invasion have had profound effects on the flammability of vegetation and fuel loads. It is a very different landscape to what it was 230 years ago and far more flammable. It is recognised that in this changed landscape fuel reduction burning is part of the strategic approach needed to protect assets, though it needs to be used judiciously.

2: Logging Effects on Burning

Logging makes forests more vulnerable to wildfires and increases their flammability by drying them, increasing fuel loads, promoting more flammable species, and changing forest structure. This includes increasing the risks of canopy fires by reducing canopy height, increasing tree density and increasing fuel connectivity from the ground into the canopy.

R2.1. Logging of forests changes their structure and increases fuels, drying them and increasing their flammability. Logging of public native forests has to stop to reduce their increasing flammability, and to allow them to recover their natural structure and inherent resilience to burning.

3: Grazing effects on Blazing

The argument used to justify grazing of conservation reserves is that it reduces fuel loads and thus the risk of wildfires, though there is little evidence to justify this claim, though there is abundant evidence that by changing the species composition and structure of forest understories, changing fauna populations, and hindering overstorey regeneration, grazing has significant environmental impacts. There is evidence that the vegetation changes caused by grazing can increase wildfire risk and intensity in some ecosystems. Too frequent burning is associated with grazing, compounding impacts.

R3.1. The vegetation changes and environmental impacts of grazing on natural ecosystems and a plethora of species is profound, and its benefits in reducing fire frequency equivocal, as such it must remain excluded from national parks and other public lands where it is currently prohibited. The option of using fuel reduction burning may be preferable where strategically required.

4: Impacts of the 2019-2020 wildfires on north-east NSW

The NSW Government's response to the environmental consequences of the 2019-2020 wildfires, as judged from their published responses and actions, has been woefully inadequate. Aside from some species lists the NSW Government is yet to identify impacts on populations of threatened species, identify priority populations for assistance, or propose recovery actions, aside for aerial baiting which will impact native carnivores as well as exotic ones.

These fires have been of unprecedented scale and intensity, the burning of half the native vegetation and habitats has had massive impacts on north-east NSW's ecosystems, plants and animal populations. A variety of populations and species are likely to have been so significantly affected that they are at imminent risk of extinction. Others have been shoved further down that path. There needs to be urgent assessments of the most heavily impacted ecosystems and populations to assess their current status and the impacts of the fires upon them.

The burning of some 160,000 ha (35%) of rainforests should have been a wake-up call. This will result in significant loss and degradation of these priceless relicts from our Gondwanan past (Section 4.2.1.). Those burnt are now more vulnerable to further burning. The damage is so severe that with the increasing likelihood of repeat events this could be the start of ecosystem collapse. The burning of rainforest is akin to the bleaching of coral reefs, and is likely to follow a similar trajectory.

The wet-sclerophyll forests were already experiencing ecosystem collapse due to logging and lantana invasion, with the burning likely to aggravate this unless the return of lantana is prevented.

R4.1. The NSW Government must undertake a though expert assessment that identifies populations of all species likely to have been significantly affected by the fires, undertake surveys and identify needed remediation measures. This needs to include repeating previous surveys to quantify population changes.

R4.2. In accordance with the Commonwealth recommendations, the NSW Government needs to immediately implement a moratorium on all logging operations and land clearing within and near the identified habitat and locations of threatened species significantly impacted by the 2019-2020 wildfires, as well as upstream of the worst affected frogs, fish and crayfish.

4.1: Affects on Fauna

There can be no doubt that a multitude of wildlife died in the fires last season, from the invertebrate world of the leaf litter to up to Koalas in the tree tops. The fires were of unprecedented proportions, in north-east NSW burning out half the forests, including a contiguous 1.9 million hectares from Tenterfield on the tablelands to Iluka on the coast and from near Bonalbo in the upper Clarence River down to near Gloucester on the Manning River. Within the burnt grounds it was so dry that fires burnt through riparian vegetation and rainforests, the usual refuges for many species.

The fires last year were superimposed on an existing fire regime, with many areas burnt just a year or two ago burnt again, and occurred during an extreme drought when the forest was exceptionally dry and stressed. The drought continued after the fires, compounding impacts and hindering recovery.

The recovery of survivors will vary with species, though the impacts on many populations were so severe that they are unlikely to recover, and many will lag the recovery of their habitat. It is the lost hollows that will take centuries to recover. Urgent action is need to stop ongoing loss of key resources, particularly large old trees, and to facilitate the recovery of the worst affected species..

R4.4. Given the likely loss of half the already critical nectar resources provided by mature trees due to fires across north-east NSW, and the time it will take for surviving trees to recover, it is essential that all mature eucalypt feed trees (across both burnt and unburnt forests) are excluded from logging as an emergency measure to stem the loss of nectar and the species that depend upon it.

R4.5. Significant extents of public forests are already subject to commercial beekeeping operations, including areas of national parks, and feral hives are widespread, it is essential that there be no expansion of commercial operations in national parks at this crucial time for native species. The commercial industry will benefit from the protection of mature trees across their existing leases.

R4.6. The wildfires have caused a major landscape wide reduction in big old trees, along with the hollows vital as homes for so many animals, by being killed in the fires, cleared in firebreaks and extensive felling post-fire. Nesting boxes are of some benefit, but the long-term solution has to be increasing the availability of natural hollows by allowing mature trees to age and decay gracefully rather than cutting them down. There needs to be a moratorium placed on logging any trees over 80 cm diameter, and the reinstating of requirements to

retain recruitment trees, while the impacts of the fires on hollow-dependent species are assessed.

R4.7. Based on our experiences we recommend that for future wildfires:

- **Key wildlife habitats need to be assessed up-front ahead of fires, and appropriate fire management actions to protect values identified (location of fire trails, areas for raking, suitable locations for backburns, retention of hollow-bearing trees, fire frequencies etc), with procedures applied during fires to ensure such guidelines are applied to appropriately minimise impacts.**
- **Indiscriminate felling of mature and oldgrowth trees after fires, that do not pose an immediate threat, must be stopped.**
- **A suitably trained Government team needs to be tasked with immediately responding after fire to rescue and support fire affected wildlife in key wildlife habitats.**
- **Burnt key wildlife habitats (i.e. parts of fire grounds) need to be prioritised for lifting of closure notices as soon as practicable after fires to facilitate volunteer wildlife rescue and public assistance for affected species, such as Koalas.**
- **Post-fire assessments by independent experts need to be urgently undertaken to identify those species most likely to have been detrimentally affected, and their habitat immediately excluded from further degradation, particularly by logging, while surveys are undertaken to quantify fire impacts.**

4.1.1. Observed effects on a Koala Population

On the night of 8 October 2019 the Busby's Flat fire burnt rapidly through most of NEFA's proposed 7,000 ha Sandy Creek Koala Park, covering Braemar, Carwong, Royal Camp, and Ellangowan State Forests. Various surveys and studies over 7 years had proven that these forests, south of Casino on the Richmond River lowlands, were of exceptional value for Koalas.

NEFA and the EPA's (2016) results for the proposed Sandy Creek Koala Park confirm that Koalas prefer larger trees for feeding and roosting, it is therefore evident that logging of larger trees (large and small sawlogs) will have a detrimental effect on the availability of feed trees used by Koalas and thus Koala populations. Over the past century logging is likely to more than halved Koala populations within this proposal by removing most of the larger trees preferred by Koalas. It is essential that logging of the larger trees preferred by Koalas be excluded from core Koala habitat to stop further population declines.

There was little evidence of Koalas surviving in the 59% of forests that were heavily burnt, and the balance of the fireground lost over half its canopy and most Koalas. Because of the ongoing drought, and lack of any concerted Government help, Koalas continued to decline for the next 3 months.

The evidence suggests an overall decline in Koalas of around 90% across the burnt forests. with around 10% of this due to the ongoing drought after the fires and lack of comprehensive assistance to survivors. Given that 440ha escaped the fires, it is assumed that 84% of the Koala population was lost.

The proposed Sandy Creek Koala Park is part of the Banyabba ARKS which encompasses 71,000 ha of likely Koala habitat (KHSM, classes 4&5), of which 59,000 ha was burnt. If a 90% mortality is assumed for the burnt areas, this suggests the loss of 75% of Koalas from the Banyabba population. Such broad estimations do not take into account the decimation of core high-density colonies responsible for maintaining the overall population.

While most forests are now recovering it is going to take decades for Koalas to rebuild their populations.

R4.8. To halt ongoing declines in Koala populations the large trees preferentially used by Koalas must be retained. It is recommended that a logging moratorium be immediately placed on clearing or logging of all mapped likely Koala habitat (KHSM classes 4&5) while the status of Koalas in each ARKS (population) is evaluated.

R4.9. Given the reduction in Koala populations because of the fires, and their loss from areas of identified core habitat, the recovery potential of areas need to considered when evaluating Koala habitat, even if not fully occupied now.

R4.10. Given the parlous status of the Banyabba ARKS, the proposed Sandy Creek Koala Park should still be created and Koala colonies within it assisted to recover.

R4.11. All DPIE (2017) Areas of Regional Koala Significance (populations) that have had more than 50% of the likely Koala habitat within them burnt must be prioritized for protection and assessment.

4.1.2: Post-fire Logging of Banyabba Koalas

On 3 March 2020 the Environment Protection Authority (EPA) approved the Forestry Corporation to undertake logging of burnt Koala habitat in three State Forests on the Richmond River lowlands. Given the failure to account for the landscape scale impacts of the fires on this Koala population, this approval was irresponsible and jeopardises the Koala's recovery, and possibly the survival of this population.

As recognised by the EPA website (accessed 10 April 2020) "*The Coastal Integrated Forestry Operation Approvals (IFOA) was not designed to moderate the environmental risks associated with harvesting in landscapes that have been so extensively and severely impacted by fire*".

The EPA have been requested to withdraw their approvals for logging of Koala habitat in Bungawalbin, Doubleduke and Myrtle State Forests and to do due-diligence by assessing the landscape impacts of the fires on Koalas. As shown by this example, a moratorium is needed on further logging of populations of all species significantly affected by the fires until surveys are undertaken to assess their vulnerability.

The approved logging is in parts of the 142,000 ha Banyabba Area of Regional Koala Significance (ARKS) that had 83% of its modelled 71,000 ha of 'likely' Koala habitat burnt in the 2019 wildfires, with the apparent loss of 90% of Koalas from burnt areas (see 4.1.1.).

Given that the Banyabba Koala population had already been reduced by at least 57% due to clearing and logging, and more due to other factors, and was identified as in decline before the fires, the loss of three quarters of survivors due to the 2019 fires is a highly significant landscape scale impact on this vulnerable population of Koalas which may jeopardise its survival.

The intent is to now cut down feed and roost trees in surviving pockets of Koalas, based on token changes to inadequate logging rules that do not contemplate such landscape impacts. As the loggers stumble about in the fire ravaged homes of these imperilled Koalas they have no idea of the damage they are doing and they simply don't care. The risks of their blundering into homes of Koalas barely surviving the fires and vital habitat needed for population recovery is too high.

Many regrowth trees have been killed, and with recovery delayed by drought it is apparent that there has been significant death of canopy trees in some heavily burnt areas. Coupled with the loss of most local pine plantations, the viability of a timber industry based on public lands in this region needs to be reconsidered.

R4.12. The EPA should never have issued approvals for logging of Koala habitat within the decimated Banyabba Koala population without consideration of the impacts of the fires on this population. The inquiry is asked to support the withdrawal of the 3 logging approvals issued by the EPA on 3 March 2020 for Bungawalbin, Doubleduke and Myrtle State Forests until the EPA have done due diligence by replicating the EPA's 2015 Koala surveys in Royal Camp and Carwong State Forests to quantify fire impacts on this population, undertaken site surveys before approving any Koala habitat for logging, and provided meaningful protection for any Koalas found. This case demonstrates the need for a moratorium on further logging of all populations of species significantly affected by the fires.

4.1.3: Affects on Hasting River Mouse

The Endangered Hastings River Mouse has been identified by the State and Commonwealth Governments as one of the species most adversely affected by the fires. With its identified susceptibility to burning and over 80% of the 1,000 locations it has ever been recorded at in NSW burnt in the 2019-20 fires it is vulnerable to having been eliminated from a large part of its range, if not extinction.

It was included as one of the Commonwealth's 113 species in most '*urgent need of emergency action over the coming weeks and months*'. The Expert Panel identified '*protecting unburnt areas within or adjacent to recently burnt ground that provide refuges*' as '*essential*'. The other essential action was to undertake surveys to identify how badly the Hastings River Mouse was affected by the fires before blundering about in its severely degraded habitat.

In Styx River State Forest the Forestry Corporation and the Environment Protection Authority ignored the advice, despite 95% of the habitat around Hastings River Mouse locations being burnt, including most of the logging exclusions, they focussed logging into the only known area of unburnt habitat left. With the species survival at stake this was a grossly irresponsible act.

While it appears that logging in compartments 540, 541, 542 and 552 of Styx River State Forest has now been completed, logging is underway elsewhere in Styx River State Forest.

R4.13. The Forestry Corporation's logging of the only unburnt patch of occupied habitat of the nationally Endangered Hastings River Mouse in Styx River State Forest despite its being identified as vulnerable to burning, DPIE identifying 82% of known localities burnt, and the Commonwealth identifying unburnt habitat as a priority to protect, displays an abject failure on behalf of both the Forestry Corporation, and the EPA, their supposed regulator, to prevent the further endangerment and potentially extinction of the Hastings River Mouse. The Inquiry needs to investigate this case and recommend measures to ensure it is not repeated.

R4.14. Given the extensive burning of Styx River State Forest all logging should be put on hold while the status of surviving fauna populations are assessed.

R4.15. There are abundant pre-burn records of Hastings River Mouse and Stuttering Frog that were located in pre-logging surveys in compartments 540, 541, 542 and 552 of Styx River State Forest and adjacent compartments. Those surveys need to be urgently replicated to assess the impacts of the fire (and logging) on these two Commonwealth priority species, and to identify appropriate rehabilitation strategies.

R4.16. For a number of years post-fire the minimal prospects of being able to delineate suitable habitat for Hastings River Mouse and to find any survivors (given the low trapping results) will render the current prescription totally ineffective. In accordance with the national Recovery Plan there needs to be an immediate reinstatement of a prohibition on logging within 800m of a Hastings River Mouse Record, though not limited to apparently suitable habitat (until sufficiently regenerated).

4.2.1: Affects on rainforests

Worldwide rainforests are coming under increasing threat due to clearing, increasing drought and burning. While the loss of Australia's rainforest will not have the worldwide climatic consequences of the declining Congo and Amazon rainforests, they will have regional climatic impacts and have devastating impacts on our biodiversity.

The impacts of rising temperatures, droughts and heatwaves on rainforests have been increasing. When mature rainforests start burning we know the situation has become dire, as they are not adapted to fire. Burning of rainforests is akin to the bleaching of coral reefs.

A third of northern NSW's ancient and irreplaceable rainforests burnt last year. Buffers need to be established, and weed control undertaken, to increase their resilience. Though until we stop global heating burning will become more frequent and intense, eroding the extent, viability, and biodiversity of our relictual rainforests, along with our future.

R.4.17. Given the role of logging in increasing forest flammability (Section 2 of this submission), including by facilitating lantana invasion (4.2.2. of this submission), it is essential that as a minimum 50m buffers are placed around all rainforests from which logging is excluded. Such buffers should be a focus for lantana control and the removal of debris from previous logging.

R.4.18. The NSW Government is advised not to rely on DPIE's (2020) Fire Extent and Severity Mapping of rainforest for assessing impacts as it misrepresents the impacts of the 2019-2020 fires upon rainforest and grossly understates the damage that was done.

R4.19. It is recommended that permanent transects be established in burnt rainforests, and particularly across their ecotones to quantify the impacts of the 2019 fires on rainforests and their susceptibility to repeat burning. Such information is essential to inform management responses to help our rainforests survive the unfolding climate emergency.

4.2.2: An Overabundance of Lantana

The weed Lantana (*L. camara)* has been the scourge of wet sclerophyll forests and rainforest, invading areas where canopy has been reduced by logging or fire, suppressing regrowth, increasing flammability and initiating dieback in adjoining logged eucalypt forests.

In order to address the increasing flammability of degraded forests it is essential that lantana be controlled to allow native forests to regenerate and increase their resilience to future fires.

The intensity of the 2019-20 fires, combined with the intense drought, has killed lantana over large areas, creating an opportunity to control it before it takes over again. Large areas can now be covered to remove reshooting and new plants quickly. This opportunity must be capitalised on if we want to increase the resilience of wet sclerophyll forests and rainforests at minimal cost.

R.4.20. Bell Miner Associated Dieback dries forests and increases flammability. Given the abundant evidence that logging is the primary cause of Bell Miner Associated Dieback, and that re-logging affected forests makes it worse, it is well past time that the logging of BMAD affected and susceptible forests is stopped and the process of restoration begun.

R.4.21. The combination of fire and drought has eliminated or reduced lantana, and other problem weeds, in extensive areas of the fire grounds, creating a rare opportunity to eliminate lantana from vast areas and reduce forest's flammability. It is recommended that as a matter of urgency widespread control of Lantana and other weeds be undertaken throughout burnt forests, focusing on bad weed infestations, rainforest ecotones and areas of Bell Miner Associated Dieback. To allow recovery such areas must have logging excluded.

5: The relationships between forests, climate and fires

The clearing of forests decreases regional rainfalls and increases temperatures, and the conversion of older forests to regrowth dries forests and decreases streamflows. These changes have particularly significant consequences during droughts by amplifying stressors. Forests play a key role in regional climates and thus landscape wetness and flammability.

We need our forests more than ever, not just because of their intrinsic worth and beauty, but for the ecosystem services they provide us, such as generating rainfall, cooling the land, calming winds, regulating streamflows, and capturing and storing the carbon we emit.

We cannot afford to allow the downward trajectory of forest cover and degradation to continue if we want to give forests and ourselves a future. We need to urgently stop clearing and logging forests, and start rehabilitating them, to allow them to go on moderating regional climates and storing carbon, while improving their resilience to further climate changes. While encouraging natural regeneration and planting of new forests to take up more carbon.

R5.1. Stoping logging of public native forests is a logical first step to limit climate heating and the increasing frequency of extreme fire weather, as the regenerating forests will store ever increasing volumes of carbon as they age. To reward landholders for their contribution to carbon sequestration and storage, whether in soils or vegetation, landholders storing above average volumes of carbon should receive annual payments proportional to the volume stored at that time and the ecosystem benefits it provides. This will recompense landholders for providing a public benefit and be an incentive for increasing storage.

5.1. The Effects of Clearing Forests on Climate and Fires

Forest directly affect regional climates and thus have a direct affect on their own flammability by:

- transpiring moisture from the ground into the atmosphere to form clouds and generate rainfall
- providing a large area of leaves and other surfaces for evaporation of moisture back into the atmosphere
- creating areas of low pressure by evapotranspiration that generate winds and draw in moisture from afar
- having an 'evaporative cooling' effect by absorbing solar energy and converting it into latent heat held in water vapour through evapotranspiration
- emission of organic aerosols, and volatile organic compounds that oxidise to form aerosols, that act as cloud condensation nuclei around which water drops form
- increasing air turbulence, causing drag on the air and reducing wind speed, increasing transfer of moisture into the air, causing updrafts and rain
- tree canopies harvesting water directly from wind and clouds, particularly in coastal and mountainous country.

Forests also directly affect streams and streamflows by regulating runoff, with oldgrowth forests facilitating the storage of water in soils and dead biomass for slow release into streams, while regrowth transpires more water into the atmosphere thereby drying soils and dead biomass while reducing streamflows and their permanence.

It is essential to account for vegetation change, most noticeably clearing, logging and reforestation, on regional changes in rainfalls, temperatures and winds when assessing the impacts of climate change and planning for reducing the flammability of forests.

R5.2. Land-clearing needs to be stopped to limit ongoing rainfall declines, temperature increases and wind intensification. Regrowth forests need to be allowed to mature to reduce water demand as they age, thereby making forests moister and increasing streamflows. Forest regeneration and reforestation needs to be encouraged to help counteract rainfall declines and temperature increases due to climate change, though account needs to be made of the effects on streamflows.

5.2.1. Forests Carbon Carrying Capacity

Trees are essential elements of the earth's carbon cycle, essential for mopping up excess atmospheric carbon and putting it out of harm's way. Trees continue to take up CO_2 and store exponentially increasing volumes of carbon in their wood and soils as they age. The older trees and forests are the more carbon they store making them vital components of the solution to rapidly escalating climate heating.

Because of their extent fires can release significant volumes of carbon, largely as CO_2, though this is primarily carbon sequestered in dead biomass and a portion of it may end up as char sequestered in alluvial deposits or soils if fires are not too frequent. Some trees may be killed, though the dead standing trees may slowly release their carbon over decades.

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.

R5.3. A significant part of the solution to the climate crisis is proforestation: protecting native forests from clearing and logging to 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. 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.

5.2.1.3. North East NSW Carbon Sequestration Potential

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

Allowing forests to recover and regain their lost carbon is termed proforestation. It is a significant and essential part of the measures needed to limit global warming to 1.5^{o} or 2^{o} C.

R5.4. 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. 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.

R5.5. In NSW the average land clearing was 2,700 hectares per year between 2006/07 and 2016/17, with this increasing under the new rules to 45,553 hectares from June 2018 until May 2019, with over 140,000 ha also approved for clearing under the guise of 'invasive native species'. Increasing land-clearing in a climate emergency is akin to pouring petrol onto the flames. Land clearing increases regional temperatures, reduces rainfalls and releases large quantities of carbon into the atmosphere, as well as stopping that vegetation from sequestering carbon, we cannot afford for it to continue, let alone escalate.

5.2.2. Soil Carbon Carrying Capacity

Soils are the largest terrestrial carbon pools on earth, with labile carbon pools subject to rapid turnover and stable pools that change over centuries and millennia. Burning and logging of above-ground biomass can result in an immediate input to surface carbon, much of which may be lost by wind and water erosion.

The gross soil disturbances by logging machinery can significantly increase the loss of soil carbon by exposing labile carbon to oxidisation and erosion, and when coupled with the long term reduction in above ground biomass from repeated logging can progressively and significantly deplete soil stores of stable carbon over time.

A significant part of the biomass burnt in fires is not fully combusted resulting in charcoal which is resistant to further decay, and thus may persist in the landscape for considerable time if not subject to further combustion. Char can add to stable carbon pools when incorporated into soils, or deposited in stream sediments. Though if fire is too frequent it can reduce both labile and stable carbon pools.

R5.6. There is a need to account for the loss of soil carbon from logging and too frequent burning, and its effect on increasing atmospheric carbon and climate change. Maintaining and restoring soil carbon is one of the benefits of stopping logging, with significant long term ramifications for climate change. The creation, fate and longevity of char from fires warrants consideration, particularly under a frequent burning regime.

5.2.3. Restoring Native Vegetation

The IPCC (2018) identify that if we want to limit global warming to below 1.5-2^{o}C then we need a10 million km^2 increase in forests by 2050 relative to 2010. This is a massive undertaking, with only limited international commitments for implementation, and most of these are for commercial plantations rather than forest restoration.

While Australia, and north-east NSW in particular, has extensive areas of cleared and semi-cleared grazing land suitable for reforesting, the Government's only commitment to date has been to assist industry in establishing 400,000 hectares of new plantations for timber production over the next decade, while also facilitating loggers access to remnant forests on Aboriginal and freehold lands.

R5.7. Plantations will be of little benefit to mitigate climate heating because their establishment releases soil carbon and so it takes 5-10 years before they become net carbon sinks, they are usually clearfelled on 10-30 year rotations for pulp therefore only providing temporary storage, and soil carbon losses may never be regained.

R5.8. Mixed species regeneration and plantings are the most efficient and effective for capturing and storing atmospheric carbon, and local indigenous species provide the greatest biodiversity benefits. Though to maximise benefits they need to be established for the long-term and appropriately protected. Rather than commercial plantations, the Government needs to encourage and support native forest regeneration and reforestation as an urgent priority. The benefits of new regrowth for enhancing regional rainfalls, reducing temperatures and supporting biodiversity, needs to considered, along with the negative effects on streamflows.

5.3. The Struggling Forests

R5.9. 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.

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1. Pre-European Fire regimes

Aborigines have inhabited Australia for over 50,000 years, through major climatic upheavals. Fire was definitely a management tool they used for various purposes.

Before their arrival fires were ignited by lightning and had a significant effect on vegetation. Many studies suggest the new arrivals did not significantly change fire regimes beyond what would be expected to result from climatic changes, though some attribute Aboriginal burning to have played a role in the retreat of Monsoonal rainforests, expansion of savanna woodlands, loss of the megafauna, and the increasing aridity of central Australia as the Monsoon rainfalls and rainforests retreated.

It is thought that Aboriginal burning likely played a discernible role in large areas of savanna woodlands in northern Australia, and dry forests and woodlands in temperate southern Australia, though not elsewhere.

There is no evidence of high frequency landscape burning of forests in north-east NSW, or forests generally, before the European invasion. Rather the evidence indicates infrequent occurrence of fire, with long periods fire free. The tablelands were rarely burnt, the wetter forests likely had fire frequencies measured in centuries, and the coastal forests likely had fire frequencies measured in multiple decades. Other ecosystems, such as heaths, may have burnt more frequently.

It is likely that there were areas subject to higher frequencies associated with larger Aboriginal settlements, particularly with population increases over the past 5,000 years and retreat inland due to rising seas.

The charcoal data does clearly show that across Australia, including north-east NSW, there was a significant increase in fire frequency and intensity in concert with European settlement. There has been a marked decline since fire suppression policies in the 1950's, but remains well above pre-European frequencies. The practice of regular burning of grazing lands, with frequencies of 1-5 years, continues, particularly on the tablelands and escarpment country of north-east NSW (see section 3).

There needs to be an honest and factual consideration of pre-European burning regimes to inform current management given the evidence that north-east NSW's forests were not subject to a frequent burning regime.

It needs to be recognised that the changes to forests since the European invasion have had profound effects on the flammability of vegetation and fuel loads through increased fire frequencies, grazing, logging and weed invasion (Sections 2, 3 and 4.2.2.). It is a very different landscape to what it was 250 years ago.

Around 50,000 years ago modern humans first arrived in northern Australia and reached southern Australia within a few thousand years. They arrived during a glacial period, when the land was cooler and drier than now. Lightning induced fire had long had a significant effect on the nature and extent of Australian ecosystems, and while the arrival of humans with their ability to make and manage fire must have had effects it is hard to distinguish this from the dominant influences of the massive climate upheavals that have since occurred.

It is apparent that Aborigines used fire to maintain open areas of vegetation for ease of travel, promote growth of food and medicinal plants, promote 'green pick' for prey, and driving animals for hunting. Some areas were excluded from burning for cultural reasons. What is not known for forests is how Aboriginal use of fire affected climate driven fire events and regimes on a landscape scale.

Aboriginal occupation has spanned periods of dramatic environmental changes as the continent passed through a glacial period and then warmed again. The mega-fauna went extinct, a climate shift made central Australia drier, monsoonal rainforests declined while east coast rainforests expanded, and seas rose by over a hundred metres flooding the continental margins.

At the time of Aboriginal arrival, Australia supported a diverse megafauna of marsupial species with body weights >44 kg, including giant forms of nearly every extant marsupial. Around 90% of the Australian megafauna became extinct within a few thousand years of the arrival of people, while the reasons for the extinctions are unresolved there is little doubt that people played some part.

Quaternary Period Timeframes

Pleistocene (2.588 million years ago to 11.7 thousand years ago)

- Last glacial period 115,000 – c. 11,700 years ago, low rainfall
- Humans arrive in Australia 50-60,000 years ago
- Last Glacial Maximum (driest and coldest) 17,000 - 24,000 years ago
- Cooling period 14 000 to 12 500 years ago

Holocene (11.7 thousand years ago to 200 years ago)

- Rapid sea-level rise of over 120m until around 6,000 years ago
- Holocene Climatic Optimum 7000 and 5000 years ago, expansion of wet sclerophyll and rainforest taxa in southeastern Australia (Sweller 2001, Black et.al 2008).
- <5,000 years ago, drying climate, ENSO events become stronger, increase in Aboriginal populations.
- 2,500-1,700 years ago increase in ENSO activity, reduced rainfall, increased rainfall seasonality.

Anthropocene (200 years ago to present)

- Arrival of Europeans

Gillespie *et. al.* (2006) reappraised evidence relating to the extinction of the Australian megafauna and concluded that:

> *We estimate that the megafauna-human overlap period on mainland Australia was about 3900 years (95% confidence interval 3158 to 4642 years) centred ~44,000 calendar years ago. Our results rule out climatic and environmental changes associated with the Last Glacial Maximum as contributing factors in Australian late Pleistocene megafauna extinctions, whereas the short overlap suggests instead that anthropogenic factors are likely to be dominant.*

From their review of the data from south-east Australia, Saltré et. al. (2019) concluded "*our results support the idea that human arrival in south-eastern Australia was an additional stressor to climate perturbations, rather than humans being a 'super predator'. Indeed, human populations were most* *likely small at the time of arrival ...*". They identify that for far southern Victoria and Tasmania they consider that the megafauna became extinct before humans arrived. They also "*acknowledge that our approach has some potential limitations, such as disregarding the possible feedbacks of human induced fire*".

It is likely that hunting was a significant factor, though the rapidity of the continent-wide extinction of so many species suggests other contributions. One theory is that a principal driver was increasing aridity of the vegetation, which could have been due to climatic changes and/or Aboriginal burning.

Considerable attention has focussed on the effects of vegetation changes on the Australian monsoon. Studies have identified a reduction in woody vegetation and increase in grasses is likely to have occurred in central Australia around 50,000 to 40,000 years ago (the late Quaternary) and surmised that these changes were due to Aboriginal burning practices creating vegetation feedbacks that weakened the continental penetration of the summer monsoon and thus changed the climate (i.e. Johnson *et. al.* 1999, Hoffmann and Jackson 2000, Miller *et. al.* 2005, Miller *et. al.* 2007, Bowman *et. al.* 2010, Notaro *et. al.* 2011, Wyrwoll *et. al.* 2013).

This burning regime has been implicated in significant vegetation changes, for example Bowman *et. al.* (2010) observe:

> *Prior to the arrival of people in the Australian–New Guinea region, the fire regime was most probably characterized by infrequent high-intensity fires (Bowman, 2002). Thus prehuman landscapes are likely to have been different from today, with fire-adapted species less abundant, the savanna (mixtures of tropical grass and trees) more geographically restricted, and evergreen dry forests and rain forests more widespread.*

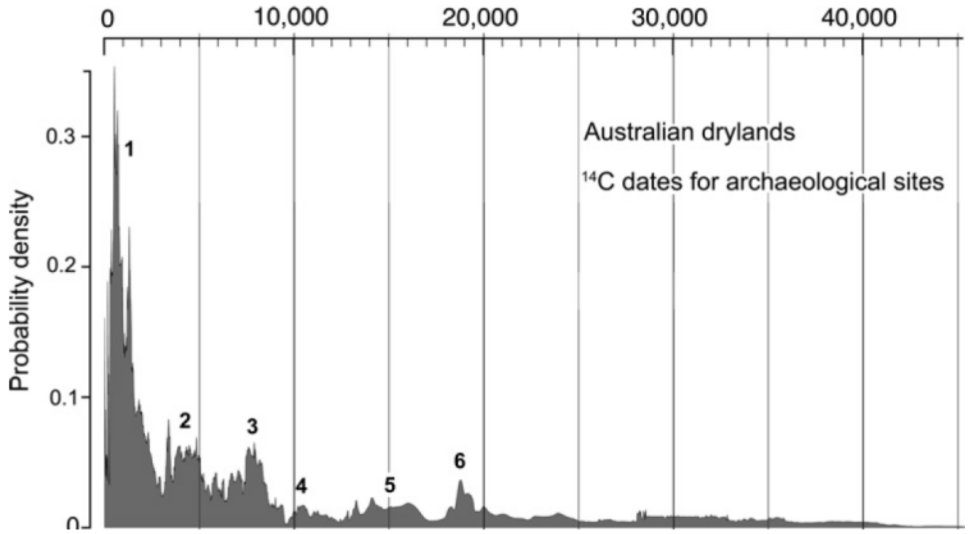
Johnson *et. al.* (1999)'s identification of likely climate changes resulting from Aboriginal burning generated considerable interest. A review Bowman (2002) concluded "*this interpretation is difficult to sustain given the great difficulty in extracting a clear 'signal' of an anthropic impact from the inherent variability and fragmentary record of the palaeo–summer monsoon".* Marshall and Lynch (2008) attributed the monsoon changes primarily to *sea level and solar insolation variations.*

The most definitive direct evidence of pre-historic fire regimes are charcoal deposits.

Over time Aboriginal occupation has shifted and varied in response to climatic and vegetation changes. There appears to have been a significant population increase 4,000-5,000 years ago as evidenced by increased site numbers, increased artefact density and an expansion in occupation.

Population growth would have varied regionally and been influenced by climatic changes. For example, Smith *et. al.* (2008) use radiocarbon data from archaeological sites in Australian drylands to reconstruct the long-term population history of this arid region, finding:

> *The time-series analysis presented here suggests a saw-tooth pattern of rapid population growth and decline on a 1–3 kyr frequency, superimposed on an overall step-wise pattern of population growth and expansion, with significant thresholds at 19, 8 and 1.5 cal. kyr BP and a marked collapse of dryland hunter-gatherer populations around 3–2.5 cal. kyr BP*



The time-series analysis of fluctuations in Aboriginal populations in arid Australia from Smith *et. al.* 2008.

It is suggested (Mooney *et. al.* 2010, Lourandos 1980, 1983) that the intensification of land use by Aboriginal groups, including a shift from more nomadic to more sedentary populations, may have been responsible for an increase in fire from ca. 5 ka onwards.

Mooney *et. al.* (2010) show the lack of correlation between apparent human activity and charcoal deposits, noting "*major inferred increase in population during the late Holocene ('intensification') is not accompanied by an increase in fire. Thus, this comparison does not support the hypothesis that changes in post-glacial fires in Australia were caused by humans*".

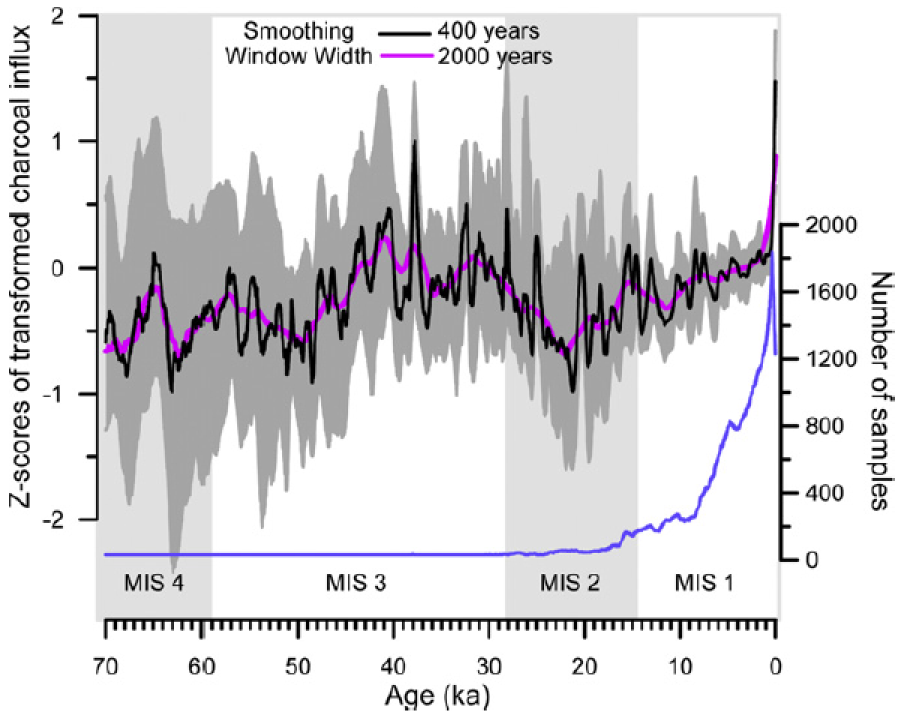


Fig. 2 from Mooney *et. al.* (2010). Reconstruction of biomass burning over the period from 70 ka to present for Australasia as a whole (20_N - 50_S; 100_E to 177_W). The curves have been smoothed using a window of 2000 years (purple curve) to emphasize the long-term trends and a window of 400 years (bold black curve) to emphasize the millennial-scale variability.

Mooney *et. al.* (2010) assessed 223 sedimentary charcoal records to assess changes in fire regimes over the last 70,000 years, finding "*fire in Australasia predominately reflects climate. with colder periods characterised by less and warmer intervals by more biomass burning*", stating:

> *There is no distinct change in fire regime corresponding to the arrival of humans in Australia at 50 ± 10 ka and no correlation between archaeological evidence of increased human activity during the past 40 ka and the history of biomass burning. However, changes in biomass burning in the last 200 years may have been exacerbated or influenced by humans.*

Enright and Thomas (2008) used multiple lines of evidence to investigate pre-European fire regimes in Australia, concluding:

> *Evidence for pre-European fire regimes suggests that while large areas of savanna woodlands in northern Australia, and dry forests and woodlands in temperate southern Australia, were subjected to increased fire under Aboriginal land management; others were not. Areas where fire regime was controlled primarily by 'natural' climate-fuel relationships probably included those that were difficult to burn because they were too wet (e.g. rainforests), fuel levels were usually too low (e.g. desert and semi-arid rangelands), or resource availability was low and did not support other than transient human occupation (e.g. some shrublands)*
>
> *Overall, this suggests that frequent Aboriginal burning may have been a feature of some parts of the landscape but not others. According to Hassell and Dodson (2003), there is a strong correlation between resource richness (access to fresh water, and moderate to high soil fertility – such as on alluvial soils of river valleys), Aboriginal population sizes at the time of European settlement, and the frequency of vegetation treatment by fire.*
>
> *Some forests with an open and grassy understorey may have been natural, while others were maintained through the managed use of fire. Other forested areas had dense, shrubby understoreys and may have experienced fire regimes similar to those of today (see Table 1). Shrublands too may have been largely unmanaged, reflecting their low resource quality (for people) relative to other parts of the landscape.*
>
> *We can conclude that many fires were small, while some were large – but can say little about absolute sizes and size frequency distributions. Fires in open, grassy areas were likely to be frequent (every few years), while many other areas were heavily wooded and may have experienced fire less frequently.*

Vegetation type	Annual rainfall[3]	Fuel load	Natural fire interval	Managed fire interval	Resource level
Tropical rainforest	>1600	Moderate	Very long (>300 years)	N/A; except ecotone with savanna	High
Tropical savanna	500–1600	High	Very short (2–4 years)	Very short (1–3 years)	Moderate
Semi-arid spinifex grasslands	250–500	Low to high	Intermediate – long (10–30 years): rainfall-spinifex biomass event driven	Short (3–10 years); spinifex areas treated when possible	Low; but occasionally high
Desert	<300	Low	Long (20–50 years): rainfall-annual grass biomass event driven	Intermittent; not actively managed with fire	Low
Shrubland	300–600	Moderate	Short – intermediate (10–30 years)	Intermittent; not actively managed with fire	Low
Dry sclerophyll forest[1]	600–1200	Low	Intermediate – long (30–100 years)	Intermittent; not actively managed	Low – moderate
Dry sclerophyll forest[2]	400–600	Moderate to high	Intermediate (10–20 years) and long (50–80 years)[4]	Short (2–5 years), understorey only	Moderate
Wet sclerophyll forest	1000–1600	High	Intermediate (10–30 years) and long (50–100 years)	Intermittent (6–10 years); mainly ecotones	Low – moderate
Temperate rainforest	>1600	High	Very long (>300 years)	N/A; except ecotone with moorlands	Low – moderate

Table 1 from Enright and Thomas (2008). Generalised relationships between vegetation type, annual rainfall (mm), fuel load (surface and near-ground live fuels), estimated 'natural' (i.e. primarily lightning

ignition) fire interval, level of use of managed fire by Aboriginal peoples in the pre-European period, and level of resources (water, plants, animals) to support indigenous populations for major ecosystem types in Australia.

Enright and Thomas' (2008) estimates of natural fire frequencies in dry and wet sclerophyll forests likely reflect the lower bands of possibilities, with longer fire free periods at places and times. The 'managed fire interval' is not considered realistic for north-east NSW forests, as it is doubtful that these forests would have burnt so frequently (Section 1.1.). For Mountain Ash wet sclerophyll forests McCarthy *et.al.*(1999) assessed the mean interval between fires as 37–75 years.

Enright and Thomas (2008) caution:

> *Scientific studies suggest that many fire-sensitive woody species would decline under more frequent burning, so that the use of a small patch size, frequent fire regime – such as may have existed over large parts of Australia in the pre-European (Aboriginal occupation) period – may have harmful biodiversity conservation outcomes if instituted without careful consideration of individual ecosystem and species requirements.*

Mooney *et. al.* (2010) emphasise "*while we cannot dismiss the idea that some individual records may contain an overprint of human influence on the local fire regime, the evidence presented here clearly demonstrates that the dominant control of fire activity is climate or climate-modulated changes in vegetation cover*".

It is estimated that sporadic occupation of the Blue Mountains by Aboriginal people began between 14,000 and 12,000 years BP (Black and Mooney 2006). Black and Mooney (2006) undertook an assessment of charcoal deposits over the past 14,200 years at Goochs Swamp in the Blue Mountains, finding dramatic increases in charcoal from 5,700-3,500 years ago, again 3,100-2,300 years ago, and *"unprecedented levels of charcoal in the post-European period"*. These periods of increased charcoal are likely to reflect phases of relatively frequent, intense fires in the landscape.

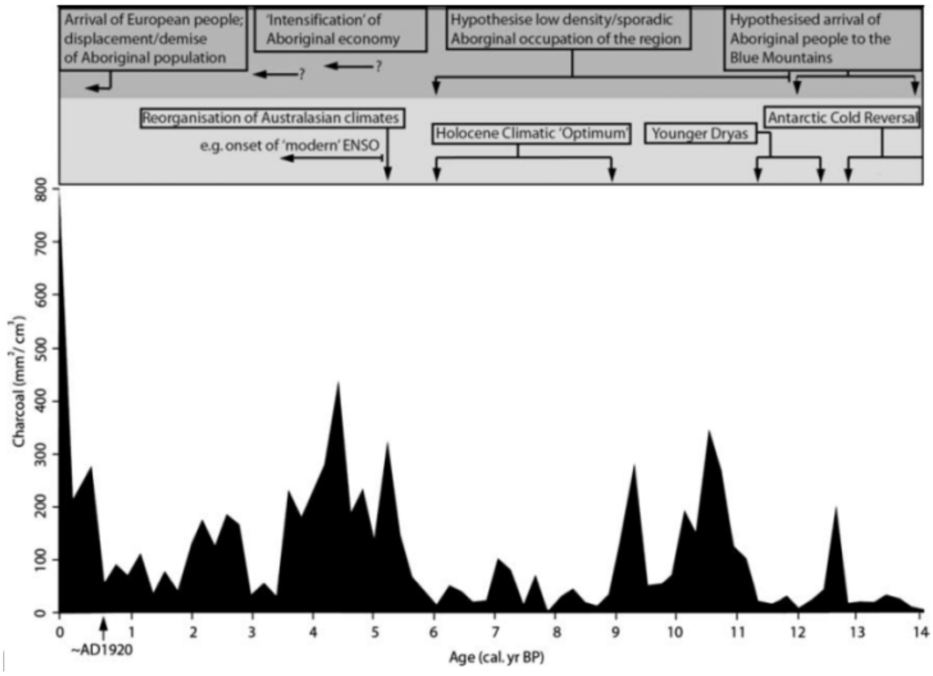


Fig. 4 from Black and Mooney (2006) showing annotated charcoal diagram, depicting possible influences on past fire activity at Goochs Swamp.

From their review of the potential causes of the changes in fire frequency, Black and Mooney (2006) concluded:

> *Despite the potential interactions between climate, humans and fire over the last _14,200 years climate appears to be the dominant control of fire activity at Gooches Crater Right. This is not true, however, in the recent historic past, which has a high fire activity without precedent in the previous _14,200 years. The suggestion that climate is a dominant control of fire activity in south-eastern Australia is very much at odds with the prevailing paradigm which depicts Aboriginal people as controlling regimes in the pre-European period. This conclusion may also imply that the use of fire for resource manipulation by Aboriginal people in the Sydney Basin has been overstated. Bowman and Brown (1986, p. 166) have previously suggested that 'Fire-stick Farming' had received ''too little critical examination'', with attendant circular arguments and, hence, it had become a ''self-fulfilling prophecy''.*

Black *et. al.* (2008) investigated this further by comparing these average charcoal concentration at Goochs Swamp with the discard rates of artefacts from a nearby archaeological site and concluded the results implied that the mid-Holocene increase in fire activity was unrelated to people.

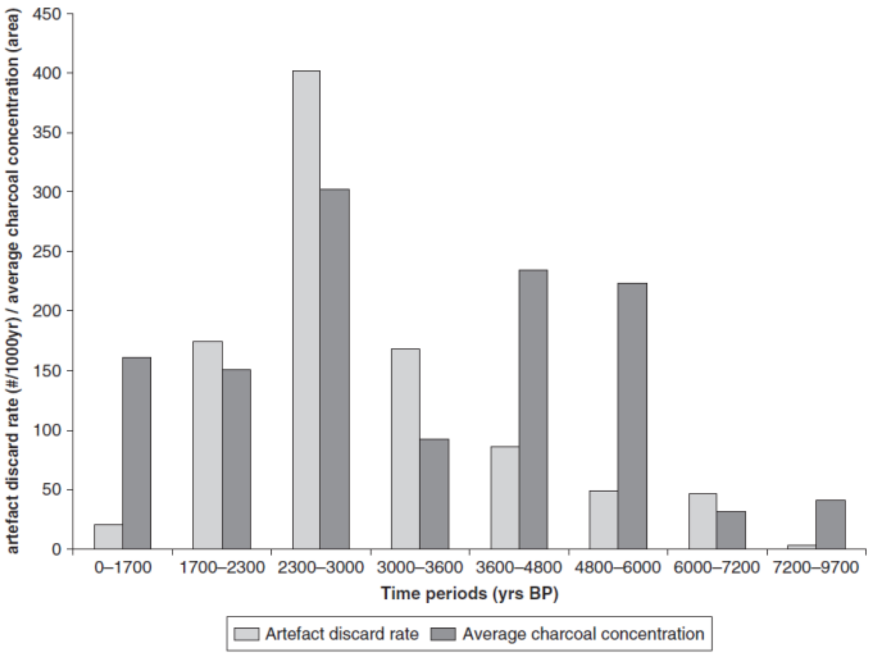


Figure 4 from Black *et. al.* (2008): Artefact discard rates (Capertee 3 site) versus average charcoal concentration (Goochs Swamp) throughout the Holocene. Note the increase in charcoal predates the increase in artefacts.

Black *et. al.* (2008) also considered their results in the context of identified fire regime changes in other pacific countries and concluded that the fire regime changes at Goochs Swamp reflected regional climatic changes:

> *A climatic solution can be used to explain all periods of change in the fire history of the landscape surrounding Goochs Swamp: ... the most significant change, after the mid Holocene (5700 cal. BP), with an abrupt increase in fire activity associated with ENSO-like climatic variability. The similarities between the charcoal accumulation from Goochs Swamp and similar records from tropical locations (Haberle and Ledru, 2001; Haberle et al., 2001) also suggest that fire activity in the Blue Mountains was a response to regional or larger-scale climatic forcing.*

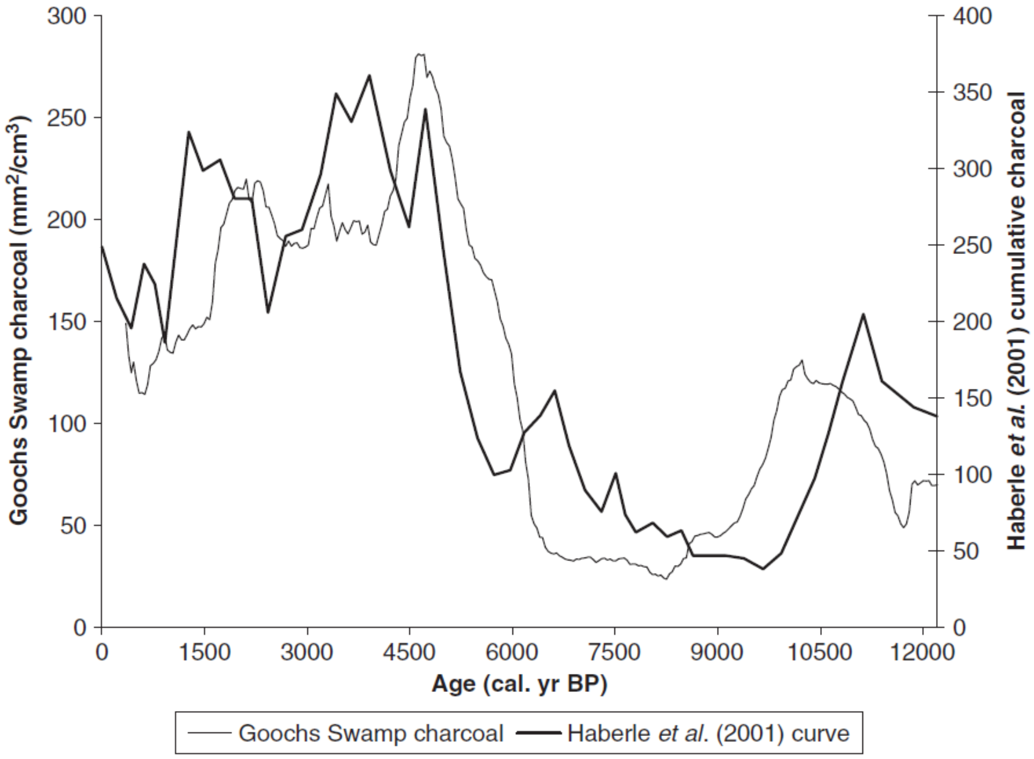


Figure 5 from Black *et. al.* (2008): A comparison of the composite charcoal results from several sites in Indonesia and Papua New Guinea, from Haberle *et al*. (2001), and the results from Goochs Swamp.

Black *et. al.* (2008) recognise:

> *Although the dominant control on fire in this environment during the Holocene appears to be climate, fire in this landscape in the late Holocene may reflect anthropogenic activity. Even if this is the case, it is possible that this may have been a response by the humans to climate variability, further complicating any artificial dichotomy between 'anthropogenic' and 'natural' causation.*

Black and Mooney (2006) consider:

> *There is no single pre-European fire regime that can be recommended as a management target or can be applied: instead several regimes have existed, each tied to the prevailing climate of the time. Furthermore, the Gooches Crater Right study highlights the important influences of climate change including ENSO on fire activity. This suggests that fire activity is likely to become an increasing concern with projected rapid anthropogenic climate change in our near future. How ENSO responds to any anthropogenic climate change is likely to be critical to future fire regimes in south-eastern Australia.*

1.1. The Change with European Settlement

The charcoal record provides mixed interpretations of the effects of pre-European fire regimes upon forests, with climatic changes a major driver. It appears that Aboriginal burning did have significant affects at some localities, but not at others, which suggest highly variable use of fire by different Aboriginal groups and at different locations. Though there is no evidence of high frequency landscape burning of forests in north-east NSW, or forests generally, before the European invasion.

The season of burning is also a key issue, as far from being cool-season burns Aboriginal burning in forests may have been undertaken during summer, when the ecological effects will have been very different. Enright and Thomas (2008) identify that "*historical records for Aboriginal fires in southwestern Australia before and during early European settlement reports that most fires (74%) were lit in summer, and nearly all (86%) occurred in the hottest 4 months of the year under typically hot and windy conditions (Abbott 2003)*".

It is evident that there has been a significant increase in burning since the arrival of Europeans (Rayner 1992, Dodson *et. al.* 1994, Burrows *et. al.* 1995, McGrath and Boyd 1998, Mooney and Maltby 2006, Black and Mooney 2006, Enright and Thomas 2008, Mooney *et. al.* 2010, Von Platen *et. al.* 2011, Moss *et. al.* 2013, Stewart 2017). Charcoal records show that this involved a significantly higher burning of biomass. Black and Mooney (2006) found *"unprecedented levels of charcoal in the post-European period"*, showing "*a high fire activity without precedent in the previous 14,200 years"*

These results show that the frequency of fire increased dramatically with settlement by Europeans, before declining more recently since the practice of fire suppression. People who are advocating a return to the good old days are primarily calling for a return of the record burning of a few decades ago, not to the Aboriginal burning regimes of hundreds or thousands of years ago.

The results of charcoal sampling in north-east NSW (Section 1.1.1.) show no evidence to support a high frequency fire regime in forests before European settlement. Rather they indicate infrequent occurrence of fire, with long periods fire free. The tablelands were rarely burnt, the wetter forests likely had fire frequencies measured in centuries, and the drier coastal forests likely had fire frequencies measured in decades. Other ecosystems, such as heaths, may have burnt more frequently, and it is likely that Aboriginal people burnt select areas more frequently.

All reviewed assessments of charcoal deposits from the Great Sandy (Section 1.1.2.) show little discernible influence of Aborigines on vegetation or fire across the landscape since the last glacial period. Though at some sites there does appear to have been an increase in both Aboriginal populations and fire frequencies around 5,000 years ago, with fire dramatically increasing after European settlement.

Charcoal assessments from other forested regions (Section 1.1.3.) reflect the results from north-east NSW. In north Queensland there was a major expansion of rainforests since the last glacial, with fire frequencies measured in centuries on many sites. In Tasmania Aboriginal fires may have retarded the post-glacial recovery of rainforests. In south-west Australian forests, before European settlement fire frequencies were measured at an average of 80 years, with no fire recorded for over 200 years at some sites, though with significant increases post invasion. In one Tasmanian dry eucalypt forest frequencies were found to average 14 years pre-European, though to have doubled thereafter.

The changeover from Aboriginal burning regimes to European regimes was quick and often brutal in settled areas. Black and Mooney (2006) observe:

> *By the time Europeans had found a route over the Blue Mountains in 1813 there were very few Aboriginal people remaining as a result of small pox epidemics and other diseases. Massacres and the destruction of traditional resources resulted in the further demise of Aboriginal populations such that traditional lifestyles had almost completely disappeared from the Blue Mountains region by 1820*

The Aboriginal people were rapidly usurped and their traditional burning practices replaced with a far more frequent, intense and extensive burning regime. As noted by Enright and Thomas (2008):

Using tree-ring evidence, Banks (1988) reports infrequent fire (one to two large fires per century) in Snow Gum (Eucalyptus pauciflora) woodlands near tree line in the Australian Alps prior to European settlement, followed by a sudden increase in the frequency of fire after the introduction of European settlers and their livestock to the alpine and sub-alpine areas of southeastern Australia.

Mooney *et. al.* (2010) assessed 223 sedimentary charcoal records and identified significant increases in fire regimes after the European invasion, with burning peaking around the1950s before declining, though still remaining well above the pre-European frequency.

Enright and Thomas (2008) identify:

The managed use of fire to reduce fuel loads in public estate forests (and other vegetation types) since the 1950s has been the major strategy employed by government to mitigate the risk of unplanned fire spreading into private lands (Esplin et al. 2003). Despite this 'prescribed burning' programme, large unplanned fires in 1983, 2003 and 2007 have cast doubt over its effectiveness.

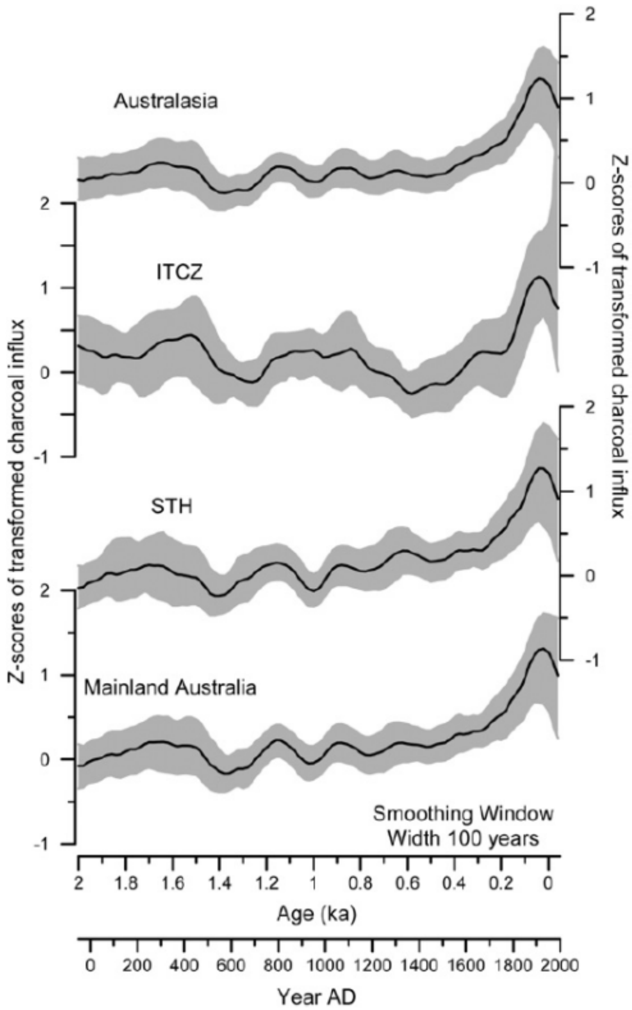


Fig. 5 from Mooney *et. al.* (2010). Reconstruction of biomass burning for the last 2 ka for Australasia as a whole (20_N-50_S, 100_E-177_W), the belt corresponding to the modern Inter-tropical Convergence Zone (ITCZ: 20_N-20_S, 100_E to 177W, broadly the tropical region), the modern sub-tropical high pressure belt (STH: 25_S-45_S, 100_E to 177_W, broadly temperate Australasia), and for all sites on the Australian mainland. The curves have been smoothed using a window of 100 years (bold black curve).

Enright and Thomas (2008) consider:

> *Evidence is also available for the presence of dense vegetation in some places, and for the development of open vegetation in others, in the absence of Aboriginal burning. Gell et al. (1993) reported a mixed shrub–grass understorey associated with low-frequency fire in the immediate pre-European period for a forest site in East Gippsland (Victoria) based on pollen and charcoal analyses of short sediment cores. Grassiness increased during the early European period in association with more frequent fire, and then decreased as shrubs gained ascendancy after fire suppression was introduced to the area.*
>
> *Overall, this suggests that frequent Aboriginal burning may have been a feature of some parts of the landscape but not others. According to Hassell and Dodson (2003), there is a strong correlation between resource richness (access to fresh water, and moderate to high soil fertility – such as on alluvial soils of river valleys), Aboriginal population sizes at the time of European settlement, and the frequency of vegetation treatment by fire.*

What is evident is that Aboriginal people managed fire over millennia through dramatically changing climates and ecosystems, and across widely divergent landscapes. From their assessment of a 14,200 year charcoal record Black and Mooney (2006) observe:

> *There is no single pre-European fire regime that can be recommended as a management target or can be applied: instead several regimes have existed, each tied to the prevailing climate of the time.*

There is a common misconception that in prehistoric times Aborigines applied a frequent patch-burning regime across the whole of Australia which is termed 'firestick farming'. This appears to have been the case in the tropical savanna woodlands, though there is no evidence of a similar regime being applied to east-coast forests on a landscape scale. To the contrary the evidence is for an infrequent fire frequency measured in decades and centuries.

Changes over time in vegetation and fire frequency are considered to have occurred primarily in response to climate rather than human influences. The rapid expansion of east coast rainforests from 9,000 to 5,000 years ago suggests a low fire frequency despite human presence. The evidence suggests that climate was the dominate influence on fire frequency, Aboriginal use of fire varied over time in response to climatic changes, and frequent burning regimes were only applied in some places at some times.

This has not stopped some people calling for frequent indiscriminate burning based on the claim that Aboriginal people burnt all the time. For example Ryan *et al.* (1995) make sweeping generalisations based on scant information:

> *… before European settlement most parts of Australia burnt more or less on an annual basis producing vegetation communities markedly different to that of common belief.*
>
> *...*
>
> *Aborigines always carried a lighted fire-stick and never put a fire out. Consequently, the Aborigines did not just burn now and again, or only in autumn, or when the birds were not nesting. They burnt all the time. Many thousands of fires were lit across the countryside on a daily basis. In addition there was nothing to stop these fires from spreading when conditions were suitable*

As noted by Black *et. al.* (2008):

> *In Australia prehistoric fire regimes are typically and uncritically related to human activity. It has thus been suggested that Aboriginal fire regimes could be used for the contemporary*

> *management of various Australian ecosystems (e.g., Rolls, 1981; Flannery, 1994; Ryan et al., 1995). Gill (1977) argued that frequent low-intensity fires were applied by Aboriginal people in some Australian ecosystems but that this was not applicable across the entire continent. Clark and McLoughlin (1986) and Baker (1997) suggested that Aboriginal people variously used fire in different vegetation types depending on what resources they were extracting. Head (1989) also noted that there is a common assumption that Aboriginal people had a single ongoing impact, thereby potentially ignoring climatic, demographic and cultural changes. This followed Mulvaney's (1971: 378) challenge to the fallacy of an 'unchanging land and people' and those who viewed Aboriginal socio-economic and demographic changes as seemingly insignificant (e.g., Birdsell, 1953).*

Much of the discussion relating to advocating Aboriginal burning is based upon untested assumptions, as identified by Mooney and Maltby (2006):

> *The use of fire has been suggested to be a fundamental aspect of the Worimi people's lifestyle (Hunter 2000; NPWS 2002b) and the MLNP Plan of Management states that the Worimi 'altered their natural environment through the use of fire' (NPWS 2002b). Hunter (2000) suggested that their intermittent firing of the landscape increased the abundance of several species of grasses. This is a common interpretation of Aboriginal fire management and subsequent vegetation change but in reality the nature and consequences of their management of fire is poorly known. Our understanding of Worimi culture is primarily based on early European ethnographic records, which occurred during a period of significant disruption.*

Benson and Redpath (1997) note:

> *Aborigines, like the Europeans, favoured some habitats over others, including grassy woodlands and river valleys where water was plentiful. The archaeological evidence suggests that they did not reside in the dense escarpment forests as much as on the coast or on the inland plains*

From their review, Enright and Thomas (2008) concluded:

> *It is our view that not enough is known about traditional Aboriginal burning strategies and objectives in temperate Australia to be able to re-create an Aboriginal fire management regime or to know its potential consequences. Knowledge has been lost due to the alienation of tribes from their land, or is fragmentary.*
>
> *...any use of a 'traditional Aboriginal burning regime' on public estate lands in southern Australia would be an experiment in land management, rather than a re-creation of Aboriginal fire regimes, and should be recognised as such. The overall weight of evidence suggests that smaller, lower-intensity fires were more common in many Australian ecosystems prior to European settlement of the continent, and that their administration was not necessarily deleterious to biodiversity values. Recent reports of inquiries into the extensive unplanned fires that have affected southeastern Australia in the past decade recommend an increase in the total area burned per year by planned fire to reduce the risk of large, high-intensity wildfires. However, any increase in the area burned, and decrease in fire interval associated with such a strategy, will need to remain based on scientific criteria that seek to meet current (and evolving) biological conservation and asset protection objectives rather than being based in any sense on uncertain past regimes.*

Enright and Thomas (2008) further consider:

> *In relation to modern fire management, we must ask whether there might be conflicts between the cultural and resource exploitation goals of Aboriginal burning and the species conservation (and other) goals of management in parks, reserves and public estate lands (Langton 1998). The objectives of fire management today include fuel load reduction to assist in asset (human life and property) protection, and fire season, interval and intensity management to maintain native plant and animal species populations, ...*
>
> *The massive number of plant and animal introductions that has accompanied European settlement of Australia means that few if any ecosystems will necessarily respond to fire in the way that they may have in the pre-European past (Werner 2005).*

1.1.1. North East NSW burning.

There have been limited assessments of pre-European fire regimes in north-east NSW. Those found are analyses of pollen and charcoal from lake deposits at Barrington Tops (Dodson *et. al.* 1994, Sweller 2001), Myall Lakes (Mooney and Maltby 2006), Bundjalung (McGrath and Boyd 1998) and Little Llangothlin Lagoon on the New England Tablelands (Woodward *et. al.* 2014), terrestrial charcoal deposits from Terania Creek (Turner 1984) and from measurement of fire scars on grass trees (Mooney and Maltby 2006).

At Barrington Tops rainforest rapidly expanded over the past 11,000 years since the last glacial period, reflecting a low fire frequency. Myall Lakes had a low recorded fire frequency over the past 2,800 years, with frequencies mostly 2-4 per century, and long periods without fire, until the arrival of Europeans. At Terania Creek Blackbutt forest had 280 year fire frequencies over the past 1,650 years and Brush Box forest 325-380 years over the past 3,005 years. Bundjalung results over the past 6,600-8,700 years show a regular, but well spaced, fire regime. Little Llangothlin Lagoon had no evidence of fire over the past 4,500 years, until an increase in the past 1,000 years.

None of these results show evidence to support a high frequency fire regime. Rather they indicate infrequent occurrence of fire, with long periods fire free. The tablelands were rarely burnt, the wetter forests likely had fire frequencies measured in centuries, the coastal forests likely had fire frequencies measured in decades. Other ecosystems, such as heaths, may have burnt more frequently (i.e. Bundjalung).

Sweller (2001) assessed pollen changes in Burraga Swamp on Barrington Tops over the past 40,000 years. She found that it was a treeless grassland between about 21,000 and 15,000 years BP after which tree ferns, eucalypts and sporadic Antarctic Beech *Nothofagus moorei* (likely from nearby refugia) appeared, by 11,500 years BP Antarctic Beech had become permanent, maximum moistures and temperatures (higher than present) were reached between about 9,000 and 5,000 years BP, with cool temperate rainforest reaching full development by 6,000 years BP.

Other findings on the plateau show cool temperate rainforests have had a complex pattern of increase and decline over the Plateau, Sweller (2001) summarises:

> *About 8,500 years BP, a peak in Nothofagus was registered at Killer Bog (about 12 km northeast of Burraga). At Black Swamp (about 7 km north/northeast of Burraga), Nothofagus peaked about 6,000 years BP, at about the same time as at Burraga and on the northerly end of the Plateau at Boggy Swamp (about 25 km north/northeast of Burraga). At Horse Swamp (about 18km north/northwest of Burraga) the Nothofagus peak occurred around 1,000 years BP.*

Sweller (2001) identifies that across the Plateau "*fire seems to have had no direct responsibility for any major vegetation shifts*", with fires of low intensity and frequency until increasing around 3,000 years ago. Sweller (2001) observes:

> *Repeated fires in eucalypt forests adjoining rainforest, can push back the rainforest boundaries. If the fire is not very severe, N. moorei can regenerate vegetatively through coppice shoots from the intact tree or from dormant buds particularly under the soil beyond the fire's limit. In the prolonged absence of fire, rainforest can advance into Eucalyptus forests (Turner, 1981).*

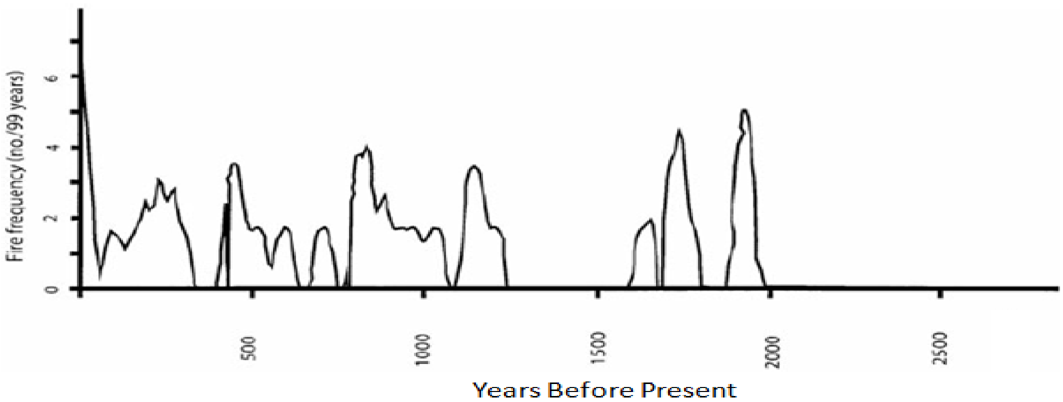
Though she also identifies that moderate burning still occurred once rainforest became established, resulting in areas of coppice regrowth.

While climatic variations and burning may have affected the spread of rainforest across the plateau, its expansion was primarily in response to climatic changes and its increase reflects the low overall fire frequency. Regarding charcoal deposits Sweller (2001) considered:

> *These results may indicate that relatively little burning occurred in pre-glacial maximum times. At face value, burning was more prevalent during the glacial period, ... In post glacial maximum times, burning was low and moderate burning occurred once rainforest became established. Thus, fire has always been part of the environment, but intensity and/or frequency has varied.*

There was no obvious human signature identified. From their studies of Burraga Swamp, Dodson *et. al.* (1994) note:

> *While no significant changes in the largely oligotrophic conditions or in fire frequency were detected, changes in erosion rates and some vegetation change can be attributed to impacts since European settlement. There has been a small decline in eucalypts and a loss of fern cover, while grasses, Urtica and exotic species have expanded.*



Adaption of Fig. 5 from Mooney and Maltby (2006). The inferred frequency of fire through time from Worimi Swamp in Myall Lakes National Park. Note the dramatic increase in the recent past.

Mooney and Maltby (2006) identified fire frequency from charcoal deposits in Worimi Swamp in Myall Lakes National Park over the past 2,800 years and fire scars on Xanthorrhoea over 300 years, finding:

> *an unprecedented level of fire activity in the last 35 years, which coincides with increased human activity in the area. In the prehistoric period charcoal and fire scars are comparatively rare, which is most parsimoniously ascribed to little fire activity, but perhaps represents skilful fire manipulation, as is often attributed to Aboriginal people. The comparatively minor fluctuations in macroscopic charcoal during the*

prehistoric period were approximately coeval with previous evidence of late Holocene environmental change in south-eastern Australia, suggesting that fire frequency at the site responded to climatic variability.

Mooney and Maltby (2006) found that the prehistoric fire regime in the Myall Lakes region did not undergo significant change until approximately AD 1890, after the European presence began in approximately AD 1820, noting:

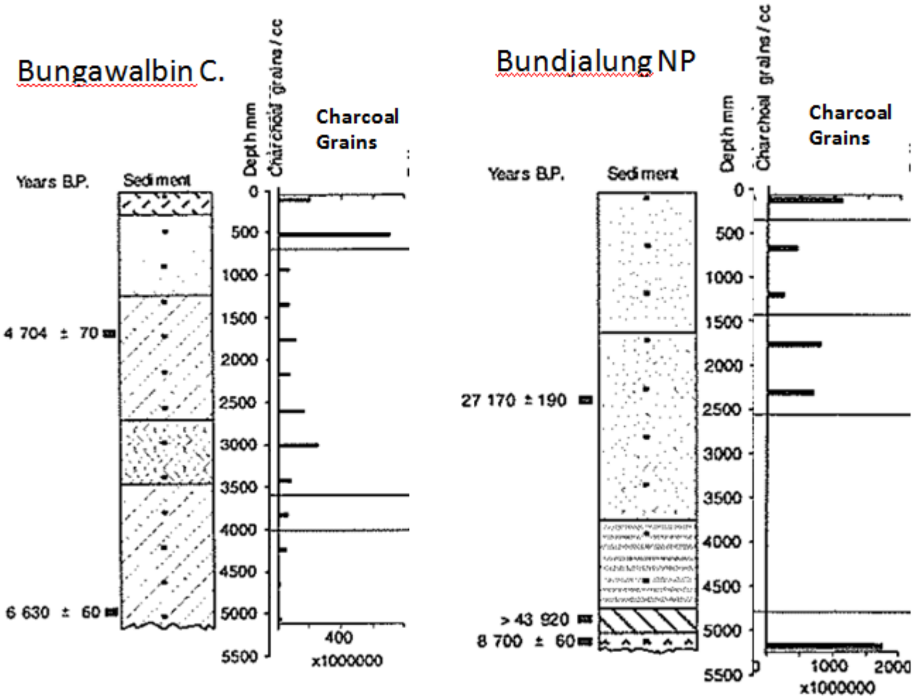
> *The analysis of the Worimi Swamp sediment revealed a slight increase in the influx of charcoal after c.AD 1890, another slight increase between 1943 and 1951, and a dramatic increase in the period since AD 1966*

Turner (1984) assessed soil and tree carbon at Terania Creek (now in Nightcap National Park), and found that the averaged fire frequency in Blackbutt forest was 280 years over the past 1,650 years, and in Brush Box forest was 325-380 years over the past 3,005 years. Part of the rainforest had apparently been burnt on one occasion 1,110 years previously.

McGrath and Boyd (1998) assessed charcoal records in Bundjalung National Park and Bungawalbin Creek for 6,600-8,700 years Before Present (BP). The carbon dating for Bundjalung NP produced a couple of spurious dates. The significant charcoal accumulation 8,700-7,500 years ago indicated "*there possibly was an active fire regime*", though "*The abundant charcoal in the basal sediments, may, however, also reflect low sedimentation rate, and thus the accumulation of charcoal from a long period of fires"*.

For the recent period from around 700 years ago to the present in Bundjalung NP, McGrath and Boyd (1998) note:

> *For the first time during this records, the swamp and neighbouring vegetation was dominated by grasses, which may have been a combined result of sedimentation and drying, or a consequence of European activity. Fire frequency or intensity once again increased during this period.*

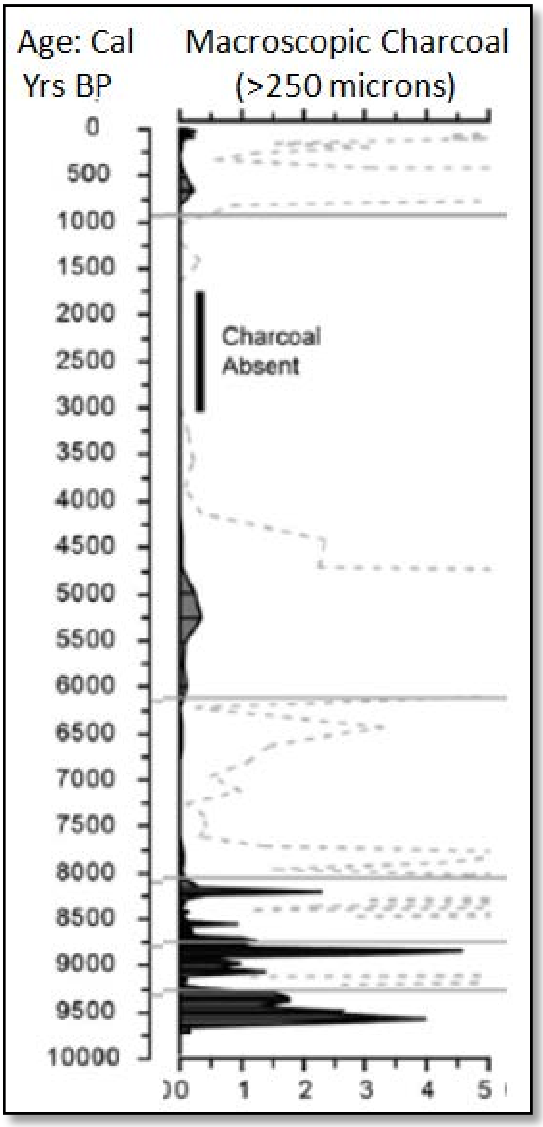


Adaption of McGrath and Boyd (1998) charcoal dating results from near Evans Head.

Overall McGrath and Boyd (1998) considered their results indicate increasingly drier terrestrial conditions, noting "*The inferred trend of the fire regime probably reflects this: fire, while having fluctuated greatly over time, does appear to have become increasingly frequent or intense"*.

Woodward *et. al.* 2014 assessed macroscopic charcoal and the macrofossil records from 5 cores dating back over 20,000 years from the Little Llangothlin Lagoon on the New England Tablelands. They consider "*there is no evidence from archaeological sites for a significant Aboriginal presence on the New England Tablelands until the Mid-Holocene (c. 6000 cal. yr BP)*".

They identify that the period 6100–1000 cal. years BP was a "*dry phase with possible short wet intervals",* and attribute the low charcoal flux over this period to "*low biomass production, limited fuel availability and consequently low charcoal production*". Shortly after 1000 years ago there appears to have been more frequent wet phases in the lagoon and Woodward *et. al.* 2014 consider "*The increase in the macroscopic charcoal flux in this zone could be because of an increase in aboriginal burning in the catchment*", though it could equally be explained by increased fuel and European settlement.



Derived from Figure 4 from Woodward *et. al.* 2014. Macroscopic charcoal and the macrofossil record from one of the Little Llangothlin Lagoon edge cores (LL10).

1.1.2. Great Sandy Region burning

The Great Sandy Regions proximity to north-east NSW, and the extensive research undertaken there, makes it a good case study to assess Aboriginal fire use in coastal areas. It needs to be considered that at the peak of the last ice age (around 20,000 years ago) sea level was around 120m lower than today, with most of the continental shelf exposed. So Aborigines moved inland onto these sites in response to shoreline changes. It was also a period of increasing aridity on Fraser Island.

There have been a variety of studies of lake sediments in the Great Sandy Region that give variable results. Evidence of the presence of humans dates back to Wallen Creek site on North Stradbroke Island around 21,800 years BP, during the Last Glacial Maximum, though few archaeological sites have been found (Atahan *et. al.* 2015).

All reviewed assessments of charcoal deposits from the Great Sandy show little discernible influence of Aborigines on vegetation or fire across the landscape since the last glacial period. Though at some sites there does appear to have been an increase in both Aboriginal populations and fire frequencies around 5,000 years ago, with fire dramatically increasing after European settlement.

Longmore and Heijnis (1999) 600,000 year assessment of a perched lake on Fraser Island found increasing aridity resulted in vegetation and fire changes that *were dominantly climatically-driven or initiated.* Atahan *et. al.* (2015) assessed 37,000 years of sediments in a Fraser Island lake and could not find any evidence of human influences on fires or vegetation. Stewart (2017) assessed 25,000 years of charcoal in a Fraser Island fen and found that over the past 18,000 years fire was infrequent, becoming more frequent 5,400 years ago, and substantially increasing with European settlement.

Moss *et. al.* (2013) found that climate played the key role in vegetation change on North Stradbroke Island over the past 10,000 years, with two sites having a low fire frequency and a third showing an apparent increase 5,000 years ago, corresponding with increased Aboriginal use.

Longmore and Heijnis (1999) assessed a 600,000 year sedimentary sequence from a perched lake (Old Lake Coomboo Depression) on Fraser Island and found that vegetation changes were primarily climate driven, noting:

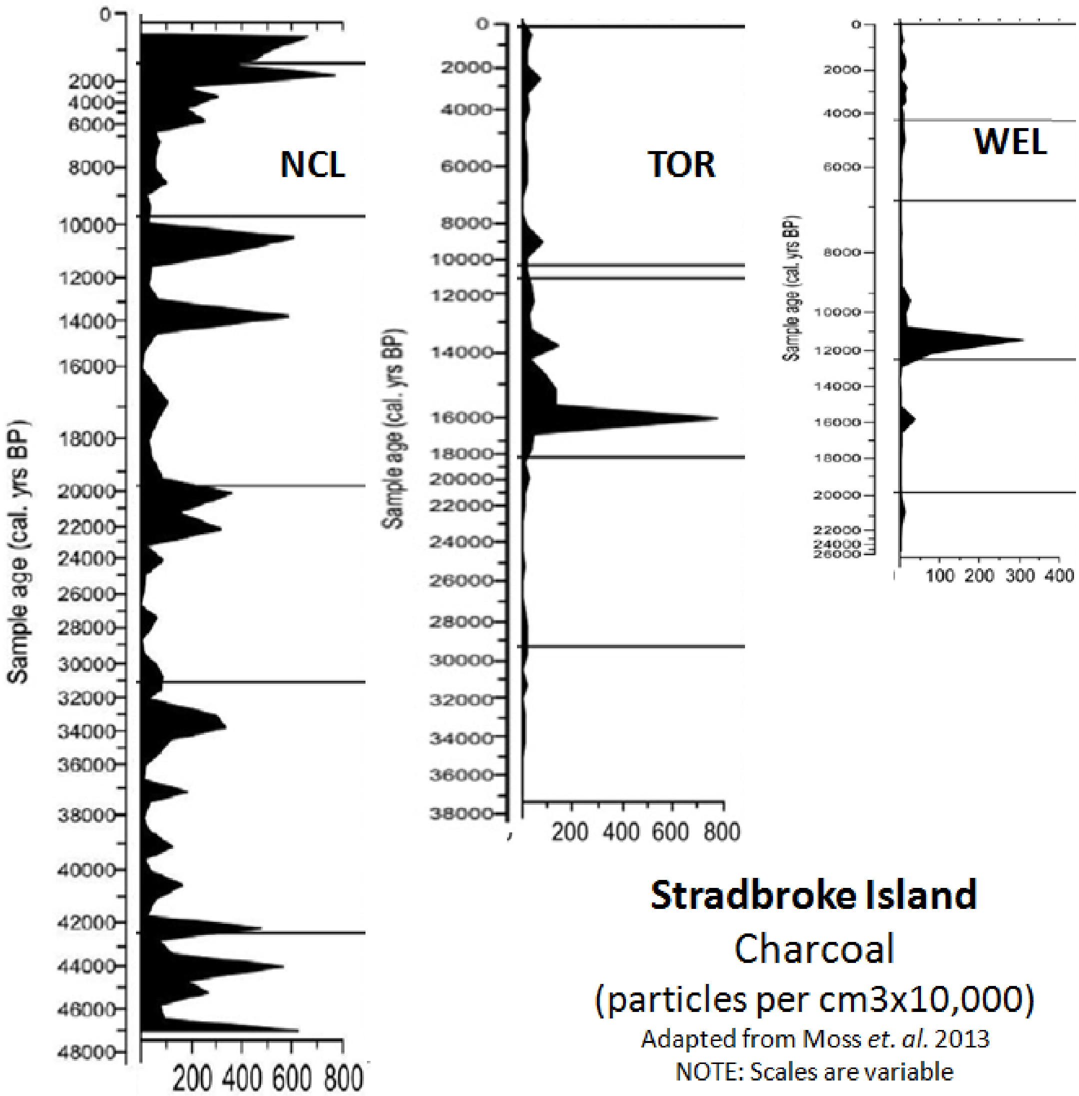
> *The evidence for fire is minimal at the beginning of the record, increases from >350 ka through the sequence culminating at or before the LGM, is low during the LGM and is relatively high during the Holocene. Succession, fire and climatic change, along with the accumulative effect of a series of 100 ka cycles, are believed to have driven the hydrologic and vegetation change and a human factor is not required to explain the record.*
>
> *Overall, there is evidence for a progressive long-term shift in the water budget with increasing 'dryness', groundwater dominance, intensity or frequency of fire, sclerophyllous vegetation from zone I, swamp and sedgeland vegetation and decreasing rainforest. The primarily deep-water lake surrounded by rainforest has been gradually replaced, through a series of glacial/interglacial cycles, by an ephemeral lake with a dominantly sclerophyllous vegetation; it is believed that successional processes, along with fire, played a role but that retrogressive stages were accelerated by climatic change (Longmore, 1997b). The evolution of the lake and catchment can be explained by a combination of succession, fire and climate*

change. Anthropogenic burning, although possibly a contributor ..., is not required to account for the reduction in rainforest at this site.

...

The role of humans in driving major environmental change appears overshadowed in the light of this apparent long-term trend towards aridity. Within the Fraser Island sequence, the apparent fall in the perched watertable (representing independent evidence of climatic change) accompanying vegetation change and the fact that these preceded apparent changes in the fire regime, suggests the ecological changes were dominantly climatically-driven or initiated.

Moss *et. al.* (2013) assessed pollen and charcoal deposits at 3 sites on North Stradbroke Island: Native Companion Lagoon (NCL) covering 47,000 years Before Present (BP), Tortoise Lagoon (TOR) covering 37,000 years BP, and Welsby Lagoon (WEL) covering 26,000 years BP.



Fire History on Stradbroke Island, adapted from Moss *et. al.* 2013. showing charcoal record against age (cal yr BP) for Native Companion Lagoon (NCL), Tortoise Lagoon (TOR) and Welsby Lagoon (WEL).

At Native Companion Lagoon, during the period 9,000 to 1,250 years BP casuarina obtained their highest abundances (between 58 and 80%), and there is relatively low representation of rainforest and sclerophyll herbs. From around 5,600 years ago there was a sharp increase in charcoal abundance. Since 1,250 years BP there was a decrease in rainforest and casuarina, and an increase in eucalypts and grasses.

At Tortoise Lagoon, over the period 10,600 to 400 years BP casuarina sharply increase (between 54 and 82%,), and there are two small peaks in charcoal around 9,300 and 4,300 years ago. After then there was a marked increase in eucalypts and melaleuca, with a corresponding decline in casuarina, though charcoal was virtually absent.

At Welsby Lagoon, from 4,350 to 190 years BP casuarina became most abundant (>75%) and grasses increased, while rainforest and ferns declined. Since then casuarina declined (to 64%), while eucalypts markedly increased.

In relation to burning Moss *et. al.* (2013) found that climate played the key role in vegetation change on North Stradbroke Island over the past 10,000 years, with two sites having a low fire frequency and a third showing an apparent increase 5,000 years ago, corresponding with increased Aboriginal use, noting:

> *A sustained increase in burning is also observed in the NCL record over the last 5000 years, which may be explained by intensified human occupation and a drier climate. Archaeological investigation of the nearby WalleneWallen Creek site reveal the longest record of continuous human occupation in the south-east Queensland region (to at least 20,000 years ago), as well as increased occupation intensity over the last 5000 years (Neal and Stock, 1986). However, significantly lower burning is observed in the TOR and WEL records, which both lack a sustained increases in charcoal values during the late Holocene, suggesting that people may have a minor influence on burning patterns of the central high dunes (TOR) and northern (WEL) parts of the island during this time. For North Stradbroke Island, it is apparent that climate plays a key role in burning across the region, but humans, if present, can substantially influence local fire regimes.*
>
> *One factor that has consistently modified the three records is European settlement on the island. At the top of all three records, there is a clear change from Casuarinaceae to eucalypt, heath and grass taxa, which reflect alterations in fire regimes associated with European land management that has profoundly impacted the community dynamics of the island. Mooney et al. (2011) observe similar patterns across the Australian continent and suggest that European settlement has greatly influenced fire regimes and vegetation patterns on a continental scale.*

Stewart (2017) assessed charcoal in sediments over the past 25,000 years in a fen at Moon Point on the west coast of Fraser Island, finding there was a decline in rainforest associated with fire peaks from 25,000 to 19,000 years BP which he attributed as a response to the dryer climates of the Last Glacial Maximum period. There is then limited fire activity until around 13,000- 7,600 cal. years BP where there were occasional fires, before again becoming extremely rare until around 5,400 cal. years BP. After then fires again became more frequent and intense, culminating in a *"substantial increase (peak) in micro charcoal concentrations observed at approximately 1850 to 1930 AD"*. After then charcoal decreases "*which may correspond to a fire exclusion policy for the island*".

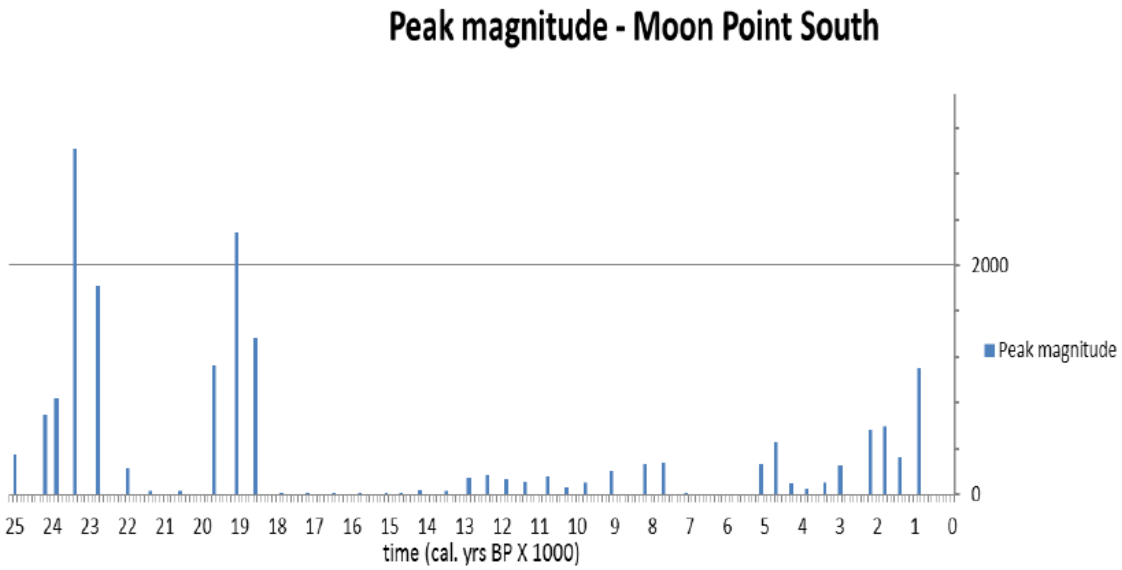
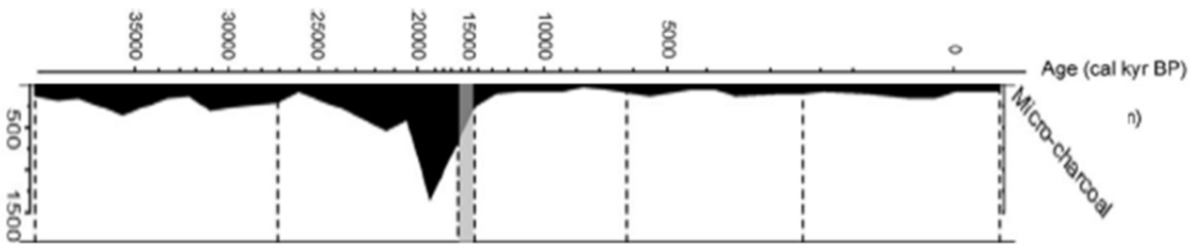


Figure 4.10 from Stewart (2017): Peak magnitude charcoal showing fire size, severity and proximity for Moon Point South.

From their study of 37,000 years of sediments from Lake McKenzie on Fraser Island, Atahan *et. al.* (2015) concluded:

> *Despite the apparent increase in human occupation of southeast Queensland during the mid-Holocene (Ulm and Hall 1996; Ulm 2011), evidence of human activity in the form of large shifts in fire activity or vegetation composition are absent in the Lake McKenzie record. This contrasts with lake records from parts of North Stradbroke Island where increased burning is detected from the mid-to late-Holocene and is linked with intensified human activity (Moss et al. 2013).*



Adaption of Fig. 5 from Atahan *et. al.* (2015). Micro-charcoal (cm2 g-1) diagram for Lake McKenzie core LM2. Note the lack of any significant peaks in charcoal for the past 15,000 years (cal kyr BP).

1.1.3. Other Forests burning

Charcoal assessments from other forested regions reflect the results from north-east NSW. In north Queensland there was a major expansion of rainforests since the last glacial, with fire frequencies measured in centuries on many sites. In Tasmania Aboriginal fires may have retarded the post-glacial recovery of rainforests. In south-west Australian forests, before European settlement fire frequencies were measured at an average of 80 years, with no fire recorded for over 200 years at some sites, though with significant increases post invasion. In one Tasmanian dry eucalypt forest frequencies were found to average 14 years pre-European, though to have doubled thereafter.

While Aborigines made extensive use of the coastal plain and more open habitats in south-west Australia, their use of forests was more limited, reflected in an apparently low fire frequency. From fire scars on Jarrah, Burrows *et. al.* (1995) found the mean fire interval to be 81.6 (13-166) years pre-European, increasing significantly after European invasion. For Karri, Rayner (1992) identified rare fire events before European settlement, some sites with no evident fire for over two hundred years, with dramatic increases thereafter.

In north Queensland's wet tropics climate is primarily responsible for vegetation change since the last glacial period. Kershaw *et. al.* (1993) identified the major change between 150 and 100 thousand years ago as the replacement of dry rainforest with eucalypt forest, which was attributed to more regular burning, though this was long before the arrival of people. A number of pollen and charcoal studies on the Atherton Tablelands show that since the last glacial maximum the transition from sclerophyll woodland to rainforest began as early as 11,500 years ago, took from 400 to 1000 years to complete and was regionally concluded by 7000 years ago (i.e. Haberle 2005). From 4,000 years ago Haberle (2005) identifies the "*appearance for major infrequent (every 250–1000 yr) peaks of charcoal*", which is reflected in other studies. Aboriginal populations were considered to be low, until significantly increasing from 2,500 to 1,500 years ago. Aboriginal burning does not seem to have had a significant effect on vegetation or fires, though the arrival of Europeans resulted in a significant increase.

In Tasmania Aboriginal burning is attributed with stopping the expansion of rainforest since the last glacial period on some sites, creating open moorland in its stead, At a dry sclerophyll site, Von Platen *et. al.* (2011) found averaged pre-European fire frequencies of 14 years, with this doubling since European settlement.

From an assessment of ecological attributes of Victorian Mountain Ash forests, McCarthy *et. al.* (1999) concluded:

> *The mean interval between tree-killing fires in mountain ash (*Eucalyptus regnans *F. Muell.) forest was inferred from information on the age structure of unlogged forest, the prevalence of mountain ash trees in the landscape, and on the abundance of live and dead hollow-bearing trees. ... The results of the analyses suggested that the mean interval between tree-killing fires was between ≈75 and 150 years in mountain ash forest. Data on mortality of mountain ash trees suggest that approximately half the trees survive fire, making the mean interval between all fires equal to 37–75 years.*

1.1.3.1. Western Australian Forests

Examples of fire frequencies in Western Australian forests show that it is unlikely that they were managed by 'firestick farming' with a high fire frequency. While Aborigines made extensive use of the coastal plain and more open habitats, few people or signs of occupation were reported by early explorers from the inland regions in the central and southern forest of the Darling Range, indicating that the forest areas were little used by man (i.e. Hassell and Dodson 2002). This is reflected in the apparently low fire frequency.

From fire scars on Jarrah, Burrows *et. al.* (1995) found the mean fire interval to be 81.6 (13-166) years pre-European, increasing significantly after European invasion. For Karri, Rayner (1992) identified rare fire events before European settlement, some sites with no evident fire for over two hundred years, with dramatic increases thereafter.

From their review of fires in south-west Australia Hassell and Dodson (2002) consider:

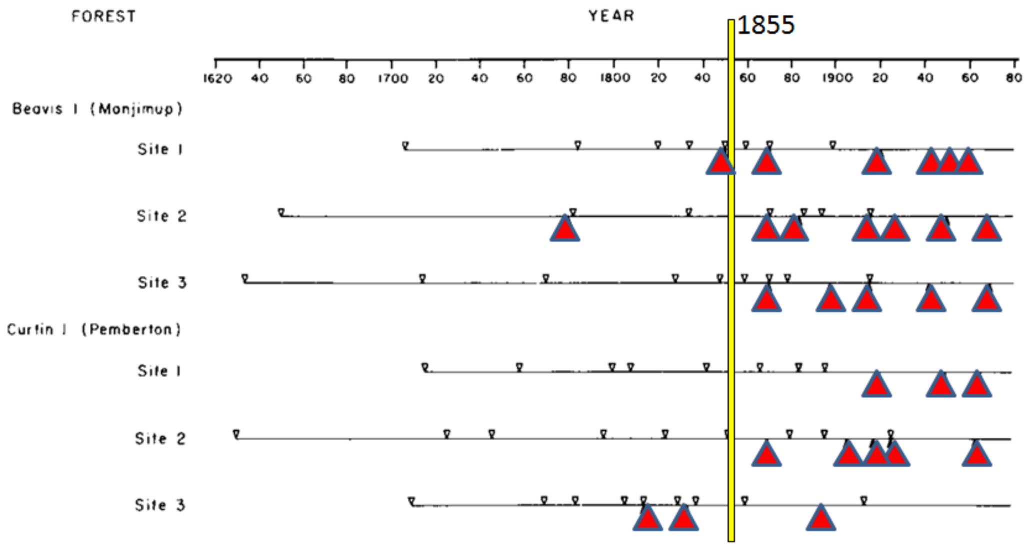
> *In areas fully occupied by Aboriginals, fire intervals appeared much shorter than in those areas not generally occupied or used as a food source, and many intervals in occupied areas were in the range of one to 10 yrs. In contrast, off-shore islands and southern forest*

regions of south-west WA little used by Aboriginals had major fires at much longer intervals. Similarly, analysis of core charcoal from a south coast estuary in semi-arid Fitzgerald River National Park, most of which was not occupied by Aboriginals in historic times, indicates intervals between major fires were in the range of 30 to 100+ yrs.

River valleys and well watered areas on the edge of the forest country on the Darling Scarp were used at least seasonally. The drier country east of the northern Jarrah forest ... and that east and north-east of the Jarrah-Karri forest in the south ...was also occupied by resident groups, but the central section of the Jarrah forest south of Perth to the wetter south coast was little used and little burnt.

When trees are burnt by fires of sufficient intensity the trunk is damaged, leaving scars that (in temperate regions) can be dated by counting tree rings and comparisons with known fire events. The longevity of eucalypts allows fire histories to be identified across hundreds of years, spanning both pre and post the European invasion.

As part of a larger project Rayner (1992) estimated fire frequency in south-western Australia derived from fire scars and tree-rings identifiable on Karri tree stumps. Their results showed that fires of sufficient intensity to cause damage to tree butts were extremely rare prior to European settlement in 1855, and that their frequency increased dramatically thereafter.



Karri fire events, adapted from Fig 4 of Rayner (1992), fire events have been highlighted as ▲
Chronology of tree establishment (Δ) and fire event (▼) years for six sites in virgin old-growth karri forest. Dates for each site are approximate (determined solely from ring counts) and represented an aggregation of 35 trees from a nominal 5 ha area. Within each forest, the stands were located 1-3 km apart.

Rayner (1992) considered:

... the almost complete absence of fire scars recorded pre-1850 at each site is difficult to interpret. Given the rate of fuel accumulation recorded in old-growth karri stands ... and the periodic occurrence of lightning strikes during summer thunderstorms within these forests ... it would seem highly unlikely that fire-free periods of up to 220 years (Beavis 1 Site 3, Curtin 1 Site 2) would have actually occurred. ...

...The most probable reason, however, is that frequent, low intensity fires occurred which did not cause scarring above stump height. ...

Another example of fire frequency in south-western Australian forests pre and post Europeans is provided by Burrows *et. al.* (1995) estimates of fire frequency from Jarrah tree stumps. They estimated that prior to Europeans (1855) the mean interval between moderate to high intensity fires which caused bole injury was 81.6 (13-166) years. From 1855-1920 the mean interval decreased to 22.3 years, from 1920-1965 it decreased again to 13.4 years, and from 1965-1989 increased slightly to 16.6 years.

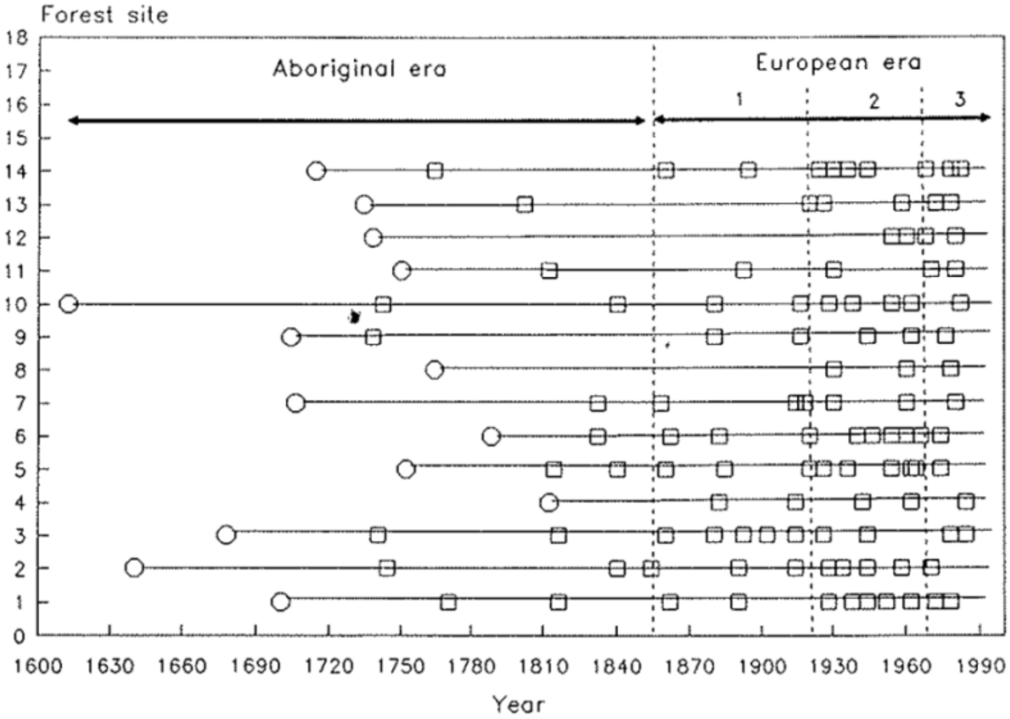


Figure 4 from Burrows *et. al.* (1995) chronology of fire injuries for jarrah forest sites compiled from stem fire scars.

As with Rayner (1992), Burrows *et. al.* (1995) then hypothesise that the pre-European low frequency of tree damaging fires is "*probably as a result of a fire regime of mostly frequent, low intensity fires with an occasional high intensity fires*". They rationalise that that this would have required a fire frequency of 2-6 years to avoid trunk damage.

Burrows *et. al.* (1995) justify their assumptions on the basis that Jarrah trees have relatively thick bark. though as identified by Rayner (1992) "*Karri has thinner bark than jarrah and is therefore more susceptible to thermal damage at an equivalent level of fire intensity (McCaw 1986). Table 4, for example, suggests that fuel reduction burns undertaken in Beavis 1 during 1961 and 1969 were of sufficient intensity to induce fire scars in some trees.*

Based on the evidence of low occupation of the south-west forests it seems highly unlikely that the Aborigines would (or could) have practiced mosaic burning across the forests on the 2-6 year (or less) frequency required to avoid trunk damage, so it is most likely that the forests were subject to infrequent burning.

1.1.3.2. Tasmanian Forests

From their study of pollen and charcoal from a variety of studies in western Tasmania, Fletcher and Thomas (2010) concluded that unlike in previous interglacial periods "*the distribution of vegetation types in western Tasmania has remained remarkably stable through the post-glacial period*", noting:

> *The arrival of humans in Tasmania during the Last Glacial Stage provided an ignition source that was independent of climate, and burning by humans through the Late Glacial period deflected vegetation development and facilitated the establishment of open moorland in regions occupied by rain forest during previous interglacial periods. It is concluded that the present dominance of the landscape of western Tasmania by open moorland is the direct result of human activity during the Late Glacial and that this region represents an ancient cultural landscape.*

In Tasmanian dry sclerophyll forests fire scars from a range of species revealed a relatively high fire frequency. Von Platen *et. al.* (2011) used fire scars to assess fire frequencies, finding that under Aboriginal management from 1740 to 1819 decadal fire frequency averaged 0.7 (i.e. 14 years), with this progressively increasing since the 1850s to 1.3-1.7 fires a decade between 1910 to 1989.

1.1.3.3. North Queensland Forests

Another example of human's pre-historical interactions with forests is provided by rainforest fluctuations in the wet-tropics of North Queensland. The vegetation history of the wet tropics over the Pleistocene is characterized by the expansion of rainforests during warm and wet interglacial periods and their contraction to refugia during cool and dry glacial periods. In the current climate there are a variety of variables affecting rainforest distribution, though in general sclerophyll communities replace rainforest in areas that receive an average annual rainfall less than 1500 mm (Moss *et. al.* 2012). Changing climates have been responsible for most vegetation change. From before people arrived fire has been a major agent of change.

From pollen and charcoal samples off the present day Queensland coast, Kershaw *et. al.* (1993) identified the major change over the past 1.5 million years as the replacement of dry rainforest with eucalypt forest between 150 and 100 thousand years ago, noting:

> *... the dramatic decline in Araucaria and increases in Myrtaceae and Poaceae indicate the regional replacement of drier araucarian rainforest by open sclerophyll vegetation and probably, more specifically, eucalypt woodland. The sharp increase in charcoal at this change, followed by the maintenance of relatively high values, strongly suggests that an increase in burning was responsible for the change*

They considered this "*may relate to an increase in burning caused by the activities of Aboriginal people*". More recent genetic work does not support such an early date for Aboriginal arrival, though this case highlights how climatic induced vegetation change can be confused with human influence.

The archaeological evidence is that people occupied the Wet Tropics for at least the past 40,000 to 30,000 years, though at a very low density until around 2,500 years ago, "*peaking after 1500 cal BP, when the exploitation of toxic nut varieties and the development of permanent occupation in the rainforests of this region occurred*" (Moss *et. al.* 2012).

On the Atherton Tablelands, Turney *et. al.* (2001) identified the virtually complete replacement of gymnosperm dominated dry rainforest by sclerophyll vegetation at Lynch’s Crater due to an increase in fire frequency 45,000 years ago, which they attributed to Aboriginal burning. Though the influence of climate change was likely a major contributor. During the last glacial period rainfall and temperatures were significantly lower than in recent times and appear to have been the dominant factors in maintenance of a sclerophyll woodland community dominated by fire sensitive Casuarinas (i.e. Haberle 2005).

A number of pollen and charcoal studies on the Atherton Tablelands show that since the last glacial maximum the transition from sclerophyll woodland to rainforest began as early as 11,500 years ago, took from 400 to 1000 years to complete and was regionally concluded by 7000 years ago (i.e. Haberle 2005). Since then there have still been changes due to climatic variations, and possibly human activities, with a fire frequency recorded at one site of 230 years or so.

At Lake Euramoo, Haberle (2005) found that the transition from sclerophyll woodland to rainforest dominance occurred over 900 years from 9600 and 8700 cal yr B.P. "*despite the persistent recurrence of fires that appear to have maintained local patches of sclerophyll woodland and may have retarded the encroachment of rainforest onto the site*", commenting:

> *The apparent contradiction that the most intensive fire period occurs during the phase of most rapid increase in fire sensitive rainforest suggests that fire may have become decoupled from the natural climate regime and was at least partially controlled by aboriginal fire practices. The motivation for maintaining open sclerophyll woodlands in an ever encroaching rainforest landscape may have stemmed from the need to maintain open habitats that were so prevalent during the late glacial period for hunting, mobility and to exploit woodland plant diversity for food procurement*

From 4,000 years ago Haberle (2005) identifies the "*appearance for major infrequent (every 250–1000 yr) peaks of charcoal*" which he considers "*may be a response to the intensification of El Nino-related climate variability and/or increased human activity within north Queensland tropical rainforest*".

This is reinforced by findings from two other craters (Haberle *et. al.* 2010) where significant increases in fire frequency and charcoal occurred at the time of transition to rainforest around 8,000 years ago, which is attributed to:

> *Increasing plant biomass produced greater quantities of charcoal as rainforest species invaded Eucalyptus (particularly E. intermedia comp.) woodland and thus high fire-event frequencies, typical of the fire prone wet sclerophyll forests of today, occurred.*

As at Lake Euramoo, fire persisted in the rainforest thereafter, fluctuating between 2-5 events per thousand years.

From sediments in Witherspoon Swamp Moss *et. al.* (2012) assessed changes over the past 8,000 years in a eucalypt woodland adjoining the Wet Tropics' rainforests, finding "*the pollen and charcoal record does not provide any clear evidence of Aboriginal impacts on the surrounding landscape through anthropogenic burning*". Moss *et. al.* (2012) note "*There are slight peaks in charcoal in the Witherspoon Swamp records at ca. 2000 cal BP that may reflect increased human impacts, but as suggested by Haberle and David (2004), it is extremely difficult to disentangle the relative roles of human impact and climate in landscape change for the humid tropics region*".

Settlement of tropical Queensland by non-Aboriginal people began only after 1860. Hill *et. al.* (2000) note the first European known to have traversed Kuku-Yalanji traditional lands in the wet tropics recorded no vegetation fires during the 30 days spent in the country in 1872. Hill *et. al.* (2000) do identify a number of early contacts where Aborigines used fire as a weapon against invaders.

At Lake Euramoo, Haberle (2005) found the most recognisable human influence is since European settlement, with *"Degraded sub-montane rainforest with increasing influence of invasive species and fire".* At Witherspoon Swamp, Moss *et. al.* (2012) found an increase in sclerophyll trees, decreased grasses and decreased burning since European settlement.

2. Logging Effects on Burning

Logging makes forests more vulnerable to wildfires and increases their flammability by drying them, increasing fuel loads, promoting more flammable species, and changing forest structure. This includes increasing the risks of canopy fires by reducing canopy height, increasing tree density and increasing fuel connectivity from the ground into the canopy.

Logging of native forests has to stop to reduce their increasing flammability, and to allow them to recover their natural structure and inherent resilience to burning.

Lindenmayer *et. al.* (2009) note:

> *Logging can alter key attributes of forests by changing microclimates, stand structure and species composition, fuel characteristics, the prevalence of ignition points, and patterns of landscape cover. These changes may make some kinds of forests more prone to increased probability of ignition and increased fire severity*

Conversion of natural multi-aged forests to predominately regrowth increases their vulnerability to burning by:

- increasing transpiration and loss of available soil moisture (Vertessy *et. al.* 1998)
- reducing canopy density, changing the microclimate and causing drying of understorey vegetation and the forest floor (Lindenmayer *et. al.* 2009)
- changing forest structure by creating a more horizontally and vertically continuous fuel layer - increasing shrub cover, increasing stocking densities, reducing inter crown spacing, reducing canopy base-height (Gill and Zylstra 2005, Lindenmayer *et. al.* 2009, Cohn *et. al.* 2011, Taylor *et. al.* 2014, Zylstra 2018, Cawson *et. al* 2018)
- natural self-thinning of post-fire regrowth creating large amounts of fine fuels from suppressed plants in the early stages of regrowth (Taylor *et. al.* 2014, Zylstra 2018),
- changing the understorey vegetation composition by opening the canopy and increasing disturbance adapted species (Gill and Zylstra 2005, Lindenmayer *et. al.* 2009, Zylstra 2018, Cawson *et. al* 2018)
- spreading lantana and increasing understorey flammability (Fensham 1994, Gill and Zylstra 2005, Murray *et. al.* 2013)
- logging slash fuelling fires (Lindenmayer *et. al.* 2009)

Forest canopies create their own microclimate by moderating temperature extremes and enhancing humidity. Davis *et. al.* (2019) found "*microclimate buffering was most strongly related to canopy cover*", while Kovács *et. al.* (2017) found "*The midstory and the shrub layer play key roles in maintaining the special microclimate of forests with continuous canopy-cover*".

Logging changes the structure of forests and thus increases ground temperatures and reduces humidity (Brosofske *et. al.* 1997, Chen *et. al.* 1999, Dan Moore *et. al.* 2005,), as identified by Chen *et. al.* (1999) "*Patches that have been recently disturbed by human-induced or natural processes tend to have higher daytime shortwave radiation, temperature, and wind speed than undisturbed patches; in addition, these variables show greater spatial and temporal variability*".

From their review of the effects of logging on riparian areas in America, primarily in catchments less than 100 ha in area or streams less than 2 to 3 m wide, Dan Moore *et. al.* (2005) concluded:

Forest harvesting can increase solar radiation in the riparian zone as well as wind speed and exposure to air advected from clearings, typically causing increases in summertime air, soil, and stream temperatures and decreases in relative humidity.

They identify "*the magnitude of harvesting related changes in riparian microclimate will depend on the width of riparian buffers and how far edge effects extend into the buffer*", citing a variety of studies which show "*that much of the change in microclimate takes place within about one tree height (15 to 60 m) of the edge. Solar radiation, wind speed, and soil temperature adjust to interior forest conditions more rapidly than do air temperature and relative humidity*".

Stand age has a significant effect on hydrological processes in forests, with regrowth significantly increasing transpiration and rainfall interception by canopy trees, which in turn creates a drier microclimate and increases drying of soil and litter. This in turn influences litter decomposition and the build up of surface fuels.

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.

Rainfall interception is the fraction of gross rainfall caught by the forest canopy and evaporated back to the atmosphere. This is water lost to the understorey and groundwaters, as noted by Vertessy *et. al.* (1998):

rainfall interception rate rises to a peak of 25% at age 30 years, then declines slowly to about 15% by age 235 years. If we assume a mean annual rainfall of 1800mm for the mountain ash forest, stands aged 30 years intercept 190 mm more rainfall than old growth forest aged 240 years.

Evaporation is also greater from soils and litter in regrowth forests.

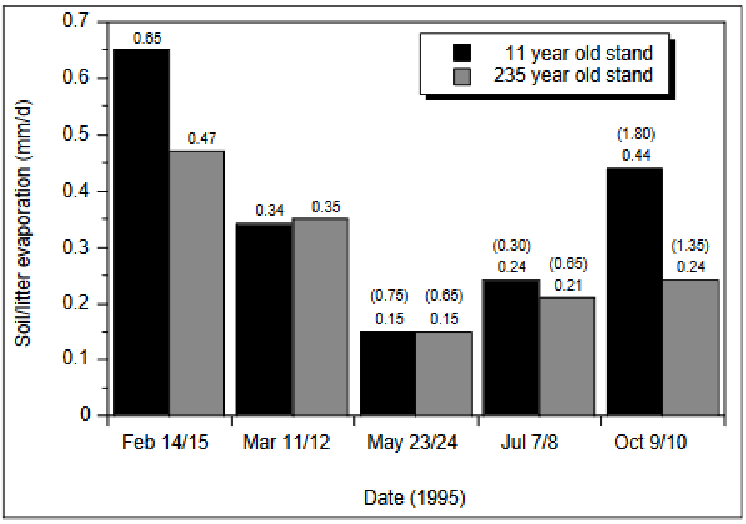
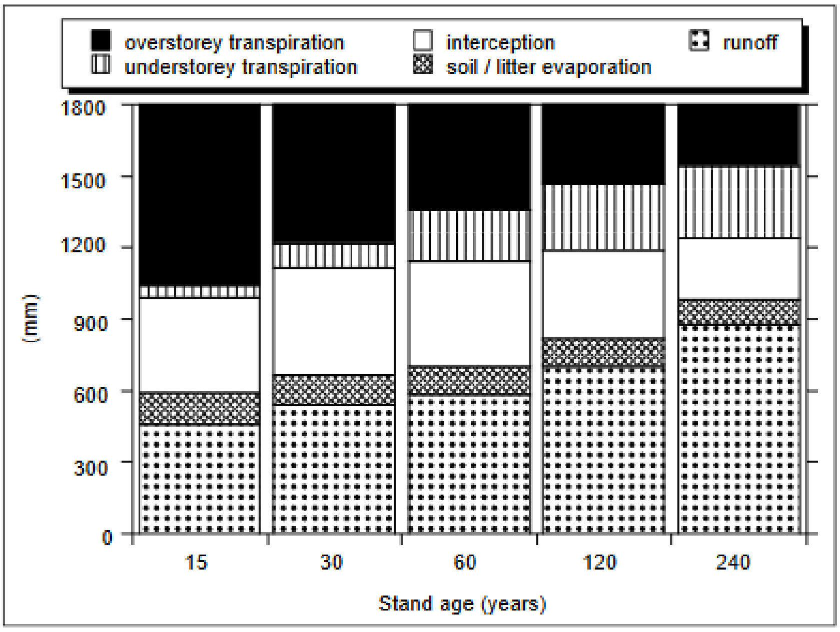


Figure 22 from Vertessy *et. al.* (1998): Comparison of soil/litter evaporation estimates beneath 11 and 235 year old mountain ash forest stands.

Reduction of oldgrowth forests to regrowth thus clearly dries out the forest and thereby increases the flammability of leaf litter.



Water balance for Mountain Ash forest stands of various ages, assuming annual rainfall of 1800 mm (Figure 24 from Vertessy et. al. 1998)

The reduced water yields particularly affect riparian areas and the availability of free water.

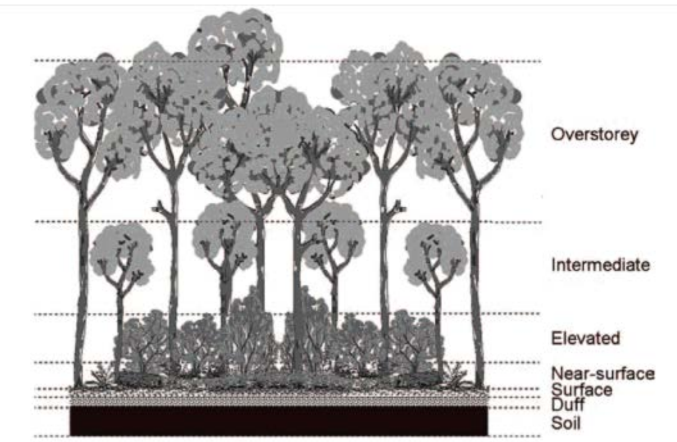


Figure 3.6 from Sullivan *et. al.* (2012) showing categories of forest fuel strata.

Flammability of surface fuels in forests is influenced by their nature and structure, though moisture content of living and dead fuels is the most fundamental constraint on biomass flammability. Forests which have denser canopies result in microclimates characterized by higher humidity, lower wind velocities, cooler temperatures, reduced evaporation and hence reduced fire risk compared to more open-canopied forests. From their comparisons of temperate rainforests and eucalypt forests, Clarke *et. al.* (2014) found "*there was no evidence of higher flammability of litter fuels or leaves from frequently burnt eucalypt forests compared with infrequently burnt rainforests*", concluding "*the manifest pyrogenicity of eucalypt forests is not due to natural selection for more flammable foliage, but better explained by differences in crown openness and associated microclimatic differences*".

Lindenmayer *et. al* (2009) observe "*logging in some moist forests in southeastern Australia has shifted the vegetation composition toward one more characteristic of drier forests that tend to be more fire prone*".

Forests can be separated into strata, with the surface fuels being primarily responsible for most of the fuel consumed and energy released by a fire, though it is the tall shrubs and regenerating trees of the elevated fuel layer that "*has a major influence on flame dimensions, particularly flame height*" and the development of crown fires (Sullivan *et. al.* 2012).

As forests age the gap between canopy and understorey plants and fuels develops, reducing stand flammability and the risk of canopy fires (Cohn *et. al.* 2011, Taylor *et. al.* 2014, Zylstra 2018). As identified by Zylstra (2018) eucalypt forests have evolved the ability to create mature environments that suppress the spread of fire. It is logical that as logging removes mature trees and promotes regrowth that it increases connectivity with ground fuels and therefore the risk of crown fires, though there is strong opposition to any suggestion that such fundamental changes in forest structure can influence crown fires (i.e. Attiwill *et. al.* 2014).

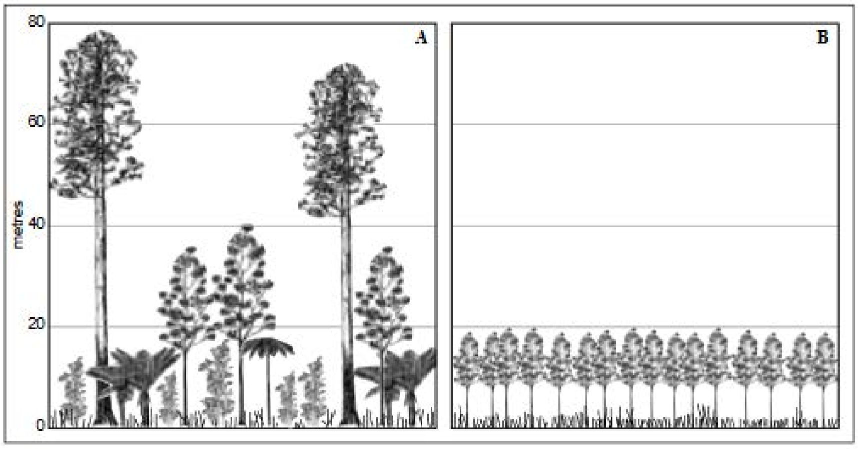


Figure 9 from Vertessy *et. al. 1998*: Comparison of forest structure in (A) old growth and (B) regrowth mountain ash stands. It beggars belief the anybody could deny that the reduced canopy height and increased canopy continuity in a drier regrowth forest is likely to result in increased crown fires.

From their studies of the 2009 Victorian fires Price and Bradstock (2012) concluded "*Probability of crown fires was higher in recently logged areas than in areas logged decades before*"

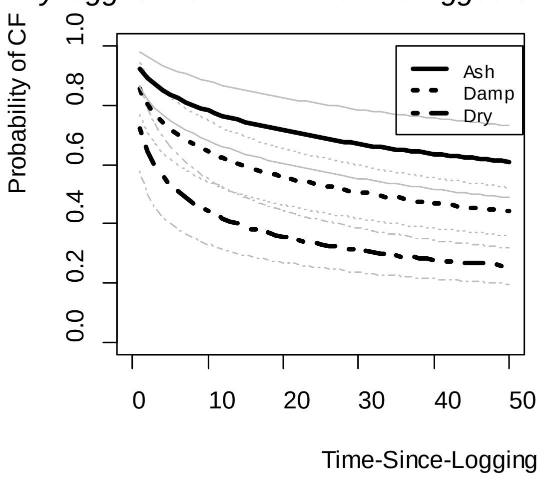
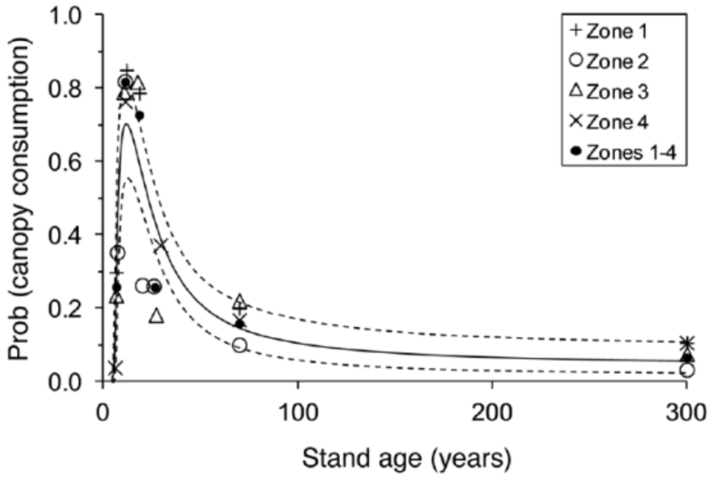


Figure 1 from Price & Bradstock (2012): Model predictions for crown fire (CF) against time-since-logging and forest type using the best model. In all cases, the models are for fire

weather Moderate, slope = 0, topographic position = 50%, time-since-fire = 25 years, and aspect = East. Confidence limits for predictions for each forest type are shown.

Taylor *et. al.* (2014) assessed the impact of Victoria's 2009 wildfires on Mountain Ash forests, finding "*the probability of canopy consumption increased rapidly with age up to approximately 15 years ... In stands older than 15 years, the probability of canopy consumption decreased with age, such that it rarely occurred in stands aged around 300 years".* They note:

> *... a strong relationship between the age of a Mountain Ash forest and the severity of damage that the forest sustained from the fires under extreme weather conditions. Stands of Mountain Ash trees between the ages of 7 to 36 years mostly sustained canopy consumption and scorching, which are impacts resulting from high-severity fire. High-severity fire leading to canopy consumption almost never occurred in young stands (<7 years) and also was infrequent in older (>40 years) stands of Mountain Ash.*



Probability of canopy consumption versus stand age (Fig 7 from Taylor *et. al.* 2014)

From his study of 58 years of fires in the Australian Alps Zylstra (2018) found that "*forests were most likely to experience crown fire during their period of regeneration*", noting:

> *The strongest response was observed in tall, wet forests dominated by Ash-type eucalypts, where, despite a short period of low flammability following fire, post-disturbance stands have been more than eight times as likely to burn than have mature stands. The weakest feedbacks occurred in open forest, although post-disturbance forests were still 1.5 times as likely to burn as mature forests.*

After logging the large quantities of tree crowns, crushed plants and reject logs make the forest more vulnerable to burning, as noted by Lindenmayer *et. al.* (2009):

> *Large quantities of logging slash created by harvesting operations can sustain fires for longer than fuels in unlogged forest and also harbor fires when conditions are not suitable to facilitate flaming combustion or the spread of fire*

For Jarrah forests, Burrows *et. al.* (1995) identify that the severity of wildfires and damage to retained trees has increased since pre-European times which "*can be attributed largely to logging debris which ignites during summer wildfires*".

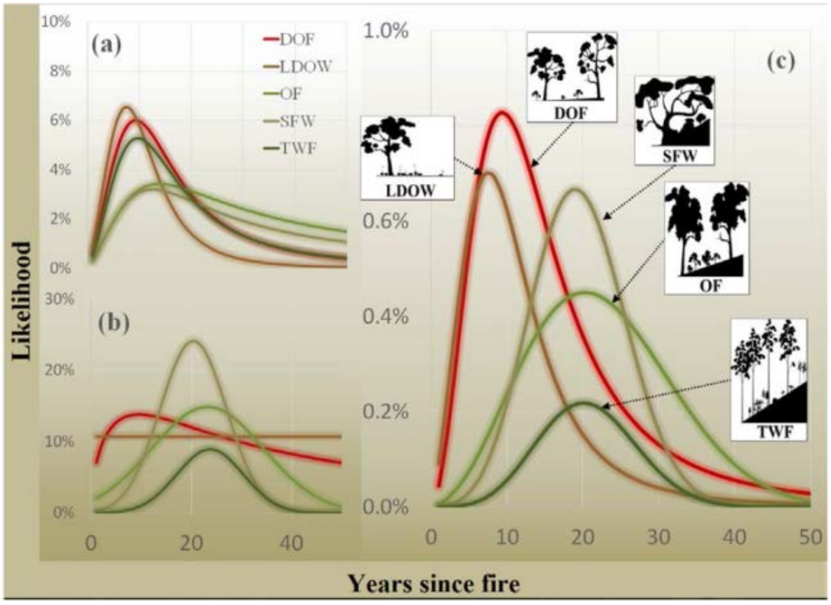


Figure 5 from Zylstra (2018). Flammability trends for each formation, where the *x*-axis gives years since the last fire, and the *y*-axis gives likelihood for (a) fire burning a point (L_f), (b) crown fire occurring if that point is burning (L_{cb}); and (c) crown fire occurring at any point (L_c). Labels refer to dry, open forest (DOF), low, dry open woodland (LDOW), open forest (OF), subalpine forest and woodland (SFW), tall, wet forest (TWF).

In the longer term weed invasion can also make the forest more vulnerable to burning. Lantana (*L. camara)* is the most widespread and successful weed throughout north-east NSW, benefitting from logging and other activities that open the forest canopy enough for it to thrive. Lantana now dominates the understorey in tens of thousands of hectares of northeast NSW"s forests. Fire and cattle grazing are significant contributors to the successful invasion of lantana (Gentle and Duggin 1997), and it in turn can increase the flammability of vegetation (Fensham *et. al*. 1994, Gill and Zylstra 2005, Berry *et. al* 2011, Murray *et. al.* 2013, Bowman *et. al.* 2014). Of the 79 species from dry sclerophyll forests tested by Murray *et. al.* (2013), lantana had the third shortest mean time to ignition for fresh leaves.

From their study of the Forty Mile Scrub National Park, Fensham *et. al*. (1994) found "*the proliferation of lantana results in the build up of heavy fuel loads across the boundary of dry rainforest and savanna woodland. Recent fires have killed the canopy trees in a large area of dry rainforest within the Park*". From their study of dry rainforests, Berry *et. al* (2011) concluded that *L camara* was less ignitable than native dry rainforest species, though:

> *Fuel bed depths, leaf litter depths, percentage cover by fuels and amount of medium size class fuels were higher in dry rainforest invaded by* L.camara *than in noninvaded forests. This suggests that the mechanism by which* L.camara *alters the fire regime in dry rainforest is by shifting the distribution of available fuels closer to the ground and providing a more continuous fuel layer in the understory*

The increasing dominance of forest understoreys by lantana in north-east NSW due to logging (see section 4.2.2) significantly increases forest's flammability and the wildfire threat.

Logging of native forests has to stop to reduce their increasing flammability, and to allow them to recover their natural resilience to burning.

3. Grazing effects on Blazing

The argument used to justify grazing of conservation reserves is that it reduces fuel loads and thus the risk of wildfires, though there is little evidence to justify this claim, while there is abundant evidence that by changing the species composition and structure of forest understories, changing fauna populations, and hindering overstorey regeneration, grazing has significant environmental impacts. There is evidence that the vegetation changes caused by grazing can increase wildfire risk and intensity in some ecosystems. Too frequent burning associated with graziers use of fire to promote green pick is compounding impacts.

The vegetation changes and environmental impacts of grazing on natural ecosystems and a plethora of species is profound, and its benefits in reducing fire frequency equivocal, as such it must remain excluded from national parks and other public lands where it is currently prohibited. The option of using fuel reduction burning may be preferable where strategically required.

The principal environmental impacts of livestock have been found to be:

- changing the structure and species composition of ground cover and understorey vegetation;
- promoting the invasion of exotic plant species;
- reducing regeneration of overstorey trees and increasing the mortality of remaining trees;
- causing reductions in populations of a broad range of mammals, birds, reptiles, amphibians, fish and invertebrates through habitat degradation;
- compacting, degrading and baring soils;
- increasing runoff and erosion, and the transportation of sediments and nutrients (i.e. N and P) into streams from soils and excrement*;*
- destabilising and eroding stream banks, and changing the morphology and flow regimes of streams;
- affecting human health through the depositing of faeces and urine in and near streams which can cause contamination by a range of viruses, bacteria and parasitic protozoa; and
- significantly impacting on water quality and stream biota by increasing turbidity and nutrients.

The severity of impacts are strongly correlated with grazing intensity, the period that grazing has been undertaken for, and the use of fire to manage grazing areas. Impacts may be compounded by other changes, particularly to fire and flood regimes. Many impacts are magnified by climatic extremes such as drought or high rainfall.

The Resource Assessment Commission's (1992a) Forest and Timber Inquiry concluded:

> *Cattle grazing can affect the diversity of native plant and animal species through its potential to permanently change the structure and composition of forest ground cover and understorey vegetation. Permanent change can lead to declines in the abundance of those species dependent on pre-disturbance conditions. Grazing has been implicated in the regional extinction of several small ground mammals in forested areas...*
>
> ...
>
> *Given the evidence for serious impacts on the forest environment from grazing of domestic stock and the inherent difficulties of enforcing codes, forest management agencies should review whether the marginal benefits are worth the environmental risks.*

Burrows (2000) considers:

> *It should not be surprising that the introduction and widespread use of a large, hoofed herbivore and the imposition of a new management regime from that of pre-European times would cause alterations to the landscape. Historically, Australia has never supported such*

numbers of such large herbivores. Grazing affects the species composition of plants in three ways – 1). Through selection by cattle of favoured food or against specific species 2) differential susceptibility of plant species to grazing 3) physical damage to plants. Changes in plant species composition then affect most, if not all, animal species in the area. In some cases, altered land management regimes have resulted in major conversions of vegetation communities. This may include woodlands becoming grasslands or increasing dominance of eucalypt woodlands.

Wardell-Johnson *et. al.* (2011) observe:

> *The impacts on rangelands of deforestation, overgrazing, introduced fauna and flora, and altered fire regimes result in a net carbon emission (e.g., Walker and Steffen 1993; Radford et al. 2007) and decreased biodiversity (e.g., Williams and Price 2010).*

Lunt (2005) concluded:

> *Given the negative effects of historical stock grazing in Australia, stock are often removed from newly declared conservation reserves, for good ecological reasons. Indeed there appears to be little if any ecological basis for maintaining stock grazing in many Australian ecosystems, such as heathlands, shrubby mountain forests, many semi-arid ecosystems and alpine grasslands.*

There is a common claim that by reducing understorey vegetation that grazing can reduce the severity of wildfires, which is likely to be true to some extent in some cases, though is certainly not always true. There is evidence that in some cases grazing and burning can alter vegetation to variously promote shrubs, grasses, and/or weeds, making the vegetation more flammable and increasing the severity of wildfires.

As noted by Bennett and Cassells (1989):

> *Traditional fire management strategies are based on entrenched and sometimes very inflexible management concepts (Good 1988, 11). Good states further that there is considerable pressure, through what he termed "pyre-politics", to maintain the status quo in fire management. In the Apsley - Macleay Gorges this would imply the continuation of regular and widespread burning during specific periods of the year.*
>
> *Current problems include: frequent burning; burning during hazardous conditions; and the escape of fires from specified areas.*

For the north-east NSW Comprehensive Regional Assessment (CRA) the environmental impacts of grazing on priority plant species were considered in the expert workshops. The flora expert panel unanimously agreed the main threats to plant biodiversity in northeast New South Wales were land clearing, inappropriate fire regimes, weeds and grazing (Environment Australia 1999). One of their recommendations was:

> *Exclude cattle (and feral grazing generally) from State Forest and National Parks areas or at least limit the area adversely affected by this threatening process.*

3.1. Grazing Impacts on Vegetation

Grazing directly affects native vegetation by changing the structure and composition of ground cover and understorey vegetation (Hobbs and Hopkins 1990, Wilson 1990, Bennet 1990b, RAC 1992a, Fleischner 1994, Pettit *et. al.* 1995, Calvert 2001, Clarke 2003, Lunt 2005, Jansen *et. al.* 2007*)*; assisting the invasion of introduced plants (Smith and Waterhouse 1988, A.N.P.W.S. 1991, Fleischner 1994, Pettit *et. al.* 1995, Gentle and Duggin 1997, Yates *et. al.* 2000, Calvert 2001, Lunt 2005, Jansen *et. al.* 2007*)*; and affecting the regeneration and health of overstorey trees (Saunders 1979, Bennet 1990a*,* Fleischner 1994, Lunt 2005*)*.

Jansen *et. al.* (2007) consider:

> *When stock graze they remove plant parts from ground cover vegetation, shrubs and saplings, and also damage them through trampling. These changes lead to loss of ground cover and biomass of vegetation, and through the loss of grazing-sensitive species, to declines in native plant diversity. Soil compaction due to trampling reduces the macrospore space in soil and this reduces infiltration, root growth and overall plant production (Bohn &Buckhouse 1985).*
>
> *...*
>
> *Stock preferentially graze more palatable plant species, either removing them from a site or reducing them to compact, low tussocks, coppices or rosettes. Plants with different life forms respond to grazing in different ways. Grazing may favour sedges, grasses and other species whose growing point is protected from grazing animals (for example, by being at or below the soil surface and thus able to survive, albeit with reduced vigour) over other life forms. These processes lead to shifts in plant community composition towards species more tolerant of grazing*

As highlighted by Lunt (2005) another "*major way in which grazing animals affect ecosystems is by redistributing nutrients. Grazing animals consume plants over large areas, and deposit nutrient-rich wastes in localised areas. ... Increases to soil nitrogen and phosphorus levels strongly affect plant composition, and promote exotic species over native species ...The combination of selective plant consumption, damage to soils and redistribution of nutrients can have profound impacts on ecosystem processes at large and small scales".*

The impacts of cattle grazing on understorey vegetation is variable depending on the species and grazing intensity, though in general it results in a decrease in the most palatable native species, and an increased abundance in exotic species and unpalatable plants (Smith and Waterhouse 1988, Hobbs and Hopkins 1990, Wilson 1990, Bennet 1990b, , A.N.P.W.S. 1991, RAC 1992a, Wahren *et. al.* 1994, Fleischner 1994, Pettit *et. al.* 1995, Gentle and Duggin 1997, Yates *et. al.* 2000, Pettit and Froend 2001, Calvert 2001, Clarke 2003, McIntyre *et. al.* 2003, Lunt 2005, Spooner and Briggs 2008, Dorrough 2012, Lunt *et. al.* 2012). Lunt (2005) provides an example: "*The importance of grazing selectivity is apparent where pastures have become dominated by unpalatable dominant grasses, such as Nassella trichotoma (Serrated Tussock). Continued grazing pressure in such paddocks further reduces associated species, which are more palatable and nutritious than Nassella (Campbell 1998).*"

Grazing pressure is also variable across the landscape, obviously being concentrated near water sources, though cattle can also closely crop patches that they persistently seek out to selectively graze, resulting in higher grazing pressure than other parts of the pasture (i.e. McIntyre *et. al*. 2003).

From their study of subtropical grassy eucalypt woodland in south-east Queensland, McIntyre *et. al*. (2003) categorised plants according to their tolerance to grazing, identifying 47 species (41 natives) as grazing decreasers "*that are associated with ungrazed, undisturbed habitats and that are sensitive to even minor soil disturbance or commercial cattle grazing"*, with a further 12 species (9 natives) intolerant to high grazing intensity. A total of 36 species were identified as grazing increasers (20 natives), with another 13 species (7 natives) identified as intolerant of low grazing (i.e. found on moderate and high grazing sites). It needs to be considered that only 4% of their study area was considered largely undisturbed in linear road reserves, so it is likely that many “grazing decreasers” had already been eliminated from the area.

Of the 145 native species that were able to be categorised, 34% were grazing decreasers or intolerant of high grazing regimes, with 19% grazing increasers or intolerant of low grazing regimes. Conversely of the 49 exotic species that were able to be categorised, 45% were grazing increasers or intolerant of low grazing regimes, and 18% were grazing decreasers or intolerant of high grazing regimes.

McIntyre *et. al*. (2003) also found there was a "*tendency for native grazing increasers to become less grazing tolerant in the presence of water enrichment or soil disturbance*".

CATEGORISATION OF PLANTS ACCORDING TO GRAZING IMPACTS (From McIntyre *et. al*. 2003)

Response group	Number of species	Number native species	% exotic species
Grazing increaser	36	20	44
Low grazing intolerant	13	7	46
Grazing decreaser	47	41	13
High grazing intolerant	12	9	20
Intermediate	21	19	10
Grazing generalist	65	49	25
Unclassifiable	130	86	34
Total	324	231	28

In the semi-arid rangelands of North Queensland. Calvert (2001) found "*palatable, perennial and productive native grasses [were] a strong decreaser, declining with cattle grazing but increasing with intermediate disturbance (macropod grazing)*".

From his study of temperate woodlands Clarke (2003) found *"Abundance and dominance of native shrubs, sub-shrubs, twiners and geophytes were strongly associated with areas of less-intense pastoralism on low-nutrient soils. The strongest effects on species richness were grazing followed by canopy cover. Continuously grazed sites had lower native species richness across all growth forms except native grasses".*

In south-west Australian woodlands Pettit *et. al.* (1995) found "*Native perennial shrubs and herbs have suffered the most significant loss of species and cover in grazed remnants, and are usually the life form groups which make up the greatest proportion of the understorey species*", and *"Of the different reproductive strategies of perennial species, the resprouters seem to be the most susceptible to grazing pressure".*

Pettit and Froend (2001) describe the grazed woodland remnants they studied as *"degraded remnants with an understorey dominated by annual species, especially exotic grasses and forbs from the surrounding improved pastures"*, noting “*This state is maintained by continual heavy grazing by livestock ... Over a long period, this state will eventually change due to the lack of recruitment of overstorey species ...* [to] *one resembling the surrounding pasture community more closely".*

Also in south-west Australian woodlands, Yates et. al. (2000) found *"the mean percentage cover of native perennials in rarely grazed/ungrazed woodland was 9.1% and in heavily grazed woodlands was 3.6%".*

From their long-term study of grazing on the alpine and subalpine vegetation of the Bogong High Plains, Wahren *et. al.* (1994) found :

> ... *species palatable to stock decreasing in cover and less palatable species little affected or increasing in cover. ... vegetation change has been slow and domestic cattle have had substantial and lasting impact on both the structure and composition of subalpine grassland and heathland vegetation.*
>
> *...*
>
> *In... grassland plots, established in 1946, cattle grazing has prevented the largescale regeneration of a number of tall, palatable forbs and short, palatable shrubs, while in the absence of grazing, the cover of these life forms increased substantially.*
>
> ...
>
> *Alpine and subalpine vegetation is slow to recover from disturbance, and the rate of recovery is unquestionably slower in areas grazed by cattle. In grassland, continued grazing will reduce the abundance of taller forbs and dwarf, palatable shrubs; some shrubs... may continue to expand.*

In relation to Queensland pastures Pressland (1982) cites research that found "*kangaroo grass is still common in areas exclosed from stock (cemeteries, railway reserves), yet is, or is almost, absent immediately outside these exclosures"*.

From his review of temperate grasslands Dorrough (2012) found "*There can be no doubt that livestock grazing and fertilisation have had great influence on the composition of grassy ecosystems within temperate Australia. Both livestock and fertilisation have contributed to dramatic changes in the composition of vegetation throughout south-eastern Australia"*.

Dorrough (2012) considered grazing impacts were most significant in Mediteranean grasslands and grassy woodlands, while *"the magnitude of effects is by no means consistent across the sub-humid grassy ecosystems of southern Australia"*.

Lunt (2005) summarises research findings for temperate (including New England) grassy ecosystems: *"Thus, despite regional variations, the general effect of increasing grazing intensity in temperate grassy ecosystems in southern Australia has been the replacement of tall, native, long-lived, perennial species by short-statured, short-lived, annual and exotic species. Nevertheless, many grazed native pastures still contain a diverse mix of native species and contribute substantially to regional biodiversity conservation".*

Grazing by domestic livestock can also significantly affect the overstorey of native vegetation. In forests and woodlands grazing can prevent recruitment, and increase mortality, of trees and shrubs, while in some arid areas it can promote unpalatable shrubs which shade out grasslands. The increasing frequency of droughts and heat waves due to climate change is causing an accelerating loss of trees, which is being aggravated by grazing.

The cumulative impacts of long-term cattle grazing and trampling of seedlings directly affect forests and woodlands by reducing regeneration of overstorey trees (Saunders 1979, Bennet 1990a, Fleischner 1994, Pettit *et. al.* 1995, Robertson and Rowling 2000, Jansen and Robertson 2001, Fischer *et. al.* 2004, Commonwealth of Australia 2007, Spooner and Briggs 2008, Fischer *et. al.* 2010, Lindenmayer et. al. 2014).

Fischer *et. al.* (2010) state "*In livestock grazing landscapes, trees are declining because of a combination of natural or accelerated tree mortality coupled with widespread recruitment failure*".

Robertson and Rowling (2000) found "*Seedlings and saplings of the dominant* Eucalyptus *tree species were up to three orders of magnitude more abundant in areas with no stock access".* For their exclusion trials in the Murray catchment Spooner and Briggs (2008) found that eucalypt regeneration significantly increased with the exclusion of cattle.

The ongoing decline of trees in rural areas due to grazing will have a significant impact upon remnant fauna populations (i.e. Martin and McIntyre 2007, Fischer et. al. 2010). From their study of woodlands and farmlands in Australia's temperate agricultural zone Fischer et. al. (2010) conclude:

> *... we predict that by 2100, the number of trees on an average farm will contract to two-thirds of its present level. Statistical habitat models suggest that this tree decline will negatively affect many currently common animal species, with predicted declines in birds and bats of up to 50% by 2100. Declines were predicted for 24 of 32 bird species modelled and for all of six bat species modelled. Widespread declines in trees, birds, and bats may lead to a reduction in economically important ecosystem services such as shade provision for livestock and pest control.... A regime shift is occurring, with a woodland system deteriorating into a treeless pasture system.*
> *...*
> *Predicted declines were most rapid for small insectivorous bird species dependent on woodland patches, such as the rufous whistler Pachycephala rufiventris or striated thornbill Acanthiza lineata ...The decline of small insectivorous woodland birds already is a major concern in Australia ...and our data suggest that ongoing tree decline may be one of the underlying drivers.*

Fischer *et. al.* (2010) conclude

> *Current ecological processes, in particular with respect to tree regeneration and mortality, are unable to sustain the system in its current condition. Ongoing tree decline will cause a cascade of changes through the system. ... we are witnessing how a woodland ecosystem is in the process of degrading into a treeless pasture system.*
> *Controlling variables underlying the regime shift are livestock grazing pressure and nutrient enrichment, both of which inhibit natural tree regeneration.*
> *...Our work strongly supports the practice of livestock exclusion from woodland patches, which is already used by many farmers and has been supported through a range of government programs (36). Tree regeneration is greatly enhanced in ungrazed woodland patches (22), and the continued existence of woodland patches is important for many species of conservation concern, such as small insectivorous birds*

Lindenmayer *et. al.* (2014) identify that recruitment of large old trees can be diminished due to high-intensity grazing or browsing from domestic herbivores, reporting "*within 50–100 years in Australian agricultural landscapes subject to intensive grazing by domestic livestock, tens of millions of large old trees will be lost and not replaced through recruitment".*

3.2. Grazing and frequent fire impacts on vegetation

The principle management tool used by graziers in the forests of north-east NSW is fire (Henderson and Keith 2002, Harris *et. al.* 2003, Bickel and Tasker 2004, Tasker and Bradstock 2006). Most like to burn the forest frequently (often every 1-3 years) to promote fresh green pick for their cattle. For example in escarpment forests *"the prevailing practice was to burn the forest understorey in spring after stock withdrawal, allowing green pick to develop during the wet summer before reintroduction of cattle into the forest"* (Henderson and Keith 2002). Frequent burning compounds and amplifies the impacts of grazing on native plants, native animals, soil structure, runoff, erosion and streams. It also confounds attempts to isolate the impacts of grazing from fire, particularly as both have been used fairly indiscriminately across public lands.

The Forestry Corporation's Management Plans for their Management Areas in north east NSW have long recognised burning as the most destructive agency, "*killing regeneration and damaging individual trees and causing defect and loss of increment"*, with graziers the most common source, for example the 1987 Grafton Management Plan notes:

> *Pastoralists of the Clarence Valley commonly have large areas of forested "hill country" which they use to overwinter their cattle. These areas may be private lands, leasehold, or leases or occupation permits within State Forests. To ensure a good supply of grass for winter the graziers commonly burn these areas on a large scale during spring. Under continuing dry conditions in the absence of following early summer rains these burns may develop into very extensive fires.*

In their study of grazing impacts on forests of the New England Tablelands, Tasker and Bradstock (2006) identify that grazing is typically accompanied by burning at frequent intervals initiated by graziers, finding:

> *Grazing practices had the greatest influence on understorey vegetation complexity of any of the measured attributes. The grazed sites were characterized by a significantly lower vegetation complexity score, different dominant understorey species, reduced or absent shrub layers, and an open, simplified and more grassy understorey structure compared with ungrazed sites. Time since logging and time since wildfire also significantly affected understorey structure. Our results indicate that cattle grazing practices (i.e. grazing and the associated frequent fire regimes) can have major effects on forest structure and composition at a regional level.*

A 1989 study (Bennett and Cassells 1989) of rainforest patches in the Apsley-Macleay Gorges found

> *Fire represents a cheap and effective agricultural management tool (Johnson and Purdie, 1981, 497) to the landholders in and adjacent to the Apsley - Macleay Gorges. It is being used extensively to improve stock forage and to reduce bushfire risks through fuel reduction burning. Burning operations are widespread and are undertaken on a relatively frequent basis (usually every one to five years). It appears, however, that fire frequencies have declined. On the adjoining tableland, the reduction of burning has occurred in response to the expanding area of improved pastures. ... the importance of the gorges as a grazing resource is apparently declining, reducing the use of fire.*

In their study of forests in the recently expanded Guy Fawkes River National Park, Henderson and Keith (2002) used disturbance indicators as an indicator of the intensity of grazing, along with fire mapping, to conclude "*species richness and population densities of woody species were lower where disturbance was more intense. It is concluded that historical grazing and burning practices had substantial impact on the woody understoreys of the north-east escarpment forests"*. They recognise that their results contrast with those of some studies from subalpine and semi-arid habitats, where grazing led to increases in shrub density, which they consider may be related to the use of high frequency fire as a grazing management tool in the escarpment forests, noting "*Woody species that are not susceptible to grazing may therefore be driven to decline by fire related processes in the forests*".

From their assessment of burning responses of taxa in six of the major vegetation formations on the New England Tableland (rainforest, wet sclerophyll forest, dry sclerophyll forest, grassy woodland, rocky outcrops, heath and wet heath), Clarke *et. al.* (2009) found:

> *... across all community types, sequential fire intervals of less than five years are likely to cause local extirpations of fire killed species through adult deaths and exhaustion of either canopy or soil stored seed banks. Relatively large proportions (38%) of species fall into this obligate seeding group, although there are relatively few species of obligate seeding species with canopy held seed banks. Habitats that are particularly vulnerable to short fire intervals are rocky outcrops and the rainforest margins of wet sclerophyll forests with high concentrations of obligate seeders.*
>
> *...*
>
> *Our finer scale analysis of vegetation types shows that the minimum interval to avoid immaturity risk to vulnerable species ranges from 8 to 11 years in fire prone formations in the New England Tableland Bioregion. ... In the Northern Escarpment Wet Sclerophyll Forests,... in areas in which Callitris maclaeyana occurs, a threshold of 25 years is suggested and in where this species is absent a threshold of 11 years is recommended.*
>
> *...*
>
> *For those species that resprout, the consequences of repeated short interval fires are poorly known ... seedling recruitment must occur to maintain current populations. Our study has predictably shown that seedlings of resprouters are slower to mature, but their ability to resprout prior to this maturation remains unknown. Similarly, whilst many rainforest shrubs and trees show ‗tolerance' to a fire event, through vigorous resprouting, it is not known if recurrent fire causes mortality and recruitment failure.*

It is thus unsurprising that there was a decline in shrubs in grazed areas of the New England Tablelands, as reported by Henderson and Keith (2002) and Tasker and Bradstock (2006). It appears that the associated high fire frequency is chiefly responsible for the decline in shrubs in grazed areas. Though it is important to recognise that on drier and less productive sites the grassy eucalypt woodlands can persist in the absence of frequent disturbance, those studied by Knox and Clarke (2004) had fire (and presumably grazing) excluded for more than 30 years and still had a sparse understorey of shrubs and a near-continuous herbaceous layer dominated by the grasses *Poa sieberiana* var. *sieberiana* and *Themeda australis.*

Grazing may significantly increase the mortality of resprouters, Pettit *et. al.* (1995) found "*Of the different reproductive strategies of perennial species, the resprouters seem to be the most susceptible to grazing pressure".* Grazing can thus significantly affect post-fire recovery and species persistence. The impacts of fire and grazing are inter-related, as burnt areas are targeted for grazing, as noted by Cowley *et. al.* (2014) "*The effect of fire on herbage mass and composition was compounded by higher grazing after fires"*.

The effect of fire and grazing on flammability will largely depend on the species present, their flammability and palatability, and how they respond to the combination of these disturbances. In their study of the effects of fire and grazing on a mosaic of mesic forest, xeric woodland and dense tall shrublands in Argentina, Blackhall *et. al.* (2015) found "*the majority of the species studied showed higher fuel flammability at recently burned sites affected by cattle. Domestic livestock, by increasing the flammability of post-fire vegetation, may be key agents in altering fire regimes in forest–shrubland mosaics".*

Blackhall *et. al.* (2015) identify that "*following forest burning, browsing by large herbivores inhibits the post-fire regeneration of tall tree species, but is less limiting for the vigorously resprouting shrubs and small trees ... Thus, herbivory by large mammals in this landscape tends to inhibit post-fire forest recovery and favours the perpetuation of fire-prone shrublands*".

Selective browsing by livestock also causes a drying of the understorey and ground litter by opening-up the shrub and canopy to create a drier microclimate (Bowman *et. al.* 2014, Blackhall *et. al.* 2015).

3.3. Does Grazing reduce Blazing

The potential flammability of vegetation is related primarily to weather conditions, dryness and slope, and secondarily to plant species and dead plant material. Frequent burning, such as that associated with forest grazing, can increase the flammability of vegetation (Floyd 1964, Gill 1975, Noble and Slatyer 1981, Hopkins 1981, McWethy *et. al.* 2013, Zylstra 2013, Paritsis *et. al.* 2013, Blackhall *et. al.* 2015). McWethy *et. al.* (2013) note "*In high productivity/ moisture environments, spatial targeting of ignitions in more flammable, early seral vegetation can initiate feedbacks that increase the amount of flammable vegetation and fire activity across the landscape promoting irreversible change in the vegetation".*

Zylstra (2013) concluded "*if fire is either intentionally introduced to Snowgum forest more frequently or facilitated more often by changes in the climate, there is greater than 95% likelihood that these areas will become more flammable".*

Grazing can accentuate burning impacts and influence the flammability of vegetation by changing the species composition and structure of vegetation, and by promoting more flammable species. Grazing and burning that promotes grasses at the expense of shrubby and mesic understoreys may also increase the flammability of vegetation.

Conversely grazing can reduce flammability by consuming palatable species, reducing fuel loads and the vertical distribution of dead and live fine fuels. Though reducing fire regimes can also have negative consequences, such as promotion of woody vegetation (Sharp and Whittaker 2003) and introduced weeds. Williamson *et. al.* (2014) state "*Large grazing herbivores can change fire regimes by altering fuel types and abundance, particularly in savanna biomes where the dominant fuel is grass. The use of herbivores as a fire management tool is receiving increasing consideration globally, but this intervention has a limited evidence-base and is controversial because of potential deleterious ecological effects"*.

In their study of Northern Territory savanna, Sharp and Whittaker (2003) found that between 1948 and 1993 there had been a dramatic increase in woody vegetation cover. with large areas now covered by scalded soil, dense invasive weed populations, and unpalatable forbs and sedges. They consider the change from a relatively treeless grassy ecosystem is likely to be a direct consequence of extreme overgrazing by cattle (peaking in the mid 70s) transforming much of the herbaceous vegetation to a new state that is not flammable and that in the absence of regular fire mortality, woody vegetation increased rapidly. They concluded "*grazing intensity in excess of a sustainable threshold has forced a transition that is irreversible in the foreseeable future"*. Conversely, in tropical savannas Murphy *et. al.* (2014) consider eucalypts to be chiefly moderated by water availability and "*relatively unresponsive to management-imposed reductions in fire frequency and intensity".*

A focus of the debate about the capacity of cattle grazing to reduce fire hazard has been the Victorian Alps. The claim that Alpine "grazing reduces blazing" has been widely promoted, though the available evidence does not support this contention.

From their long-term study of alpine and subalpine vegetation Wahren *et. al.* (1994) concluded "*Evidence presented here does not support claims that shrub cover in general, and thus the risk of fire, is reduced by cattle"*, and that livestock grazing "*will therefore not reduce the risk of fire in such communities".*

Williams *et.al.* (2006) examined the patterns of burning across 108 km of transect lines in the alpine (treeless) landscapes of the Bogong High Plains in Victoria, following the extensive fires of January 2003, finding:

> *There was no statistically significant difference between grazed and ungrazed areas in the proportion of points burnt. Fire occurrence was determined primarily by vegetation type, with the proportion burnt being 0.87 for closed-heath, 0.59 for open heath, and 0.13 for grassland and all snow-patch herbfield points unburnt. In both closed-heath and open-heath, grazing did not significantly lower the severity of fire, as measured by the diameter of burnt twigs. We interpret the lack of a grazing effect in terms of shrub dynamics (little or no grazing effect on long-term cover of taller shrubs), diet and behaviour of cattle (herbs and dwarf shrubs eaten; tall shrubs not eaten and closed-heath vegetation generally avoided), and fuel flammability (shrubs more flammable than grass). Whatever effects livestock grazing may have on vegetation cover, and therefore fuels in alpine landscapes, they are likely to be highly localized, with such effects unlikely to translate into landscape-scale reduction of fire occurrence or severity. The use of livestock grazing in Australian alpine environments as a fire abatement practice is not justified on scientific grounds.*

Williamson *et. al.* (2014) used remote sensing to determine the effect of active grazing licences on fire severity (crown scorch) in eucalypt forests and woodlands following large fires in the Alps during the summers of 2002/2003 and 2006/2007, finding *"crown scorch was strongly related to vegetation type but there was no evidence that cattle grazing reduced fire severity. There was some evidence that grazing could increase fire severity by possibly changing fuel arrays".*

The frequent burning associated with grazing can make bush more flammable by encouraging the growth of more flammable species, for example a thick understorey of Bracken and/or Blady grass can increase fire frequency, intensity and flame height, and thus magnify fire hazards. Erskine *et. al.* (2007) identify that forests dominated by fire-prone grasses, such as blady grass "*are susceptible to fires until such time as a developing layer of woody rainforest species is able to form a closed canopy and shade out grasses. This new canopy will also create a new microclimate that hastens fuel decomposition and increases humidity, both of which decrease the fire hazard".*

3.4. Grazing increases Weeds

Livestock have been found to help the spread of exotic plant species by (1) opening up habitat by grazing and trampling, for weedy species which thrive in disturbed areas; (2) dispersing weed seeds in fur and dung; (3) reducing competition from native species by eating them, and (4) contributing large quantities of nutrient in their faeces and urine to the soil that further encourage weed spread and growth. (i.e. Fleischner 1994, Gentle and Duggin 1997, Burrows 2000, Yates *et. al.* 2000, Pettit and Froend 2001, McIntyre *et. al*. 2003, Lunt 2005, Jansen *et. al.* 2007, Spooner and Briggs 2008, Dorrough 2012). As noted by Jansen *et. al.* (2007):

> *Livestock can also promote invasion of weeds (usually annual, ruderal species), which can bring about changes in vegetation structure (Fleischner 1994). The creation of open sites by grazing or trampling provides a perfect opportunity for weed species to become established. Weeds are also spread by the movement of stock, either in their faeces or by attachment to the animal. Stock faeces and urine also contribute large quantities of nutrient to the soil (especially nitrogen and phosphorus), that further encourages the growth and spread of weed species.*

In their study of woodlands in south-west Australia, Yates *et. al.* (2000) found *"The mean percentage cover of exotic annuals in heavily grazed woodlands was 29.7% and in rarely grazed/ungrazed woodlands was 0.5%".*

Lunt (2005) considers *"The magnitude of the ecological changes induced by heavy grazing in southern Australia is extraordinary: in many areas perennial dominated systems have been almost totally replaced by exotic annuals".*

From his review Lunt (2005) concluded "*In temperate grassy ecosystems, soil disturbances commonly promote exotic weeds rather than native species (McIntyre & Lavorel 1994a,b). This occurs because many exotics have larger seed banks than most native species (Lunt 1990b, Morgan 1998a), and because soil disturbance increases nutrient levels which favour many exotics*".

In grazed West Australian jarrah woodlands with an "*understorey dominated by annual species, especially exotic grasses and forbs",* Pettit and Froend (2001) established grazing exclusion plots, finding that there was an initial increase in annual exotic pasture species, which decreased in subsequent years with an increase in native perennials, *"with the return (within 6 years) of native species richness to levels similar to those found in ungrazed vegetation"*. The ungrazed vegetation had understories dominated by native perennial shrubs and herbs.

Dorrough (2012) considers that nutrient enrichment consistently affects species composition and favours dominance by exotics, noting that *—the role of nitrogen and phosphorus enrichment in loss of native plant diversity and invasion by exotic species has been documented globally".* Dorrough (2012) notes:

> *Livestock are one of the key sources of nutrient inputs into remnant vegetation. The benefit of excluding livestock may be more to prevent nutrient inputs than herbivory. Nutrient run-on from adjacent sites can also be important, but is less commonly documented. Strategies should be put in place to limit the potential for nutrient transfers into remnant woodlands.*

In NSW's coastal forests grazing and frequent burning are known to promote undesirable species and problem weeds. Rose (2009) identifies that "*Blady grass (Imperata cylindrica) often dominates Mid North Coast pasture where the practice of spring burning to produce a green pick has been overused. ... leading to extensive areas of blady grass monocultures"*. This has been a problem for a long time, Floyd (1964) notes that in northern NSW the succulent kangaroo grass has been replaced due to fire (mostly instigated by graziers) by the tough and largely unpalatable blady grass and whisky grass, concluding that "*Perhaps the grazier is merely an unwitting slave to the fire over which he claims mastery".* For Blady Grass Pressland (1982) notes "*repeated burning leads to progressive dominance of that species and is a key factor in its spread".*

Lantana (*L. camara)* is the most widespread and successful weed throughout north-east NSW, benefitting from logging and other activities that open the forest canopy enough for it to thrive. Lantana now dominates the understorey in tens of thousands of hectares of northeast NSW"s forests. Logging, fire and cattle grazing are significant contributors to the successful invasion of lantana (Gentle and Duggin 1997), and it in turn can increase the flammability of vegetation (Fensham *et. al*. 1994, Gill and Zylstra 2005, Berry *et. al* 2011, Murray *et. al.* 2013, Bowman *et. al.* 2014). Gentle and Duggin (1997) concluded "*The effects of biomass reduction and soil disturbance associated with fire and cattle grazing are significant in the successful invasion of* L. Camara".

Murray *et. al.* (2013) found that the average higher flammability of dry leaves of exotics, combined with their larger leaves, meant "*exotic plant species have the potential to increase the spread of bushfires in dry sclerophyll forest"*. Of the 79 species from dry sclerophyll forests tested by Murray *et. al.* (2013), lantana had the third shortest mean time to ignition for fresh leaves.

From their study of the Forty Mile Scrub National Park, Fensham *et. al*. (1994) found "*the proliferation of lantana results in the build up of heavy fuel loads across the boundary of dry rainforest and savanna woodland. Recent fires have killed the canopy trees in a large area of dry rainforest within the Park*". From their study of dry rainforests, Berry *et. al* (2011) concluded that *L camara* was less ignitable than native dry rainforest species, though:

> *Fuel bed depths, leaf litter depths, percentage cover by fuels and amount of medium size class fuels were higher in dry rainforest invaded by* L.camara *than in non-invaded forests. This suggests that the mechanism by which* L.camara *alters the fire regime in dry rainforest is by shifting the distribution of available fuels closer to the ground and providing a more continuous fuel layer in the understory*

The increasing dominance of forest understoreys by lantana in north-east NSW must pose a significant wildfire threat.

Rossiter *et. al.* (2003) identify that "*Invasive alien grasses can increase fuel loads, leading to changes in fire regimes of invaded ecosystems by increasing the frequency, intensity and spatial extent of fires*", citing the example of the African Gamba grass invading the Top End savannas and increasing fuel loads up to seven times higher than native grasses.

While grazing may reduce the threat of wildfires in some cases by reducing the overall load of flammable material and eliminating the midstorey strata, in other cases grazing can create species and structural changes, along with microclimatic changes, that increase the flammability of the landscape. Given the abundant evidence of the significant impacts of grazing on native ecosystems, and its ability to increase flammability of some vegetation, any claims that grazing can reduce the threat of wildfire need to be critically evaluated on a case by case basis.

4. Impacts of the 2019-2020 wildfires on north-east NSW

The NSW Government's response to the environmental consequences of the 2019-2020 wildfires, as judged from their published responses and actions, has been woefully inadequate. Aside from some species lists the NSW Government is yet to identify impacts on populations of threatened species, identify priority populations for assistance, or propose recovery actions, aside for aerial baiting which will impact native carnivores as well as exotic ones.

These fires have been of unprecedented scale and intensity, the burning of half the native vegetation and habitats has had massive impacts on north-east NSW's ecosystems, plants and animal populations. A variety of populations and species are likely to have been so significantly affected that they are at imminent risk of extinction. Others have been shoved further down that path. There needs to be urgent assessments of the most heavily impacted ecosystems and populations to assess their current status and the impacts of the fires upon them.

The burning of some 160,000 ha (35%) of rainforests should have been a wake-up call. This will result in significant loss and degradation of these priceless relicts from our Gondwanan past. Those burnt are now more vulnerable to further burning. The damage is so severe that with the increasing likelihood of repeat events this could be the start of ecosystem collapse. The burning of rainforest is akin to the bleaching of coral reefs, and is likely to follow a similar trajectory.

The wet-sclerophyll forests were already experiencing ecosystem collapse due to logging and lantana invasion, with the burning likely to aggravate this unless the return of lantana is prevented.

The NSW Government must undertake a though expert assessment that identifies populations of all species likely to have been significantly affected by the fires, undertake surveys and identify needed remediation measures. This needs to include repeating previous surveys to quantify population changes.

In accordance with the Commonwealth recommendations NEFA is calling on the NSW Government to immediately implement a moratorium on all logging operations and land clearing within and near the identified habitat and locations of threatened species significantly impacted by the 2019-2020 wildfires, as well as upstream of the worst affected frogs, fish and crayfish.

In 2019, New South Wales had its warmest January to August period on record for overall mean temperature (1.85 °C above average), By 9 September, more than 50 fires were active in NSW, with five fires burning out of control and 3 watch and act alerts in place for blazes at Drake near Tenterfield, Ebor near Armidale and Shark Creek in the Clarence Valley.

From August 2019 until January 2020 the wildfires devastated 2.4 million hectares of north-east New South Wales (north from the Hunter River to the Queensland border, and from the coast west to include the New England Tablelands), encompassing 29% of the region and around half the remnant native vegetation. For this review primary reliance was placed on DPIE's GEEBANG v2 burn mapping (see Section 4.2.1 for a discussion)

These fires were unusually extensive and intensive because of record low rainfalls and extreme temperatures. In summary comparison of GEEBAM v2 fire mapping with other data for north-east NSW shows the fires burnt:

- 1,324,772ha of Public Lands (54.2% of burn) and 1,118,659ha of Private Lands
- 868,714 ha (59%) of National Parks, with 517,802 ha suffering significant (full or partial) canopy loss. This includes 180,295 ha (58.3%) of the NSW section of the Gondwana Rainforests of Australia World Heritage area, including some 26,283 ha (24.4%) of World Heritage listed rainforest.
- 456,058 ha (54.4%) of State Forests, with 259,293 ha suffering significant canopy loss. This includes 16,000 hectares (43%) of Pine Plantations, most of which burnt intensively, rendering them useless for future production.
- Some 160,000 ha (34.7%) of rainforest, with 124,494 ha (78% of burnt rf) suffering significant canopy loss
- 851,847 ha (66%) of mapped oldgrowth forest, with 420,257 ha suffering significant canopy loss
- 322,191 (29.4%) of Koala Habitat Suitability Model (north-east NSW) classes 4&5, with 196,663 ha suffering significant canopy loss. (Note this is limited to the north-east NSW bioregion)

To consider the magnitude of the wildlife impacts in context, the north-east NSW fires represent 44% of the 5.4 million hectares burnt in NSW, which means that they killed in the order of 350 million animals, out of the estimated 800 million animals killed in bushfires in NSW.

Many species have been more heavily impacted than Koalas, NEFA's assessment of some north-east NSW priority fauna species, using both Bionet records and CRA modelled habitat, identifies 6 species as having more than half their recorded locations burnt include Pugh's Frog, Hastings River Mouse, Sphagnum Frog, Stuttering Frog, Powerful Owl, and Barking Owl. Further Peppered Tree Frog, Spotted-tailed Quoll and Swift Parrot have had more than half their modelled habitat burnt.

NEFA initial assessment of fire effects on modelled habitat and records of some priority species in north-east NSW.

Species	Modelled Habitat (NE NSW)			Records (NE NSW)		
	Ha	Ha Burnt	% burnt	No	No Burnt	% burnt
Pugh's Frog	60,778	57,658	94.9	129	125	96.9
Peppered Tree Frog	1,601	1367	85.4	9	3	33.3
Sphagnum Frog	471,007	321,859	68.3	500	280	56.0
Hastings River Mouse	677,016	419,048	61.9	980	836	85.3
Stuttering Frog	995,197	592107	59.5	1300	703	54.1
Spotted-tailed Quoll	1,208,989	682,153	56.4	7190	3212	44.7
Swift Parrot	751301	398194	53.0	375	45	12.0
Powerful Owl	1,492,332	754419	50.6	2177	1141	52.4
Squirrel Glider	704,053	346443	49.2	1736	432	24.9
Rufous Scrub Bird	227552	111,796	49.1	938	298	31.8
Barking Owl	188,119	78,355	41.7	323	167	51.7

(Note that the number of records for some species vary from those given in the NSW assessment, though this does not significantly affect outcomes)

This is only a partial assessment, though emphasises the ease with which threatened species can be identified for immediate management response within hours of receiving fire mapping. Habitat for all these species should be considered priorities for protection while the impacts of the fires upon them are evaluated.

Most priority fauna species in the north-east NSW Comprehensive Regional Assessment had fauna models prepared, identifying disjunct populations based on likely dispersal barriers for target setting (Environment Australia 1999, Flint *et. al.* 2004). Given that these represent distinct populations the effects of the fires should be considered at this (SETA) level. Koalas have since been through a separate process to identify populations, termed ARCS (see 4.1.1), that similarly should be the basis for impact assessment. It is those populations identified as most significantly impacted that should be the priority for protection while urgent assessments are undertaken.

North-east NSW (north from the Hunter River) provides core habitat for half of the 113 animal species that the experts commissioned by the Commonwealth Department of Agriculture, Water and the Environment identified as needing urgent help to survive in the wake of devastating bushfires.

The 57 species occurring in north-east NSW identified as being at highest risk of extinction are comprised of 10 birds, 13 mammals, 9 reptiles, 11 frogs, 12 spiny crayfish and 2 freshwater fish species. These include the Rufous Scrub-bird, Regent Honeyeater, Hastings River Mouse, Long Sunskink, Manning River Helmeted Turtle, Broad-headed Snake, Pugh's frog, Mountain frog, Sphagnum frog, Peppered Tree Frog, New England treefrog, Tyler's toadlet, Small Crayfish, Smooth Crayfish, Ellen Clark's Crayfish, Hairy Cataract Crayfish, Oxleyan Pygmy Perch, and Clarence River Cod.

The crayfish in particular are not recognised as threatened species in NSW and thus not provided with any specific protection. Given their stream habitats they are directly affected by logging due to its affects on riparian habitat, water quality and streamflows, there needs to complete protection of upstream catchments so as not to compound burning impacts. This applies to listed frogs, turtles and fish as well.

The Commonwealth identifies the highest priority actions for all species as protecting unburnt habitat patches and carrying out rapid ground assessments of remnant populations.

In their simplistic assessment the NSW Government also identified Pugh's frog, Hastings River Mouse, Brush-tailed rock-wallaby, Parma wallaby, Yellow-bellied glider, New England Tree Frog, and Davie's Tree Frog as having more than half their known localities burnt.

Many north coast species have had most of their known localities burnt, with Pugh's Frog losing 89% and Hastings River Mouse 82%. Rainforests have been burnt, with some unlikely to recover, numerous hollow-bearing trees have been burnt out and cut down, eucalypt flowering has been set back for years, many understorey feed trees (i.e. forest oaks for Glossy Black Cockatoos) have been killed, streams have been polluted. Due to the extent of the fires, these are significant impacts on the populations and survival of numerous threatened species.

The NSW Government has failed to prioritize protection of the most vulnerable species or protect their habitat. This is demonstrated by the NSW Government's targeting of a small patch of occupied Endangered Hastings River Mouse habitat for logging (Section 4.1.2), in a landscape where all the small patches excluded from logging had been burnt. That this occurred after the Commonwealth's recommendations displays an abject failure of governance of threatened species post-fire in NSW.

While the Commonwealth has yet to complete their assessment of threatened plants, NSW's preliminary assessment identified 19 of north-east NSW's threatened plants that had more than 90% of their localities burnt, with another 27 as having more than 50% burnt. Again, aside from a list, no indication of management response is identified.

It is telling that in 2018 Integrated Forestry Operations Approval (IFOA) the NSW Government removed or reduced already inadequate logging protections for most of these plants and animals. They don't stand a chance if their surviving habitat is now further degraded by logging.

4.1. Affects on Fauna

There can be no doubt that a multitude of wildlife died in the fires last season, from the invertebrate world of the leaf litter to up to Koalas in the tree tops. The fires were of unprecedented proportions, in north-east NSW burning out half the forests, including a contiguous 1.9 million hectares from Tenterfield on the tablelands to Iluka on the coast and from near Bonalbo in the upper Clarence River down to near Gloucester on the Manning River. Within the burnt grounds it was so dry that fires burnt through riparian vegetation and rainforests, the usual refuges for many species.

The fires last year were superimposed on an existing fire regime, with many areas burnt just a year or two ago burnt again, and occurred during an extreme drought when the forest was exceptionally dry and stressed. The drought continued after the fires, compounding impacts and hindering recovery.

The recovery of survivors will vary with species, though the impacts on many populations were so severe that they are unlikely to recover, and many will lag the recovery of their habitat. It is the lost tree hollows that will take centuries to recover. Urgent action is need to stop ongoing loss of key resources, particularly large old trees, and to facilitate the recovery of the worst affected species..

To arrest the ongoing declines in Koala populations the large trees preferentially used by Koalas must be retained. It is recommended that a logging moratorium be immediately placed on clearing or logging of all mapped likely Koala habitat (KHSM classes 4&5) while the status of Koalas in each ARKS (population) is evaluated.

Given the likely loss of half the already critical nectar resources provided by mature trees due to fires across north-east NSW, and the time it will take for surviving trees to recover, it is essential that all mature eucalypt feed trees (across both burnt and unburnt forests) are excluded from logging as an emergency measure to stem the loss of nectar and the species that depend upon it.

Significant extents of public forests are already subject to commercial beekeeping operations, including areas of national parks, and feral hives are widespread, it is essential that there be no expansion of commercial operations in national parks at this crucial time for native species. The commercial industry will benefit from the protection of mature trees across their existing leases.

The wildfires have caused a major landscape wide reduction in big old trees, along with the hollows vital as homes for so many animals. Nesting boxes are of some benefit, but the long-term solution has to be increasing the availability of natural hollows by allowing mature trees to age and decay gracefully. There needs to be a moratorium placed on logging any trees

over 80 cm diameter while the impacts of the fires on hollow-dependent species are assessed.

North-east NSW is one of the Koalas remaining strongholds, though the recent fires have taken a heavy toll on many significant populations, killing thousands of Koalas and leaving many more sick, dehydrated and starving (4.1.1.3). While overall 29.4% of modelled 'likely' Koala habitat burnt in the recent fires, many populations had 73-90% of their likely Koala habitat burnt and may consequently be in imminent danger of collapse (Section 4.1.1.). Extinction is the end result of the cumulative loss of populations, it is essential we address the extinction crisis at the population level.

Koalas are particularly vulnerable to wildfires due to their tendency to climb higher into the canopy. As larger trees are targeted for logging, resulting in smaller trees, more contiguous canopies and increased connectivity between ground and canopy fuels, this leaves less refuges for Koala to escape fires. Koalas also clearly prefer larger trees for feeding and roosting (Section 4.1.1.1.). At the same time as their survival is being challenged by increasing wildfires it is also threatened by the accompanying droughts and heatwaves. Koalas west of the Great Dividing Range have been some of the early victims of climate heating, in the 1990's the Pilliga was found to be a stronghold for NSW's Koalas, though by 2014 there had been an 80% drop in occupancy, and now there may be none left.

To arrest the ongoing declines in Koala populations the large trees preferentially used by Koalas must be retained. It is recommended that a logging moratorium be immediately placed on clearing or logging of all mapped likely Koala habitat (KHSM classes 4&5) while the status of Koalas in each ARKS (population) is evaluated.

It is the bigger and older trees that provide the high level of resources required by the majority of specialised threatened vertebrate species. It may take trees one or two decades before they begin to flower and set seed, which they produce in increasing abundance as they mature. Numerous species of invertebrates, many birds, and a variety of mammals feed on these flowers and seeds. The older a tree gets the more browse, nectar, seeds and other resources they provide for wildlife. Once eucalypts are over 120-180 years old they begin to provide the small hollows needed by a variety of native wildlife for denning, nesting and shelter. Though it is not until they are over 220 years old that they provide the larger hollows required by species such as owls, cockatoos and gliders. They may live for 300-500 years, sometimes longer.

A major problem for many threatened vertebrate forest fauna species is the ongoing and cumulative decline in larger trees.

Nectar Trees

Eucalypt species can produce copious nectar though most flower unreliably, often at intervals of several years, so nectivorous species need to be able to track nectar across the landscape or switch to other foods when nectar is in short supply.

For Spotted Gum forest in southern NSW Law and Chidel (2007, 2008, 2009) found large trees (>40cm dbh) carried 3,600 flowers compared to 816 flowers on medium trees and 283 flowers on small trees (<25cm dbh), noting "*mature forest produced almost 10 times as much sugar per ha as recently logged forest, with regrowth being intermediate*" And for Grey Ironbark *Eucalyptus paniculata* forests large trees carried 12,555 flowers compared to 1024 flowers on medium trees and 686 flowers on small trees, noting "*old regrowth forest (232 g sugar per night per 0.2 ha)* *produced just over 7 times the sugar of recently logged forest (32 g), while regrowth forest was intermediate (91 g)*."

As well as producing more flowers larger trees also tend to flower more often (Law *et. al.* 2000, Law and Chidel 2007), for example Law *et. al.* (2000) found that large Spotted Gum *Corymbia variegata* flowered every 2.3 years whereas medium sized trees flowered every 5.9 years.

The flowering of trees and abundance of nectar is directly affected by rainfall over the previous 6 months (Hawkins 2017), reducing in droughts and following bushfires (Law *et. al.* 2000, Law and Chidel 2009, Moore *et. al.* 2016). The erratic production of nectar is likely to become more so in the future as climate heating gathers momentum, as stated by Butt *et. al.* (2015) "*as a consequence of the increasing incidence of droughts and heat waves, the net quantity of nectar at flower, stand and landscape scales may be reduced, and its temporal variability increased*".

The Endangered Swift Parrot *Lathamus discolor* had 53% of its modelled habitat in north-east NSW burnt last season, and it can be expected that most of its nectar resources were consumed over that area, with the surviving trees expected to have reduced flowering and nectar for years to come. This is a major impact on the winter flowering resource for a species identified as having a 31% chance of extinction within the next 20 years (Geyle *et. al.* 2018). The 2011 National Recovery Plan for the Swift Parrot identifies the loss of mature trees and the abundance of nectar they provide as a major threat, noting:

> *Based on current knowledge of the ecology and distribution of the Swift Parrot the persistence of this species is mainly threatened by loss and alteration of habitat from forestry activities including firewood harvesting, clearing for residential, agricultural and industrial developments, attrition of old growth trees in the agricultural landscape, suppression of forest regeneration, and frequent fire. The species is also threatened by the effects of climate change, food and nest source competition, flight collision hazards, psittacine beak and feather disease, and illegal capture and trade.*
>
> *Forestry activities, including firewood harvesting result in the loss and alteration of nesting and foraging habitat throughout the Swift Parrot's range ... The harvesting of mature box-ironbark woodlands of central Victoria and coastal forests of New South Wales for forestry reduces the suitability of these habitats for this species by removing mature trees which are preferred by Swift Parrots for foraging and that provide more reliable, as well as greater quantity and quality of food resources than younger trees (Wilson and Bennett 1999; Kennedy and Overs 2001; Kennedy and Tzaros 2005)*

With half north-east NSW's forests burnt, there has been a significant loss of eucalypt flowers, with most of the surviving key nectar trees unlikely to recover for years. Many eucalypts don't flower until they are over 20 years old, and the abundance of flowers increases rapidly with age. It is the mature eucalypts that provide the abundance of nectar necessary for the survival of some of our most threatened species, from flying foxes to winter migrants, such as the critically endangered Swift Parrot.

Even before the fires got out of control in 2019 there were reports of flying foxes starving to death (in addition to mass deaths from heatwaves in previous years), an indication of the dire straits of many nectarvores, due to the combined effects of logging removing older trees and the drought. Burning has compounded these problems by consuming buds and flowers, and will retard flowering for years to come. This is in addition to the loss of numerous large trees by being burnt down in fires (i.e. see Section 4.1.1.3), apparent mortality of many standing trees (pers. obs.), and the cutting down of numerous mature and hollow-bearing trees as fire control measures (both during and after the fires).

Starving flying foxes demonstrate that the drought was already having a critical impact on flowering before the fires, and their subsequent retreat to unburnt areas illustrates the dramatic impact of the wildfires on nectivorous species.

The loss of nectar due to the fires affects many species that rely upon nectar as part of their diet, for example nectar and pollen were particularly important for Squirrel Gliders during winter and early spring (Sharpe and Goldingay 1998), with their populations varying with the number of flowering trees, and susceptible to crashing when key nectar trees fail to flower. From their study of Squirrel Gliders in Victoria, Holland et. al. (2007) concluded:

> *The high density of large trees is a critical element of habitat quality. Not only were large trees preferentially selected for foraging, they also provide gliders with hollows for nesting (van der Ree 2000). Retention of large trees should therefore be a priority, and lack of regeneration is of serious concern, with trees not being replaced as they senesce.*

Until 2018 the IFOA covering State Forests required the retention of 3 mature eucalypts per hectare of species known to produce copious nectar as "eucalypt feed trees". This retention increased to 5 'eucalypt feed trees' per hectare in compartments with nectivorous Swift Parrot, Regent Honeyeater or Black-chinned Honeyeater records, and was often adopted as the default in lieu of surveys in potential habitat. The new IFOA initially removed any need to retain eucalypt feed trees, though they changed this to the retention of 5 nectar trees per hectare within 2km of an existing record of Swift Parrot or Regent Honeyeater (given the limited records this will have little effect).

Law and Chidel (2007) found that while in good years eucalypts can produce a surplus of nectar, in poor years the limited nectar was rapidly consumed, leading them to observe "*Depletion of nectar in poor flowering years justifies management prescriptions that retain mature trees of locally important flowering species (currently six per ha) in the areas zoned for logging. The fact that total sugar content tends to be higher in lower slope areas (e.g. riparian zones) is also important in ameliorating logging impacts*".

The changes also reduced riparian buffers on headwater streams and removed the requirement to protect 8ha around new records of the Squirrel Glider.

Given the likely loss of half the already critical nectar resources provided by mature trees due to fires across north-east NSW, and the time it will take for surviving trees to recover, it is essential that all mature eucalypt feed trees (across both burnt and unburnt forests) are excluded from logging as an emergency measure to stem the loss of nectar and the species that depend upon it.

Nectar is also a key resource for numerous insects which have also been significantly impacted. As identified O'Connor *et. al.* in a recent article in The Conversation:

> *Native pollinator populations have been decimated in burned areas. They will only recover if they can recolonise from unburned areas as vegetation regenerates.*
>
> *But our native pollinators badly need these resources – and the recovery of our landscapes depends on them. While we acknowledge the losses sustained by the honey industry, authorities should not jeopardise our native species to protect commercial interests.*

> *Currently, beekeepers' access to conservation areas is limited. This is because bees from commercial hives, and feral bees from previous escapes, damage native ecosystems. They compete with native species for nectar and pollen, and pollinate certain plant species over others.*
>
> *Australia's native birds, mammals and other insects rely on the same nectar from flowers as honeybees, which are abundant and voracious competitors for this sugary food.*
>
> *Many native plant species are not pollinated, or are pollinated inefficiently, by honeybees. This means a concentration of honeybee hives in a conservation area could shift the entire makeup of native vegetation, damaging the ecosystem.*
>
> *A long-term solution is to increase the area of native vegetation for both biodiversity and commercial beekeeping, by stepping up Australia's meagre re-vegetation programs.*

Significant extents of public forests are already subject to commercial beekeeping operations, including areas of national parks, and feral hives are widespread, it is essential that there be no expansion of commercial operations in national parks at this crucial time for native species. The commercial industry will benefit from the protection of mature trees across their existing leases.

Oldgrowth Forests

Once trees are over a century old they begin to develop hollows in their branches and trunks that provide essential homes for a multitude of Australian animals. Old trees have already been severely depleted by logging, wildfire, prescribed burning and drought.

Fires progressively eat away at the bases of old trees until they collapse, and old trees are often targeted for removal in wildfire control. Every fire removes more of our already depleted old hollow-bearing trees, and the homes they provide.

Across north-east NSW 851,847 ha (66%) of mapped oldgrowth forest was burnt last season, with 420,257 ha suffering significant canopy loss. The wildfires that ripped through north-east NSW's forests occurred when plants were stressed and leaf litter and logs unusually dry, making older trees with butt or root damage from logging or previous fires extremely vulnerable. There has been a significant loss of large old-growth trees across all fire grounds, from within oldgrowth stands and amongst the scattered survivors in logged forests. Given the accumulated damage to their bases over the centuries they are particularly vulnerable to being burnt out. At Terania Creek I observed numerous huge Brush Box, likely over a thousand years old, burnt out and collapsed.

There are numerous species occurring in north-east NSW that depend upon the large hollows provided by old eucalypts for nesting or denning. Before European intervention it has been estimated these forests had 13–27 hollow-bearing trees per hectare (Gibbons and Lindenmayer 2002). They have been subject to widespread clearing, and for years those not logged were ring-barked in the coastal forests to make way for regrowth. It is only in the past 20 years that logging prescriptions have required the retention of around 5 hollow-bearing trees per hectare, by then there weren't that many left in extensive areas.

Retaining the remaining hollow-bearing trees is essential for maintaining remaining breeding populations of hollow-dependent species in the forests. Seventy species (28%) of vertebrates use hollows in north-east NSW (Gibbons & Lindenmayer 2002). The loss of the hollows provided by large old trees has been identified as a primary threat to a variety of priority species in north east

NSW (Environment Australia 1999, Appendix 1); 4 mammals (non-flying), 20 bats, 3 birds, 2 frogs, 3 reptiles and 4 snakes.

The NSW Scientific Committee (2007) has identified *Loss of Hollow-bearing Trees* as a Key Threatening Process. The maintenance of large old hollow-bearing trees in perpetuity is the single most important requirement for the survival of the numerous animal species that rely on their hollows for denning, nesting or roosting**.** To maintain continuity of supply of these resources by such long lived organisms it is essential to ensure that there are enough new hollow-bearing trees to replace the large hollow-bearing trees when they die, and enough strong and health mature trees to develop into the hollow-bearing trees of the future.

As noted by Gibbons and Lindenmayer (2002):

> *Hollow-bearing eucalypts are extremely long-lived 'organisms'. Eucalypts typically have a life span of 300-500 years, and dead trees may provide hollows for a further 100 years. The age at which they 'reproduce' hollows (typically 150-250 years) represents one of the slowest 'reproductive cycles' for any organism. Failure to replace hollow-bearing trees as they are lost will result in prolonged temporal gaps in the resource that will not only reduce the area of suitable habitat for hollow-using fauna, but could also fragment populations of species unable to occupy areas lacking hollows. The dispersal of hollow using species also will be impaired".*

Lindenmayer *et. al.* (2014) recognise that:

> *... drivers of large old tree loss can create a "temporary extinction," that is, a prolonged period between the loss of existing large old trees and the recruitment of new ones (Gibbons et al. 2010b). The length of a temporary extinction may vary (e.g., 50 to 300+ years) ... Temporary extinction has the potential to drive species strongly dependent on large old trees to permanent local or even global extinction. In other cases, existing large old trees may be doomed to eventual extinction because the animals that dispersed their seeds have disappeared".*

Lindenmayer *et. al.* (2014) consider *"A critical step in large old tree management is to stop felling them where they persist and begin restoring populations where they have been depleted"*.

Hollow-bearing trees, and with them hollow-dependent species, have already been decimated across north-east NSW's forests. The problems such fauna are facing is expected to exponentially worsen as the few remaining large old hollow-bearing trees (in both forests and pastoral lands) die-out without replacement trees being available. The full ramifications of irreversible changes already set in place will take a century or more to become fully manifest. A "temporary extinction," due to a prolonged period between the loss of existing large old trees and the recruitment of new ones is inevitable under current management. The few patches from which logging is excluded will do little to ameliorate this.

Under the IFOA up until 2018 there were requirements to retain up to 5 hollow-bearing trees per hectare, with increases up to 8 per hectare near owls. The rules used to be to retain one of the next largest trees as recruitment trees for each hollow-bearing tree (up to a maximum of 5), as these are essential to replace hollow-bearing trees as they die. Under the new IFOA there are no requirements to retain any recruitment trees.

Logging results in significant damage to retained trees, which is compounded by fires, resulting in increased mortality of both hollow-bearing and recruitment trees. Tree retention requirements were a prescription for reducing hollow-bearing trees over time. This problem was compounded the Forestry Corporation's systematic failure to retain the large healthy trees required as recruitment trees. From a study of the effects of logging and fire on hollow-bearing trees on the Dorrigo, Guy Fawkes and Chaelundi plateaux, McLean *et. al.* (2015) concluded:

> *Logging intensity was negatively correlated with tree diameter at breast height (DBH), and the density of both hollow-bearing trees and hollows. Losses of hollow-bearing trees and hollows occurred through an interaction between logging intensity and fire frequency, resulting in an absence of recruitment of hollow trees. However in unlogged forest, fire was positively correlated to the density of hollows. Under a regime of frequent fire, in areas that have had some degree of logging activity, a net loss of hollows may occur. We recommend additional hollow recruitment trees be retained on logged sites in the future if no net losses of hollows are to occur in the future, or for wider unlogged buffers to be established adjacent to the cutting area.*

Hollow-bearing trees are in decline across the landscape as they succumb to logging, burning, drought, and sometimes old age. There are even less big sturdy trees left to replace them as the next generation of hollow-bearing trees as these are the targets of logging operations, it will be a long time before regrowth will develop hollows again.

The fire control activities included widespread felling of mature and oldgrowth trees along roads and tracks after the fire on the spurious grounds of safety. This included the felling of numerous trees that represented no threat to property or road users. The fires were taken as an opportunity, for a variety of motivations, to cut down trees without environmental assessment in a landscape that had lost a significant proportion of essential hollow-bearing trees.


Large mature trees with no significant fire damage cut down in a post-fire spree along the Summerland Way and other roads after the fire. These posed no threat of collapsing.


Left a mature tree and right a hollow-bearing oldgrowth tree, neither of which had structural damage because of the fire, or posed a risk, that were cut down in the Tooloom National Park World Heritage Area.

The wildfires have caused a major landscape wide reduction in big old trees, along with the hollows vital as homes for so many animals, by being killed in the fires, cleared in firebreaks and extensive felling post-fire. Nesting boxes are of some benefit, but the long-term solution has to be increasing the availability of natural hollows by allowing mature trees to age and decay gracefully rather than cutting them down. There needs to be a moratorium placed on logging any trees over 80 cm diameter while the impacts of the fires on hollow-dependent species are assessed.

Learning from Experience

Following the wildfires NEFA focussed our efforts on the burnt Koala population straddling Royal Camp, Carwong, Braemar and Ellangowan State Forests south of Casino (Section 4.1.1,), Hastings River Mouse in Styx River State Forest (Section 4.1.2), and rainforests in Nightcap, Whian Whian, Tooloom and Border Ranges National Parks (Section 4.2.1.). In all cases we have been disappointed with the lack of Government response to the plight of our native flora and fauna.

In an interview in Mongabay, John Zichy-Woinarski, Co-Chair of the IUCN SSC Australian Marsupial and Monotreme specialist group, identifies 5 global lessons to be learnt from the fires:

> *1., climate change will have devastating consequences for biodiversity, so if we are serious about species conservation then we need to strive harder to constrain it,*
> *2., significant biodiversity assets need to be better factored into fire control operations,*
> *3., conservation and recovery planning needs to factor in the possibility of catastrophe, in part by trying better to spread the risk,*
> *4., rapid responses post-fire (e.g. salvage of populations of threatened species from sites no longer capable of supporting viable populations, protection of unburned refugial areas) are important and can help maintain significant local populations, and*
> *5., support should be prioritized strategically, for example to species most likely to become extinct without such support.*

Based on our experiences we recommend that for future wildfires:

- **Key wildlife habitats need to be assessed up-front ahead of fires, and appropriate fire management actions to protect values identified (location of fire trails, areas for raking, suitable locations for backburns, retention of hollow-bearing trees, fire frequencies etc), with procedures applied during fires to ensure such guidelines are applied to appropriately minimise impacts.**
- **Indiscriminate felling of mature and oldgrowth trees after fires, that do not pose an immediate threat, must be stopped.**
- **A suitably trained Government team needs to be tasked with immediately responding after fire to rescue and support fire affected wildlife in key wildlife habitats.**
- **Burnt key wildlife habitats (i.e. parts of fire grounds) need to be prioritised for lifting of closure notices as soon as practicable after fires to facilitate volunteer wildlife rescue and public assistance for affected species, such as Koalas.**
- **Post-fire assessments by independent experts need to be urgently undertaken to identify those species most likely to have been detrimentally affected, and their habitat immediately excluded from further degradation, particularly by logging, while surveys are undertaken to quantify fire impacts.**

4.1.1. Observed effects on a Koala Population

On the night of 8 October 2019 the Busby's Flat fire burnt rapidly through most of NEFA's proposed 7,000 ha Sandy Creek Koala Park, covering Braemar, Carwong, Royal Camp, and Ellangowan State Forests. Various surveys and studies over 7 years had proven that these forests, south of Casino on the Richmond River lowlands, were of exceptional value for Koalas.

NEFA and the EPA's (2016) results for the proposed Sandy Creek Koala Park confirm that Koalas prefer larger trees for feeding and roosting, it is therefore evident that logging of larger trees (large and small sawlogs) will have a detrimental effect on the availability of feed trees used by Koalas and thus Koala populations. Over the past century logging is likely to more than halved Koala populations within this proposal by removing most of the larger trees preferred by Koalas. It is essential that logging of the larger trees preferred by Koalas be excluded from core Koala habitat to stop further population declines.

There was little evidence of Koalas surviving in the 59% of forests that were heavily burnt, and the balance of the fireground lost over half its canopy and most Koalas. Because of the ongoing drought, and lack of any concerted Government help, Koalas continued to decline for the next 3 months. It appears that over 90% of the Koala's were lost from the firegrounds.

The proposed Sandy Creek Koala Park is part of the Banyabba ARKS which encompasses 71,000 ha of likely Koala habitat (KHSM, classes 4&5), of which 59,000 ha was burnt. If a 90% mortality is assumed for the burnt areas, this suggests the loss of 75% of Koalas from the Banyabba population. Such broad estimations do not take into account the decimation of core high-density colonies responsible for maintaining the overall population.

While most forests are now recovering it is going to take decades for Koalas to rebuild their populations.

To halt ongoing declines in Koala populations the large trees preferentially used by Koalas must be retained. It is recommended that a logging moratorium be immediately placed on clearing or logging of all mapped likely Koala habitat (KHSM classes 4&5) while the status of Koalas in each ARKS (population) is evaluated.

Given the reduction in Koala populations because of the fires, and their loss from areas of identified core habitat, the recovery potential of areas need to considered when evaluating Koala habitat, even if not fully occupied now.

Given the parlous status of the Banyabba ARKS, the proposed Sandy Creek Koala Park should still be created and Koala colonies within it assisted to recover.

In early December NEFA made a submission to the NSW Koala inquiry, while the fires were still underway. The two highest of 5 categories identified in Koala models (Law et.al. 2017 and DPIE 2019) were combined as an indication of potential Koala habitat. This was then confined to the 29 Areas of Regional Koala Significance identified by OEH to identify 1,093,296 ha of potential Koala habitat. Then this was intersected with a compilation of fires identified on Fires Near Me from July until 8 December 2019.

At that stage fires had burnt out 266, 959 ha (24%) of the high quality Koala habitat identified in north-east NSW (this later increased), it was noted:

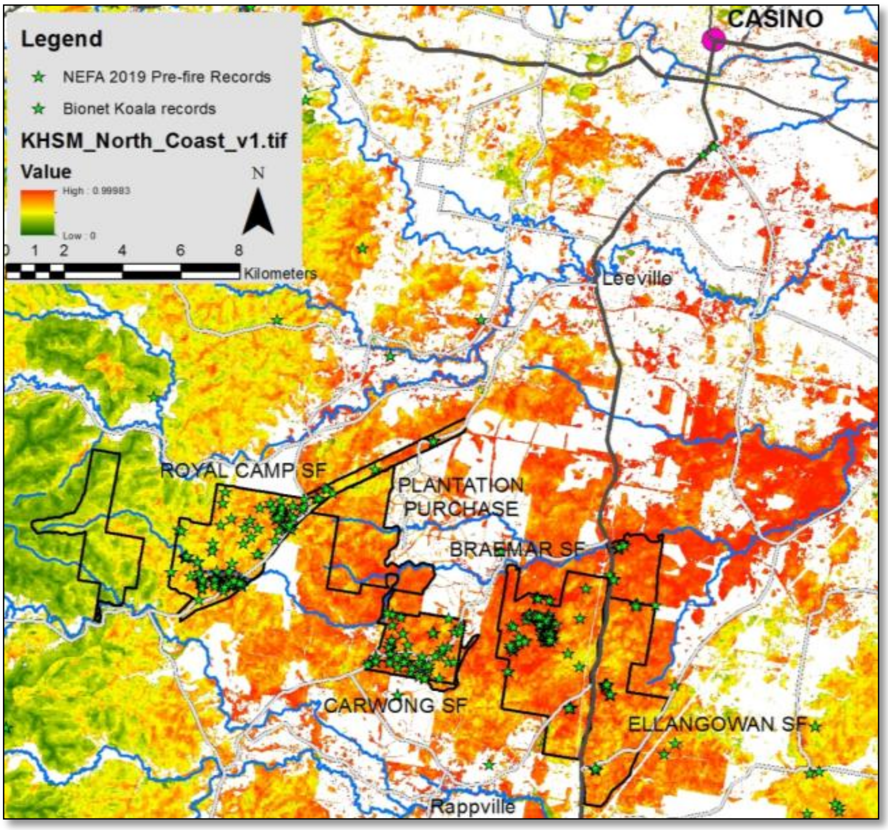
Though the situation is more dire than indicated by these broad figures, as eight Koala populations (Gibraltar Range, Clouds Creek, Nowendoc, Banyabba, Crowdy Bay, Girard-Ewingar, Kiwarrak and Knappinghat ARKS), encompassing 59% of Koala habitat, have had 73-90% of their Koala habitat burnt and are thus in imminent threat of collapse. Also much of the modelled high quality habitat that has escaped burning has been degraded by intensive logging, previous burning or other threats and no longer supports many Koalas.

All DPIE (2017) Areas of Regional Koala Significance (a surrogate for populations) that have had more than 50% of the likely Koala habitat within them burnt must be prioritized for protection and assessment.

4.1.1.1. Habitat Assessments.

In 2012 NEFA found FCNSW actively logging Koala High Use Areas in Royal Camp State Forest. Logging there stopped and FCNSW were fined $900. In a 2013 pre-logging assessment of another part of Royal Camp SF, NEFA identified Koala High Use Areas where FCNSW said there were no Koalas. Logging was stopped. In 2013 and 2015 Koala surveys for the EPA (2016) confirmed the outstanding significance of Royal Camp and Carwong State Forests for Koalas, with 58% and 80% occupancy (respectively) proving core breeding colonies.

In 2019 pre-logging inspections of Braemar SF by NEFA, large and extensive Koala High Use Areas were found. As NEFA prepared for a blockade to stop imminent logging, we also prepared a proposal for the Sandy Creek National Park and undertook random surveys in suitable habitat elsewhere in Braemar and Ellangowan State Forests, proving the presence of a widespread Koala population throughout these forests.



Pre-fire Koala findings overlaid on DPIE Koala Habitat Suitability Modelling, with red indicating the best likely habitat. By then only Royal Camp and Carwong SFs had been comprehensively surveyed

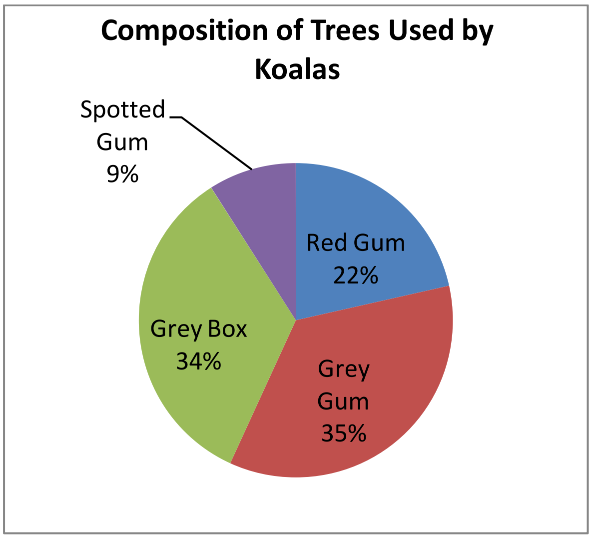
by EPA. NEFA had only started surveying Braemar SF and adjacent lands, finding an extensive high use area and widespread occurrence of Koalas.

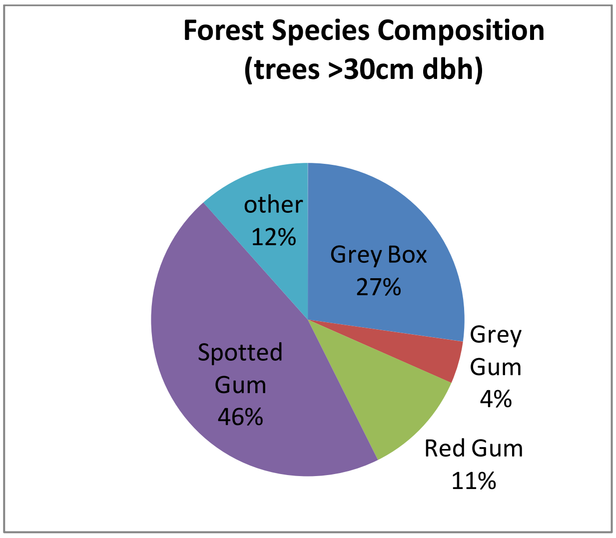
The large number of resident Koalas, stable colonies, and extent of suitable habitat testify to the importance of these forests for Koalas. The DPIE Koala Habitat Suitability Model ranks 78.4% of the proposed Sandy Creek Koala Park as high and very high suitability 'likely' Koala habitat.

On the night of 8 October 2019 a wind change pushed the Busby's Flat fire rapidly through most of NEFA's proposed 7,000 ha Sandy Creek Koala Park, covering Braemar, Carwong, Royal Camp, and Ellangowan State Forests, as well as native forest on land purchased by the Forestry Corporation for pine plantations.

Before the fire, the proposed Sandy Creek Koala Park was found to have areas of intense Koala use, with usage related to the distribution of preferred feed species and larger trees. Koalas occasionally used trees down to 20cm, though had a distinct preference for trees over 30 cm diameter (dbh), with usage increasing with tree size.

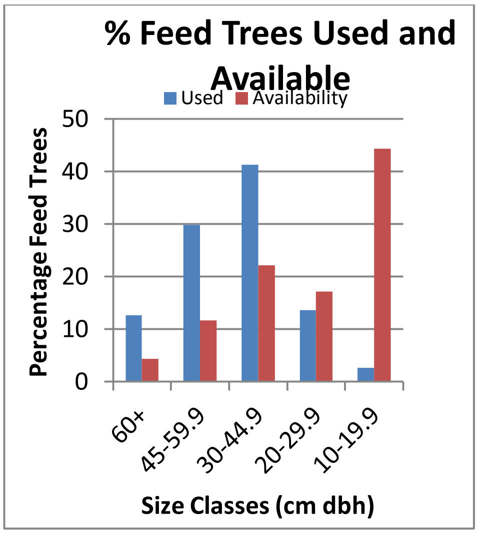
From NEFAs assessments of the proposed Sandy Creek Koala Park we have identified a distinct preference for Coastal Grey Box (*E. moluccana*), Grey Gum (*E. propinqua*), Forest Red Gum (*E. tereticornis)* and Slaty Red Gum (*Eucalyptus glaucina),* with limited use of Large-leaved Spotted Gum (*Corymbia henryi).* There is also a distinct preference for larger trees, with use increasing with tree size. Though even then they preferentially select individual trees.

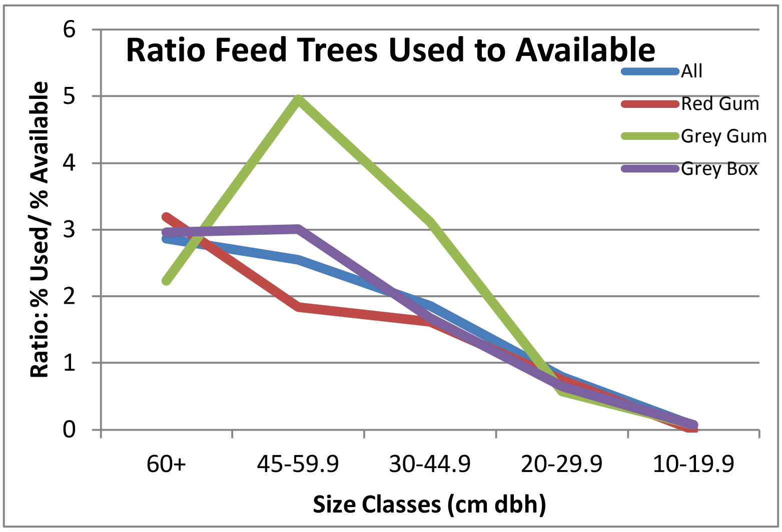




Species composition of trees utilised by Koalas (LEFT) from 476 of the trees identified with Koala scats by NEFA, compared to composition of feed trees in the forest (RIGHT) identified by NEFA from structural plots.

Many studies have identified the Koala's preference for larger trees (Hindell and Lee 1987, Lunney *et. al.* 1991, Sullivan *et. al.* 2002, Moore *et. al.* 2004b, Smith 2004, Moore and Foley 2005, Matthews *et. al.* 2007, EPA 2016). Tree size has been found to be the most significant variable after tree species in a number of studies, though this seems to be often ignored or downplayed for resource and political reasons. NEFA's results from the proposed Sandy Creek Koala Park confirm this preference for larger trees.





Usage of 476 feed trees according to 5 size classes compared to availability of sizes determined from plots. These show a clear preference for larger trees, generally the larger the better.

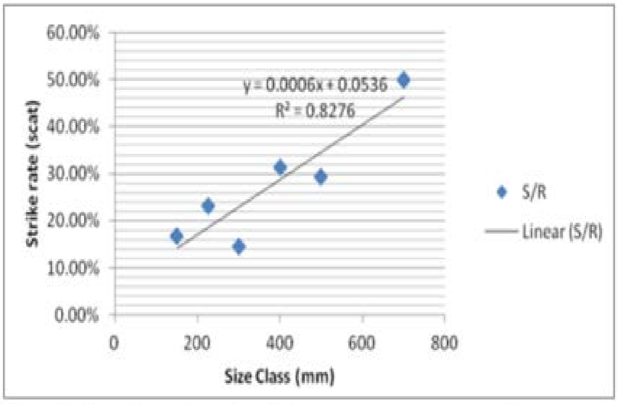


Figure 4: Size class of small-fruited grey gum versus scat strike rate

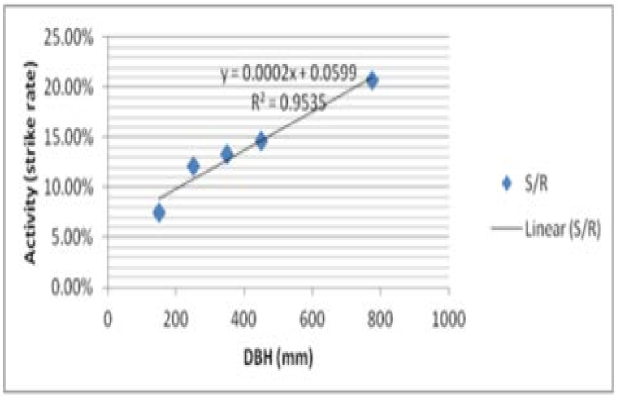
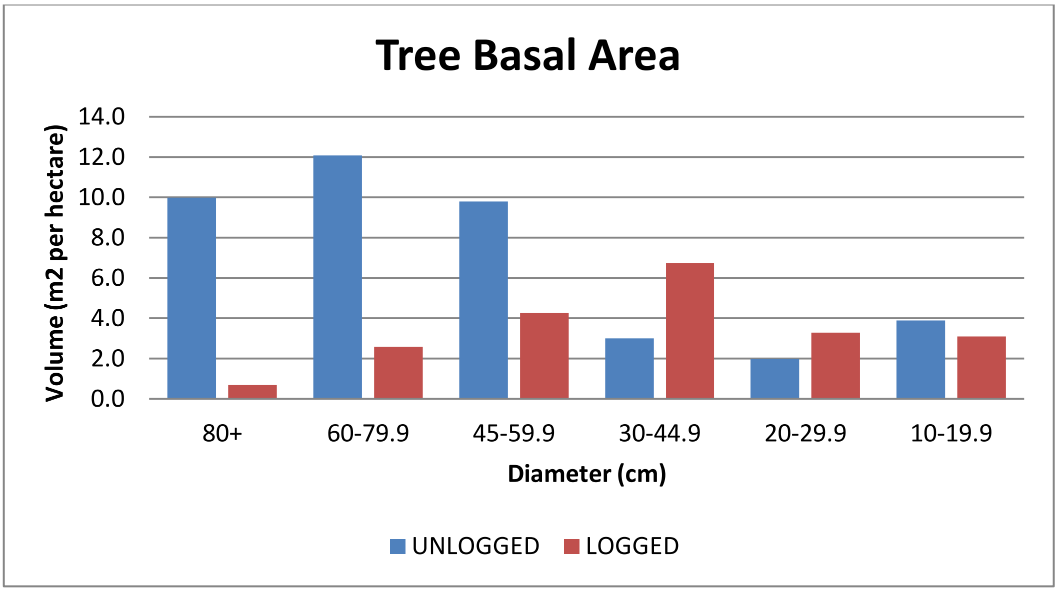


Figure 5: Size class of grey box versus scat strike rate

EPA (2016) observed data for pooled size classes (diameter at breast height) of Small-fruited Grey Gum (*E. propinqua*) and Grey Box with and without scats for Royal Camp and Carwong State Forests reinforces NEFA's findings that Koalas prefer larger trees.

NEFA and the EPA's (2016) results for the proposed Sandy Creek Koala Park confirm that Koalas prefer larger trees for feeding and roosting, it is therefore evident that logging of larger trees (large and small sawlogs) will have a detrimental effect on the available feed trees used by Koalas and thus Koala populations. It is essential that logging of the larger trees preferred by Koalas be prohibited in core Koala habitat to stop further population declines.

While there are a variety of factors that will have been affecting Koalas, most notably heatwaves and droughts, it is probable that Koala populations in the proposed Sandy Creek Koala Park have been more than halved because of the logging of food trees in the proceeding decades. Comparison between plots in the proposed Koala Park and floristically similar unlogged plots indicates that browse potentially available for Koalas is likely to have declined by at least half, with the bigger trees and species preferred by Koalas likely declining by over 75%.



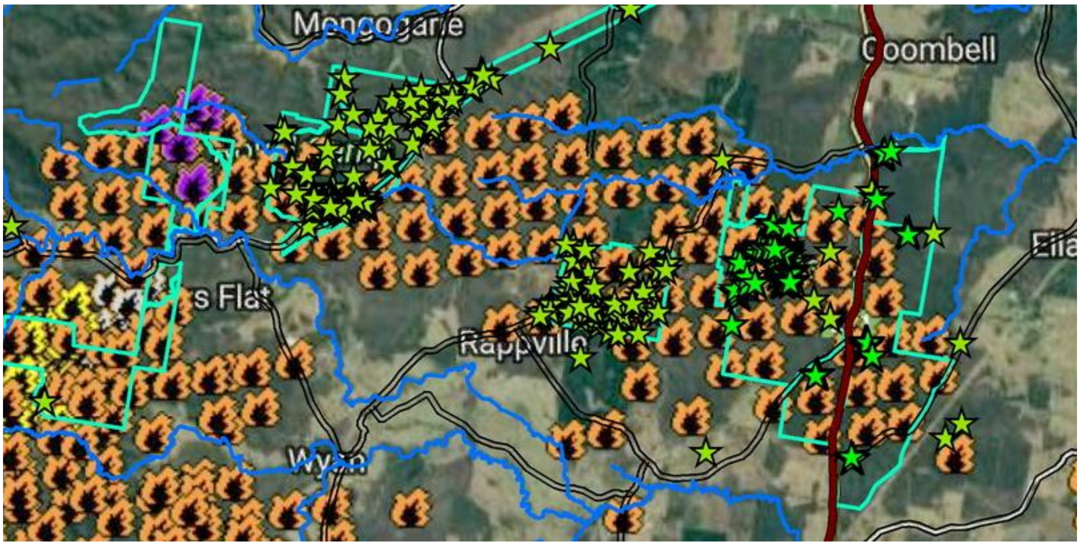
Comparison of the basal area of logged and unlogged forests based on plot data. This illustrates the halving of tree volume due to logging, with the removal of over 75% in the large trees preferred by Koalas.

This shows the potential, without logging, to increase the availability of the large trees preferred by Koalas over time as the larger age classes are restored.

4.1.1.2. The Aftermath of the Fire

On the night of 8 October 2019 the fire burnt out most of the proposed Sandy Creek Koala Park in one go, leaving little time for wildlife to escape. The fire moved rapidly through most of these areas, incinerating the ground litter and most logs, stumps and understory shrubs, but rarely crowning. Though the heat from the fire dried out and ultimately killed canopy leaves over extensive areas. Few ground refugia escaped the fires, with riparian vegetation incinerated, though some scattered and patches of tree crowns survived and became refugia for surviving Koalas.

It was the taller and larger trees with more isolated canopies that suffered the least canopy scorch and likely provided the best refuges for Koalas from the fires.



Sentinel mapping of fire at 7am 9 October 2019, with Koala records overlaid

LEFT: The understorey was very dry, with incineration of most leaf litter, dead wood and stumps. RIGHT: Many Koala feed trees were burnt out at the base and later collapsed.

After the fires NEFA initially focussed on trying to convince the Government to assist in a search for surviving Koalas using drones or dogs. The fire-ground was under Section 44 Management in the control of the RFS Commissioner, and was closed to the public, and remained so for 3 months.

For a few weeks after the fire many Grey Box burnt out at the base collapsed, and Grey Gums and some red gums shed their leaves, reducing the food supply for the surviving Koalas. As the drought persisted the forest then stood still for a further two months, with blackened soil and desiccated canopies enhancing heatwaves and the drought. There was no regrowth.

When our appeal for Government help for the Koalas failed, NEFA undertook scat searches despite the closure, informed by our own canopy scorch mapping, that were successful in identifying five remnant colonies in Braemar, Royal Camp and Carwong State Forests, and the purchased plantation land. NEFA documented 74 trees with post-fire Koala scats beneath them, including 4 with live Koalas. It was clear that the surviving Koalas were in trouble, with food loss, likely fire effects and dehydration. Interim water was provided to survivors and a report was provided to the Government, though no help was forth-coming.

LEFT: This sick male Koala, found in Braemar State Forest on 14 October, survived the fire, though the heat of the understorey fire desiccated the eucalypt foliage throughout large areas of the forest,

leaving him with no moist foliage or access to free standing water. CENTRE and RIGHT: Koalas found in Royal Camp on 22 October.


Deformed scats found on Forestry Corporation purchased lands on 30 October indicating severe dehydration.

Despite it being apparent that surviving Koalas were in trouble the Government would do next to nothing. The Forestry Corporation put out 6 water stations at Braemar, though did not refill them.

At this stage it became clear that our strategy to encourage Government intervention to rescue and support the Koalas had failed. As the fireground remained closed, NEFA could not continue our work with volunteers, even though by then the forest was safe. Thereafter I focused on providing water to one colony in Braemar State Forest, and monitoring its decline. It appears this assisted at least 2 observed Koalas to remain in a partially burnt area, though likely had broader benefits.


LEFT: Apparently healthy scats from mother and young joey making intensive use of an area of feed trees (including a large Spotted Gum) in a small patch with intact canopies. RIGHT: One of the temporary water stations placed by NEFA, many more were needed.

An exceptional 2,022 scats were found under a Spotted Gum on 23 December (after the fire), with scats of various sizes and some burnt scats indicating use before the fire. The tree had an intact canopy and a good structure for roosting. Subsequent video footage and observations showed this tree was being used on an almost daily basis, likely primarily as a roost tree. Without surveys such exceptionally important trees will not be identified.

On 25 December there was heavy rainfall, which moved extensive areas of ash and soil and caused flash flooding of some streams with ash laden runoff. It took some weeks for the forest to begin to respond with flushes of growth, and by mid January Koala feed trees were considered sufficiently recovered to support the few surviving Koalas.

Dead Koalas located in Carwong and Ellangowan State Forests.

Overall from 15 October 2019 until 10 January 2020 NEFA located 3 dead Koalas, 7 live Koalas, and recorded species and diameters for 131 trees found with post-fire Koala scats under them. Many of these trees were revisited on one or more occasions to monitor use over time. Water was initially put out where we found Koalas or intensive Koala use, though later this was limited to only maintaining water stations in a small part of Braemar State Forest.

The only other assistance for these Koalas we are aware of, are (a) FCNSW putting out 6 water stations at one site, which then dried out, and (b) a single drive through of Braemar State Forest by

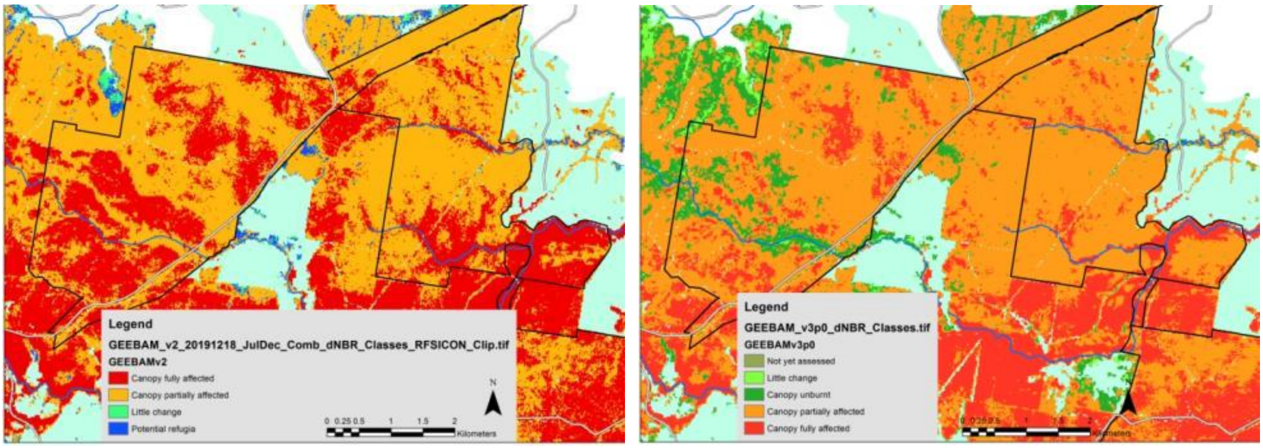
Friends of the Koala in company with the RFS and Forestry Corporation, without undertaking any searching. Apparently only a mother and joey were rescued from the fire grounds near Carwong, and they were released outside the area.

NEFA also measured 75 x 500m^2 vegetation plots on 10 transects chosen to reasonably sample the range of logging histories and environmental variation across the forests. Species, diameters and heights of all trees over 10 cm diameter were recorded, giving good baseline data. An additional 2 transects comprising 12x500m^2 plots were measured in CRAFTI mapped oldgrowth forest in Banyabba State Forest to provide an indicative pre-logging baseline.

4.1.1.3. Fire Impacts on Koalas

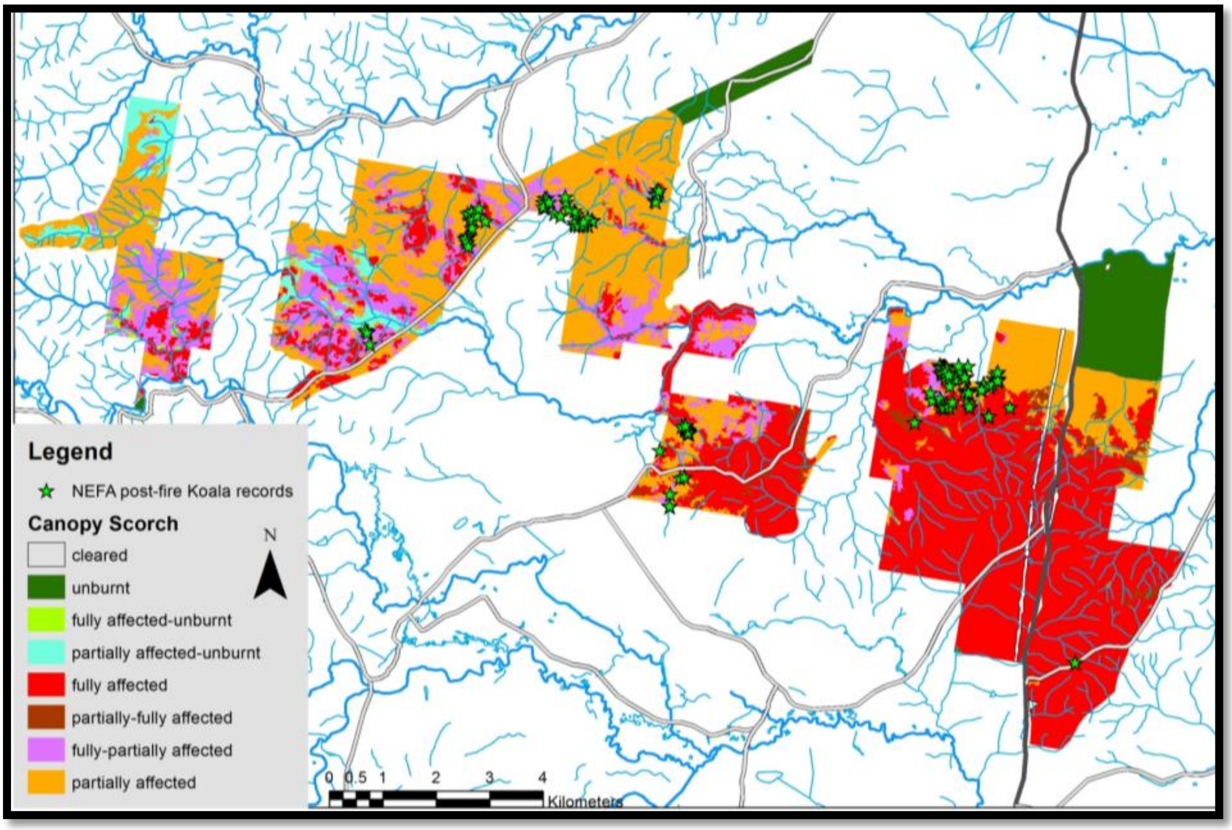
A key issue for consideration of impacts is the effects of fire on tree canopies. This provides an indication of the heat of the fire, and thus likely Koala mortalities, and the availability of forage after the fires.

Three versions of the NSW Government's Geebam mapping were reviewed and while generally consistent were found to be significantly different in places. Some patches mapped as canopy "fully affected" in one version were mapped as "unburnt" in another. None of the versions were found to be satisfactory based on NEFA's observations.



Examples of GEEBAM mapping showing significant differences between versions. The earlier version (v2) was considered to better represent the extent of the 'canopy fully affected class' for the purpose of assessing impacts on Koalas.

For NEFA's assessment versions 'v3p0_dNBR_Classes' and 'v2_20191218_JulDec_Comb_dNBR_Classes' were manually digitised to amalgamate areas and smooth boundaries, at the same time combining both mappings into a single set of classes reflecting the overlaps between the two mappings. This was considered to best represent our observations. The most significant change with the later mapping was the remapping of large areas from fully to partially affected (classed as fully-partially affected below), which was particularly concerning as NEFA's observations had identified these as significantly affected. This categorisation gave apparent conflicting classes, such as "fully affected-unburnt" that were taken to have had medium disturbance.



NEFA's mapping of affected forests (derived from NSW's GEEBAM fire intensity mapping and ground assessments) overlaid with NEFA's post fire Koala records.

While data from structural plots was not collected with a view to validating the Geebam mapping, it was belatedly realised that collection of canopy data would assist in quantifying fire affects. Data on tree canopy condition was collected at 45 plots, where canopies were classed as poor brown (no or few green leaves), poor green (< 25% of canopy with green leaves), med green (25-75% with green leaves) and good green (>75% of canopy with green leaves). This was combined with tree size data (basal area was used as a surrogate for relative canopy size) and mapped canopy loss classes to derive estimates of canopy loss (of trees over 20cm dbh). Across the 6,458 ha of burnt forest a total of 77% of the canopy is estimated to have been lost due to the fires and associated drought.

Burn Class	Extent (ha)	Canopy loss %
partially affected-unburnt	202.5	0.2*
fully affected-unburnt	24.9	0.5*
fully affected	2972.3	0.99
fully-partially affected	819.7	0.88
partially-fully affected	110.0	0.7*
partially affected	2328.4	0.52
TOTAL	6457.8	0.77

* guesstimates

NEFA's post fire searches found little evidence (scats) of post-fire Koala use of areas of fully fire affected canopies. NEFA searched some previously identified extensive Koala High Use Areas, known Koala locations, as well as random searches in areas where canopies were fully affected, with no post-fire Koala scats found in most areas. Given the reported propensity for Koalas to escape fires by climbing higher, the lack of post-fire scats indicates the Koalas were killed. Koala scats were found in a few marginal sites, though in most cases they were one-off uses (i.e. before Grey Gums shed their remaining canopy), with the exception of one Grey Box which had a good canopy remaining. With little food, any surviving Koalas would have soon been in trouble.

It is therefore assumed that all Koalas were lost from the 3,792 ha of 'fully affected' and 'fully-partially affected' forests, comprising 59% of the burnt area.

The average canopy loss across the 2328.4ha mapped as 'partially affected' was around 52%. As expected, canopy loss decreased in line with tree size, with the larger trees retaining most canopy. This emphasises the importance of retaining large trees both as fire refuges and for food after fires.

Size Class (cm dbh)	No	Canopy Loss (%)
60+	15	40
45-59.9	24	44.8
30-44.9	86	57.3
20-29.9	100	63.7
TOTAL	**225**	**51.8**

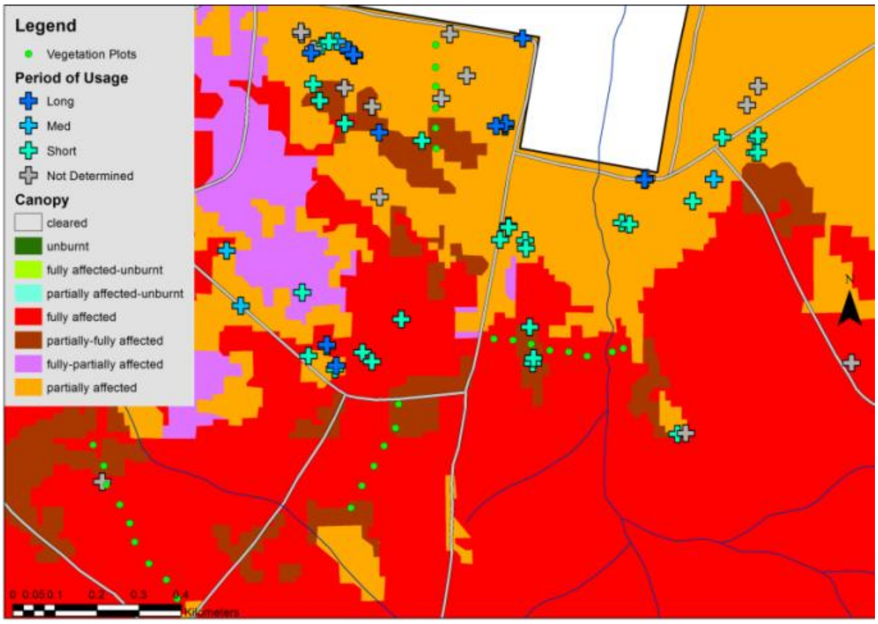
Percentage of canopy loss by size class within partially burnt canopy areas

The plot data support the observation that of the Koala feed trees, Grey Gum was disproportionately affected by the fire with 82% loss of canopies. This will have had a disproportionate affect on Koalas given that Grey Gums are favoured feed trees and Koala's preference for a variety of feed trees. Conversely Grey Box was relatively least affected with 24% loss of canopies, which partially reflects the relatively higher numbers of larger trees, though also indicates higher resilience to fires. The smooth trunked Grey Gum and Red Gum continued to shed their canopies for a month after the fires. After then Grey Box became the mainstay of surviving Koalas.

Koala Feed Trees	Canopy loss on partially burnt sites (%)
Grey Gum	82.2
Red Gum	58.9
Grey Box	23.5
TOTAL	49

While the canopies of Grey Box were relatively resilient, their bases were particularly susceptible to burning leading to tree collapse. Numerous larger trees were burnt out at the base and collapsed over the few weeks after the fire front passed through. A random sample of a total of 73 such trees from 4 sites found that they had an average diameter of 40.4 cm dbhob (range 15-100cm dbhob), with Grey Box comprising 83% (61) of fallen trees, Red Gum 7% (5) and Spotted Gum 10% (7). Grey Box are the most abundant Koala feed trees in the proposal, so the impacts of the loss of a proportion of mature feed trees will depend on whether the lost trees were some of those preferentially utilised by Koalas.

The total loss was around 52% of canopies in the partially affected forests which it is considered likely reflects the magnitude of the initial decline of Koalas in these areas. Because of the ongoing drought and extreme conditions there appeared to be a further 67-79% decline in the use of trees over time after the fire based on monitoring of scats, which coincided with a decline in the variety of scats being found, indicating a significant population decline in the 3 months after the fires. It is hoped that some may have found refuge elsewhere.



Trees found with Koala scats, identifying those considered to have been sufficiently revisited to identify ongoing use. Basically, many trees used initially were found to have been abandoned over time indicating a population decline, with only ten trees used consistently,

Overall an indicative loss of over 75% of Koalas is assumed from the 2,666 ha of partially burnt forests. Such a magnitude of decline corresponds with general observations. When added to the apparent 100% loss of Koalas in the 3,792 ha of 'fully affected' and 'fully-partially affected' forests, this suggests an overall decline of around 90% across the burnt forests.

The evidence thus suggests an overall decline in Koalas of around 90% across the burnt forests. with around 10% of this due to the ongoing drought after the fires and lack of comprehensive assistance to survivors. Given that 440ha escaped the fires, it is assumed that 84% of the Koala population was lost.

Even though 84% of the Koalas within the proposed reserve are likely to have been lost, good recovery of most Koala feed trees appeared to be occurring at the end of the observation period. It will take decades for the Koala population to recover, provided there is not another wildfire of similar magnitude. Though with the ability of habitat values to dramatically increase as the forest ages it has the potential to once again become exceptional Koala habitat.

The proposed Sandy Creek Koala Park is part of the Banyabba ARKS, stretching from Casino south to Lawrence on the Clarence River and from the foothills of the Richmond Range through to Iluka on the coast. This encompasses 71,000 ha of likely Koala habitat (KHSM, classes 4&5), of which 59,000 ha was burnt. If a 90% mortality is assumed for the burnt areas, this suggests the loss of 75% of Koalas from the Banyabba population.

Such broad estimations do not take into account the decimation of core high-density colonies responsible for maintaining the overall population. The loss and decimation of core Koala colonies is the biggest threat to the ongoing viability of the Banyabba population. With the known core colonies identified in Royal Camp, Carwong and Braemar State Forests, along with over 800ha of the Ashby core Koala habitat, all significantly reduced - these fires are likely to have significantly increased the vulnerability of this population to extinction.

Across north-east NSW 29.4% of likely Koala habitat (KHSM, classes 4&5) has been burnt. The results from the proposed Sandy Creek Koala Park suggests 26% of Koalas have likely been killed, with the numbers depending on what the population was to start with. An expert workshop in 2012 estimated that Koala populations on the north coast had declined by 50% in the past 20 years, leaving an extant population of around 8,400 Koalas, over 2000 of which may of been killed last year. Though the key issue is how individual populations have fared, and their current status.

4.1.2. Post-fire Logging of Banyabba Koalas

On 3 March 2020 the Environment Protection Authority (EPA) approved the Forestry Corporation to undertake logging of burnt Koala habitat in three State Forests on the Richmond River lowlands. Given the failure to account for the landscape scale impacts of the fires on this Koala population, this approval was irresponsible and jeopardises the Koala's recovery, and possibly the survival of this population.

The EPA have been requested to withdraw their approvals for logging of Koala habitat in Bungawalbin, Doubleduke and Myrtle State Forests and to do due-diligence by assessing the landscape impacts of the fires on Koalas. As shown by this example, a moratorium is needed on further logging of populations of all species significantly affected by the fires until surveys are undertaken to assess their vulnerability.

The approved logging is in parts of the 142,000 ha Banyabba Area of Regional Koala Significance (ARKS) that had 83% of its modelled 71,000 ha of 'likely' Koala habitat burnt in the 2019 wildfires, with the apparent loss of 90% of Koalas from burnt areas (see 4.1.1.).

Given that the Banyabba Koala population had already been reduced by at least 57% due to clearing and logging, and more due to other factors, and was identified as in decline before the fires, the loss of three quarters of survivors due to the 2019 fires is a highly significant landscape scale impact on this vulnerable population of Koalas which may jeopardise its survival.

The intent is to now cut down feed and roost trees in surviving pockets of Koalas, based on token changes to inadequate logging rules that do not contemplate such landscape impacts. As the loggers stumble about in the fire ravaged homes of these imperilled Koalas they have no idea of the damage they are doing and they simply don't care. The risks of their blundering into homes of Koalas barely surviving the fires and vital habitat needed for population recovery is too high.

Many regrowth trees have been killed, and with recovery delayed by drought it is apparent that there has been significant death of canopy trees in some heavily burnt areas. Coupled with the loss of most local pine plantations, the viability of a timber industry based on public lands in this region needs to be reconsidered.

The EPA should never have issued approvals for logging of Koala habitat within the decimated Banyabba Koala population without consideration of the impacts of the fires on this population. The inquiry is asked to support the withdrawal of the 3 logging approvals issued by the EPA on 3 March 2020 until there has been the needed assessment of the effects of the fires on the population, and professional surveys before logging. This case demonstrates the need for a moratorium on further logging of all populations of species significantly affected by the fires.

Based solely on the decline in food resources, it can be assumed that 23% of the Koalas in the Banyabba ARKS have been lost because of land clearing. In a regional context across the Richmond Lowlands the losses are likely over 80%.

Within the Banyabba ARKS Koala populations are likely to more than have halved in the 87% of 'likely' Koala habitat logged, making logging responsible for a loss of more than a third of Koalas over the past 100 years. There are numerous other factors affecting Koala survival such as fragmentation, vehicle collisions and dog attacks near urban areas, increasingly droughts and heatwaves due to climate heating, and on top of all this are wildfires which are also increasing in frequency and intensity because of climate heating

Before the 2019 fires, Koalas across the Banyabba ARKS had been assessed as being in rapid decline (White *et. al.* 2015, Phillips and Weatherstone 2015). Within the area assessed by NEFA there was estimated to be a loss of around 90% of Koalas from the forests burnt in the 2019 fires. This indicates the loss of some 75% of Koalas from the remnant Banyabba population.

It is now evident that across extensive areas of the Banyabba ARKS that most Koalas have been killed, and that on heavily burnt sites a high proportion of trees have been killed, causing long-term degradation of Koala habitat and significant loss of current and future timber resources.

The current Koala feed tree retention requirements are less than half that recommended by the EPA, OEH and the Government's Expert Fauna Panel. The EPA's new approval does little to explicitly redress this deficiency, aside from requiring the Forestry Corporation to temporarily set aside 7% of the logging area, with Koala feed trees one consideration in their selection. Even without accounting for fire impacts these requirements are patently inadequate.

Despite the evidence of the fires' significant impacts on the already declining Banyabba Koala population, there is apparently no effort being made to assess the status and current vulnerability of the surviving Koalas. It is business as usual as they continue to log and degrade the least affected forests that may be vital to the ongoing viability of this population. This careless approach to the survival of Banyabba Koalas is reprehensible.

The EPA (2016) undertook intensive systematic Koala surveys in Royal Camp and Carwong State Forests in 2015, and therefore have good quality baseline data from before the fire that they could resample to accurately identify the magnitude and nature of impacts of the fires upon Koalas, yet both the EPA and their Minister have refused NEFA's requests to resurvey these forests to assess the impacts of the fire.

The NSW Government still don't know what the magnitude of the impacts are or whether the Banyabba population is in imminent danger of collapse, and nobody wants to know. As they stumble about in the ravaged homes of these imperilled Koalas they have no idea of the damage they are doing and they simply don't care.

The burnt koala habitat they are proposing logging in Bungawalbin, Doubleduke and Myrtle State Forests comprise integral parts of the imperilled Banyabba population. There are high risks of their blundering into homes of Koalas barely surviving the fires, and vital habitat necessary to rebuild the depleted population.

The EPA should never have issued these approvals without consideration of the impacts of the fires on the Banyabba Koala population, and the inquiry is asked to support the withdrawal of these logging approvals. This case demonstrates the need for a moratorium on further logging of all populations of species significantly affected by the fires.

Ellangowan State Forest 3 months after the fires - displaying the delayed recovery.

4.1.2.1. The failure of the Logging Rules

The 2019-2020 wildfires burn out 2.4 million hectares of north-east NSW (north from the Hunter River), burning through around half the remnant native vegetation. These fires were unusually extensive and intensive because of record low rainfalls and extreme temperatures. Such extensive disturbance undermined the basic assumptions on which the Integrated Forestry Operations Approval for Forestry Corporation's logging are based.

As recognised by the EPA website (accessed 10 April 2020) "*The Coastal Integrated Forestry Operation Approvals (IFOA) was not designed to moderate the environmental risks associated with harvesting in landscapes that have been so extensively and severely impacted by fire*".

The 2018 IFOA is based on *"a new multi-scale landscape-based protection approach that applies habitat protections at the site, local landscape and broader landscape scales*", with the aim "*to ensure that multi-aged forests and connected habitat are maintained in the landscape to allow for native species persistence and re-colonisation of harvested areas*".

Underpinning the setting of prescriptions for threatened species was the assumption that when combined with the dispersal of logging operations in time and space, sufficient habitat for threatened species would be retained in formal and informal reserves to offset logging impacts.

An EPA factsheet for the IFOA states:

> *The multi-scale approach in the proposed Coastal IFOA delivers a comprehensive threatened species protection model for the coastal timber production forests of NSW. It provides important habitat resources at the site, local and broad landscape scales. Stronger protections are applied as you work down the scales.*
>
> *This multi-scale approach also ensures the maintenance of multi-aged forest across the landscape and the retention of undisturbed habitat. This will provide areas of refuge, as well as connectivity and dispersal opportunities for native species.*

The Integrated Forestry Operations Approval (IFOA, 15.2) has as objectives:

> *15.1 In relation to **threatened species** conservation and **biodiversity**, the **approval** has the following specific objectives:*
>
> > *(a) to set out the minimum measures required to be implemented to protect **species**, communities and their **habitats** from the impacts of **forestry operations**;*
> >
> > *(b) to set out multi-scale protection measures that ensure sufficient and adequate **habitat** is provided at the site, **local landscape area**, and **management zone** scales; and*
> >
> > *(c) to set out measures for **species** or communities that require specific measures to ensure **habitat** is protected around known occurrences; and*

Given the EPA's acknowledgement that the IFOA is no longer fit-for-purpose, they state "*This has required the EPA to issue additional site-specific conditions that tailor protections for the specific circumstances of these burnt forests*".

On the 3 March 2020 the EPA issued site-specific operating conditions for logging of burnt Koala habitat in **Bungawalbin State Forest**, Compartments BWN 001, 002, 003, 004, 005, **Doubleduke State Forest** compartments DOU001, DOU002, DOU003, DOU004, DOU005, DOU006, DOU007 and DOU008, and **Myrtle State Forest** compartments MYR010, MYR011, MYR012, MYR014, MYR015 and MYR016.

These were part of a tranche of generic site-specific requirements issued for Bagawa, Collombatti, **Girard, Riamukka and Styx River State Forests.**

These were intended to complement the requirements of the 2018 Coastal Integrated Forestry Operations Approval (IFOA) and included a suite of generic 'site-specific operating conditions' issued pursuant to condition 23.4 of the Integrated Forestry Operations Approval for the Coastal Region which states:

> *23.4 If applying a condition of the **approval** at a specific site would result in a poor environmental outcome, or if in a specific and unique circumstance **FCNSW** would not be able to comply with the conditions of the **approval**, then prior to commencing the relevant **forestry operation**:*
>
> > *(a) **FCNSW** may submit a report to the **EPA** in accordance with **Protocol 5: Approvals for restricted activities**; and*
> > *(b) the **EPA** may grant a **site-specific operating condition** in response to the report ...*

NEFA is not privy to the FCNSW report that the variations are based on

NEFA agrees that the IFOA is not fit-for-purpose in a heavily burnt landscape. Though neither is one-size-fits-all set of generic add-ons that are applied across dispersed and very different environments and circumstances across north-east NSW.

The EPA website claims "*Approvals are issued on a case by case basis*", yet it is clear that in issuing these generic approvals with the same conditions across widely dispersed operations that the EPA has not assessed nor considered the impacts of the fires on threatened species at a site specific or local-landscape level. The generic wording proves that the EPA did not bother to undertake a desk-top assessment of the individual compartments, assess the effects of the fires on local populations, nor undertake ground based assessments, before issuing their new conditions.

Even before the fires, and with landscape provisions intact, the EPA clearly did not consider the IFOA's baseline retention of 0-5 small Koala feed trees per hectare applied to these forests as adequate. Based on the advice of the Government's Expert Fauna Panel, for Koalas the EPA proposed a retention rate of 25 feed trees per hectare >25 cm dbh within High/high quality habitat, 20 feed trees per hectare in High/moderate quality habitat, and 15 feed trees per hectare in Moderate/moderate quality habitat. On the basis of resource impacts this was reduced to 10 feed trees per hectare >20cm dbh in High/high quality habitat and 5 feed trees per hectare within compartments with more than 25% High/moderate or moderate/moderate habitat.

The OEH (2018) complained that there will "*be a reduction in protections offered to koalas*", with Koala feed tree retention rates "*less than half those originally proposed by the Expert Fauna Panel*", noting:

> *"The increased logging intensity proposed under the draft Coastal IFOA is expected to impact Koalas through diminished feed and shelter tree resources. Animals will need to spend more time traversing the ground as they move between suitable trees that remain, which is likely to increase koala mortality".*

The EPA's (2016) study in these forests found that Koala's prefer trees >30cm diameter, with use increasing with tree size, which NEFA's findings support.

As detailed in Section 4.1.1. the Banyabba Koala population is one of the worst affected by the fires in NSW, with the likely loss of 90% of Koalas from burnt forests and an overall 75% reduction in the Banyabba population. The EPA's failure to consider the status of the Banyabba Koala population is amply demonstrated by the example of Bungawalbin State Forest, the whole of which the EPA have approved for logging under their new generic prescription.

Of the 1,200 ha Bungawalbin State Forest just 160ha (13%) remains unburnt. The southern 73% of the forest was logged in 2017-18 and then burnt in 2019 with the canopy fully affected over most of the area (including exclusions), leaving no refuges for Koalas or other vulnerable species.

The northern 27% was not then logged, and half it escaped burning, with the other half lightly burnt with limited canopy damage. This is likely the only remaining refuge for Koalas within Bungawalbin State Forest, and our brief visit proved widespread Koala usage before the fire and that they have utilised both the burnt and unburnt areas since. The burnt part is the area the EPA have approved for logging, apparently without any site assessment.

At the Banyabba ARKS population level 83% of 'likely' Koala habitat burnt, meaning that at all scales this population has been significantly affected by the wildfires. With it likely that 90% of Koalas were killed in burnt forests, any patches with surviving Koalas that are capable of supporting breeding females are of exceptional importance to the recovery of the Banyabba population.

It is also now apparent that there is widespread death of canopy trees in areas heavily burnt, including in what had been Koala high use areas, which will greatly hinder the recovery of Koalas, and the sustainability of logging. This needs to be accounted for.

The risks of the Forestry Corporation blundering into homes of Koalas barely surviving after the fires, and patches of habitat vital to the population's recovery, is too high. Should they identify such patches there is nothing requiring them to be protected.

Aside from the protection of unburnt forests, the only new measure in the variation that appears intended to mitigate impacts on Koalas is a requirement to retain 'Temporary feed tree clumps', additional to other exclusions, over 7% of the burnt logging areas. Koala browse trees over 20 cm diameter are one consideration in selecting these temporary retention areas, though their selection is at the discretion of the forester on the day and they can be used to satisfy the IFOA Koala feed tree retention requirements or other requirements. So these additional exclusion will not necessarily protect many, if any, additional potential Koala feed trees.

This is yet another politically compromised theoretical desktop construct, to add to the already deficient (as emphasised in the EPA's submission to the NRC) requirement to retain at most 5 small Koala feed trees per ha in these forests. Both these are untested, with no trials, monitoring or evaluations. The EPA's intent to require some unspecified monitoring to assess the efficacy of the prescriptions without any baseline is a poor joke.

Given the low density of Koalas, the dispersed nature of their feed trees, and their preference for larger trees of a variety of species, small arbitrarily chosen trees and exclusions are likely to be of limited, if any, benefit to surviving Koalas in this heavily impacted population, as the EPA well know.

The EPA cannot justify a claim that "*the environmental risk*" of logging burnt Koala habitat in the Banyabba population will be "*reasonably mitigated*" by the revised prescriptions. It s clear that they made no attempt to assess the risk to the Banyabba Koala population or identify the specific mitigations required.

With such extensive landscapes and populations burnt, impacts on threatened species cannot be dispersed through time and space as was the precept of the IFOA. With the regional mitigation measures so compromised the local landscape and site mitigation measures cannot work, even if they were designed to do so. Logging now will just compound already severe impacts.

The EPA (2016) undertook intensive systematic Koala surveys in Royal Camp and Carwong State Forests in 2015, and therefore have good quality baseline data from before the fire that they could resample to accurately identify the magnitude and nature of impacts of the fires upon the Banyabba Koalas, yet both the EPA and their Minister have refused NEFA's requests to resurvey these forests to quantify the impacts of the fire.

Despite the evidence of the fires' significant impacts on the already declining Banyabba Koala population, there is apparently no effort being made by the Government to assess the status and current vulnerability of the surviving Koalas. This is the sort of baseline data the EPA need before they can validly assess impacts of prescriptions on burnt Koala habitat and make any claims regarding the additional impacts of logging.

Across the fire grounds the fires have overwhelmed the ecological offsets and sustainability of resources on which the IFOA is predicated. The broad landscape impacts of the 2019 wildfires were not envisioned in the formulation of the IFOA, as such it cannot meet its objectives and is now invalid. There is an urgent need to undertake a total revision of the settings of the IFOA in accordance with its objectives. This will require significantly increasing protections for an array of species, including the Koala, to offset the significant impacts of the fires on populations of these species. In the interim there must be a moratorium on logging of habitat of the most impacted species.

As the sun sets on Ellangowan SF 6 months after the fires it is apparent that most trees in this heavily burnt stand are not going to recover, diminishing Koala's future prospects.

4.1.2.2. Impacts on Banyabba Koala population.

The Environment Protection Authority (EPA) has approved the Forestry Corporation to undertake logging of burnt Koala habitat in parts of three State Forests on the Richmond River lowlands: Bungawalbin, Doubleduke and Myrtle State forests.

The DPIE have identified Areas of Regional Koala Significance (ARKS) across NSW. These need to be considered the population level at which we consider Koalas. The Banyabba ARKS stretches from Casino south to Lawrence on the Clarence River and from the foothills of the Richmond Range through to Iluka on the coast. Bungawalbin and Doubleduke State Forests are within this ARKS, and Myrtle State Forest is an inholding.

NEFA has undertaken numerous random searches for Koala scats at various localities and times since 2012 within the Banyabba ARKS - in Royal Camp, Gibberagee, Braemar, Carwong, Ellangowan and Bungawalbin State Forests.

NEFA's results from most of these assessments have been published on NEFA's website as components of various audits. These, and additional observations since the fires, are discussed in Section 4.1.1. and are currently being compiled into a Sandy Creek Koala Park proposal which will be published on NEFA's website when finished.

Koalas have long been assessed as in decline in the Banyabba ARKS. A study of Koalas in the south-east of the Banyabba ARKS (White *et. al.* 2015) found:

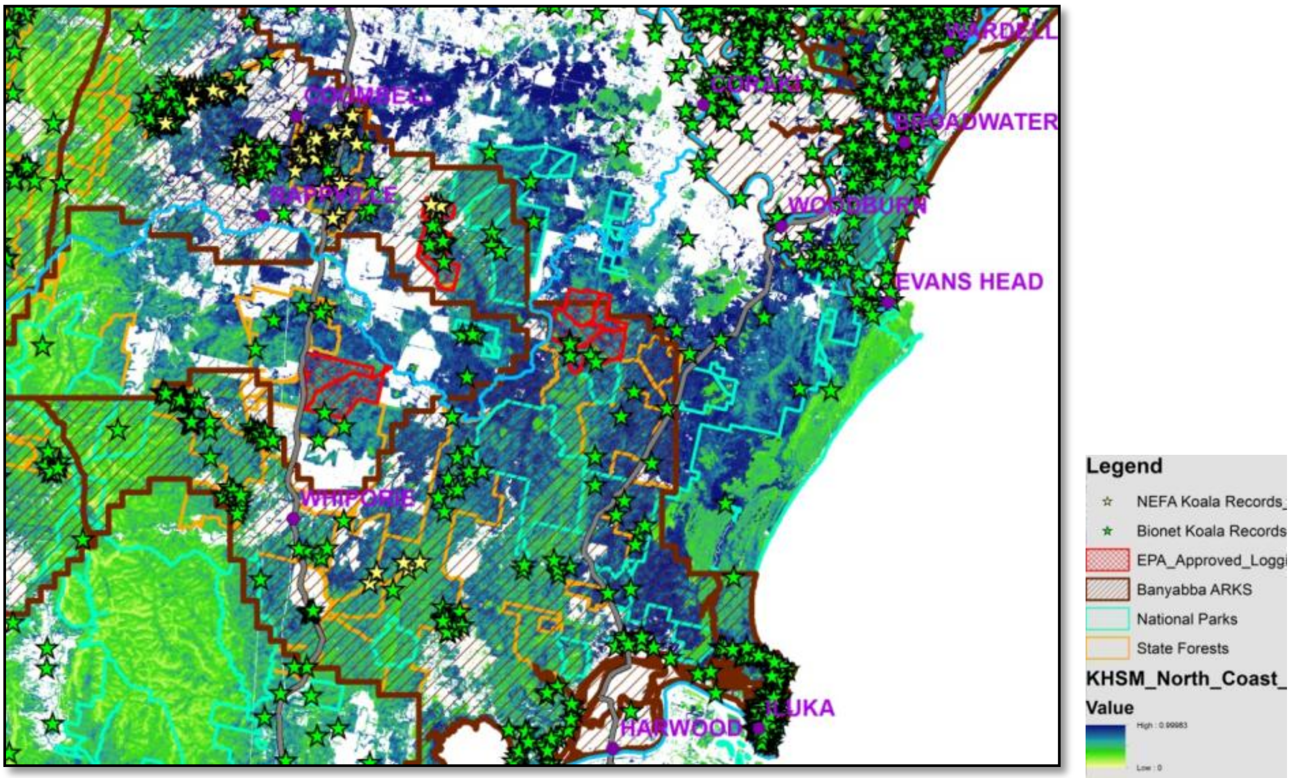
> *Koala numbers within the Ashby area are under threat due to continuing fragmentation of suitable habitat. The Woombah koala population is in imminent danger of extinction and there is only evidence of recent activity in the North Western part of Woombah. The NSW recovery plan (research by Luney et al 2002) suggests that the Iluka koala population was extinct in 1999 but ongoing sightings in the village and along Iluka Road suggest there may be a viable population in the National Park to the North.*

A study of Koalas across the Richmond Valley LGA (Phillips and Weatherstone 2015) identified:

> *Extent of Occurrence of koalas across the RVLGA has remained relatively unchanged over time. However, further analyses of habitat occupancy rates has indicated a statistically significant decrease over the last 3 koala generations of ~33% in the amount of habitat actually being occupied by koalas. This trajectory, if left unchecked, will lead to increasing endangerment of the RVLGA's koala populations over coming years.*

The DPIE have prepared a Koala Habitat Suitability Model (KHSM) for the north coast that predicts the spatial distribution of potential koala habitat across NSW using a value between 0 and 1 (i.e. a higher value represents a higher probability that a specific location will contain habitat suitable for koalas). The model provides an indication of where koalas have the potential to reside but are not necessarily currently occupied. The Government's recent Koala SEPP incorporates a 'Koala Development Application Map' which identifies this highest classes of the KHSM as '*highly suitable koala habitat ... likely to be occupied by koalas*'. KHSM classes 4 and 5 are used in this assessment to be 'likely' Koala habitat.

The KHSM shows the patchiness of very high quality "likely" Koala habitat within a matrix of variable quality habitat. This illustrates that there are pockets of high quality Koala habitat within a landscape matrix with the potential for a large and viable Koala population. This model does not account for past logging, and the resultant removal of the large feed trees relied upon by Koalas. Koalas are now concentrated in patches where there are enough larger (>30cm diameter) feed trees, with use increasing with the diversity and size of feed trees. Their distribution and abundance is further limited by fragmentation, droughts, fires, road strikes, and dog attacks.



DPIE Koala Habitat Suitability Model, with the dark blue areas showing 'likely' habitat. Overlaid with Koala records and the EPA approved logging areas.

Before the fires, core colonies occurred in patches across the landscape where there were sufficient resources for breeding, these patches were vital to allow the dispersal of young Koalas to sink habitat. Where resources were limited or subject to perturbations Koala likely suffered a high mortality, with numbers sustained by dispersal from core habitat.

The clearing of the Richmond River lowlands has been severe. For example according to the DPIE multi-attribute mapping native forests cover 19% of the Richmond River Floodplain and footslopes. The clearing of 80% of native forests will have had a significant impact on Koalas. The Banyabba ARCS encompasses a significant proportion of the vegetation remaining south of the Richmond River.

Within the Banyabba ARKS around 32,000 ha (23%) of native vegetation has been cleared. While this is likely to have been the most productive vegetation, if the ratio of high quality Koala habitat in remaining vegetation (65%) is applied, then at least 21,000 ha of high quality Koala habitat has been cleared, likely resulting in at least a 23% decline in the Koala population.

In the Spotted Gum dominated forests NEFA and the EPA (2016)'s records show that Koala's use a variety of select species, though because of their widespread abundance primarily depend on Coastal Grey Box (*E. moluccana),* Small-fruited Grey Gum (*E. propinqua*), and the red gums Forest Red Gum (*E. tereticornis)* and Slaty Red Gum (*Eucalyptus glaucina)* for food. The evidence from both our observations and the EPA (2016) study is unequivocal that Koalas rarely use trees smaller than 20 cm diameter and that use increases linearly with tree size. They prefer larger trees, though even then they are selective in their use of apparently similar trees. They also prefer patches with at least two or three larger feed tree species. See Section 4.1.1.1.

The smooth bark of Grey Gum is the most readily scratched by Koalas, and can retain patches of lower bark for a number of years, they thus provide a record of Koala use over years. Grey Gum is common, with larger trees patchily distributed across the forests. The distinctive scratches show that Koalas are roaming widely through the forests over time, even where larger Grey Gum are widely scattered and there are no scats to indicate recent use.

Within the areas of potential 'likely' Koala habitat, suitability and use is determined by the numbers and variety of larger feed trees.

NEFA's 12x500m^2 structural plots in oldgrowth and 75x500m^2 plots in regrowth forests indicate that there has been an overall decline of 25% in the number of trees over 30 cm dbh due to logging over the past century, with 79% of trees over 60cm dbh and 57% of trees 45-60 cm dbh removed. There has been a corresponding 215% increase in trees 30-45 cm dbh, showing the significant reduction in the age of the forests. It is evident that the increased losses of larger feed trees preferred by Koalas will have had a disproportionate impact on their food and population.

NEFA identified a reduction in basal area from 40.7 m^2 per hectare in oldgrowth down to 20.2 m^2 in logged forests (Section 4.1.1.1.). Halving of the biomass is part of the cost of a hundred years of logging, and can be costed as the value of timber lost, the volume of Koala browse lost, and the volume of carbon released to the atmosphere from the biomass and the soils. It also shows the massive contribution trees can make to climate heating if they are allowed to recover and recapture that carbon from the air and store it in their growing trunks and soils (see Section 5.2).

Of the 71,000 ha of 'likely' Koala habitat (KHSM classes 4 and 5) across the Banyabba ARKS, some 9,000 ha remained as oldgrowth in 1998 (CRA CRAFTI mapping). While this will have since declined due to logging, it can be assumed that over 62,000 ha of 'likely' Koala habitat has been logged, and likely lost over half their potential koala browse and half their Koalas over the past 100 years. Logging has significantly affected the distribution of resources used by Koalas, and with other stressors made many areas uninhabitable.

Based solely on the decline in food resources, it can be assumed that 23% of the Koalas in the Banyabba ARKS have been lost because of land clearing and 34% due to logging over the past 100 years. There are numerous other factors affecting Koala survival such as fragmentation, vehicle collisions and dog attacks near urban areas, increasingly droughts and heatwaves due to climate heating, and on top of all this are wildfires which are also increasing in frequency and intensity because of climate heating.

The Forestry Corporation and EPA have determined to halve the basal area again, reducing retention requirements down to $10m^2$ per hectare in logged forests, focussing on removing most of the already depleted larger trees. With the increased regrowth drying out the forests and making them more vulnerable to wildfires, this further reduction in the larger feed trees required by Koalas further threatens their survival.

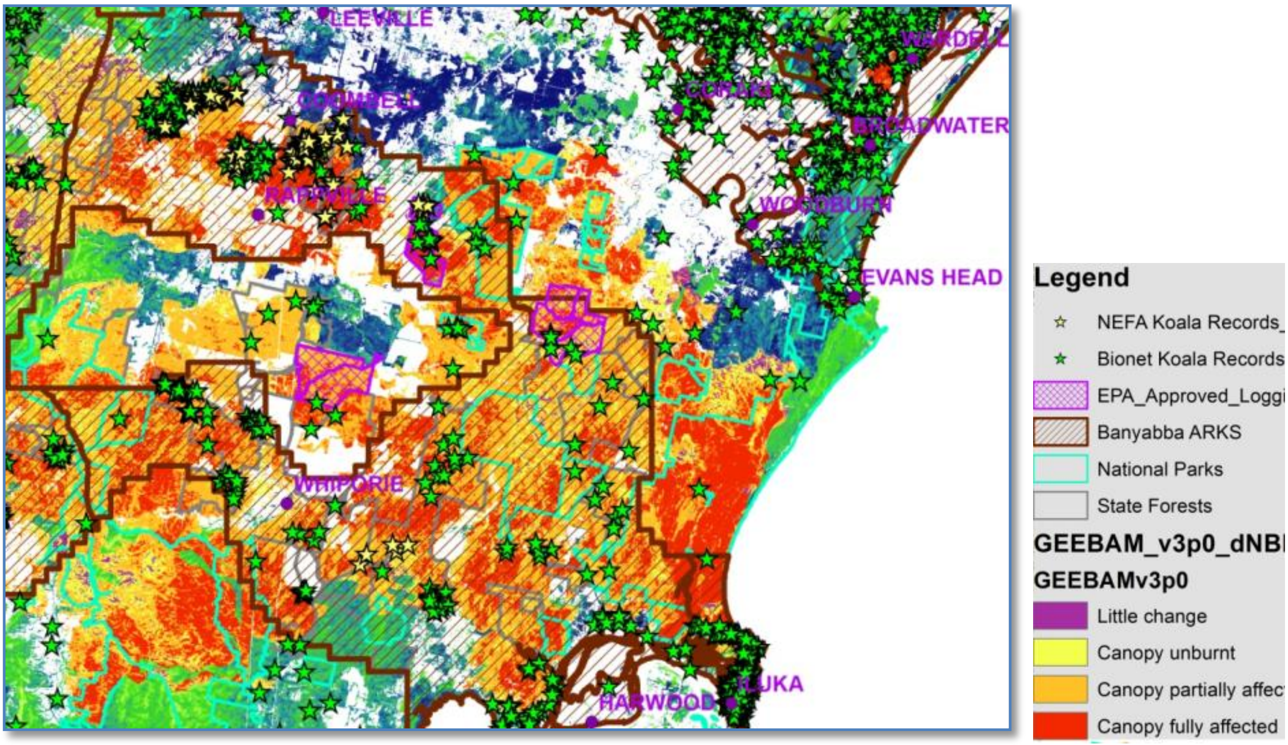
The 2019 Busby's Flat and Myall Creek fires burnt through 59,000 out of the 71,000 ha of 'likely' Koala habitat (KHSM classes 4 and 5) across the Banyabba ARKS, starting with the Busby's Flat fire burning out most of the Koalas in Mount Royal, Carwong, Braemar and Ellangowan State Forests on the night of 8 October2019.

The 2019 fires burnt through 83% of the 'likely' Koala habitat in the Banyabba ARKS,

Across the7,000 ha assessed by NEFA (Section 4.1.1.), the fire consumed most of the understorey, turning most logs and stumps to ashes. The overstorey was mostly desiccated by the heat of the ground fire, with limited crowning. The leaves rapidly turned brown leaving 59% of the fireground with dead canopies. NEFA found little sign of Koala activity, such as scats, in the heavily burnt areas after the fires to indicate any survivors, including in areas we had found high usage before the fires. It is thought that the fire was too hot for most Koalas in these areas and they were killed, though only three dead Koalas were found.

The forests were regularly assessed up until mid January 2020. By then most Koala feed trees were showing the beginning of epicormic growth, though most Spotted Gum in heavily burnt areas were showing little sign of recovery.

A recent visit in late March 2020 to heavily burnt Koala sites in Ellangowan SF showed some loss of previously identified feed trees (mostly Grey Box), though most surviving feed trees were reshooting. None of the previously used Koala feed trees had been used since the fire. Many potential feed trees were observed to have been killed in surrounding areas. Though it is now clear that in these heavily burnt forests that a high proportion of the Spotted Gum are not going to recover, which will significantly degrade the structure of the forest, and the quality of the habitat.



Burn native vegetation in the 2019 wildfires, with GEEBAM canopy burn mapping by DPIE

Photos of a badly burnt section of Ellangowan State Forest in late March 2020 show the widespread death of trees, with shrubs gone, most small trees killed and a significant proportion of large trees killed or badly damaged. Even though most Koala feed trees are recovering, many Grey Box died, and it is unknown how many decades it will take before this badly degraded structure is able to support stable Koala colonies again. With no evidence of Koala use since the fire was their repopulation will depend upon young Koalas dispersing from remnant patches of good habitat, though it will take a long time to repopulate such areas.

There is already dense wattle regrowth in areas, so the opening of the canopy will allow dense regrowth which will further dry the forest, add fuel and make the most heavily burnt areas far more susceptible to repeat and hotter burning, further jeopardising the survival of this population.

In the area assessed by NEFA (Section 4.1.1.3.) there was an overall estimated loss of around 90% of Koalas from burnt areas. NEFA's results indicate the loss of some 75% of Koalas from the pre-fire

Given that the population had already been reduced by at least 57% due to clearing and logging, and more due to other factors, a loss of three quarters of the remnant population is a highly significant landscape scale loss.

Such broad estimations do not take into account the decimation of core high-density colonies. These are the source areas essential to maintain the viability of colonies and ultimately the survival of the overall population. Their loss or degradation will have a disproportionate impact on the overall Banyabba population.

Photos of a badly burnt section of Ellangowan State Forest in late March 2020, almost 6 months after the fires, note the widespread tree death.

population and its persistence, to the point of disintegration and collapse. Known core Koala colonies at Ashby and in Royal Camp, Carwong and Braemar State Forests were badly affected.

The impacts of the 2019 fires on the Banyabba Koala population occurred during a period of extreme temperatures and dryness, with recovery only starting after rains in late December. This delayed recovery greatly compounded the impacts of the fires on all wildlife, including Koalas.

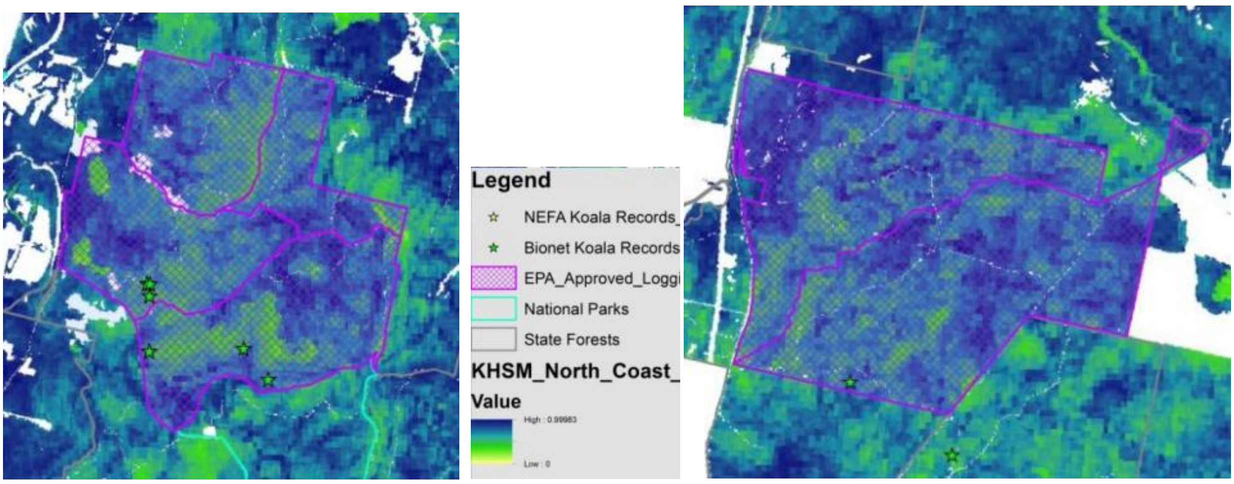
It is now evident that across extensive areas of the Banyabba ARKS that most Koalas have been killed, and that on heavily burnt sites a high proportion of trees have been killed, causing long-term degradation of Koala habitat and significant loss of current and future timber resources.

The survival of the Banyabba Koala population has to be considered in jeopardy, logging of remaining feed and roost trees could push this population over the precipice. Despite the evidence of the fires' significant impacts on the already declining Banyabba Koala population, there is apparently no effort being made to assess the status and current vulnerability of the surviving Koalas. It is business as usual as they continue to log and degrade the least affected forests that may be vital to the ongoing viability of this population. This careless approach to the survival of Banyabba Koalas is reprehensible.

4.1.2.3. Post-fire Logging

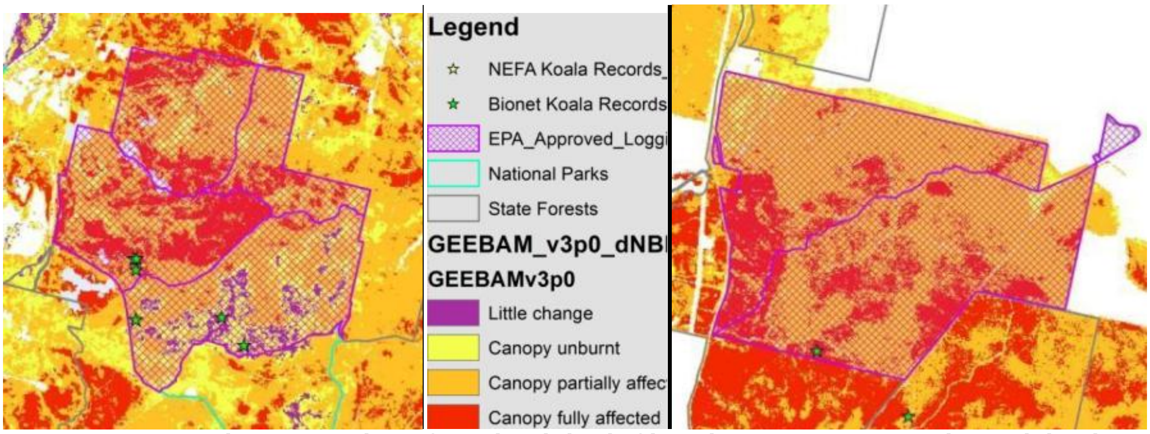
The EPA have approved 3 areas for logging on the Richmond Lowlands, Bungawalbin and Doubleduke State Forests are within the Banyabba ARKS. Myrtle State Forest is an inholding within the mapped ARKS, and was presumably excluded because of the low number of Koala records, though this could reflect low survey effort, as NEFA have found elsewhere. Myrtle SF has significant areas of modelled 'likely' Koala habitat, so it should be considered as potentially being part of the Banyabba ARKS, though in need of surveys to assess its significance for Koalas.

All three areas contain significant areas of modelled 'likely' Koala habitat, and have been subject to variable burnings, so surviving Koalas may be present. Only Bungawalbin SF was able to be assessed on the ground because of the growing COVID-19 travel restrictions. The author undertook a brief assessment of the northern part for this review in late March 2020.



KHSM Koala habitat in Doubleduke (left) and Myrtle SFs. Both have 'likely' Koala habitat, though with only 1 record in Myrtle. In these forests NEFA often find Koalas in areas with few or no records.

The Forestry Corporation and the Environment Protection Authority have agreed to additional logging prescriptions to be applied to imminent logging operations of burnt forests in compartments 1-5 (previously 46-8) of Bungawalbin State Forest. None of the forest remains as oldgrowth, so Koala populations can be expected to have already more than halved before the recent logging and fires.



GEEBAM canopy burn mapping of Doubleduke (left) and Myrtle SFs, note the variable burning and that Koalas may have survived in partially burnt areas.

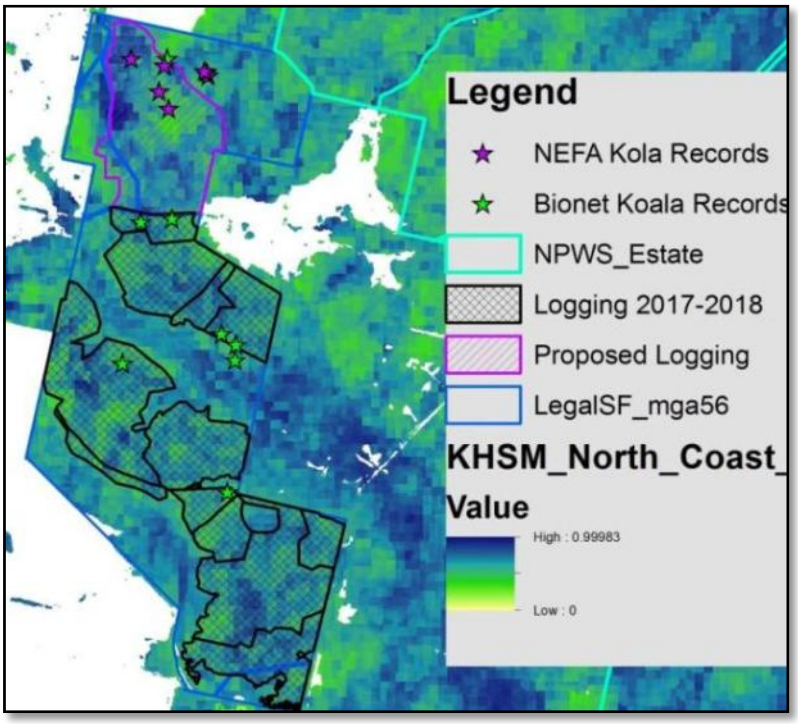
The 879 ha south of Avenue Road was logged in 2000 and re-logged in 2017 and 2018 under a 2016 Harvesting Plan. Substantial areas of the Endangered Ecological Community Subtropical Coastal Floodplain Forest in riparian areas, and a Squirrel Glider exclusion area, were not logged. The whole area south of Avenue road was burnt in the 2019 wildfires, with the loss of most canopy and therefore likely the loss of most, if not all, Koalas by the double whammy of logging then burning, with the unlogged exclusions also burning. While the heavily burnt and logged southern end of Bungawalbin SF wasn't inspected after the fire, the fire mapping indicates it is in a similar parlous state to Ellangowan State Forest (see photos above).

Logging was suspended in 2018 with the 333 ha north of Avenue Road remaining unlogged. It was likely previously logged in the 2000 event. The 2019 fire burnt out half this area, though was relatively low intensity with most trees retaining most canopy, or regaining it since. This is assumed to be the area now being targeted for logging.

The EPA have issued 'Site-specific operating conditions for Bungawalbin State Forest, Compartments BWN 001, 002, 003, 004, 005' which include a variety of generic prescriptions to be applied in addition to those required by the IFOA. These were derived in a desk-top process without ground based assessments or apparently any evaluation of the status of the fire affected Banyabba Koala population.

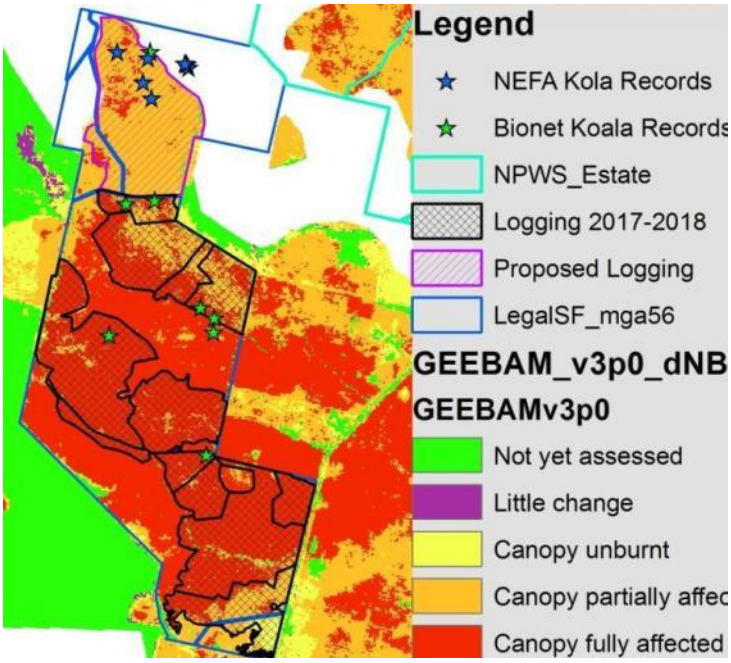
They include a requirement that unburnt areas be protected, limiting logging to the 160ha lightly burnt area. They also require the expansion of riparian buffers on headwater streams from 5 to 20m, and other riparian exclusions by 10m, which will be of some benefit to aquatic species, and by increased tree retention in these moister areas, to Koalas.

Under the 2018 IFOA 5 Koala browse trees over 20cm diameter per hectare are required to be retained in these forests (which both the EPA and OEH consider inadequate, see 1). There is also a requirement to set aside 10% of the logging area, which can be in the unburnt area. The only additional special prescription directly relevant to Koalas is a requirement to retain 'Temporary feed tree clumps', additional to other exclusions, over 7% of the burnt logging areas. Koala browse trees over 20 cm diameter are one consideration in selecting these temporary retention areas, though their selection is at the discretion of the forester on the day and they can be used to satisfy the IFOA Koala feed tree retention requirements. Given the low density of Koalas and the dispersed nature of their feed trees, small arbitrarily chosen exclusions are likely to be of limited benefit to Koalas.



The DPIE Koala Habitat Suitability Model for the north coast for Bungawalbin SF, showing the 2017-18 logging and the proposed logging, note the northern area was not recently logged.

Otherwise the generic additional prescriptions are the outcome of negotiations between the EPA and Forestry Corporation, intended to sound good but deliver limited increased protection or loss of resources on the ground. And while variants of the prescriptions in the IFOA have been applied for over 20 years they remain as politically compromised theoretical constructs with no monitoring to assess their effectiveness.



GEEBAM canopy burn mapping of Bungawalbin SF, note the intensive burning of both the logged areas and unlogged informal reserves in the southern areas, which likely eliminated Koalas,

conversely the northern area was not logged at that time and the half burnt was only lightly burnt, Koalas survived in this area.

In the March inspection of Bungawalbin State Forest I found that most Grey Gums had Koala scratches, with distinctive scratches observed on 73 patchily distributed Grey Gum, some older trees with patches of older bark showed long term usage. These show that before the fires Koalas were using the whole of the assessed area over time, and likely reasonably frequently. Because of the fires the Grey Gum are currently shedding their bark so this record will soon be lost.

The brief inspection of Bungawalbin included both burnt and unburnt areas each side of a ridge. The unburnt area varied from more open grassy understories to diverse shrubby understories with many logs and deep leaf litter. In the burnt area most large trees had survived and had good canopy development, though smaller trees and the diverse understorey had been killed and replaced with a dense covering of grasses and herbs.

A concern is that many of the Grey Gum had borer holes around their bases, an indicator of stress, and damage from Yellow-tailed Black Cockatoos digging the grubs out, though affected trees had good regrowth. This obvious damage does not bode well for the long-term persistence of these vital feed trees.

Within the burnt area 2 (of the 51 with scratches) Grey Gum (32.5 and 39.8 cm diameter - dbh) had Koala scats (7 and 5). Two Spotted Gum (38.6 and 50.5 cm dbh) had shed their lower bark after the fire had scratches on the fresh bark. Within the small area assessed, these limited results show some usage after the fires, though not much.

The brief superficial assessment of the dense decomposing leaf litter in the unburnt area identified two red gums (34.8 and 51.5 cm dbh) and a Grey Gum (62.4 cm dbh) with 4, 3, and 3 scats (respectively). The deep wet litter limited searches. Twelve Grey Gum had Koala scratches.

No trees with very recent Koala scats were observed, though this is not surprising given the small area assessed and the apparent major decline in Koalas because of the combination of the 2019 drought and fires. The post-fire scats and scratches indicate some survivors in the area that warrant further assessment.

Likely Koala habitat in the rest of Bungawalbin State Forest to the south was heavily logged in 2017-2018 and then subject to severe canopy loss in the 2019 fires. It wasn't reassessed to ascertain likely Koala usage, though Koala survival is likely to be extremely low through most of this area due to the combined impacts.

This photo shows unburnt forest to the left and burnt forest to the right, in Ellangowan State Forest.

The forest proposed for logging is recorded as being logged in 1986, though was likely re-logged more recently (2000), resulting in a low number of larger trees, a low basal area and lots of small trees. There are reasonable numbers of Grey Gums, though relatively few complementary feed species such as red gums and Grey Box (or alternates) in most of the inspected area. The limited availability of suitable feed trees is likely already limiting Koala numbers.

The fire burnt out half the northern area of Bungawalbin State Forest yet to be logged, though the area was less intensively burnt than the logged area to the south. Most canopy survived the fires, particularly larger trees. The canopy is now recovering. The remainder of the area was unburnt and retained a diverse understorey of grasses and shrubs, and deep leaf and wood litter.

So in general the forest inspected is moderately degraded, with some patches significantly so, yet before the fires it likely had relatively low but widespread Koala use in the preceding 12 months, likely with some core areas of activity in the vicinity where there are patches of a variety of mature feed trees.

It is occupied Koala habitat that is likely the only patch left in Bungawalbin State Forest and helps support part of the Banyabba population. It is situated in a pivotal linking position and is likely the key area for supporting dispersal across cleared land to Ellangowan in the west. Its potential significance has dramatically increased since most of the Banyabba ARKS was burnt, making any patches such as this, with surviving Koalas that are capable of supporting breeding females, of exceptional importance to the recovery of the Banyabba population. Habitat values will improve as feed trees grow larger.

Such unburnt and lightly burnt patches of Koala habitat must be saved from further degradation if the Banyabba population is to be saved from oblivion and given a chance of rebuilding. They are also important for the recovery of a multitude of other species.

4.1.3. Affects on Hasting River Mouse

The Endangered Hastings River Mouse has been identified by the State and Commonwealth Governments as one of the species most adversely affected by the fires. With its identified susceptibility to burning and over 80% of the 1,000 locations it has ever been recorded at in NSW burnt in the 2019-20 fires it is vulnerable to having been eliminated from a large part of its range.

It was included as one of the Commonwealth's 113 in most 'urgent need of emergency action over the coming weeks and months'. The Expert Panel identified *'protecting unburnt areas within or adjacent to recently burnt ground that provide refuges*' as '*essential*'. The other essential action was to undertake surveys to identify how badly the Hastings River Mouse was affected by the fires before blundering about in its severely degraded habitat.

In Styx River State Forest the Forestry Corporation and the Environment Protection Authority ignored the advice, despite 95% of the habitat around Hastings River Mouse locations being burnt, including most of the logging exclusions, they focussed logging into the only known area of unburnt habitat left. With the species survival at stake this was a grossly irresponsible act.

While it appears that logging in compartments 540, 541, 542 and 552 of Styx River State Forest has now been completed, logging is underway elsewhere in Styx River State Forest.

The Forestry Corporation's logging of the only unburnt patch of occupied habitat of the nationally Endangered Hastings River Mouse in Styx River State Forest despite its being identified as vulnerable to burning, DPIE identifying 82% of known localities burnt, and the Commonwealth identifying unburnt habitat as a priority to protect, displays an abject failure on behalf of both the Forestry Corporation, and the EPA, their supposed regulator, to prevent the further endangerment and potentially extinction of the Hastings River Mouse. The Inquiry needs to investigate this case and recommend measures to ensure it is not repeated.

There are abundant pre-burn records of Hastings River Mouse and Stuttering Frog that were located in pre-logging surveys in these and adjacent compartments. These surveys need to be urgently replicated to assess the impacts of the fire (and logging) on these two Commonwealth priority species, and to identify appropriate rehabilitation strategies.

For a number of years the minimal prospects of being able to delineate suitable habitat for Hastings River Mouse and to find any survivors (given the low trapping results) will render the current prescription totally ineffective. There needs to be an immediate reinstatement of a prohibition on logging within 800m of a Hastings River Mouse Record, though not limited to apparently suitable habitat (until sufficiently regenerated).

The Endangered Hastings River Mouse is one of those species worst affected by the 2019 fires in Australia. While there is a debate about long-term impacts, it is a species that is known and agreed to be significantly affected in the short-term by burning and logging.

Fire burnt into Styx River State Forest in mid November and by late December 2019 78-89% of the forest had burnt, of the 198 locations identified for Hastings River Mouse only 5 (2.5%) escaped burning, with some 95% of potential habitat burnt. In addition some 32% of potential habitat has been logged in the past decade.

Logging continued after the fire in Styx River State Forest, at some stage intentionally focussing logging into the remaining unburnt stand where the 5 Hastings River Mice had been found.

On the 20 January the NSW Government identified that 82% of the known localities of Hastings River Mouse had been burnt, the third worst affected species in NSW. On 11 February 2020 the Commonwealth identified the Hastings River Mouse as one of 113 animal species nationally assessed by an expert panel as the highest priorities for urgent management intervention, noting:

> *Two priority actions should be carried out for all high priority species: 1) Rapid on-ground surveys to establish extent of population loss and provide a baseline for ongoing monitoring. 2) Protecting unburnt areas within or adjacent to recently burnt ground that provide refuge, as well as unburnt areas that are not adjacent to burnt areas, especially from extensive, intense fire.*

Contrary to this advice the NSW Government continued to log the only unburnt patch of occupied Hastings River Mouse habitat known in Styx River State Forest. It is astounding that the Environment Protection Authority allowed this to continue from mid-November 2019 until after conservationists went public in the beginning of March 2020.

Aside from conjecture about the long-term impacts of logging and appropriate burning regimes, it is apparent that the short-term impacts of both logging and fire on the habitat and populations of Hastings River Mouse are significant. Therefore the already diminished populations of Hastings River Mouse will have been significantly reduced by the vast majority of their habitat being burnt. To now log their unburnt refuges, or the burnt refuges where mice have survived, is criminal and has to stop. At least until the impacts on their populations have been assessed.

The Hastings River Mouse *Pseudomys oralis* is listed as 'Endangered' under the EPBC Act and TSC Act. It is restricted to upland open forests and woodlands with grass, heath or sedge understorey in north-east New South Wales and south-east Queensland, where it is patchily distributed with seven known genetically discrete populations.

There is no '*Conservation Advice'* or *'Listing Advice"* though there is a Recovery Plan developed by NSW in 2005 and adopted by the Commonwealth in 2008: Recovery Plan for the Hastings River Mouse *(Pseudomys oralis)*.

HASTINGS RIVER MOUSE RESERVE STATUS IN NORTH EAST NSW AS AT 2004 (From Flint *et. al.* 2004)

	Population Targeted for Reservation	Estimated Total Population Reserved	Percentage of Reserve Target Achieved
Hastings River Mouse - pop.1	4238	3	1%
Hastings River Mouse - pop.2	4251	116	3%
Hastings River Mouse - pop.3	4251	322	8%
Hastings River Mouse - pop.4	4251	47	1%
Hastings River Mouse - pop.5	4238	523	12%
Hastings River Mouse - pop.6	4238	1231	29%
Hastings River Mouse - pop.7	4251	287	7%
Hastings River Mouse - pop.8	4251	334	8%
TOTAL	33,969	2,863	8%

The Hastings River Mouse was one of those targeted for reservation in the CRA process, with population targets established for 8 discrete populations based on classes of modelled habitat.

These targets were adopted to represent the number of breeding females required to be included in reserves to achieve the long term survival of the species. As with most endangered species the CRA process abjectly failed to deliver on the reservation requirements for this species, with only 8% of the mean of the habitat targeted for reservation included in the reserve system in north-east NSW, with 6 populations achieving less than 10% of their reservation targets (see Table).

The Hastings River Mouse has already been identified as having a high likelihood of becoming extinct within the next 50 years. The extremely low level of reservation achieved has guaranteed that this will be the case unless strong and effective management is applied off-reserve. The RFA requires that IFOA prescriptions take into account the extent of reserved habitat (1A 9, 1(B)13).

4.1.2.1. Burning and Logging Impacts

In their 28 January 2020 belated 'immediate' response the NSW Department of Planning, Infrastructure and Environment identified the Hastings River Mouse as the third most fire impacted threatened animal in NSW with 82% of its known localities burnt.

In 11 February the Commonwealth's Wildlife and Threatened Species Bushfire Recovery Expert Panel identified the Hastings River Mouse as one of 113 animals nationally in most urgent need of emergency action over the coming weeks and months. It was the mammal with the second highest vulnerability for fire and post-fire mortality.

The Expert Panel identified *'protecting unburnt areas within or adjacent to recently burnt ground that provide refuges*' as '*essential*'. The other essential action is to undertake surveys to identify how badly the Hastings River Mouse was affected by the fires before blundering about in its severely degraded habitat.

The Hastings River Mouse lives in dry sclerophyll forests that are naturally subject to infrequent burning events. There is conflicting evidence about the longer term effects of fire and logging, though there is agreement that they are adversely affected for some time following intense or frequent fires, as well as logging.

With 82% of its known localities burnt the Hastings River Mouse is one of the endangered species most severely impacted by the recent fires in Australia. In accordance with the Recovery Plan prescription, an 800m radius area was mapped around all NSW records of Hastings River Mouse to assess recent impacts. This was intersected with Forestry Corporation logging history from July 2000 to March 2019 for State Forests to identify the magnitude of logging impacts since the RFA (note that logging records are incomplete). To assess the magnitude of the impacts of the recent fires, the 800m buffers were intersected with GEEBAM v2 mapping of recent fires to identify the extent of disturbances in the vicinity of records.

There are 17,836 ha of State Forests within 800m of records of Hastings River Mice. Over the past 20 years more than 6,777 ha (38%) of this has been logged. Last year up to 15,955 ha (89%) was burned. This represents significant disturbance in the vicinity of records.

In recent years the Forestry Corporation has done most research on Hastings River Mouse and because of their vested interest their dubious assessments are targeted at trying to show that logging is benign or even necessary. If many of the claims are accepted it is hard to fathom how such species survived until the loggers arrived.

Habitat alteration and fragmentation of Hastings River Mouse habitat is predominantly a result of frequent fire, forestry activities, clearing activities, grazing and weed infestation (DECCW 2005).

The **Recovery Plan for the Hastings River Mouse (Pseudomys oralis)** notes:

> *High frequency fire is listed as a KTP under the TSC Act and is considered to be a threat to the Hastings River Mouse. Burning at intervals of less than five years is common in grassy open forests in northern NSW to promote pasture development and as a management tool to reduce the risk of wildfire. Frequent fire can simplify and alter understorey composition towards a proliferation of fire-dependent species (S. Townley pers. comm.). Pre- and post-logging burning to promote eucalypt regeneration adversely impacts on the Hastings River Mouse through the removal of shelter provided by hollow logs. Fire also removes critical resources such as food and nesting sites and increases exposure to predation. ...*
>
> *No experimental work on the response of the Hastings River Mouse to fire regimes is known. Current information is based on captures within sites that have been burnt by wildfires or by leaseholders for stock grazing. Thirteen individuals were captured at Boundary Creek in Forestland State Forest in 1986. The site was subsequently burnt by wildfire and three trapping surveys over eight years post-fire failed to trap any Hastings River Mouse. However, some 16 years later the Hastings River Mouse was captured in the area during 2001-2002. At Werrikimbe National Park three trapping surveys of a previously known Hastings River Mouse site have failed to locate individuals after fire.*
>
> *...*
>
> *Timber harvesting impacts adversely on the Hastings River Mouse by reducing shelter provided by hollow logs and old-growth stems with butt cavities. Harvesting activities also open up the understorey and create roads and tracks potentially leading to increased predation pressure. The Hastings River Mouse has been found in logged areas (Meek et al 2003), however, the largest and most stable populations located to date occur in unlogged old-growth forest (Townley 2000a).*

At Carrai and Werrikimbe, Tasker and Dickman (2004) undertook surveys to assess differences between small mammals at sites that had been grazed and burnt compared to sites with no evident recent burning or grazing, finding 3 Hastings River Mice at 2 grazed sites out of 6,705 trap-nights. This was too small a sample to analyse statistically, though Tasker and Dickman (2004) commented:

> *The only two of our grazed/burnt sites at which this species was found had by far the highest number of logs and mid-storey shrubs ("Rolf" site), and the densest cover of ferns ("Fitzroy" site) of any of the grazed/burnt sites.*
>
> *Thus, although the moderately frequent burning associated with many cattle-grazed areas produces an ideal food supply, too-frequent burning or more intense grazing (as in other grazed forests), may remove the essential shelter component for this species. The fire ecology of P. oralis is a topic that warrants further study and manipulative experimentation.*

The Forestry Corporation are strong advocates for the self-justifying (i.e., Pyke and Read 2003) argument that because Hastings River Mouse occurs in localities where logging or burning has occurred that such disturbances are benign or even necessary, as exemplified by Meek's (2003) statement "*where there has been a continuous history of burning, grazing and/or logging, P. oralis survives and breeds successfully*". (i.e. Meek *et. al.* 2003, Meek 2003, Law *et. al.* 2016).

As identified by Pyke and Read (2002) not all fire is equivalent as there are numerous variables associated with fires, they consider:

> *The management of fire in and around P. oralis populations is likely to be particularly difficult to resolve because it may be an inappropriate fire regime (i.e., fire frequency, intensity and seasonal timing) rather than the presence or absence of fire that has adverse impacts on the species. As already noted, the presence of fire has been found to be associated with positive, negative or neutral impacts on P. oralis. The challenge will therefore be to determine fire regimes that are beneficial to the species.*

A Law *et. al* (2016) study firstly involved resampling Hastings River Mouse logging exclusions, identifying a decline in the total number trapped since the pre-logging surveys, leading them to conclude the results support their hypothesis that Hastings River Mouse declines *"when disturbance is excluded or too frequent*". Though their results are also open to the interpretation that the exclusion areas are inadequate to mitigate logging impacts, an interpretation is that supported by the apparent increasing numbers with time since logging.

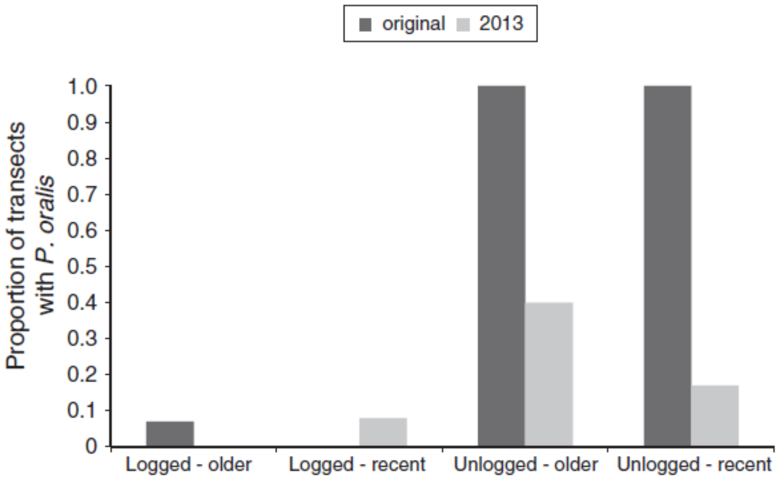


Fig. 1. from Law et. al (2016). Proportion of transects at which Hastings River mouse, *Pseudomys oralis*, was caught in original pre-harvest and repeat surveys (2013). Older (7–15 years) and recent (2–6 years) refer to the time periods since the original surveys were undertaken. Unlogged refers to areas where the species was recorded originally and logging was excluded. Logged refers to areas where the species was originally absent but was subsequently logged.

Law *et. al* (2016)'s interpretation is somewhat simplistic as there is apparently no consideration of other factors that could have contributed to the decline, such as logging around the exclusions or subsequent burning events or grazing. While Law *et. al* (2016) do not account for burning or grazing they recognise them as a significant unaccounted issue:

> *One of the key findings from our study was that our repeat survey in 2013 recorded few P. oralis individuals compared with the initial surveys, which were conducted either 2–6 years or 7–15 years previously. Many sites did not appear to offer suitable habitat for P. oralis, either because the original habitat model was not reliable (B. Law, T. Brassil, L. Gonsalves, pers. obs.) or because subsequent management rendered sites unsuitable. For example, extensive grazing and frequent burning have favoured simple and patchy ground cover dominated by blady grass, Imperata cylindrica, at some sites, such as in Chaelundi State Forest. This would partly explain the continuing low occurrence of P. oralis in 2013 at sites where the species was previously absent. Many of these sites were originally marginal for the species and remained so when we surveyed them. There are likely to be many factors at*

> *play leading to the lower numbers of P. oralis trapped in 2013, including some sites that were originally suitable subsequently being rendered unsuitable. For example, at one site (Marengo State Forest), seven P. oralis individuals were trapped originally on two transects in November 2010; however, the site was then burnt three times in 2 years by either arson or grazing leasees (J. Willoughby, pers. comm.) and no individuals were trapped in November 2013, when a patchy ground cover had recovered and floristic diversity was slightly above average. At another site, six P. oralis individuals were caught on one transect in 2009, whereas heavy grazing was evident at this site in 2013, resulting in closely cropped grass cover and a lack of P. oralis captures. These observations suggest that frequent disturbance that simplifies ground cover (Catling 1991) is detrimental for P. oralis. Dense ground cover and abundant shelter sites (e.g. logs, rocks) are recognised as key components of the habitat of P. oralis (Townley 2000; Meek 2002; Meek et al. 2006), which is also consistent with the results of our PCA.*

Without accounting for all significant factors any conclusions from such data is spurious.

Law *et. al* (2016) undertook a second set of surveys "*targeting high-quality P. oralis habitat as determined by expert field inspection*" in areas that were no longer classified as high quality habitat under changes to the IFOA made in 2011 and thus "*logging was permitted under the IFOA*". It is perplexing as to why the EPA changed the rules, at Forestry's insistence, in 2011 to exclude such high quality modelled habitat. Though it is not surprising. Sites were stratified by time since logging: immediate (<1 year since logging, *n* = 1), recent (2–6 years since logging, *n* = 4), intermediate (7–15 years since logging, *n* = 3) and exclusion of logging (35–45 years since logging, *n* = 3).

Law et. al (2016) found that Hastings River Mouse is positively "*associated with a greater cover of heath, lomandra and logs and, to a lesser extent, floristic diversity*" and negatively associated with Bush Rats. They do note that "*rat numbers were high on some transects after logging*", though summarily dismiss it as an inconvenient fact.

Most relevantly they found a total of just 27 Hastings River Mice on the sites with "*a four-fold greater number in intermediate-logging sites than in logging-exclusion sites (Dunnett's test, P < 0.05), whereas recently logged sites were in between (Dunnett's test, P > 0.05). In addition, the single site (two transects) surveyed less than a year after logging recorded no P. oralis".* In summary Law *et. al* (2016) state "*We found that recovery after logging was rapid, peaking ~15 years post-logging, but then declining beyond 35–45 years post-logging*".

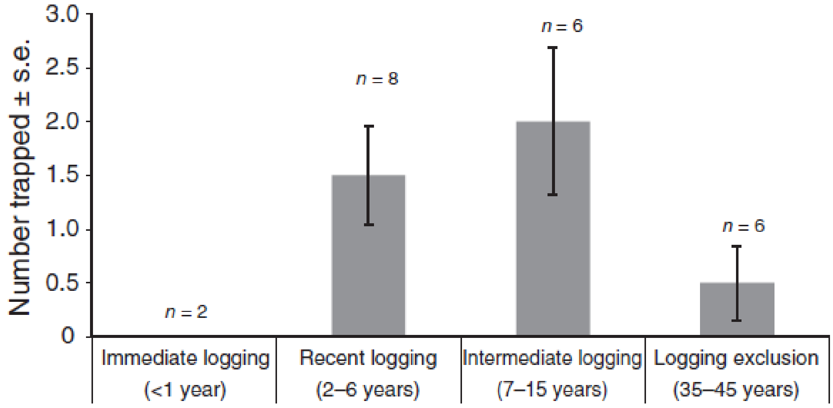


Fig. 3 from Law *et. al* (2016). Mean number of Hastings River mouse, *Pseudomys oralis*, trapped per transect at different times since logging.

As there are no baseline pre-logging data, and so many potential variables that could have affected these results it is hard to fathom how Law *et. al* (2016) could conclude that their findings just relate to time since logging. Yet again the influence of fire is recognised, but not accounted for. Law *et. al* (2016) observe "*Three sites had bare ground generated by recent fire and these were characterised by an absence of P. oralis and other small mammals*", and "*Binns (1995) observed in the Dorrigo forests that unlogged areas were, on average, less recently burnt than were logged sites and this could have contributed to the decline of P. oralis we documented in our surveys where logging was excluded*".

Law *et. al* (2016) hypothesise:

> *Initially, P. oralis is likely to be absent or rare in the 1–2-year period of recovery from the mechanical damage to ground cover from logging (and post-logging burn). Thereafter, a dense ground cover flourishes, whereas the canopy remains open. Then, depending on the site and fire frequency, the site remains suitable for P. oralis or the shrub and eucalypt regrowth layer develops in a more dominant state than it was preharvest and the quality of the ground cover diminishes. If the site progresses along this latter path, then R. fuscipes dominates in shrub, fern, and eucalypt regrowth habitat that has only sparse grassy understorey.*

While Law *et. al* (2016) use their hypothesis to justify frequent logging disturbance (based upon questionable premises), their conclusions can equally be interpreted to argue that the loss of oldgrowth forest, and the ongoing decline in larger trees, with the promotion of dense tree regrowth that shades the understorey, will have significant impacts on the feed species and groundcover attributes required by Hastings River Mouse. It is likely that their habitat is being degraded with each logging event.

Though, aside from conjecture about the long-term impacts of logging and appropriate burning regimes, it is apparent that the short-term impacts of both logging and fire on the habitat and populations of Hastings River Mouse are significant. Therefore the already diminished populations of Hastings River Mouse will have been significantly diminished by the vast majority of their habitat being burnt. To now log their unburnt refuges, or the burnt refuges where mice have survived, is criminal and has to stop.

4.1.2.2. Logging Prescriptions

It is extraordinary that the Forestry Corporation and Environment Protection Authority have contravened the National Recovery Plan for the Hastings River Mouse on numerous occasions as they have repeatedly reduced survey requirements and logging prescriptions. What is most concerning is that they have done this based on dubious survey results and without any monitoring of the effectiveness of the old or new prescriptions.

It is astounding that the EPA (2010) justify the reduced prescriptions on the grounds that the Hastings River Mouse is "*now more widespread and numerous".* While more localities of mice had been identified because of the requirements for pre-logging surveys, it is pertinent that from its re-discovery in 1969 up until the EPA's claim of numerous mice, it had been recorded from less than 700 localities. This is by no measure a large number of records over 40 years. Even with all the Forestry surveys over the past decade there are only 311 locality records for this short lived species on State Forests.

There is evidence that Hastings River Mice declined in exclusion areas following logging, even with significantly larger exclusions than now applied (Law *et. al* 2016, see above discussion). Foresters complain that the models being relied upon for prescriptions are unreliable, with modelled habitat deleted from a 2011 revision found to have significant occupancy (Law *et. al* 2016). Trapping effort to locate any mice present was halved despite evidence that this would mean Hastings River Mice would no longer be detected at some sites (Meek *et. al.* 2003, see below).

The outcome is that many areas of occupied Hastings River Mouse Habitat is being logged without any prescriptions being applied what-so-ever (Law *et. al* 2016, see above discussion), while prescriptions applied are apparently inadequate.

Now with the fires burning most known localities there can be no excuse for continued complacency. Populations will have been decimated, and habitat degraded, making the current logging prescriptions redundant because habitat is likely not to be recognisable for some time and the low numbers of survivors will render trapping ineffective. All compartments with records or modelled habitat of Hastings River Mouse should be put under moratorium while surveys of known localities are undertaken to assess appropriate criteria and trapping effort to identify habitat, and to quantify whether it should now be considered critically endangered.

For private properties all modelled habitat should be immediately placed under moratorium while an effective prescription is developed.

The 2005 **Recovery Plan for the Hastings River Mouse (Pseudomys oralis)** includes as "Appendix 3. Interim Hastings River Mouse Management Guidelines":

> *Timber Harvesting*
>
> *Surveys: Pre-logging habitat and population surveys (Appendixes 1 & 2) should be carried out by the relevant agencies in areas not covered by the Integrated Forestry Operations Approvals for the Upper North East and Lower North East Regions.*
>
> *Timber Harvesting: Timber harvesting and associated activities should be excluded from areas of medium to high quality Hastings River Mouse habitat.*
>
> *Within a 200 m buffer around medium to high quality Hastings River Mouse habitat and mapped Hastings River Mouse corridors the following should apply:*
>
> - *if the area is unlogged or has not been logged since 1950 it will remain unlogged;*
> - *in other areas a minimum of six mature trees with basal hollows, or trees likely to develop basal hollows, per hectare will be retained; all burning will be excluded; and no fire wood collection should occur within 200 m of a known Hastings River Mouse population.*

For public lands the 1988 Threatened Species Licence gave forests NSW the choice of establishing *"An exclusion zone, or exclusion zones, ... to protect all modelled habitat within the compartment*" or undertaking specified habitat assessments to identify habitat of moderate or high suitability within which targeted trapping surveys are required (TSL 8.8.9).. The Threatened Species Licence (TSL 6.13) required that exclusion zones of 200 metres must be established around records of Hastings River Mouse, extending to 800m in Hastings River Mouse habitat assessed as of moderate or high suitability. So the requirement is to only protect part of the medium and high quality habitat if they happen to catch a Hasting River Mouse, with no application of a 200m buffer to that habitat..

This is effectively a major reduction on what the Recovery Plan identifies as a Management Guideline in Appendix 3 for logging, though the Recovery Plan recognises this prescription, stating:

> *In NSW, an Integrated Forestry Operations Approval (IFOA) granted under part 4 of the NSW Forestry and National Park Estate Act 1998 (FNPE Act) regulates the carrying out of certain forestry operations, including logging, in the public forests of a region. The terms of the Threatened Species Licence of the IFOA outline the minimum protection measures required to limit the impact of forestry activities on threatened species and their habitats and forms the basis for DECC regulation of those activities. The Threatened Species Licence for the Upper North East and Lower North East Regions include measures for the protection of the Hastings River Mouse.*
>
> *Specific prescriptions for the Hastings River Mouse state that where there is a record of the species in a compartment or within 800 m outside the boundary of the compartment the following must apply:*
>
> > *a) Within 800 m of a record of the Hastings River Mouse, 'specified forestry activities' as defined in the IFOA, are prohibited from all areas assessed as moderate or high suitability Hastings River Mouse habitat.*
> >
> > *b) An exclusion zone of at least 200 m radius must be implemented around all records of the Hastings River Mouse.*
>
> *The prescriptions dictate how targeted surveys for the Hastings River Mouse and habitat suitability assessments must be conducted. Hastings River Mouse microhabitat models (Smith & Quin 1997) used to determine the level of habitat suitability are included in the prescriptions (See Appendix 1).*
>
> *There are potential threats from logging to Hastings River Mouse sites on private property. Issues relating to timber harvesting include road construction, use of heavy machinery, timber removal and burning to stimulate regeneration and limit wildfires (Smith et al. 1994).*
>
> *Many of the identified threats to the Hastings River Mouse are intrinsically linked and the magnitude of the effect of one threat is often related to the presence or absence of other threatening processes*

The Threatened Species Licence was amended in 2007 and in 2010 so as allow logging operations within 31 compartments in 6 State Forests to be undertaken within areas that would otherwise be required to be protected (TSL 6.13B). These included Mount Mitchell State Forest Compartments 16, 17 and 18. This over-rides TSL 6.13 by establishing mapped HRM exclusion zone and HRM operational zones, with snigging and roading allowed in the operational zones.

These changes were in contravention of the Recovery Plan Action 5.1: Develop Hastings River Mouse population management programs based on the best available knowledge and the Interim Management Guidelines provided in Appendix 3. It is a safe bet that this major wind-back in protection for the Hastings River Mouse was never subject to monitoring to assess impacts on Hastings River Mouse and the effectiveness of the new measures.

What is most alarming is that this reduced protection appears to have been approved because of the high numbers of Hastings River Mice in these areas. For example, there were 16 records of Hastings River Mouse made in compartment 16 of Mount Mitchell SF, indicating a much larger population inhabiting the area and one likely to be of national significance. Such areas should be designated critical habitat and fully protected (particularly given the poor reservation status of this species) rather than being allowed to be logged with reduced protection.

The EPA 2010 Review of NSW Forest Agreements and Integrated Forestry Operations Approvals: Upper North East, Lower North East, Eden and Southern regions stated:

> *Current Hasting River Mouse survey requirements and exclusion zones do not reflect current knowledge of Hasting River Mouse occurrence. Habitat suitability surveys are used to identify areas where trapping is required but are limited to areas within modelled habitat. The model is deficient because many records of the species fall outside of modelled habitat.*
>
> *To counter this deficiency, habitat suitability surveys within compartments containing 'known habitat' as well as those containing modelled habitat is appropriate; however, there is a need for Forests NSW to document the process of 'rapid assessment' of habitat suitability.*
>
> *Forests NSW proposes that the Hastings River Mouse is now more widespread and numerous than when existing conditions were developed, and that the home range of the species is now known to be relatively small. As such, Forests NSW considers that exclusion zones of up to 800 m diameter are not appropriate.*

One of the recommended changes was:

> *Forests NSW is to apply an exclusion zone covering 12 ha (equivalent to a circle of approximately 200 m radius) where there is a record of Hastings River Mouse of suitable habitat.*

In contravention of the Recovery Plan requirement the prescription for the Hastings River Mouse was changed on the 7 November 2011. There does not appear to have been any attempt to critically review Forests NSW's claims, or to assess the likely consequences of the changes on Hastings River Mouse. The retention of habitat around Hastings River Mouse records was dramatically reduced from an exclusion area encompassing all habitat of moderate or high suitability within 800m (a potential maximum of 200ha) and all land within 200m, down to a 12ha exclusion area encompassing as much habitat as practical around a record:

> *6.13 Hastings River Mouse Pseudomys oralis*
>
> *Where there is a record of a Hastings River Mouse in the compartment or within 200 metres outside the boundary of the compartment, the following must apply:*
>
> *a) A 12 ha exclusion zone that takes in as much Suitable Habitat for Hastings River Mouse as practical, must be established around the record. The exclusion zone need not be symmetrical and should, where possible, link to other areas excluded from harvesting activities.*

This had the effect of opening-up large areas of Hastings River Mouse Habitat protected for well over a decade for logging.

The 2005 Recovery Plan includes "*Appendix 2. Interim Hastings River Mouse Trapping and Population Survey Guidelines*" identifying "*The minimum specifications for trapping are as follows*":

> *a) The minimum trap effort at a locality must be 100 size A Elliott traps over four nights (400 trap nights) for areas up to 50 hectares of moderate or high quality habitat or both. An additional 400 trap nights (100 traps for four nights) per 50 hectares above the original 50 hectares.*

The 7 November 2011 change to the TSL also significantly reduced the likelihood of locating Hastings River Mouse by, for example, halving the Recovery Plan's (Appendix 2) trapping effort of a minimum of 400 trap nights per 50ha down to 200 trap nights per 50ha:

> *8.8.9 B Targeted surveys*
>
> *Surveys to determine the presence of Hastings River Mouse must be conducted as follows:*
>
> *a) The minimum specifications for trapping are as follows:*
>
> > *i. The trap effort is to be at a rate of 1 size A Elliott trap over four nights for each hectare identified as having Suitable Habitat for Hastings River Mouse (either as the result of habitat suitability surveys under 8.8.9A or otherwise such as during compartment traverse or incidentally recorded).*
> >
> > *ii. The minimum number of traps will be 50 for up to 50 hectares, with 25 additional traps for each 25 hectares increment above 50 hectares, as follows:*
> >
> > - *10-50 hectares 50 traps*
> > - *50-75 hectares 75 traps*
> > - *75-100 hectares 100 traps*
> > - *> 100 hectares add additional 25 traps for each 25 ha increment*

This change makes it less likely that the Hastings River Mouse will be located where it occurs. For example Meek *et. al.* (2003) report the results of pre-logging surveys for Hastings River Mouse at 7 sites where it was recorded (there is no information on how many apparently suitable sites it was not recorded at) identifying "*Trap success for P. oralis at Marengo was 1.7% (excluding recaptures), 0.1% at Chaelundi, 0.3% at Hyland, 0.7% for Styx River, 0.8% for Glen Elgin, 0.4% for Enfield and 0.2% for Gibraltar Range*". At 3 sites only single Hastings River Mouse were recorded, being 1 per 800 trap nights at Chaelundi, 1 per 400 trap nights at Hyland and 1 per 250 trap nights at Enfield (given the minimum effort was meant to be 400 trap nights it is not known why the Enfield trap nights were so low).

Given this confirmation of the low likelihood of detecting Hastings River Mouse, even when it is present, it is perplexing as to why the EPA effectively removed protection from many localities by reducing required trap-nights and thus the probability of detecting any Hastings River Mice that are present.

Though the most stark difference is that only a small part of each 50 ha of suitable habitat is being assessed and the required protection is only applied to individuals found within that sample. There is no requirement to identify or protect the full extent of occupation, only any individuals found in a small sample with limited effort.

This major reduction in habitat protection is contrary to the National Recovery Plan for this species, most significantly Appendix 2. minimum specifications for trapping and Appendix 3 Timber Harvesting Guidelines. Such ad-hoc and unjustified changes are contrary to the objective to implement effective management of Hastings River Mouse populations in accordance with actions 5.1. and 5.2:

The TSL prescription is often ignored, for example, in three separate forests Sparks (2010) identified a total of 83 hectares of modelled habitat of the Hastings River Mouse that was logged without the required habitat or trapping surveys having been undertaken to justify not excluding the areas from logging. Because the required surveys were not done it is not known what effect this had on Hastings River Mouse. In a typically grossly inadequate response, the EPA (then DECCW) issued warning letters for two of these three breaches.

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> *Surveys to determine the presence of Hastings River Mouse must be conducted as follows:*
> *a) The minimum specifications for trapping are as follows:*
>> *i. The trap effort is to be at a rate of 1 size A Elliott trap over four nights for each hectare identified as having Suitable Habitat for Hastings River Mouse (either as the result of habitat suitability surveys under 8.8.9A or otherwise such as during compartment traverse or incidentally recorded).*
>> *ii. The minimum number of traps will be 50 for up to 50 hectares, with 25 additional traps for each 25 hectares increment above 50 hectares, as follows:*
>>> • *10-50 hectares 50 traps*
>>> • *50-75 hectares 75 traps*
>>> • *75-100 hectares 100 traps*
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For Hastings River Mouse the new Coastal IFOA requires:

> *Where there is a record of a Hastings River Mouse in the operational area, or within 200 metres outside the boundary of the operational area:*
>
> > *(a) an exclusion zone that is 12 hectares or greater must be retained around each record, which must:*
> >
> > > *i. be dominated by Hastings River Mouse micro-habitat;*
> > > *ii. have a low edge to area ratio; and*
> > > *iii. link to other ESAs.*

The previous requirement to encompass "as much Suitable Habitat for Hastings River Mouse as practical" has effectively been reduced to "dominated by Hastings River Mouse micro-habitat" which is a lesser requirement.

The new IFOA Protocol 20: Pre-operational surveys (8) (f) Hastings River Mouse trapping surveys proposes "*25 traps for each 25 hectares of Hastings River Mouse micro-habitat in the base net area, with a minimum effort of 50 traps*", with traps "*placed for a minimum of four nights*". This is equivalent to the current prescription, though still remains well below what the recovery plan requires.

The Private Native Forestry Code of Practice for Northern NSW requires:

> *Where there is a Hastings River mouse record within the area of forest operations or within 200 metres of the area of forest operations, the following must apply:*
> *(a) An exclusion zone with a 200-metre radius (about 12.5 hectares) must be identified, centred on the location of the record, within which the following additional prescriptions must be implemented:*
>
> > *(i) No forest operations or removal of understorey plants or groundcover are permitted.*
> > *(ii) No post-harvest burning is permitted.*
> > *(iii) Disturbance to any seepage areas within or adjacent to the exclusion zone, as well as to ground logs, rocks and litter, must be minimised.*

The Recovery Plan (DECCW 2005) identifies that "*Eight percent of known Hastings River Mouse sites are located on private land. There is a high probability that additional populations are located on private land*". There are likely to be significant populations on freehold land as 21% of high quality habitat is modelled on freehold land.

The prescription applied to forestry operations on freehold land are a sham. Contrary to the Recovery Plan, the Private Native Forestry Code of Practice for Northern NSW ignores modelled habitat for this species and requires that a 200m exclusion area must be established around any known records. Because there are no requirements for surveys to locate this species (even in modelled habitat), and it is unlikely they will have been previously recorded on most private property sites where it occurs, this prescription will have absolutely no effect on most logging operations undertaken within occupied Hastings River Mouse habitat on private land.

4.1.2.3. Accelerating Post-fire Extinction at Styx River

Logging since the fires in Styx River State Forest displays a total contempt by the Forestry Corporation, Environment Protection Authority and the NSW Government for the plight of our threatened species since the 2019 wildfires. They knew that the Hastings River Mouse had been severely affected by the wildfires and showed total contempt for its survival by logging the last known area of unburnt occupied habitat of the mouse in Styx River State Forest without even applying the minimum exclusions identified in its Recovery Plan.

The Forestry Corporation have concentrated their logging activities in Styx River State Forest in recent years with 19 compartments totalling 6,211 ha (36%) logged since 2011. Some 32% of the potential habitat of the Hastings River Mouse has been logged in the past decade. Logging started in Compartments 540, 541, 542 and 552 in August 2017 and continued until around 6 March 2020.

Fire burnt into Styx River State Forest in mid November 2019 and by late December 78-89% of the forest had burnt, of the 198 locations identified for Hastings River Mouse only 5 (2.5%) escaped burning, with some 95% of potential habitat burnt.

Most significantly logging was focussed onto unburnt forest around records and exclusion zones for Hastings River Mouse from late February.

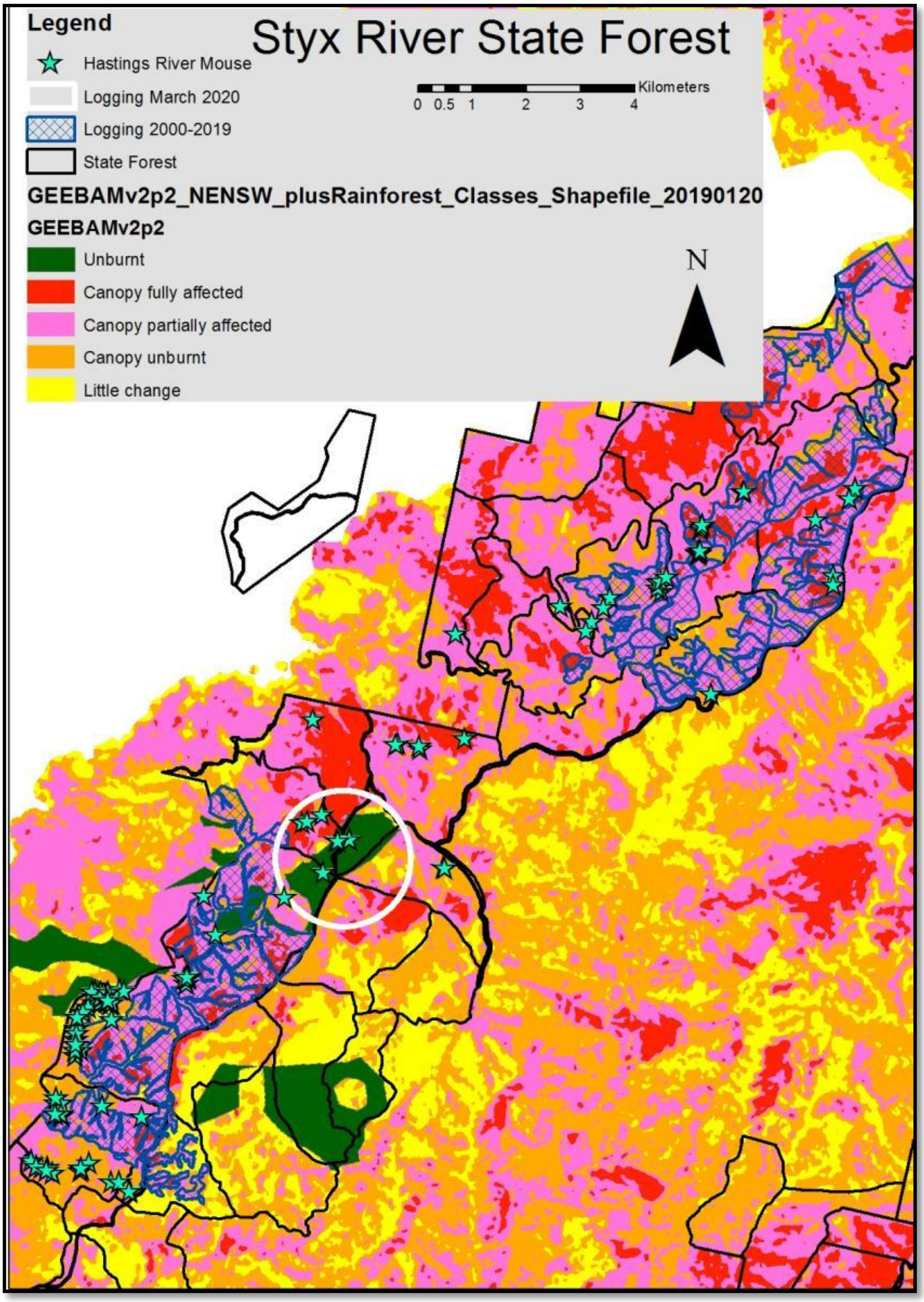
In accordance with the Recovery Plan prescription, an 800m radius area was mapped around all NSW records of Hastings River Mouse to assess recent impacts. This was intersected with Forestry Corporation logging history (net area logged) from July 2005 to March 2019 for State Forests to identify the magnitude of logging impacts since the RFA (note that logging records are incomplete). To assess the magnitude of the impacts of the recent fires, the 800m buffers were intersected with GEEBAM v2 mapping of recent fires to identify the extent of disturbances in the vicinity of records.

There are 4,158 ha of Styx River State Forest within 800m of records of Hastings River Mice. Over the past 10 years more than 1,322 ha (32%) of this has been logged. Last year up to 3,948 ha (95%) was burned. The combination of logging and burning impacts represents a very significant level of disturbance in a short period of time for a disturbance sensitive species.

Canopy burning (GEEBAM v2p2) within 800m of records of Hastings River Mouse in NSW for (a) all tenures, (b) State forests, and (c) Styx River State Forest.

	Canopy fully affected (ha)		Canopy partially affected		Canopy unburnt		Little change		Unburnt		TOTAL
	ha	%	ha	%	ha	%	ha	%	ha	%	ha
All records	4,801	13.1	13,097	35.8	8,340	22.8	3,006	8.2	7,383	20.2	36,727
State Forest	2,729	15.3	8,010	44.9	4,365	24.5	851	4.8	1878	10.5	17,933
Styx River SF	677	16.3	2,230	53.6	936	22.5	105	2.5	210	5.1	4258

The harvesting plan for compartments 540, 541, 542 and 552 of Styx River State Forest was finalised in March 2017. While the quality of some of this habitat would vary for Hastings River Mouse (HRM) in terms of breeding or foraging requirements, the distribution of records and similarity of habitat suggests that it is likely that most of the gross area of 1,500 would likely have been utilised by Hastings River Mouse to variable extents over time, with interaction between colonies as there are no major geographical barriers.



Map showing Hastings River Mouse records, canopy loss from 2019 fire, and logging 2011-March 2019 (note later logging records not available), with the unburnt patch logged in late February 2020 indicated.

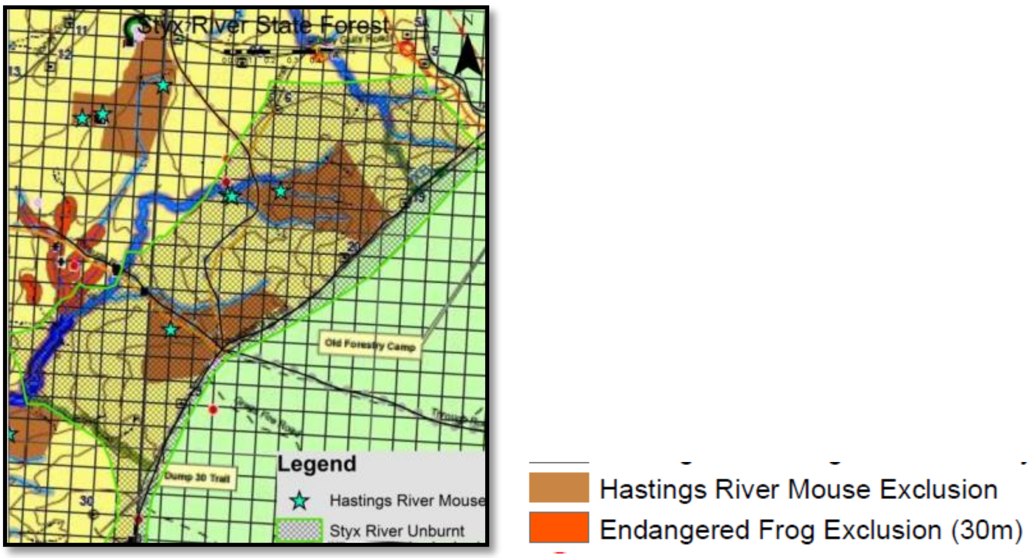
The logging rules only require surveys of limited samples of the area and then for small 12ha exclusions around one or more records. There are no requirements to identify the full extent of occupancy and protect all mice. The Harvesting Plan map identifies 9 exclusion areas, each around

12 ha in size, around 26 locations of Hastings River Mouse. Strangely the Harvesting Plan itself does not acknowledge the presence of Hastings River Mouse or discuss its requirements.

Because the recent fires occurred during a record drought and heatwave the intensity of the fire has severely impacted the canopy in many places, with the ground layer of vegetation, leaf litter and woody debris, which is the habitat for the Hastings River Mouse, consumed or compromised throughout. Resprouting of plants from underground rhizomes is occurring in burnt areas but is dominated by soft bracken *Pteridium esculentum* and *Lomandra* spp. While this may provide some cover for surviving small mammals it is not the preferred habitat of HRM and will likely favour competing species such as the Bush Rat *Rattus fuscipes*. The uniform nature of the ground fire has not produced cooler patch areas which would allow for a range of ground plants to establish and provide the diverse range of food source which HRM require.


LEFT: Area previously logged and now burnt. RIGHT: Log dump in unburnt forest.

Of the 9 Hastings River Mouse exclusion areas only the two in the unburnt patch escaped burning, with the other 7 fully burnt, comprised of 16% canopy fully affected, 47% canopy partially affected and 37% canopy unburnt according to GEEBAM v2.



Extract from Harvesting Plan for Compartments 540, 541, 542 and 552 of Styx River State showing locations of Hastings River Mouse and exclusion areas, overlaid with the unburnt patch of forest found being logged in late February 2020.

The unburnt patch encompassing the two Hastings River Mouse exclusions is 160 ha, of which the HRM exclusions total around 29ha. There are some additional stream exclusions though most of the balance of the unburnt patch was being logged at the time of the assessment, adjacent and right up to the exclusion zones. This included areas outside the exclusions that were likely HRM habitat.

LEFT: Hastings River Mouse Exclusion Area with adjacent logging RIGHT: Logging in unburnt potential habitat of Hastings River Mouse.

Logging in unburnt areas adjacent to Hastings River Mouse Exclusion Zones that was potential HRM habitat.

The remaining habitat not severely impacted by logging and intense ground fire is of immense importance for any surviving populations of HRM and other ground fauna. Very few similar areas of unburnt habitat were observed in the surrounding forests. The exclusion of disturbance from two small patches of habitat totalling 29ha, with just 5 recorded mice, out of 1500 ha of potential HRM habitat is an extremely bad outcome. It is likely that due to a lack of foraging resources and habitat to shelter from predators, that the HRM population in these forest compartments could go extinct.

Within these compartments there are a large number of records of Stuttering Frog *Mixophyes balbus*, along the streams throughout the area, along with the Golden-tipped Bat *Phoniscus papuensis*, and Spotted-tailed Quoll *Dasyurus maculatus maculatus*. These are all on the Commonwealth's list of 113 animals nationally in most urgent need of emergency action. Additionally there are records of Rufous Scrub-bird *Atrichornis rufescens*, Koala *Phascolarctos cinereus*, Sphagnum frog *Philoria sphagnicola* and New England treefrog *Litoria subglandulosa* nearby.

The decision by the Forestry Corporation and Environment Protection Authority to ignore the Commonwealth advice to protect unburnt habitat while the status of surrounding populations are assessed was grossly irresponsible and contrary to the requirements of good governance. Those responsible should be held to account.

4.2. Affects on flora

The Commonwealth has yet to complete their assessment of threatened plants though identify 13 Commonwealth listed plant species in north-east NSW with 80% or more of their records burnt and 19 with 50-80% burnt. NSW's preliminary assessment identified 19 of north-east NSW's threatened plants that had more than 90% of their localities burnt, with another 27 as having more than 50% burnt.

Unfortunately there does not appear to have been any attempts to asses plants further or identify management responses. This needs to be rectified.

Plant species have traits which enable them to survive fire, which can be divided into two broad groups, resprouters and non-resprouters (obligate seeders). Resprouters survive fire by resprouting from fleshy below ground organs, lignotubers or rhizome, epicormic buds or apical buds whereas obligate seeders die post fire if they receive 100% leaf scorch or stem girdling, regenerating from seed through serotiny or soil stored seed

To be able to persist on a site, obligate seed regenerating shrubs and trees need sufficient time following fires to mature and set seed before they are burnt again. Many species require at least 5 years to begin to set seed, for example for 38% of species on the New England Tablelands *sequential fire intervals of less than five years were found likely to cause local extirpations of fire killed species through adult deaths and exhaustion of either canopy or soil stored seed banks*.

A variety of species have been found to require fire intervals over 10-20 years. The most stark example is the elimination of 87% of alpine ash forests from extensive parts of the Australian Alps due to multiple high-severity wildfires since 2003, which *switched fuel arrays from low loads of herbaceous and litter fuels to high loads of flammable shrubs and juvenile trees, priming regenerating stands for subsequent fires.* In mountain and alpine ash forests frequent fires are killing regeneration and wiping out trees that need to be 20 years old to set new seed. It is ecosystem collapse.

From their assessment of burning responses of taxa in six of the major vegetation formations on the New England Tableland (rainforest, wet sclerophyll forest, dry sclerophyll forest, grassy woodland, rocky outcrops, heath and wet heath), Clarke *et. al.* (2009) found:

> *... across all community types, sequential fire intervals of less than five years are likely to cause local extirpations of fire killed species through adult deaths and exhaustion of either canopy or soil stored seed banks. Relatively large proportions (38%) of species fall into this obligate seeding group, although there are relatively few species of obligate seeding species with canopy held seed banks. Habitats that are particularly vulnerable to short fire intervals are rocky outcrops and the rainforest margins of wet sclerophyll forests with high concentrations of obligate seeders.*
>
> *...*
>
> *Our finer scale analysis of vegetation types shows that the minimum interval to avoid immaturity risk to vulnerable species ranges from 8 to 11 years in fire prone formations in the*

> *New England Tableland Bioregion. ... In the Northern Escarpment Wet Sclerophyll Forests,... in areas in which Callitris maclaeyana occurs, a threshold of 25 years is suggested and in where this species is absent a threshold of 11 years is recommended.*
>
> *...*
>
> *For those species that resprout, the consequences of repeated short interval fires are poorly known ... seedling recruitment must occur to maintain current populations. Our study has predictably shown that seedlings of resprouters are slower to mature, but their ability to resprout prior to this maturation remains unknown. Similarly, whilst many rainforest shrubs and trees show ‗tolerance' to a fire event, through vigorous resprouting, it is not known if recurrent fire causes mortality and recruitment failure.*

It is thus unsurprising that there was a decline in shrubs in grazed areas of the New England Tablelands, as reported by Henderson and Keith (2002) and Tasker and Bradstock (2006). It appears that the associated high fire frequency is chiefly responsible for the decline in shrubs in grazed areas.

In forest landscapes, “wet-sclerophyll” forests generally represent the dynamic interface between the fire sensitive rainforests and more flammable eucalypt forests. Where nutrients are not limiting, these forests may become increasingly dominated by rainforest taxa over time as the more flammable sclerophyll taxa senesce. Characteristically these forests may have a developing rainforest understorey with a dense canopy, overtopped by emergent eucalypts. Conversely, with more frequent burning, more flammable sclerophyll taxa, grasses, bracken and weeds may dominate the understorey, inherently increasing the flammability of the vegetation.

As a management tool fire is of limited use in "wet sclerophyll" forest. In stands with a naturally grassy understorey occasional fires can control lantana, though as the past 100 years prove it is not a successful means of managing sites that naturally have a low fire frequency and rainforest understory. Logging and burning simply promote lantana in these forests.

In areas, like north-east NSW, where the vegetation is a mosaic of rainforest, “wet sclerophyll” eucalypt forests, heathy forests and open grassy forests, the consequences of grazing and burning increasing the flammability of wet-sclerophyll forests can have significant affects on the landscape's susceptibility to burning.

In north east NSW‟s “wet-sclerophyll” forests, Floyd (1976) found that the seeds of many species remain dormant and buried in the soil until heated, and that each species required specific heating requirements for regeneration, identifying that fire intensity and frequency can cause major changes in composition of understorey vegetation, with burning at intervals less than 14 years resulting in species of *Callicoma*, *Piptocalyx*, and *Halogaris* replaced with more aggressive pioneers, such as *Phytolacca* sp. and *Acacia bivernata.* In their study of prescribed burning on wet sclerophyll forest in southeast Queensland, Guinto et. al (1999) found:

> *For most species, tree mortality was both diameter-dependent and fire-related, that is, smaller trees have a lower chance of survival than larger trees and frequent burning further reduces this probability. Without fire, recruitment was dominated by* S.glomulifera *and to a lesser extent by* L. confertus*. Recruitment of these species was adversely affected by burning. This result and the greater mortality of smaller trees with frequent burning suggest that if these trends continue, future stand growth and hence productivity of these species could be jeopardized because of the reduction of the regenerative capacity of the forest. Recruitment was negligible for other tree species in this forest regardless of fire treatment.*

Bowman *et. al.* (2014) cite research comparing eucalypt and rainforest finding "*there were no differences in the flammability of foliage of congeners in these contrasting forest types"*, leading the authors to conclude "*that community flammability differences were related to the contrasting microclimates under the open eucalypt and the dense rainforest canopies".*

As noted by Blackhall *et. al.* (2015) *"microclimatic conditions may affect plant flammability, which in turn affects ignition probability, rate of fire spread and fire intensity".* Forests which have dense canopies result in microclimates characterized by higher humidity, lower wind velocities, cooler temperatures, reduced evaporation and hence reduced fire risk compared to open forest. Cawson *et. al* (2018) agree that fuel moisture is the key to burning of Mountain Ash wet sclerophyll forests, noting:

> *Under climate change, a drier climate could make the fuels in wet sclerophyll forests available to burn more frequently. This poses a major challenge for forest managers as too frequent wildfire threatens the viability of these forests.*

From their study in Patagonia, Partsis *et al.* (2013) found "*The juxtaposition of fire-resistant tall forests with fire-prone shrublands and woodlands creates the potential for positive feedbacks from human-set fires to gradually increase the flammability of extensive landscapes through repeated burning*."

4.2.1. Affects on rainforests

Worldwide rainforests are coming under increasing threat due to clearing, increasing drought and burning. While the loss of Australia's rainforest will not have the worldwide climatic consequences of the declining Congo and Amazon rainforests, they will have regional climatic impacts and have devastating impacts on our biodiversity.

A third of northern NSW's ancient and irreplaceable rainforests burnt last year. Buffers need to be established, and weed control undertaken, to increase their resilience. Though until we stop global heating burning will become more frequent and intense, eroding the extent, viability, and biodiversity of our relictual rainforests, along with our future.

The impacts of rising temperatures, droughts and heatwaves on rainforests have been increasing. When mature rainforests start burning we know the situation has become dire, as they are not adapted to fire. Burning of rainforests is akin to the bleaching of coral reefs.

Given the role of logging in increasing forest flammability (Section 2 of this submission), including by facilitating the invasion lantana and other weeds (Section 4.2.2. of this submission), it is essential that as a minimum 50m buffers are placed around all rainforests from which logging is excluded.

The NSW Government is advised not to rely on DPIE's (2020) Fire Extent and Severity Mapping of rainforest for assessing impacts as it misrepresents the impacts of the 2019-2020 fires upon rainforest and grossly understates the damage that was done.

It is recommended that permanent transects be established in burnt rainforests, and particularly across their ecotones to quantify the impacts of the 2019 fires on rainforests and their susceptibility to repeat burning. Such information is essential to inform management responses to help our rainforests survive the unfolding climate emergency. Such buffers should be a focus for lantana control and the removal of debris from previous logging.

Worldwide our rainforests are coming under increasing threats from climate change and burning (Lovejoy and Nobre 2019) that threaten their survival and our future.

Cooper *et. al.* (2020) found that "*shifts in Earth ecosystems occur over 'human' timescales of years and decades, meaning the collapse of large vulnerable ecosystems, such as the Amazon rainforest and Caribbean coral reefs, may take only a few decades once triggered*", noting:

> *... we must prepare for regime shifts in any natural system to occur over the 'human' timescales of years and decades, rather than multigenerational timescales of centuries and millennia. Second, the apparent long-term stability of the largest, least disturbed ecosystems is a deceptive guide to the potential speed of their collapse. Therefore, the self-organising mechanisms (e.g. modularity) that help to instil systems with resilience prior to a tipping point may have limited ability to control the rate of collapse once a shift has been triggered.*

In early 2019 Richard Flanagan (The Guardian Mon 4 Feb 2019) reported that Tasmania rainforests were burning and under unprecedented threat because of climate change:

> *Davies told me that the south-west of Tasmania – the island's vast, uninhabited and globally unique wildland, the heart of its world heritage area – was dying. The iconic habitats of rainforest, button grass plains, and heathlands had begun to vanish because of climate change.*
>
> *Then there was the startlingly new phenomenon of widespread dry lightning storms. Almost unknown in Tasmania until this century they had increased exponentially since2000, leading to a greatly increased rate of fire in a rapidly drying south-west. Compounding all this, winds were also growing in duration, further drying the environment and fuelling the fires' spread and ferocity. Such a future would see these fires destroy Tasmania's globally unique rainforests and mesmerising alpine heathlands. Unlike mainland eucalyptus forest these ecosystems do not regenerate after fire: they would vanish forever. Tasmania's world heritage area was our Great Barrier Reef, and, like the Great Barrier Reef, it seemed doomed by climate change.*
>
> *... What has become clear is that another global treasure in the form of Tasmania's ancient Gondwanaland remnant forest and its woodland alpine heathlands are at profound and immediate risk because of climate change.*
>
> *... And so, without a far greater investment of money in the coming years, scientists believe these global treasures are doomed to destruction. This week or next year or the next, the certainty is that without extraordinary effort, they will burn and be gone forever.*
>
> *... Climate change isn't just happening. It's happening far quicker than has been predicted. Each careful scientific prediction is rapidly overtaken by the horror of profound natural changes that seem to be accelerating, with old predictions routinely outdone by the worsening reality – hotter, colder, wetter, drier, windier, wilder, and ever more destructive*

Later that year it was the mainland's turn as the drought affected subtropical and temperate rainforests of NSW caught fire.

These rainforests are descendants from over 70 million years ago when Australia was clothed in rainforest as part of the supercontinent of Gondwana. They have been in decline since Australia separated from Antarctica and became increasingly arid around 30 million years ago, with fire a major diver over the past 130,000 years. Increased burning accelerated their loss after the arrival of people around 50,000 years ago (see Section 1).

The arrival of Europeans resulted in extensive clearing and degradation of the surviving rainforests. Widespread logging changed their structure, dried them out and increased their flammability. Decades later many stands are still struggling to recover.

The relatively small remnants left are packed with survivors from the ancient forests. Rainforests now cover only about 0.25 per cent of Australia, yet they contain about half of our plant species and a third of our mammals and birds.

The exceptional importance of NSW's rainforests is recognised by parts being created as the Gondwana Rainforests of Australia World Heritage Area.

Rainforest's resilience to fire is primarily due their dense canopies maintaining a moister microclimate. Last year was Australia's hottest and driest year on record, resulting in north-east NSW's rainforests becoming unusually dry and flammable.

The NSW Government's mapping of fire extent and canopy scorch (GEEBAM v2) shows that some 160,000 hectares (35%) of north-east NSW's 462,000 ha of rainforests were burnt last fire season. For this assessment reliance is placed on DPIE's GEEBAM v2 that is adapted specifically to account for rainforest, rather than the more recent and grossly erroneous FESM v2 mapping (see below). This was clipped with CRAFTI mapped rainforest for north-east NSW, north from the Hunter River. Based on this and my limited ground truthing:

- 34,000 ha of rainforest has had its 'canopy fully affected', with the understorey fully burnt and the loss of most canopy trees (see 4.2.1.3 for an example).
- 91,000 ha has had its understorey extensively burnt, with the bases of many trees damaged (which is likely to cause ongoing fungal problems and mortality), and 'partial' canopy loss (see 4.2.1.4 for an example).
- 47,000 ha has been variably burnt, with some areas unburnt and other areas with extensive understorey burning and damage to the bases of many trees, and some loss of canopy trees. For the purpose of this preliminary review it is assumed that 36,000 ha may have burnt.

It is frightening that with only one degree of global heating over a third of these priceless relicts burnt in one year. Across the fire-grounds most leaf litter, logs and understorey plants were burnt, along with their inhabitants. Many tree bases were damaged. Even riparian areas burnt.

Most worrying is the significant loss of large canopy trees, hundreds of years old, across 125,000 ha of rainforests. Those areas heavily burnt will struggle to regenerate. Some stands are unlikely to ever recover, further diminishing our rainforest heritage.

From her investigations of burnt Tasmanian rainforests, Barker (1990) concluded “*The results suggest that burnt rainforest would be very susceptible to further fires because of the dense cover of highly flammable non-rainforest species present*".

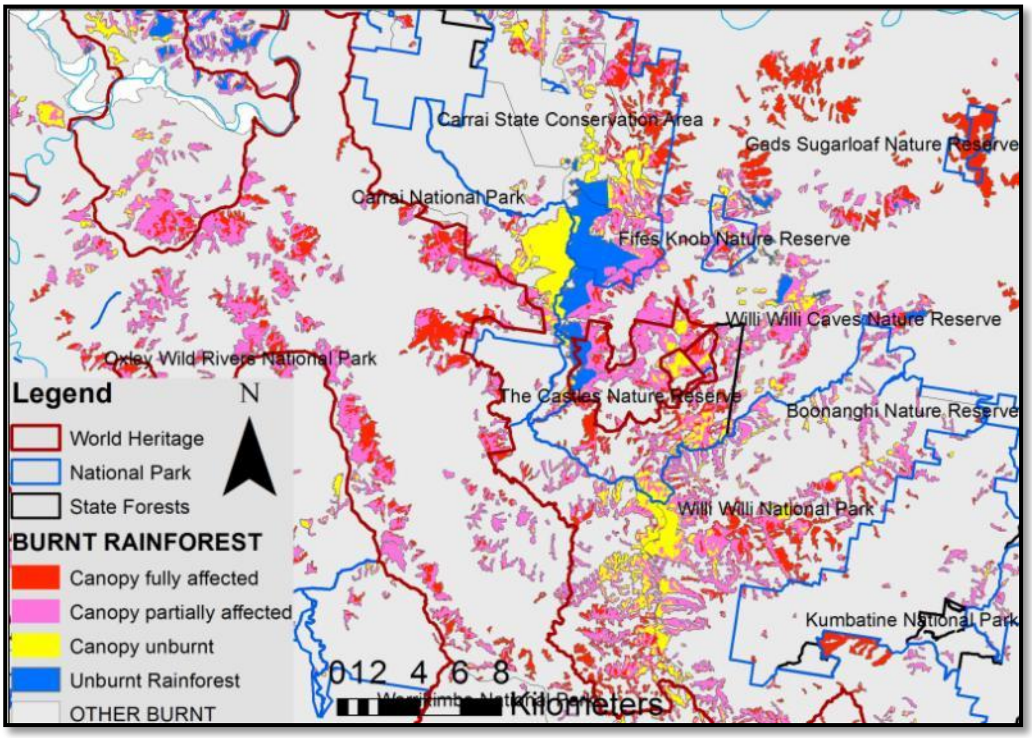
A 1989 study (Bennett and Cassells 1989) of rainforest patches in the Apsley-Macleay Gorges found that the effects of fire were likely responsible for restricting their extent, and that "*the majority, just over three quarters of the total area of rainforest, is highly prone to fire*", noting that an expert workshop:

... considered that "unmanaged" fire was indeed a significant factor controlling the distribution of dry rainforest in the Gorges. It was also concluded that dry rainforest expansion would be promoted with a reduction or total cessation of burning.

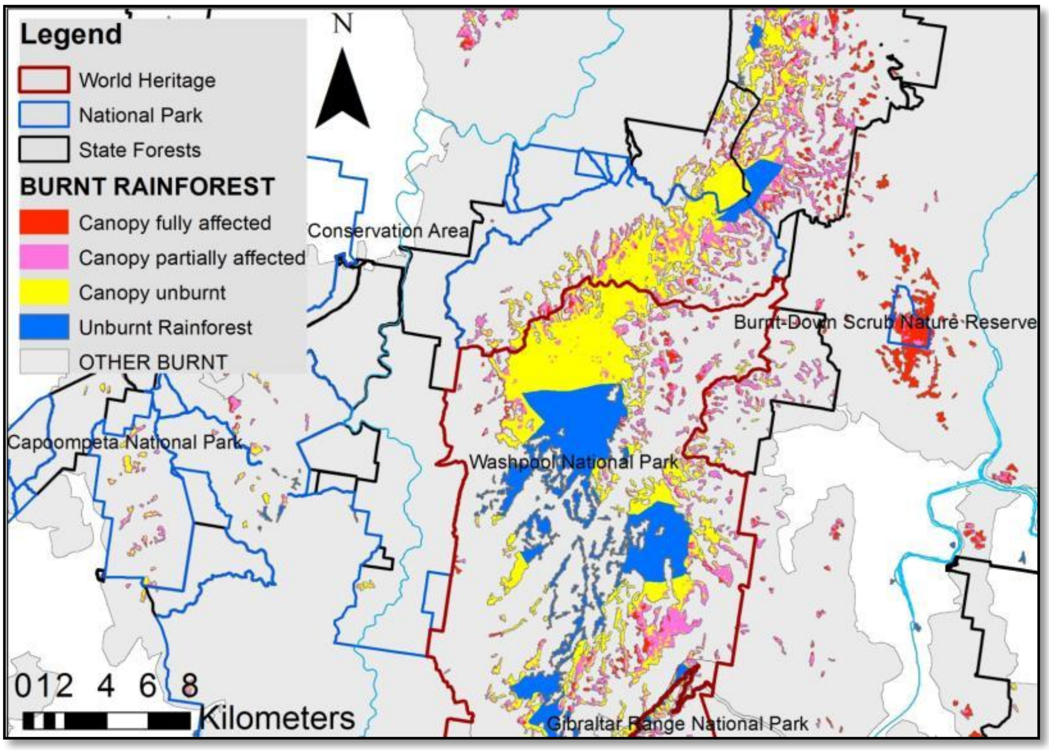
The size of rainforest patches is an indicator of their vulnerability to fire. Bennett and Cassells (1989) note:

The configuration of patches (i.e., their shape, size and area perimeter ratio) is thought to be the primary variable influencing their fire susceptibility. For example, it appears that the significance of and potential for fire damage was greater for the smaller and more linear shaped dry rainforest patches and less for the larger, more compact patches. Furthermore, the greater distance of boundary relative to the patch area (characteristic of the smaller, linear shaped patches and reflected in the measurement of their area: perimeter ratio) ensure that potential fire impacts would be significant to the integrity and continued existence of the patch as a whole. The protective nature of the rainforest microclimate is less well developed in these patches and would be likely to break-down more rapidly than in the larger, compact patches with high area : perimeter ratios.

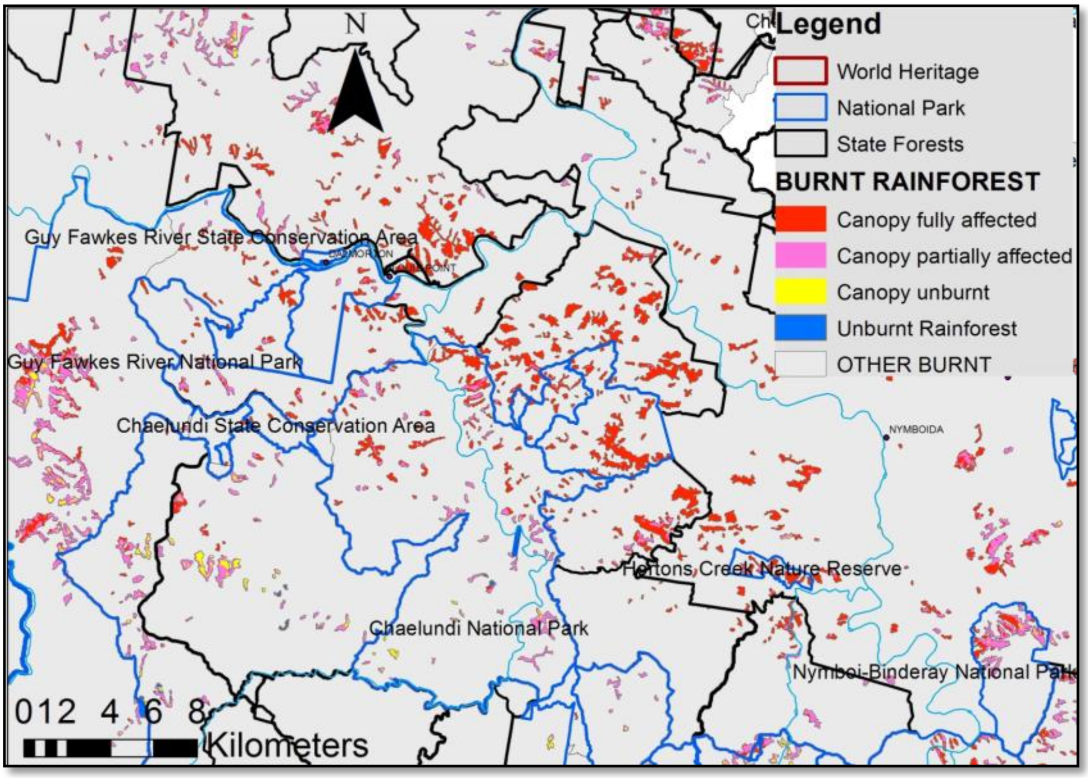
The current configuration of a patch may, in addition to indicating its current fire susceptibility, also reflect the past impact of fire. Indeed, patch configuration may largely be the result of fire superimposed on other controlling factors, including edaphic and topographic condition



Map showing burnt rainforest (GEEBAM v2) in part of the Apsley-Macleay Gorges region showing the extensive and intensive impacts on rainforest stands. Note the particularly severe impacts on small patches. This is a far greater impact than envisioned by Bennett and Cassells (1989) as being possible.



Map showing burnt rainforest in the Washpool area.



Map showing burnt rainforest in the Chaelundi area.

With climate heating increasing droughts, temperatures, heatwaves and extreme fire weather, many of our relictual rainforests are under a looming threat to their continued existence.

Some 230,000 ha within 100m of rainforest stands also burnt. These encompass vital buffers, characteristically with an overstorey of eucalypts and an understorey of hardier rainforest species.

These transition zones are essential to maintain rainforest microclimates, reduce fire threat, and provide complementary habitat and resources for some species. Their degradation increases the drying of rainforests and vulnerability to the next fire.

A 1989 study (Bennett and Cassells 1989) of rainforest patches in the Apsley Macleay Gorges found that fire proneness is largely governed by the predominant aspect, topographic position, slope angle and adjoining vegetation community of patches. They identify that it is the vegetation buffering rainforests that it primarily responsible for carry fire into them:

> *... the vegetation communities adjoining rainforest dry out more rapidly than the rainforest and carry fire much more effectively and frequently. These fires can enter rainforest under certain conditions, but more often they result in scorching and mortality of the rainforest margin to varying degrees. If these events recur frequently or intensely enough, alteration to the rainforest margin structure or its geographic location will result.*

It is a bad idea to increase fuel reduction burning in these wet refugia where fires are naturally rare. More frequent fires in the vicinity of rainforests will just make the situation worse by drying and increasing the flammability of their vital buffers.

For their study area, Bennett and Cassells (1989) do recommend "*early buffer burning to isolate the patch edges from the impact of later, more damaging fires that might either scorch the rainforest edge or encroach into the rainforest proper*" for larger rainforest patches, though for smaller patches recommend:

> *However, an additional requirement would be the need to maintain an unburnt buffer of at least 40 - 50 metres around each patch to allow for any rainforest expansion that might occur.*

Given the role of logging in increasing forest flammability (Section 2 of this submission), including by facilitating lantana invasion (4.2.2. of this submission), it is essential that as a minimum 50m buffers are placed around all rainforests from which logging is excluded. Such buffers should be a focus for lantana control and the removal of debris from previous logging.

It is too early yet to assess the full consequences of the fires on rainforests, though there can be no doubt that they have inflicted significant damage, affected their viability and increased their vulnerability to further burning. The obvious priority is to assess the impacts of the fires on the forests and those species whose habitat was most affected. Once we know how badly they have fared, we then need to monitor their recovery and provide help where needed.

It is important to recognise that rainforests have a degree of resilience to fires. In a severe drought in 1915 fire penetrated up to 800m into the Tooloom Scrub, killing many Hoop Pines, and reburning 2 weeks later (Pugh 1981). Fire was recorded burning into rainforest 1,100 years ago in the Terania Creek basin (Turner 1984). From their study of rainforest patches in the Apsley Macleay Gorges Bennett and Cassells (1989) consider "*Based on landholder recollections and aerial reconnaissance, over 50% of the area of rainforest has potentially experienced fire since about the early 1960's*". They found:

> *Bushfires are impacting on dry rainforest. Indeed, reconnaissance field investigations of some rainforest patches identified significant fire scarring of rainforest trees. This scarring occurred quite deeply into the communities, with the ecotone reflecting particularly high levels of tree fire scars.*

Burning makes rainforest more vulnerable to repeat burning and can eliminate rainforest (i.e. Bennett and Cassells 1989).

It is recommended that permanent transects be established in burnt rainforests, and particularly across their ecotones to quantify the impacts of the 2019 fires on rainforests and their susceptibility to repeat burning. Such information is essential to inform management responses to help our rainforests survive the unfolding climate emergency.

While we can help the rainforests recover from the recent fires, and enhance their resilience, their salvation lies in urgently stopping runaway climate heating.

Canopy Burn Mapping

During the fires the Rural Fire Service undertook daily updating of mapping of the “area affected by fire” which was displayed on the Fires Near Me website. This was undertaken from aerial assessments at the time, and included some internal areas that may not have burnt. This mapping was the basis of NEFA's earliest assessments.

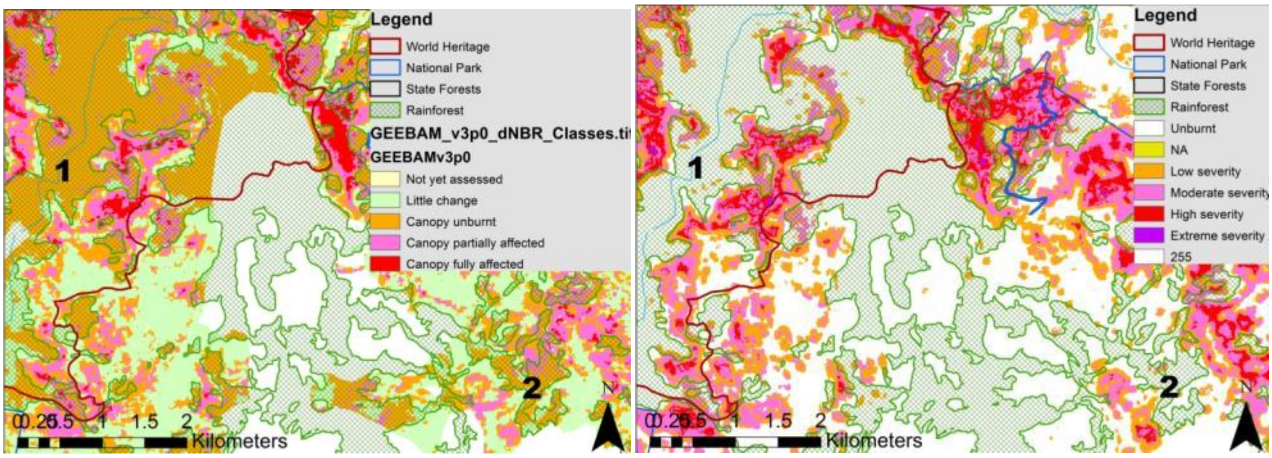
In collaboration with the University of NSW, the NSW Department of Planning Infrastructure and Environment (DPIE) Remote Sensing and Landscape Science team developed a rapid mapping approach using Sentinel 2 satellite imagery to map fire affected vegetation, called the *Google Earth Engine Burnt Area Map* (GEEBAM). GEEBAM represents the difference between the NBR (Normalized Burnt Ratio) before and after fire. It is based on a cumulative difference between imagery collected before the fires in and the most recent imagery available. A threshold was chosen through visual interpretation to create GEEBAM classes, with, for example, significantly lower thresholds adopted for rainforest. This was not available until after the fires, and was initially updated every two weeks.

The various iterations of this varied significantly, particularly in response to changing thresholds for mapping classes. The second version GEEBANG 2 was relied upon for most of this assessment. It was only after they adopted significantly lower thresholds to identify rainforest disturbance that their mapping began to reflect reality. Two versions were combined for NEFA's Koala assessment to better reflect what we found on the ground. The principal failing of this method is its ability to identify ground fires, particularly in areas with dense canopies.

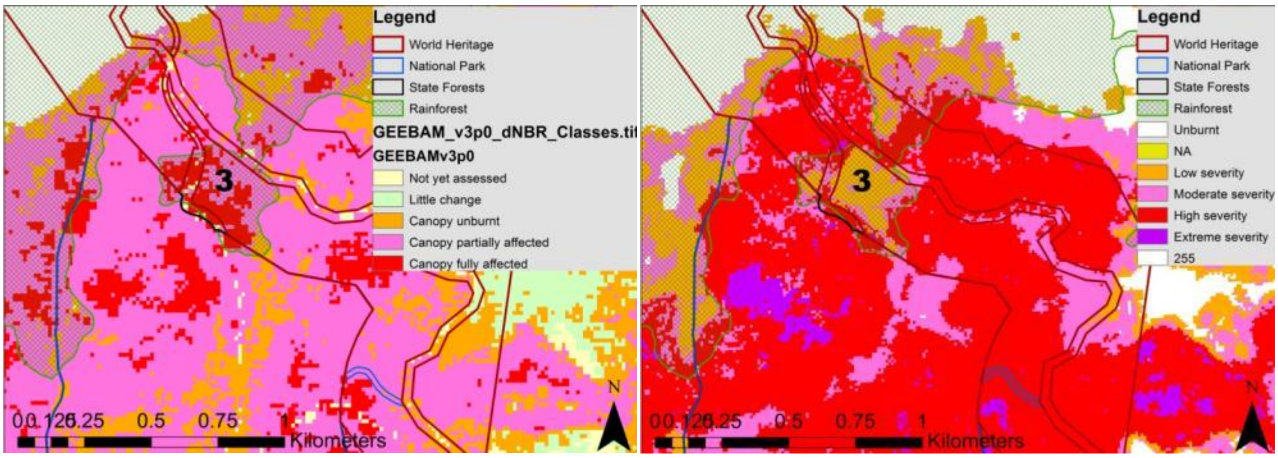
In collaboration with the NSW Rural Fire Service, DPIE Remote Sensing & Regulatory Mapping team developed a semi-automated approach to mapping fire extent and severity through a machine learning framework based on sentinel 2 satellite imagery. This is termed Fire Extent and Severity Mapping (FESM). The state-wide severity map has standardised classes including: unburnt, low severity (burnt understory, unburnt canopy), moderate severity (partial canopy scorch), high severity (complete canopy scorch, partial canopy consumption), extreme (full canopy consumption). It is an evolving product, and it is identified that there is a need to "*quantify uncertainty bounds for low severity under dense canopy*". This has only recently become available, and like the erroneous vegetation mapping previously produced, this has been found to be very inaccurate.

One of the foci of my post-fire assessments has been rainforest. I have watched the evolution of GEEBAM as different thresholds were applied to better delineate burnt rainforest. I used GEEBAM v2 as a basis for assessing rainforest impacts. From my limited ground assessments this mapping appeared relatively accurate, with the problem being the "canopy unburnt" category as this comprised a mixture of burnt and unburnt forest.

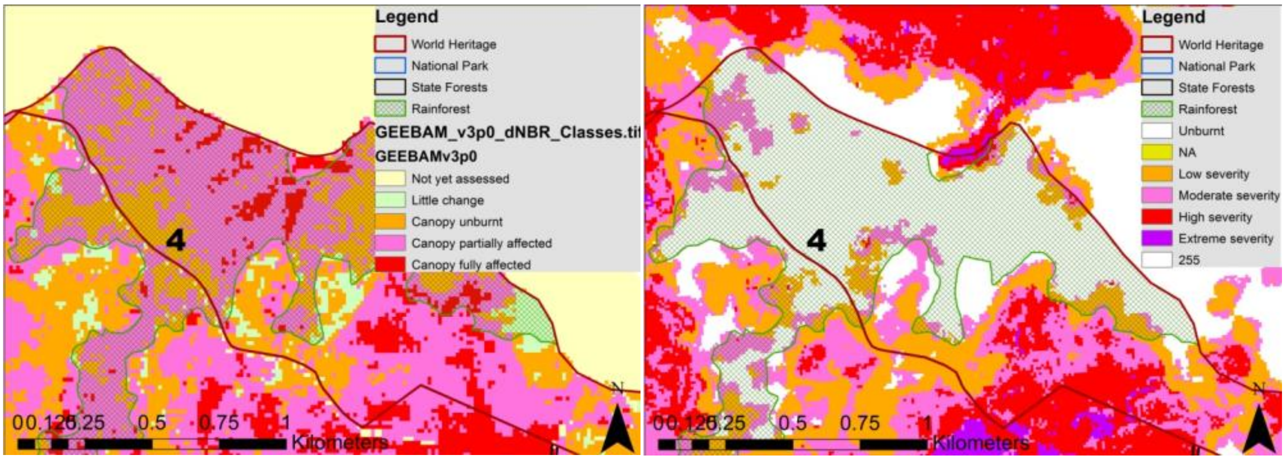
I was shocked when I compared my findings (Section 4.2.) to the new FESM. This mapping bears little resemblance to reality as large areas previously mapped (GEEBAM v2) as 'canopy partially affected' and 'canopy unburnt' are reclassified as 'unburnt', when they have been clearly and significantly burnt. This revised mapping is erroneous and extremely dangerous as it clearly misrepresents the burning affects on rainforest.



Comparison between GEEBAM v3 burn mapping and FESM burn mapping, note the assessed areas: 1 Terania Creek in Nightcap NP, and 2 Whian Whian. See representative photos in sections 4.2.1.1. and 4.2.1.2., You Tube videos of Terania Creek are at https://www.youtube.com/watch?v=0KbkMJXjvgw and https://www.youtube.com/watch?v=MZhGNT7SNQg&t=111s, with understorey shots mostly within the new "unburnt" category. Despite significant parts being burnt with some canopy loss, both have been reclassified from 'canopy unburnt' to 'unburnt'



Comparison between GEEBAM v3 burn mapping and FESM burn mapping, note the assessed area 3 in Tooloom NP. See representative photos in section 4.2.1.3. You Tube videos of Tooloom taken in this vicinity are at https://www.youtube.com/watch?v=LOU9CVWYT9M. Despite most of the canopy being lost this was reclassified from mostly 'canopy fully affected' to mostly 'low severity', which is described as 'Burnt surface with unburnt canopy'.



Comparison between GEEBAM v3 burn mapping and FESM burn mapping, note the assessed area 4 at Mount Lindesay in Border Ranges NP. See representative photos in section 4.2.1.4. You Tube videos of Mount Lindesay taken in this vicinity are at https://www.youtube.com/watch?v=LOU9CVWYT9M, with footage within the now 'unburnt' category. Despite having most of the understorey burnt and significant canopy loss this was reclassified from a mix of 'canopy unburnt' and 'canopy partially affected' to 'unburnt'.

It is obvious from these examples that DPIE's (2020) Fire Extent and Severity Mapping of rainforest is clearly wrong, grossly understating the extent and severity of burning in rainforests. It therefore should not be used for assessing or monitoring impacts. The GEEBAM mapping provides far more reliable mapping of impacts for further assessments.

The NSW Government is advised not to rely on DPIE's (2020) Fire Extent and Severity Mapping of rainforest for assessing impacts as it misrepresents the impacts of the 2019-2020 fires upon rainforest and grossly understates the damage that was done.

4.2.1.1. Nightcap National Park: Canopy Unburnt or Totally Unburnt?

This area of the Terania Creek valley was mapped as 'canopy unburnt ' in GEEBAM v2, though has now been remapped under FESM v2 as 'Unburnt'.

It was found that some areas, particularly on creek terraces, had escaped burning, though the understorey was burnt over extensive areas, extending down to Terania Creek. Many trees were injured and a large number killed, particularly strangling figs and large (up to 2.8m diameter) Brush Box. It is surprising these weren't detected in the FESM mapping.

4.2.1.2. Whian Whian State Conservation Area: Canopy Unburnt or Totally Unburnt?

This area of the Whian Whian SCA was partially mapped as 'canopy unburnt ' in GEEBAM v2, though has now been remapped under FESM v2 as 'Unburnt'. The mapped rainforest was found to have been mostly burnt, including riparian areas, by a fairly intense understorey fire causing widespread damage to tree bases and occasional tree loss.

An adjoining patch of eucalypt forest was mapped as 'little change' (unburnt) in GEEBAM v3, though correctly remapped by FESM v2 as 'low severity'.

4.2.1.3. Tooloom National Park: Canopy Fully Affected or Low Severity?

This was mapped as 'canopy fully affected' in GEEBAM v2, and mostly as fully affected in v3, though has now been remapped under FESM v2 as 'low severity': 'Burnt surface with unburnt canopy'. Nothing could be further from the truth as this stand and the nearby rainforest edge, were severely burnt with the loss of most canopy trees. Many such severely impacted rainforests will never recover.

4.2.1.4. Mount Lindesay: Partial Canopy Loss or Totally Unburnt?





This was mapped as 'canopy partially affected ' in GEEBAM v2, though has now been remapped under FESM v2 as 'Unburnt'. Most of the understorey was burnt, including many tree bases, and scattered canopy trees were killed, along with some patches.

4.2.2. An Overabundance of Lantana

The weed Lantana (*L. camara)* has been the scourge of wet sclerophyll forests and rainforest, invading areas where canopy has been reduced by logging or fire, suppressing regrowth, increasing flammability and initiating dieback in adjoining logged eucalypt forests. (see Section 4.2.2.)

In order to address the increasing flammability of degraded forests it is essential that lantana be controlled to allow native forests to regenerate and increase their resilience to future fires.

The intensity of the 2019-20 fires, combined with the intense drought, has killed lantana over large areas, creating an opportunity to control it before it takes over again. Large areas can now be covered to remove reshooting and new plants quickly. This opportunity must be capitalised on if we want to increase the resilience of wet sclerophyll forests and rainforests at minimal cost.

Given the abundant evidence that logging is the primary cause of Bell Miner Associated Dieback, and that re-logging affected forests makes it worse, it is well past time that the logging of BMAD affected and susceptible forests is stopped and the process of restoration begun.

It is recommended that as a matter of urgency widespread control of Lantana and other weeds be undertaken throughout burnt forests, focusing on bad weed infestations, rainforest ecotones and areas of Bell Miner Associated Dieback. To allow recovery such areas must have logging excluded.

Lantana is the most widespread and successful weed throughout north-east NSW, benefitting from logging and other activities that open the forest canopy enough for it to thrive (Section 3.4.). Lantana now dominates the understorey in tens of thousands of hectares of northeast NSW's forests. The NSW Scientific Committee has listed the 'Invasion, establishment and spread of Lantana (*Lantana camara* L. *sens. lat*)' as a Key Threatening Process, noting *"There is a strong correlation between Lantana establishment and disturbance ..., with critical factors being disturbance-mediated increases in light and available soil nutrients".*

Logging, fire and cattle grazing are significant contributors to the successful invasion of lantana (Gentle and Duggin 1997, Raizada and Raghubanshi 2010), and it in turn can increase the flammability of vegetation (Fensham *et. al*. 1994, Gill and Zylstra 2005, Berry *et. al* 2011, Murray *et. al.* 2013, Bowman *et. al.* 2014). Gentle and Duggin (1997) concluded "*The effects of biomass reduction and soil disturbance associated with fire and cattle grazing are significant in the successful invasion of* L. Camara". This is supported by Wardell-Johnson et. al. (2006): "*the proliferation of dominant understorey weeds, such as Lantana (Lantana camara), in the north-eastern region of NSW has largely been attributed to the disturbance caused by logging and associated activities".*

Raizada and Raghubanshi (2010) found that germination of the numerous lantana seeds that survive is enhanced along with seedling vigour by fires, commenting *"that the use of fire as a management option to control L.camara should be discouraged, because fire may result in encouraging, rather than in checking its spread".*

Murray *et. al.* (2013) found that the average higher flammability of dry leaves of exotics, combined with their larger leaves, meant "*exotic plant species have the potential to increase the spread of bushfires in dry sclerophyll forest"*. Of the 79 species from dry sclerophyll forests tested by Murray *et. al.* (2013), lantana had the third shortest mean time to ignition for fresh leaves.

From their study of the Forty Mile Scrub National Park, Fensham *et. al*. (1994) found "*the proliferation of lantana results in the build up of heavy fuel loads across the boundary of dry rainforest and savanna woodland. Recent fires have killed the canopy trees in a large area of dry rainforest within the Park*". From their study of dry rainforests, Berry *et. al* (2011) concluded that *L camara* was less ignitable than native dry rainforest species, though:

> *Fuel bed depths, leaf litter depths, percentage cover by fuels and amount of mediumsize class fuels were higher in dry rainforest invaded by* L.camara *than in non-invaded forests. This suggests that the mechanism by which* L.camara *alters the fire regime in dry rainforest is by shifting the distribution of available fuels closer to the ground and providing a more continuous fuel layer in the understory*

A 1989 study (Bennett and Cassells 1989) of rainforest patches in the Apsley Macleay Gorges identified Lantana as the most flammable community adjoining rainforest.

The increasing dominance of forest understoreys by lantana in north-east NSW significantly increases their flammability and poses a significant wildfire threat.

The evidence is clear that by opening up the overstorey and disturbing the understorey logging can facilitate the invasion and spread of lantana and thereby initiate and promote Bell Miner Associated Dieback (BMAD). Logging's legacy lasts well after the harvest, with lantana and BMAD still present and expanding in National Parks where logging was stopped over 20 years ago.

Severe BMAD affected forest in Donaldson SF (note the obvious dead trees), 9 years after "restoration" works.

Bell Miner Associated Dieback (BMAD) is spreading through our forests as a consequence of logging opening the canopy and promoting understorey dominance by lantana. It is principally a problem of wet forests and gullies, though is increasingly affecting surrounding forests subject to lantana invasion. For over two decades the Forestry Corporation have intentionally procrastinated over the causes and management of BMAD so that they can go on logging affected and susceptible stands.

The "moist hardwood" forests have long been recognised as a management problem due to difficulty in achieving regeneration of the eucalypt component following logging as a result of competition from rainforest elements or weeds (e.g. van Loon 1966, Forestry Commission 1982, King 1985). The NSW Forestry Commission (1982) notes *"The Moist Coastal Hardwood types can be among the most difficult in the state to regenerate successfully. The dense rainforest understorey precludes hardwood regeneration without major disturbance; some of the most important species are relatively slow growing in their younger stages; weed growth after disturbance can be prolific and vigorous."* The more developed the rainforest component, the harder it is to achieve eucalypt regeneration (i.e. Forestry Commission 1982).

State Forests (1995) identified moist hardwood forests as 'Potentially High Yielding, Difficult to Manage Forest', one of three categories (along with 'Low Wood-Yield Forest' and 'Geographically Remote Forest') for consideration for exclusion from the core productive forest estate on the basis that:

> *"Under the current restrictions that apply to logging intensity, many past and current areas of potentially high wood productivity such as moist hardwood and rainforest ecotone forest cannot be satisfactorily regenerated back to the same stand level of sclerophyll species following logging. Generally, the light logging practised in these forests has the effect of promoting either the mesophyll (rainforest) component or a viney, weedy component. Either way, the effect is one of reducing the sclerophyll component and lowering commercial productivity."*

The NSW Scientific Committee's (2008) final determination for listing 'Forest eucalypt dieback associated with over-abundant psyllids and Bell Miners' as a Key Threatening Process notes that:

> *Broad-scale canopy dieback associated with psyllids and Bell Miners usually occurs in disturbed landscapes, and involves interactions between habitat fragmentation, logging, nutrient enrichment, altered fire regimes and weed-invasion (Wardell-Johnson et al. 2006). ... Over-abundant psyllid populations and Bell Miner colonies tend to be initiated in sites with high soil moisture and suitable tree species where tree canopy cover has been reduced by 35 – 65 % and which contain a dense understorey, often of Lantana camara.*

Stone et. al. (1995) found that *"The vast majority of plots (97%) had been exposed to some degree of logging and were on their second or third rotations ... A possible long-term explanation of why the dieback problem may be increasing, is that the proportion of moist sclerophyll forest being exposed to selective logging is increasing throughout the State."*

Wardell-Johnson *et. al*. (2006) identify that many authors who have studied BMAD have identified logging as a cause, noting:

> *Hence, logging operations may be both implicated in the development of BMAD, and affected by changes in yield induced by BMAD. Nevertheless, the literature remains*

very limited concerning the impacts of logging and associated disturbance on the initiation or development of BMAD.

Based on her research for the Forestry Corporation and review of the literature, Stone (1999) put forward a conceptual model for BMAD identifying logging as a primary cause:

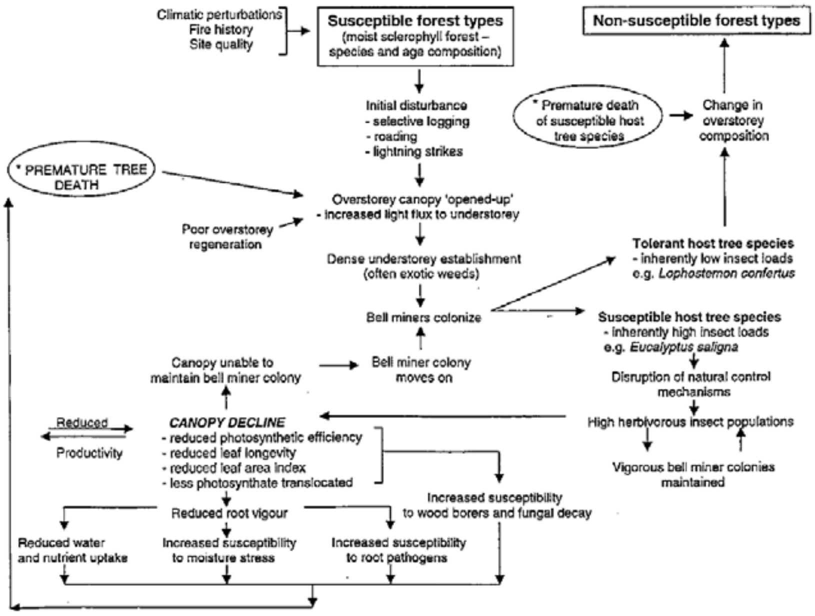
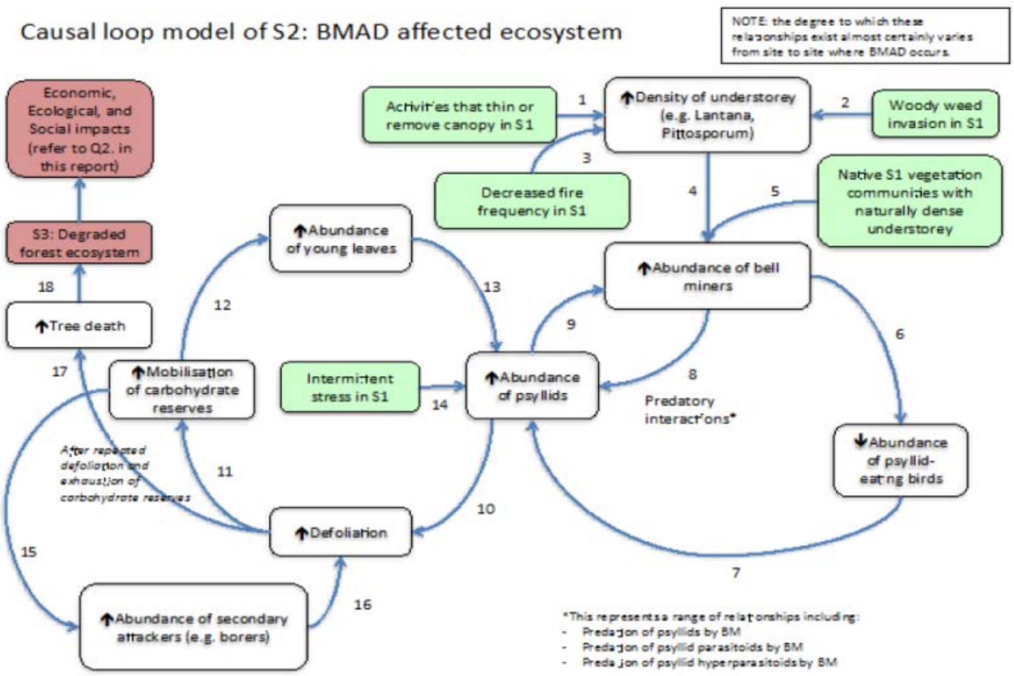


Figure 1. A conceptual model illustrating possible relationships and several feedback loops between processes which may contribute to canopy dieback associated with bell miners in moist eucalypt forests.

NSW DPI recently completed another literature review of the causes of BMAD (Silver and Carnegie 2017). They derived yet another conceptual model, which yet again identifies "activities that thin or remove canopy" as the primary cause of BMAD.

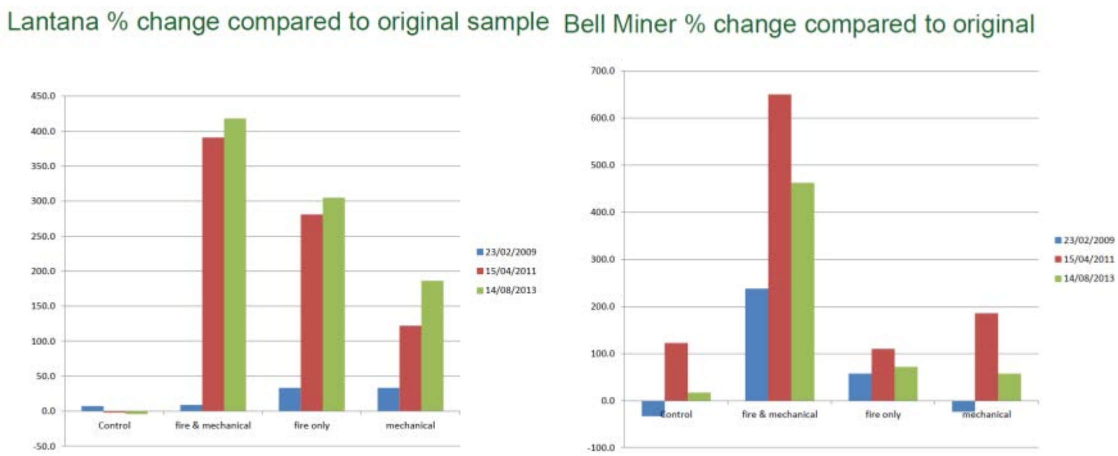


Under the auspices of the Bell Miner Associated Dieback Working Group the then State Forests established management "trials" of BMAD in compartments Donaldson State Forest in 2005 and Mt Lindesay State Forest in 2007, utilising some $117,000 of Environmental

Trust monies, with 120 monitoring plots established and commitments to 15 years monitoring. Only the initial 2 years results for Mount Lindesay were written up by the Forestry Corporation (St.Clair 2010), and it was only because of NEFA's complaints about the lack of monitoring and reporting (i.e. Pugh 2014) that the Forestry Corporation (2015) was forced to collate at least some results (though only a brief PowerPoint presentation), claiming many of the records were missing.

ABOVE Photos of BMAD in Donaldson SF taken in May 2014.

It is no surprise that the Forestry Corporation tried to suppress the results (and still tries to) as the Donaldson Trials clearly show that the use of mechanical and fire treatments together resulted in 420% increases in lantana and 460% increases in Bell Miners after 8 years (FCNSW 2015), and the Mt. Lindesay trials found that logging increased lantana 145% and Bell Miners 104%, after 6 years (averaged across all plots, including those not affected by BMAD).



The Forestry Corporation (2015) results for Donaldson State Forest.

Logging of BMAD affected forests in Yabbra State Forest in 2009.

It is recognised that stress may be a factor involved in the proliferation of BMAD and that BMAD becomes worse during periods of low rainfall (i.e. Stone 2005, Jurskis and Walmsley 2012, Silver and Carnegie 2017). This suggests that global warming, with its increasing temperatures, skyrocketing evaporation and intensifying droughts is likely to be a major contributor to increasing BMAD.

The latest subjective aerial mapping of BMAD (undertaken from 2015-17) (Silver and Carnegie 2017, and subsequent updates) is claimed to have covered some 1,250,000 hectares of forest north from Taree, with 44,777ha of BMAD mapped. Comprised of 17,005ha on State Forest, 12,822ha on National Park, 1,540 on Crown Land, 12,885ha on private property and 525ha on plantations.

One problem is that comparison with 2004 mapping of the western Border Ranges undertaken by the same mapper using similar methods identified very different results, with only a 13% overlap between the two mappings. This and other evidence suggests that the 2017 mapping has grossly under estimated BMAD extent, by some 40% if the 2004 mapping has any credibility.

There has also been no recent BMAD mapping south from Taree. yet past mapping has identified significant areas of BMAD in that region, it would be reasonable to assume that a third of BMAD occurs south of Taree. Given these considerations it is reasonable to assume that there are over 100,000 ha of BMAD affected forests in north-east NSW.

NEFA's extensive experience with BMAD leaves us in no doubt that logging and associated disturbances are the principal factor responsible for the alarming spread of BMAD through our forests. The solution to BMAD is to stop logging affected and susceptible forests and to rehabilitate affected areas to reduce their suitability for Bell Miners.

The solution to BMAD is to remove the lantana (or other low dense vegetation) component, thereby removing the habitat favoured by Bell Miners and allowing for regeneration.

Stone (2005) states:

> *If bell miners are responsible for a breakdown in the top-down processes maintaining the insect herbivore populations at non-damaging levels, then management options*

could concentrate on reducing or removing at least one of the habitat factors favoured by bell miners.

Wardell-Johnson et. al. (2006) concluded:

> *...It may be appropriate for management to prevent the creation of habitat that is preferred by the Bell miner, as such habitat will also facilitate the primary cause of eucalypt dieback. However, to attempt such management intervention in isolation from an understanding of both the processes and the behaviour of Bell miners under different levels of disturbance may compound the problem.*

From his work in Donaldson and elsewhere in the region, Mews (2008) observed *"It is apparent that there is reluctance by NSW government to deal with this phenomenon and to recognise the linkages between BMAD and poor management practices".* He concluded:

> *There is evidence that bottom up factors such as soil nutrients, physical and structural properties play an important role in allowing or encouraging BMAD to occur and these processes. However it will most likely be easier to influence populations of* M. melanophrys *in most cases by physical manipulation of their habitat rather than the soil directly"*.

Given the abundant evidence that logging is the primary cause of Bell Miner Associated Dieback, and that re-logging affected forests makes it worse, it is well past time that the logging of BMAD affected and susceptible forests is stopped and the process of restoration begun.

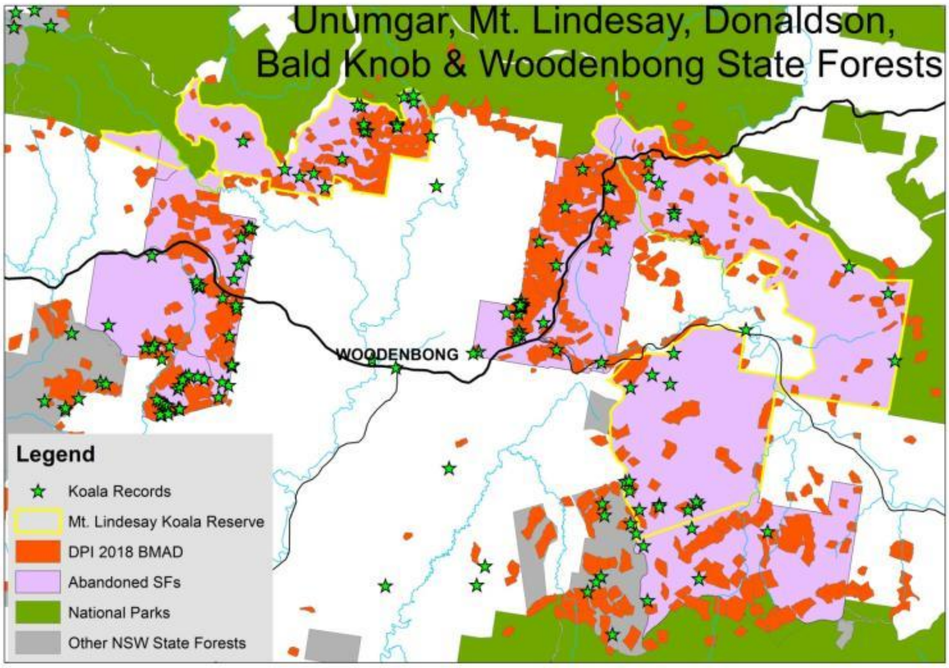
4.2.2.1. The Effects of the Wildfires on Lantana

There can be no doubt that lantana benefits from low and medium density fires, such as those termed 'cool' burns, primarily because the moist microclimate its dense canopy creates makes it more resistant to burning and it can recover quickly. Cool burning is thus one of the factors contributing to its spread.

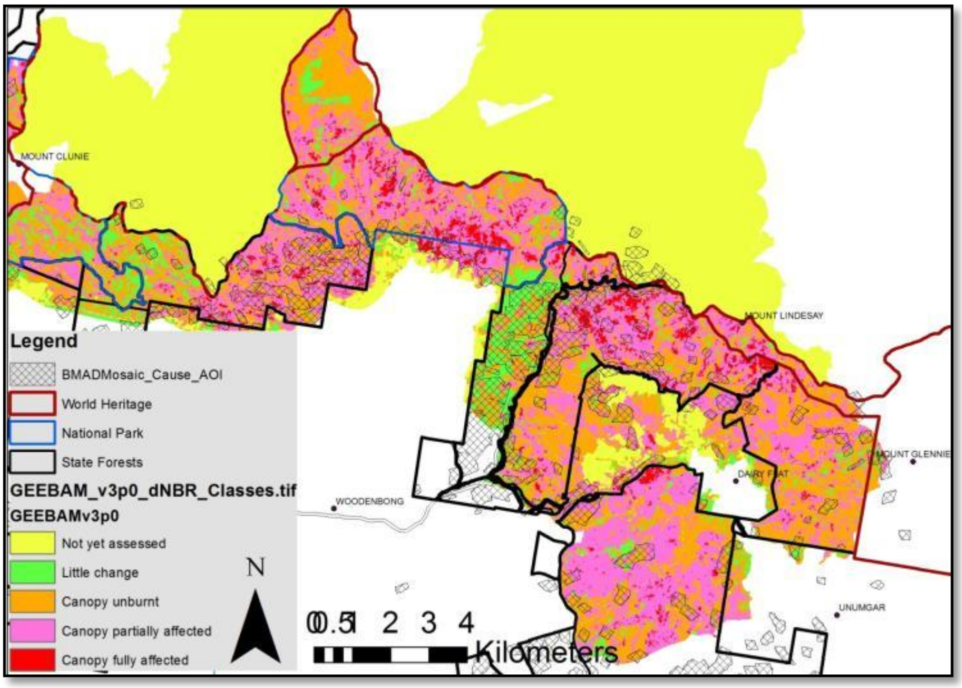
The 2019-20 wildfires occurred during a drought when the lantana was under stress and unusually dry (as evidenced by the widespread burning of rainforests). It therefore burnt readily and hotly killing or severely affecting vast swathes of lantana, with recovery hampered by the drought there has been widespread death of lantana.

The western Border Ranges have some of the worst and extensive Bell Miner Associated Dieback in Australia. The Forestry Corporation recently responded to this dieback by abandoning 11,000 ha of these State forests for timber production (Natural Resources Commission 2016). Half of the abandoned forests have been identified for conversion to the Mount Lindesay Koala Reserve which will entail transferring management to the NPWS, with as yet no funding.

Conservation groups consider it more appropriate that these areas, along with the balance of the State Forests for which the Githabul have native title, be transferred to Githabul care and control, with funding for management and rehabilitation.



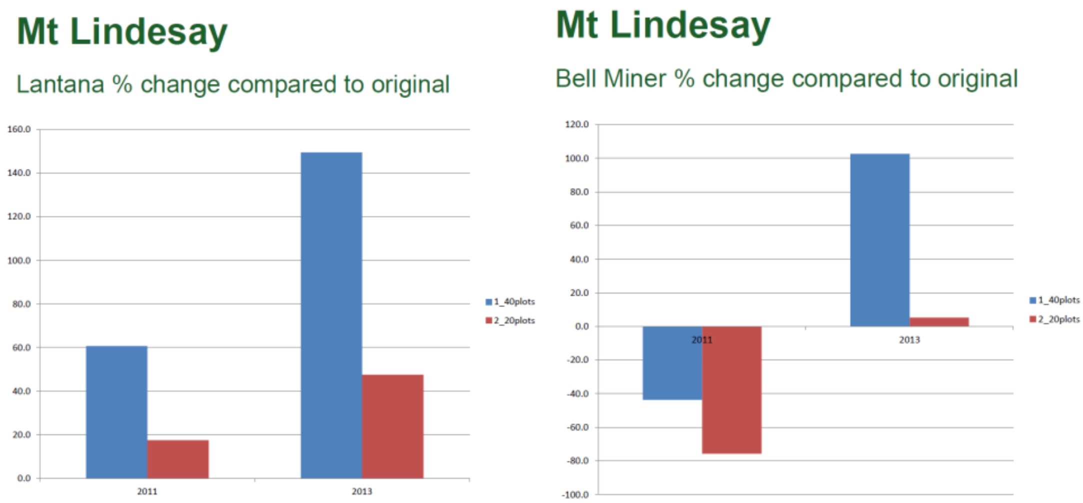
Map showing OEH Koala hubs and Koala records in relation to Bell Miner Associated Dieback as under-mapped by DPI-Forestry (2018) from 2015-17 (orange areas), areas of State Forests identified by Natural Resources Commission (2016) as being abandoned for timber production (pink areas), and the NSW Government's proposed Koala park (yellow outline). Note the high correlation of historical Koala records with dieback areas, emphasising the urgent need for protection and rehabilitation of these important areas.



Map showing burn forests, including the understated areas identified as BMAD affected, in the Mt.Lindesay area, illustrating the ability to undertake rapid elimination of lantana and rehabilitation of affected areas.

The Forestry Corporation established logging trials in BMAD in compartments 276 and 279 of Mt Lindesay State Forest in 2007 with over $50,000 of Environmental Trust monies contributed through the BMAD Working Group as one of four trials of using understorey control to redress BMAD (Pugh 2014). The trials involved logging in combination with variable applications of mechanical disturbances, weed spraying, and burning, with some follow up weeding and planting.

The trials were a failure, in that while the Forestry Corporation achieved their aim to log it, the expenditure on rehabilitation was futile as the forest health declined. For Mt. Lindesay over 6 years the Forestry Corporation (2015) found significant increases in both lantana and Bell Miners with a variety of treatments, including logging and burning: increases of 145% in lantana 145%, and104% in Bell Miners.



Forestry Corporation (2015) results for 2011 and 2013 reported for Mt. Lindesay State Forest. For these graphics blue represents the 40 trial plots and brown the 20 control plots.

St.Clair (2009) notes "*Whilst the cost of the project was significant, the opportunity cost of doing nothing is greater. The cost of rehabilitation was less than the likely loss of production if the forest continued to decline and die*". St.Clair's (2009) estimated rehabilitation costs per hectare over 40 years ranged from $200-2,500, though given the poor prognosis for much of his sites this may just reflect initial costs.

Through the Githabul Rangers program there are a number of areas of BMAD actively being rehabilitated They have a site of around 11 hectares at Mount Lindesay that they have been rehabilitating for years. The 2019 fires thoroughly burnt it, killing most regeneration.

Photos of a BMAD rehabilitation area that has been subject to years of work, the regeneration has been killed.

Photos of significantly affect BMAD forests at Mt. Lindesay after the fires. Beforehand this stand had a dense understorey of lantana up to 3m tall, with most trees sick and dying. Currently the lantana has been almost completely eliminated. Now is the time to intervene to stop its return.

Across the track from the rehabilitation area there was an unremediated area with a severe infestation of lantana with a copy up to 3m high, and most trees affected by BMAD sick and dying. Now since the fires the lantana has been temporarily eliminated.

Now, for minimal cost and maximum effectiveness, there is an opportunity to rapidly cover large areas to stop the regeneration of lantana. In the case of the proposed Mt. Lindesay Koala Reserve there is an opportunity to treat the whole area. While further assistance may be required to assist regeneration, this is an opportunity to get rid of the lantana.

It is recommended that as a matter of urgency widespread control of Lantana and other weeds be undertaken throughout burnt forests, focusing on bad weed infestations, rainforest ecotones and areas of Bell Miner Associated Dieback. To allow recovery such areas must have logging excluded.

5. The relationships between forests, climate and fires

Vegetation plays a significant role in climatic processes, from creating microclimates beneath their canopies, to modifying regional winds and temperatures, to enhancing rainfall, and changing atmospheric heat and moisture fluxes at continental scales.

The clearing of forests decreases regional rainfalls and increases temperatures, and the conversion of older forests to regrowth dries forests and decreases streamflows. These changes have particularly significant consequences during droughts by amplifying stressors. Forests play a key role in regional climates and thus landscape wetness and flammability.

Forests provide the critical ecosystem services of enhancing rainfalls and modifying temperatures in an era where climate heating is making rainfall more erratic and increasing heatwaves, and thereby increasing extreme fire weather.

It is essential to account for vegetation change, most noticeably clearing, logging and reforestation, on regional changes in rainfalls, temperatures and winds when assessing the impacts of climate change and planning for reducing the flammability of forests (Section 5.1.).

Forests attract moisture laden air, cause air to rise, transpire water into the atmosphere and seed clouds, thereby generating rainfall that spreads across the surrounding countryside. In our increasingly erratic climate, it's imperative to stop ongoing regional rainfall declines due to land clearing. (Section 5.1.1.)

Through a variety of processes, including the transfer of heat into the atmosphere through transpiration, forests cool themselves and the surrounding country, thereby reducing regional temperatures. We need forests to help counterbalance rising temperatures from climate heating. (Section 5.1.2)

The increased streamflows generated as forests age is a key ecosystem benefit, with the reduced streamflows from regrowth forests becoming a key issue during drier times. With increasingly erratic stream flows putting increasing pressure on aquatic ecosystems (as evidenced by the widespread fish kills), rural communities and water storages, the ability to restore stream flows over time as forests age has to be a key consideration. (Section 5.1.3.)

Forests are a key component of the carbon cycle, sequestering carbon from the atmosphere and storing it in their wood and soils. They have been doing this for millions of years, leaving behind the coal and oil we are rapidly releasing back into the atmosphere. Even in their diminished state the world's forests absorb around a third of our carbon emissions. While part of the solution to climate heating is to reduce carbon emissions, limiting warming to 1.5^{o} or 2^{o}C requires increasing the ability of trees to extract carbon from the air and store it in their wood and soils. Our forests are the most important natural climate solution (Section 5.2).

Clearing quickly releases the accumulated carbon, while stopping the trees ability to take up more. It has to stop as it directly increases regional temperatures and lowers rainfall, while also having global impacts on temperatures and rainfall through the carbon cycle, thereby increasing the frequency and intensity of extreme fires.

Logging has more than halved the carbon stored in our forests, releasing most of it into the atmosphere. While this is partially responsible for the mess we are in, it also provides the most significant short term fix to buy us time, just by stopping logging and allowing forests to regain their lost carbon. The trees are already there and growing, and they will sequester ever increasing volumes of carbon as they grow bigger. This is proforestation (Section 5.2.1.). If we just stopped logging of public native forests in north-east NSW they would immediately begin sequestering in the order of 6.5% of NSW annual emissions, and there would be additional benefits in avoided emissions. If we offer incentives to private landholders to protect forests there is the additional potential to sequester up to 19.5% of NSW's annual emissions (Section 5.2.1.3.)

Smoke from last year's Australian bushfires are estimated to have released between 650 million and 1.2 billion tonnes of carbon dioxide into the atmosphere, far more than Australia's annual emissions (Section 5.2.1.1). Vast quantities of carbon were also lost through erosion, though some portion of this may end up stored in soils as char.

Proforestation provides an immediate opportunity, though we need more trees to take up enough carbon to meet the objective of zero net carbon emissions by 2050. They take a while to start being effective so we need to get moving. Mixed species regeneration and plantings are the most efficient and effective for capturing and storing atmospheric carbon, and local indigenous species provide the greatest biodiversity benefits (Section 5.2.3.).

Our forests are under increasing stress due to climate change, with widespread tree dieback (Section 5.3.), drying ecosystems, mass killing of animals in heatwaves, and species range contractions. The increasing intensity and frequency of bushfires is compounding and amplifying changes.

The widespread dieback of forests due to logging and lantana invasion is a case of ecosystem collapse that is being amplified by climate heating (Section 4.2.2). The burning of a third of north-east NSW's rainforests in 2019-2020 exemplifies what could become a process of rapid ecosystem collapse as droughts and intense fires become more frequent. (Section 4.2.1). Intact tropical rainforests are taking up a third less carbon than they did in the 1990s, owing to the effects of increasing droughts and heatwaves on trees. Once forests become carbon sources rather than sinks we are stuffed.

There is no time to waste. We cannot afford to allow the downward trajectory of forest cover and degradation to continue if we want to give forests and ourselves a future. We need to urgently stop clearing and logging forests, and start rehabilitating them to allow them to go on moderating regional climates and storing carbon, while improving their resilience to further climate changes. While encouraging natural regeneration and planting of new forests to take up more carbon.

We need our forests more than ever, not just because of their intrinsic worth and beauty, but for the ecosystem services they provide us, such as generating rainfall, cooling the land, calming winds, regulating streamflows, and capturing and storing the carbon we emit.

Stoping logging of public native forests is a logical first step to limit climate heating as the regenerating forests will store ever increasing volumes of carbon as they age. To reward landholders for their contribution to carbon sequestration and storage, whether in soils or vegetation, landholders storing above average volumes of carbon should receive annual payments proportional to the volume stored at that time and the ecosystem benefits it provides. This will recompense landholders for providing a public benefit and be an incentive for increasing storage.

It is a matter of fact that climate change is increasing temperatures and making rainfall more erratic, thereby making extreme fire weather such as north-east NSW experienced in 2019 more frequent and intense. The principal requirement to redress the increasing frequency of extreme fires is to stop climate heating. Given the extreme environmental impacts of the 2019-2020 fires we cannot afford to delay any longer.

On the 26 February 2020 a number of Australia's leading scientists wrote an open letter to Australian parliaments calling for the immediate nationwide cessation of all native forest logging in response to the climate, fire, drought and biodiversity loss crises currently facing Australia

> *An open letter to the Parliament of Australia,*
>
> *Sadness at the losses from the fires sears our souls. Worse might lie in wait. We write to ask you to respond to the climate, fire, drought and biodiversity loss crises with an immediate nationwide cessation of all native forest logging.*
>
> *We need our forestry workers to be immediately redeployed to fire services support and national park management to help protect the forests and us from fire.*
>
> *Large, old-growth trees are important for carbon capture and storage and they keep on capturing carbon for their entire life. Logging increases fire hazard in the short term. Many native species rely on unlogged forests.*
>
> *Our timber needs can be met from existing plantations, with no need to log native forests. Native forest logging is heavily subsidised by our taxes, which can be better spent on fire mitigation.*
>
> *This is above politics –please show the leadership Australia desperately needs.*

The Inquiry needs to heed this call and set in train the changes we need to avoid a fiery future.

5.1. The Effects of Clearing Forests on Climate and Fires

Forest directly affect regional climates and thus have a direct affect on their own flammability by:

- **transpiring moisture from the ground into the atmosphere to form clouds and generate rainfall**
- **providing a large area of leaves and other surfaces for evaporation of moisture back into the atmosphere**

- **creating areas of low pressure by evapotranspiration that generate winds and draw in moisture from afar**
- **having an 'evaporative cooling' effect by absorbing solar energy and converting it into latent heat transported into the atmosphere in water vapour through evapotranspiration**
- **emission of organic aerosols, and volatile organic compounds that oxidise to form aerosols, that act as cloud condensation nuclei around which water drops form**
- **increasing air turbulence, causing drag on the air and reducing wind speed, increasing transfer of moisture into the air, causing updrafts and rain**
- **tree canopies harvesting water directly from wind and clouds, particularly in coastal and mountainous country.**

Forests also directly affect streams and streamflows by regulating runoff, with oldgrowth forests facilitating the storage of water in soils and dead biomass for slow release into streams, while regrowth transpires more water into the atmosphere thereby drying soils and dead biomass while reducing streamflows and their permanence.

It is essential to account for vegetation change, most noticeably clearing, logging and reforestation, on regional changes in rainfalls, temperatures and winds when assessing the impacts of climate change and planning for reducing the flammability of forests.

Land-clearing needs to be stopped to limit ongoing rainfall declines, temperature increases and wind intensification. Regrowth forests need to be allowed to mature to reduce water demand as they age, thereby making forests moister and increasing streamflows. Forest regeneration and reforestation needs to be encouraged to help counteract rainfall declines and temperature increases due to climate change, though account needs to be made of the effects on streamflows.

Far from being passive, vegetation plays an active role in its partnership with climate (Zeng and Neelin 2000). Across the semi-arid Sahel in central Africa, the forests and woodlands of southern Australia, and the mighty Amazon rainforests, clearing, logging and burning of natural vegetation is causing a considerable increase in temperatures, decrease in evapotranspiration and decrease in rainfalls. As observed by Fu (2003):

> *Both the observational and theoretical studies have proved that the destruction of natural vegetation cover, such as destructive lumbering of forests and over cultivation and overgrazing of grassland has been one of the major causes for the deterioration of regional climate and environment.*

At the site level, compared to cleared areas, it is apparent that forests can create their own microclimate, with more stable temperatures (warmer on cold winter nights and cooler on hot days), and with moister soils and higher humidity in dry times (Meher-Homji 1991). Vegetation, and particularly forests, can affect regional climates (Pugh 2017) by:

- transpiring moisture from the ground into the atmosphere to form clouds and generate rainfall
- providing a large area of leaves and other surfaces for evaporation of moisture back into the atmosphere

- creating areas of low pressure by evapotranspiration that generate winds and draw in moisture from afar
- having an 'evaporative cooling' effect by absorbing solar energy and converting it into latent heat held in water vapour through evapotranspiration
- emission of organic aerosols, and volatile organic compounds that oxidise to form aerosols, that act as cloud condensation nuclei around which water drops form
- increasing air turbulence, causing drag on the air and reducing wind speed, increasing transfer of moisture into the air, causing updrafts and rain
- tree canopies harvesting water directly from wind and clouds, particularly in coastal and mountainous country.

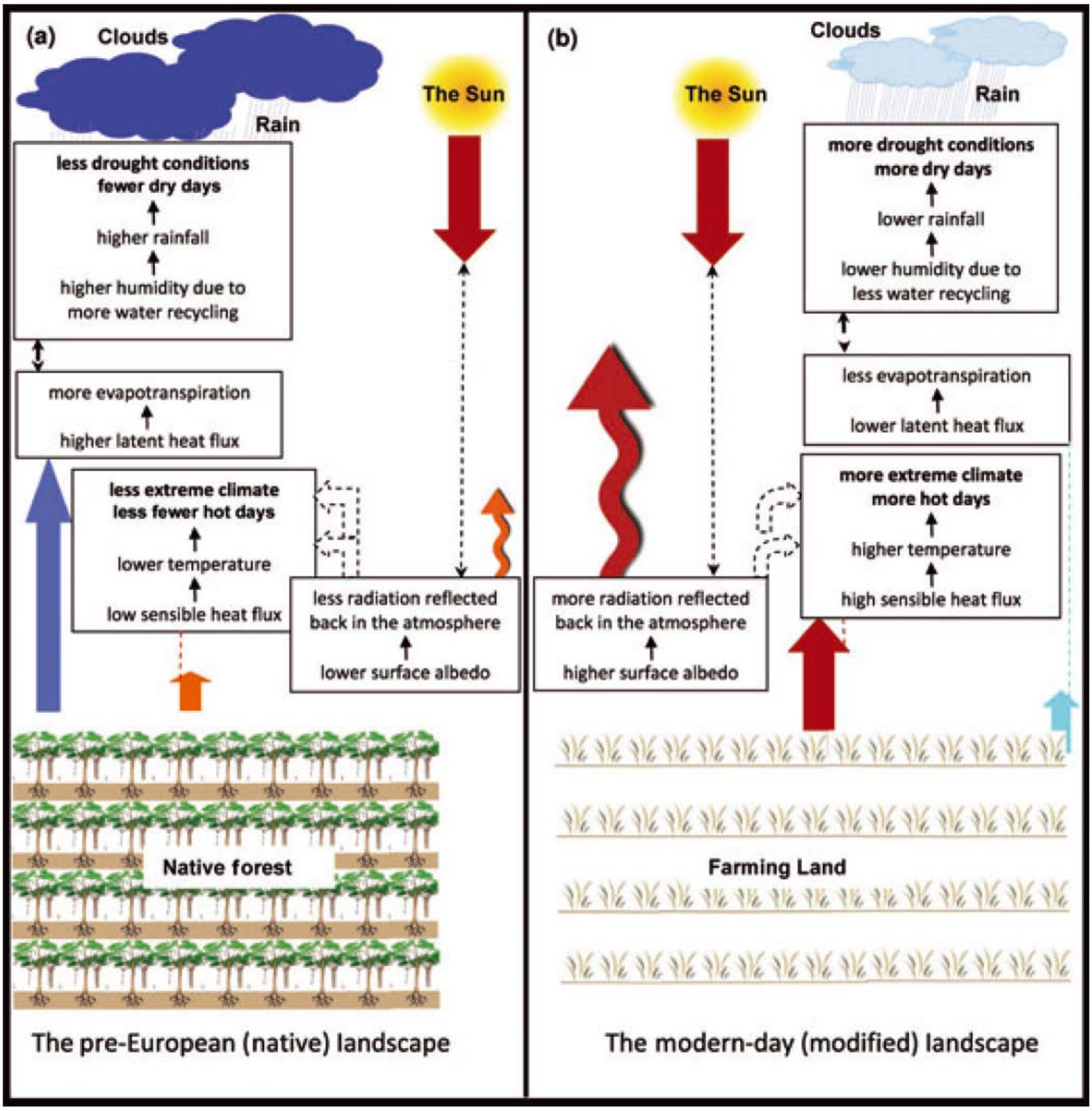


Figure 3 from Deo (2011). The impact of vegetation-cover change on surface energy balance, hydrological cycle and climate for two hypothetical landscapes: (a) pre-European (native) landscape, and (b) modern-day (modified) landscape. The coloured arrows show various energy/heat fluxes and black arrows show consequence of events or processes

An array of parameters that influence climate have now been identified in scientific studies as being significantly affected by deforestation, including evapotranspiration, vegetation rooting depth, surface roughness, canopy height, leaf area, stomatal resistance, humidity, wind, soil moisture, the ratio of latent/sensible heat, albedo, cloud cover, and snow cover (variously Shukla *et. al.* 1990, Nobre *et. al* 1991, Betts *et. al.* 1996, Claussen 1998, Zeng and Neelin 2000, Taylor *et.al.* 2002, Findell *et. al.* 2007, Findell *et. al.* 2009, Foley *et. al.* 2003, Foley *et. al.* 2003b, McAlpine *et. al.* 2009, Lawrence and Chase 2010, Bagley 2011, Kala *et. al.* 2011, Spracklen *et. al.* 2012, Pitman *et. al.* 2012, de Noblet-Ducoudré *et. al.* 2012, Andrich and Imberger 2013).

There is now abundant evidence that over the past few centuries and decades deforestation (Land Cover Change) has had significant biogeophysical impacts on rainfalls and/or temperatures in the regions subject to significant deforestation (Pugh 2017). Deforestation and degradation of vegetation causes significant reductions in rainfall by:

- reducing the recycling of rainfall to the atmosphere by transpiration
- reducing the drawing in of moist coastal air
- reducing updrafts of moist air
- reducing rooting depth and the recycling of deep soil moisture
- increasing loss of water from the land by runoff
- reducing the organic aerosols necessary for the condensation of rain drops.

Deforestation has other climatic impacts; the reduction of surface roughness increases wind speeds, the reduction of transpiration increases temperatures by reducing evaporative cooling and cloud cover, and the burning of vegetation releases soot to the atmosphere where it can reduce rainfall.

There have been a large number of assessments of the likely impacts of anthropogenic Land Cover Change (LCC - clearing of native vegetation for crops, pasture or houses), and to a small extent Land Management Change (LMC - change off vegetation by logging, grazing and/or fire), on both regional climates and the world's climate (Pugh 2017).

It is evident that deforestation plays a significant role in many of the climate changes currently underway, we ignore these impacts at our peril. Pitman *et. al.* (2012) modelled variable changes in rainfall due to deforestation, finding that in regions subjected to significant land-use change "*the impact of landscape change on temperature and some hydrometeorological variables can be similar in magnitude to a doubling of atmospheric* CO_2*", and* that "*land cover change would offset the impact of elevated* CO_2*. Surprisingly, this also included partially offsetting a* CO_2 *induced increase in rainfall over S.E. Asia in three of the four models*".

In relation to the significant effects of Land Use-Land Cover Change (LULCC) de Noblet-Ducoudré *et. al.* (2012) caution:

> *Increased concentration of greenhouse gases in the atmosphere, and the subsequent changes in sea surface temperatures and sea ice extent, are often used as the main drivers of climate change also over land. Our results suggest that such an assumption leads to erroneous conclusions regarding the land surface impacts of climate change in regions where LULCC has been significant. LULCC affects a number of variables to a similar magnitude, but of opposite sign, in increasing greenhouse gas concentrations. LULCC therefore has the potential to mask a*

> *regional warming signal, with the resulting risk that detection and attribution studies may miss a clear greenhouse signal or misattribute a greenhouse signal if LULCC is poorly accounted for.*

The complex feedback systems contributing to rainfall can come under increasing stress due to the degradation of vegetation, sometimes resulting in sudden catastrophic changes when an event triggers regime shifts. McAlpine *et. al.* (2009) consider:

> *Climate changes due to increased anthropogenic greenhouse gases coupled with land surface feedbacks appears to be amplifying the natural climate variability and has the potential to tip Australia's climate, especially in southeast Australia, into a new regime of more extensive, frequent and severe droughts. The term 'tipping' refers to a critical threshold at which a small change in the control parameters can alter the state of the climate system*

It is essential to account for vegetation change, most noticeably clearing, logging and reforestation, on regional changes in rainfalls, temperatures and winds when assessing the impacts of climate change and planning for reducing the flammability of forests.

As noted by Huang *et. al.* (2020)

> *Overall, in addition to the inherent uncertainty of future regional projections of climate change, the vegetation response to climate feedbacks is highly complex and difficult to quantify, and parallel developments of modelling and empirical approaches are needed to refine land management strategies by anticipating variability in future regional climate.*
>
> *The regional or local scale is the scale at which most decisions about land management are taken or implemented, and the availability of site-specific metrics on land-climate interactions is central to deploy effective land-based climate change mitigation and adaptation strategies.*

5.1.1. Generating rainfall

At its simplest, the basis for the hydrological cycle is that water is evaporated from the ocean into the atmosphere, the water vapour is carried by winds across the land until it condenses and falls as rainfall, with excess water entering streams and travelling downhill back into the oceans.

All the terrestrial water contained in glaciers, lakes and soil could be depleted by global river runoff in just a few years if it was not replenished by atmospheric flows from the ocean. Rainfall is an outcome of rising atmospheric moisture cooling and condensing around particles (mostly organic) in the air to form water droplets which grow by colliding and merging to create larger droplets until gravity takes over and they fall to earth.

Vegetation does not just respond to rainfall, it actively generates its own. It recycles water from the soil back into the atmosphere by transpiration, creates the updrafts that facilitate condensation as the warm air rises and cools, creates pressure gradients that draw moist air in from afar, and, just to be sure, releases the atmospheric particles which are the nuclei around which raindrops form.

The structure of vegetation has a significant impact on rainfall that is related to its height, leaf area density, and canopy roughness. Natural vegetation reduces wind speed through its aerodynamically rough, undulating canopy, causing turbulence and the mixing of air. Due to the decrease in wind velocity, the air masses are forced to stack and rise, which is enhanced by the height of the vegetation. This increases the influx of water vapour into the lower atmosphere, and thus promotes condensation and rainfall. As described by Bagley (2011):

> *Depending on whether surface roughness increases or decreases the change enhances or diminishes fluxes of water, energy, and momentum from the earth's surface to the atmospheric boundary layer through the enhancement or diminishment of eddy formation in the surface layer*

Just by their height trees can have an orographic effect (moist air rising over a physical barrier), as noted by Andrich and Imberger (2013) for Western Australia: "*Rainfall changes by ~40 mm for every 100 m in altitude between Fremantle and the hill reservoirs*". Cutting down trees thus reduces the "*surface boundary layer height*" and rainfall.

The low and even canopies of crops and grasslands reduce surface roughness, turbulent mixing in the boundary layer, evapotranspiration and thus rainfall. This is considered by many researchers to be a key contribution to the decrease in rainfall resultant from land cover change (Pugh 2017).

The atmosphere receives vast inputs of water vapour as evaporation from the oceans and land, as well as transpiration by vegetation. This water vapour is returned to earth as rainfall, with the water in the atmosphere turned over about 34 times every year.

Evapotranspiration is used to account for the evaporation of water from the ground and wet vegetation, along with the conversion of water to vapour through the process of transpiration by plants. Transpiration involves the transport of water (and nutrients) from roots to leaves, where it is released by evaporation to the atmosphere through stomata on leaves.

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. Van der Ent *et. al* (2010) consider that "*It is computed that, on average, 40% of the terrestrial precipitation originates from land evaporation and that 57% of all terrestrial evaporation returns as precipitation over land*". It has been found in the Amazon that evapotranspiration from forests accounts for more than 50% of rainfall (Nobre *et. al* 1991, Spracklen *et. al.* 2012). Recycled water vapour becomes increasingly important for inland rainfall.

The amount of water that can be recycled by evapotranspiration from vegetation is related to canopy volume (the area of leaves -Leaf Area Index) and root depth (the ability to access deeper water sources), thus it is tall forests with their large canopies and deep roots that provide the highest rate of evapotranspiration. When vegetation is cleared there is a reduction in surface area for evaporation, reduced transpiration, increased runoff and a reduced ability to access deeper soil moisture. By reducing evapotranspiration, deforestation results in less water being pumped into the atmosphere, thereby directly contributing to a decrease in rainfall (Shukla *et. al.* 1990, Nobre *et. al* 1991, Spracklen *et. al.* 2012, Andrich and Imberger 2013).

Most of the rain that falls upon a forest is recycled to the atmosphere through evapotranspiration, where it again becomes available for rainfall. Water may be recycled numerous times as it passes over the land before it returns to the oceans in streamflows or as rainfall. This process is vital for maintaining rainfall over inland areas.

Van der Ent *et. al* (2010) identify that local moisture recycling is a feature of some regions, though in most regions the majority of rainfall originates from elsewhere, for example:

> *Moisture evaporating from the Eurasian continent is responsible for 80% of China's water resources. In South America, the Río de la Plata basin depends on evaporation from the Amazon forest for 70% of its water resources. The main source of rainfall in the Congo basin is moisture evaporated over East Africa, particularly the Great Lakes region. The Congo basin in its turn is a major source of moisture for rainfall in the Sahel*.

Forests have been described as 'biotic pumps' (Makarieva and Gorshkov 2006) 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. Makarieva and Gorshkov (2006) found that areas with strong evaporation/transpiration draw in moisture from areas with low evaporation, thereby enhancing rainfall. Makarieva and Gorshkov (2006) postulated that natural forests are the biotic pump of atmospheric moisture:

> *Due to the high leaf area index, natural forests maintain powerful transpiration exceeding evaporation from the oceanic surface. The transpiration flux supports ascending fluxes of air and "sucks in" moist air from the ocean. In the result, forest precipitation increases up to a level when the runoff losses from optimally moistened soil are fully compensated at any distance from the ocean.*

A review of the Biotic Pump theory by Sheil and Murdiyarso (2009) concluded:

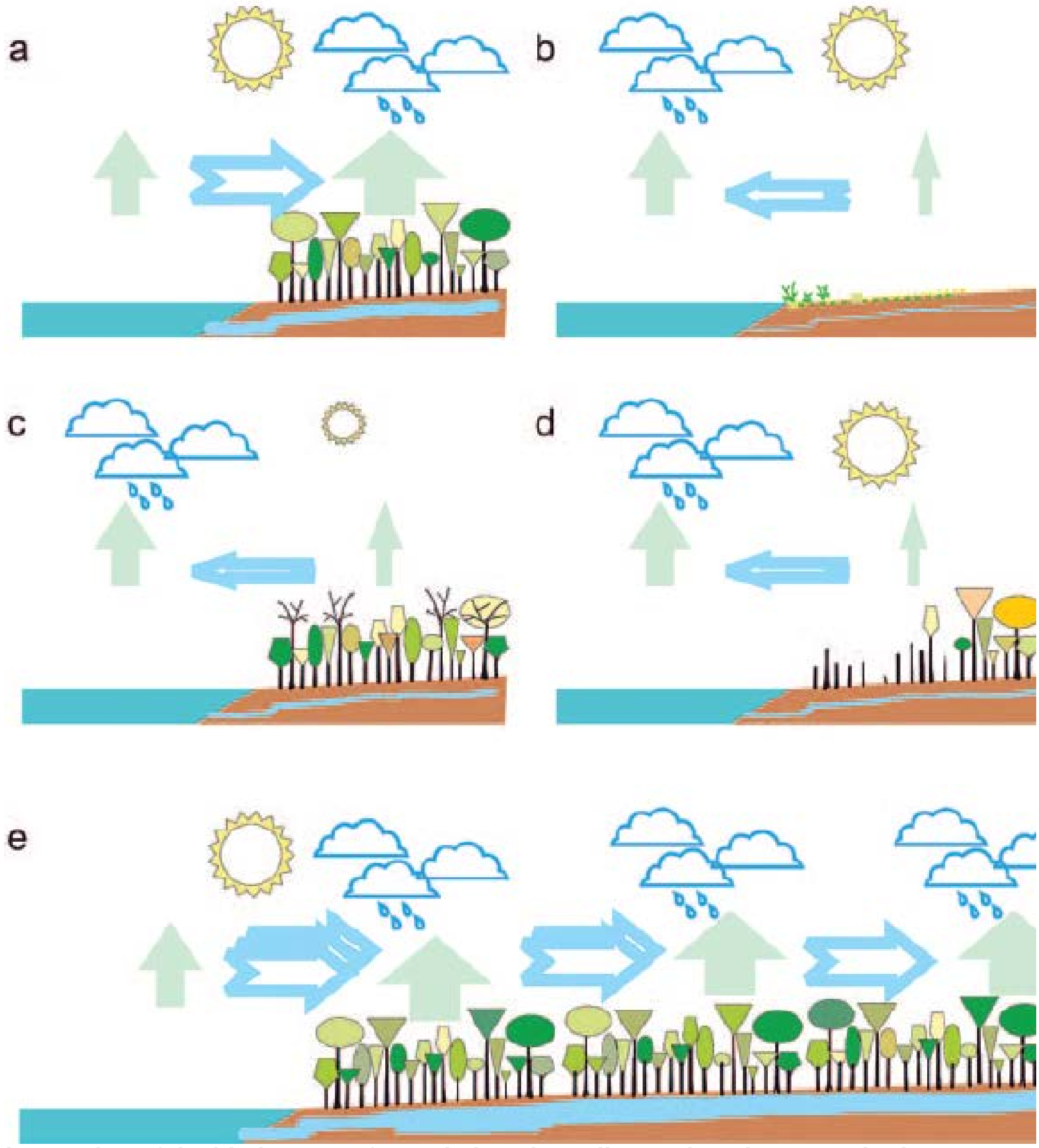
> *The underlying mechanism emphasizes the role of evaporation and condensation in generating atmospheric pressure differences, and accounts for several phenomena neglected by existing models. It suggests that even localized forest loss can sometimes flip a wet continent to arid conditions. If it survives scrutiny, this hypothesis will transform how we view forest loss, climate change, hydrology, and environmental services. ... It also provides a compelling new motivation for forest conservation.*

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 water drops form (Suni *et. al.* 2008).

Vegetation can also directly strip water from fog and clouds in mountainous areas and along coastal fog zones with significant affects on the water available for the forests, transpiration and streamflows (i.e. Lima 1984, Meher-Homji 1991, Hutley *et. al.* 1997, Foley et. al. 2003b, Sheil and Murdiyarso 2009). Meher-Homji (1991) note:

> *Even a single tree or a group of trees can trap a substantial quantity of rainwater through the process called horizontal precipitation .... The amount so trapped can vary from 7 to 18% of the rainy-season precipitation and up to 100% of dry-season*

rains .... The destruction of such cloud forests (as in the Western Ghats of India) can diminish stream flows and ground-water recharge.



An illustration of the biotic pump, from Sheil and Murdiyarso (2009): Atmospheric volume reduces at a higher rate over areas with more intensive evaporation solid vertical arrows, widths denotes relative flux). The resulting low pressure draws in additional moist air (open horizontal arrows) from areas with weaker evaporation. This leads to a net transfer of atmospheric moisture to the areas with the highest evaporation. (a) Under full sunshine, forests maintain higher evaporation than oceans and thus draw in moist ocean air. (b) In deserts, evaporation is low and air is drawn toward the oceans. (c) In seasonal climates, solar energy may be insufficient to maintain forest evaporation at rates higher than those over the oceans during a winter dry season, and the oceans draw air from the land. However, in summer, high forest evaporation rates are re-established (as in panel a). (d) With forest loss, the net evaporation over the land declines and may be insufficient to counterbalance that from the ocean: air will flow seaward and the land becomes arid and unable to sustain forests. (e) In

wet continents, continuous forest cover maintaining high evaporation allows large amounts of moist air to be drawn in from the coast. Not shown in diagrams: dry air returns at higher altitudes, from wetter to drier regions, to complete the cycle, and internal recycling of rain contributes significantly to continental scale rainfall patterns. Source: Adapted from ideas presented in Makarieva and Gorshkov (2007).

Hutley *et. al.* (1997) identify that numerous observers have considered that the occurrence of low cloud, fog and mist may be important to the survival of Australian rainforests at upland sites. They assessed a rainforest site on the Great Dividing Range west of Brisbane, finding that leaves were wet for 25% of the time solely from dew and fog events, with frequent wetting of the canopy reducing transpiration rates, and allowing the leaves to directly absorb liquid surface water. Hutley *et. al.* (1997) conclude:

> *Fog deposition to the forest provides the equivalent of an additional 40% of rainfall to the site as measured using a conventional rain gauge. A frequently wet canopy results in reduced transpiration rates and direct foliar absorption of moisture alleviates water deficits of the upper crown leaves and branches during the dry season. These features of this vegetation type may enable long-term survival at what could be considered to be a marginal rainforest site.*
>
> *...*
>
> *Near-coastal massifs, such as the Great Dividing Range in southern Queensland, will have an ability to intercept and deflect moist air, which will have a significant local impact on rainfall. The present study has demonstrated the importance of fog and cloud occurrence. This could also be true of upland sites along the entire Eastern Highlands of Australia and may be significant given the frequency of the occurrence of water deficits in Australian rainforests.*

Forests attract moisture laden air, cause air to rise, transpire water into the atmosphere and seed clouds, thereby generating rainfall that spreads across the surrounding countryside. In our increasingly erratic climate, it's imperative to stop ongoing regional rainfall declines due to land clearing and forest degradation.

5.1.2. Cooling the planet

Around half the incoming solar energy is absorbed by the earth's surface, vegetation and waters. The solar energy can either heat the surface and raise its temperature (sensible heating) or it can change the phase of water from liquid to vapour (evaporate) without a corresponding temperature change (latent heating). Latent refers to the heat which "disappears" without causing a temperature change.

Conversion of solar energy absorbed by the earth's surface into latent heat (without a rise in temperature) by evaporation is an integral part of the climate system, linking the surface energy balance to the hydrological cycle. When water changes from a liquid to its gaseous phase energy is stored in the water vapour in the form of latent heat and produces evaporative cooling. Water vapour fluxes transport latent heat from the location where water evaporates to where the water condenses, often in clouds. The increase in clouds associated with increased evaporation increases reflection of solar radiation and thereby causes a surface cooling.

The transpiration of vegetation 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. Water has a high capacity for the storing and transporting of heat and so is able to redistribute much of the solar heat energy through the water cycle.

The conversion of liquid water into vapour by transpiration has been estimated to require roughly half of all solar energy absorbed by the continents (Jasechko *et. al.* 2013). Evapotranspiration thus has a cooling effect on climate, which is reinforced by the formation of clouds with their higher albedo.

Because of their deep roots, deep canopies and large leaf areas, forests are the most effective vegetation at maximising evapotranspiration, giving forests a greater latent heat flux relative to sensible heat flux than grasslands or crops.

Deforestation results in a net decrease in evapotranspiration and thus latent heat, making more energy available for sensible heat flux and increasing the surface temperature. The reduced transpiration decreases atmospheric moisture and cloud cover. The increase in sensible heat means more longwave radiation leaving the earth's surface and, because of the reduced low cloud cover, less of this radiation is returned to the surface. The reduced cloud cover means more shortwave radiation can reach the earth's surface.

By reducing evapotranspiration, deforestation tends to cause an increase in sensible heat and surface temperatures (Shukla *et. al.* 1990, Pielke 2001, Foley *et. al.* 2003b, von Randow *et. al.* 2004, Findell *et. al.* 2007, Findell *et. al.* 2009, Lawrence and Chase 2010, Davin and de Noblet-Ducoudré 2010, Kovářová *et. al.* 2011, Deo 2011, Lee *et. al.* 2011, Bagley 2011, Ban-Weiss *et. al.* 2011, Pitman *et. al.* 2012, Eiseltová *et. al.* 2012, Wanderley *et. al.* (2019). Kovářová *et. al.* (2011) found "*The air temperature increases at areas where a decline of available water occurs and latent heat of evapotranspiration shifts to sensible heat*". Pielke 2001 consider "*Once the surface energy budget is altered, fluxes of heat, moisture, and momentum within the planetary boundary layer are directly affected"*.

Von Randow *et. al.* (2004) undertook comparisons of energy fluxes in Amazonian pasture and rainforest, finding:

> *Large differences between the two types of surface are also noticed in the energy partition between sensible and latent heat fluxes. In the wet season the sensible heat fluxes are 45% higher, while the evapotranspiration rates are 20% lower in the pasture, compared to the forest. In the dry season, the differences are lower in the sensible heat (fluxes are 28% higher in the pasture), while the changes in evapotranspiration are large (rates are 41% lower in the pasture).*

From their comparisons of thermal satellite images in Europe and Africa Eiseltová *et. al.* (2012) identified significant increases in ground temperatures from deforestation, noting that in Kenya deforestation from 1986-2009 resulted in "*Extreme rises in temperature (by more than 20° C ...)*", and concluding "*Sites with bare ground undoubtedly belong to the warmest places in the landscape; due to the lack of water evapotranspiration, more solar energy is transformed into sensible heat (raising the site's temperature) than into latent heat of water vapour. The higher albedo of bare ground (concrete, etc.) and the lower albedo of forests does not play such an important role when compared to the cooling effect of evapotranspiration*".

Novick and Katul (2020) compared temperature over a grass field and mature hardwood stand in North Carolina, USA, finding that the cooling effect of forests is not limited to the surface, with the air cooling effect of forests is in the order of 2–3^{o}C during summer daytime periods:

> *During growing season daytime periods, T_{surf} is 4–6^{o}C cooler, and T_{aero} and near-surface T_{extrap} are 2–3^{o}C cooler, in the forests relative to the grassland. During the dormant season, daytime differences are smaller but still substantial. ... Overall, reforestation appears to provide a meaningful opportunity for adaption to warmer daytime T_a in the southeastern United States, especially during the growing season.*

The reduction in surface roughness due to deforestation is also considered to have a strong warming influence (Foley *et al*. 2003, Davin and de Noblet-Ducoudré 2010, Deo 2011, Chen and Dirmeyer 2016), Davin and de Noblet-Ducoudré (2010) noting "*reduced surface roughness leads to weaker turbulent exchanges. Since the energy available at the surface cannot be transferred to the atmosphere through turbulent fluxes, the surface tends to warm*"

Chen and Dirmeyer (2016) consider that surface roughness effects usually dominate the direct biogeophysical feedback of deforestation, while other effects play a secondary role, finding:.

> *Grasslands or croplands are aerodynamically smoother than forest and transfer heat less effectively, thus experiencing higher surface temperatures during daytime and lower surface temperatures at night*

Based on comparisons of surface temperature change from forest to open land at paired observation sites, Chen and Dirmeyer (2016) identified that in summer deforestation leads to an observed daytime warming (+2.23$\pm$0.94 K) and a cooling effect at night (−2.05$\pm$1.02 K), noting "*roughness change exhibits the largest impact (1.96+0.60 K during the day, −1.62+0.61 K at night)*".

Wanderley *et. al.* (2019) assessed the relationship between land surface temperature (LST) and the fraction of non-forested land over tropical forests in south eastern Brazil finding:

> *The relationship showed an approximated linear increase in surface temperature with increasing degree of non-forested area, whereby approximately each 25% areal increase of non-forested cover resulted in 1˚C of surface warming. From this average projection, the maximum temperature warming would occur as about 4˚C over a 100% non-forested area.*

Though reforesting can bring down temperatures. For Europe Huang *et. al.* (2020) integrated maps of historical LCCs with a regional climate model, finding:

> *an average temperature change of −0.12 ± 0.20 °C, with widespread cooling (up to −1.0 °C) in western and central Europe in summer and spring. At continental scale, the mean cooling is mainly correlated with agriculture abandonment (cropland-to-forest transitions)*

Through a variety of processes, including the transfer of heat into the atmosphere through transpiration, forests cool themselves and the surrounding country, thereby reducing regional temperatures. We need forests to help counterbalance rising temperatures from climate heating.

5.1.3. Runoff

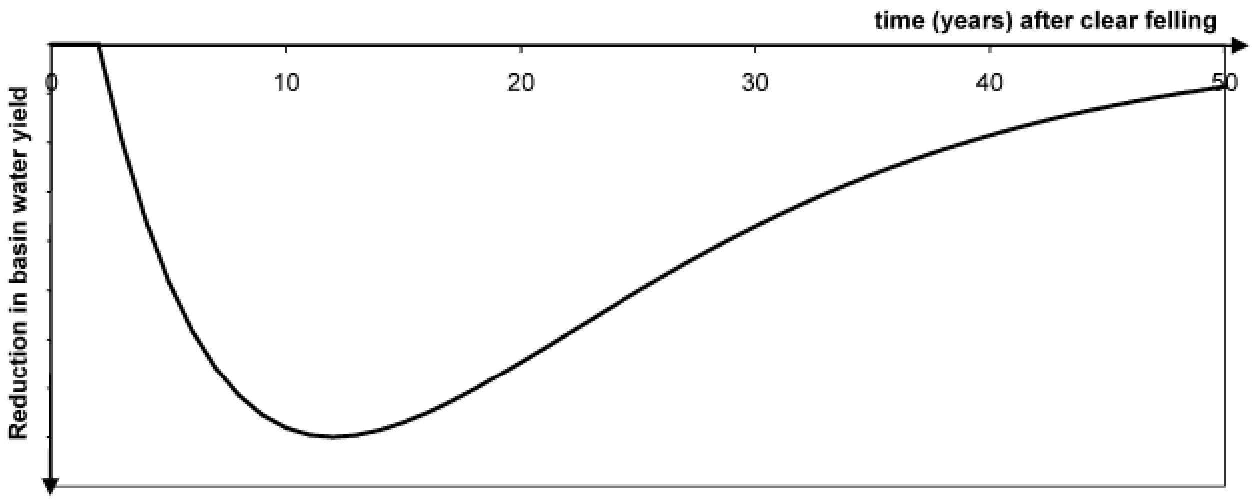
Australia's low and highly variable rainfall pattern, and the use of most rainfall by vegetation, means that we have one of the lowest amounts of runoff to rivers and deep drainage to groundwater in the world. Native vegetation in semi-arid Australia is dominated by trees or woody shrubs with relatively deep roots that is effective at taking full advantage of any available water, using most of the rainfall in ways that minimize the amount of water that leaks past the root zone. (Williams *et. al*. 2002)

The evidence is that by reducing rainfall interception by vegetation, reducing evapotranspiration and changing soil properties, deforestation generally results in an increase in runoff to streams (Bosch and Hewlett 1982, Williams *et. al*. 2002, Silberstein *et. al.* 2003, Bari and Ruprecht 2003, Brown *et. al.* 2005, Bagley 2011). This has the effect of hastening water loss and reducing water storage in the landscape.

Logging changes the structure of the forest, removing older trees while promoting regrowth that has higher transpiration rates and therefore water use. Soil moisture and stream runoff decline as transpiration increases.

The conversion of oldgrowth forest to regrowth can reduce runoff and suppress streamflows for extended periods. The generalised pattern following heavy and extensive logging of an oldgrowth forest is for there to be an initial increase in runoff 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. (Kuzcera 1987, Vertessy *et. al.* 1998, Cornish and Vertessy 2001, Bari and Ruprecht 2003, Brown *et. al.* 2005, Burrows *et. al.* 2011).

Kuczera (1985, cited in Vertessy *et. al*. 1998) developed an idealised curve describing the relationship between mean annual stream flow and forest age for mountain ash forest in Victoria. 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.

The increased streamflows generated as forests age is a key ecosystem benefit, with the reduced streamflows from regrowth forests becoming a key issue during drier times. With increasingly erratic stream flows putting increasing pressure on aquatic ecosystems (as evidenced by the widespread fish kills), rural communities and water storages, the ability to restore stream flows over time as forests age has to be a key consideration.

5.2. Natural Climate Solutions

Climate heating, native vegetation and bushfires are intimately linked in that they all affect each other through the carbon and water cycles and other interactions. As the climate heats and rainfall becomes more erratic extreme fire weather is becoming more frequent and intense. Droughts and heatwaves dry foliage and kill plants, while desiccating potential fuels, increasing the flammability of vegetation. Burning forests promotes more flammable vegetation while releasing stored carbon to accelerate climate heating.

Compounding these interactions are land clearing and logging. Clearing forests releases carbon, increases regional temperatures and reduces rainfalls, thereby increasing fire risk, which is worsened by fragmentation and edge effects. Logging forests releases carbon, dries and heats the microclimate, changes fuel arrays and increases the loss of water through transpiration to make forests more vulnerable to burning.

The climate is heating at an accelerating rate, and along with it the threat of catastrophic wildfires. While we urgently need to reduce our emissions to limit global heating, we can only keep global temperature rises to below 2^{o}C if we increase removal of carbon from the atmosphere using *natural climate solutions*. The only realistic means of rapidly achieving carbon sequestration of the magnitude required is to protect native forests to allow them to realise their carbon carrying capacity.

To keep climate heating below the Paris target of 2^{o}C, and limit the growing threat of catastrophic fires, it is essential that natural climate solutions are vigorously pursued, with urgent action taken to stop the clearing and logging of native forests (proforestation) so as to restore their carbon carrying capacity. With the collapse of forests already commenced, as evidenced by the 2019-2020 wildfires, there is no time to waste.

There is a need to account for the loss of soil carbon from logging and too frequent burning, and its effect on increasing atmospheric carbon and climate change. Maintaining and restoring soil carbon is one of the benefits of stopping logging, with significant long term ramifications for climate change. The creation, fate and longevity of char from fires warrants consideration, particularly under a frequent burning regime.

Plantations will be of little benefit to mitigate climate heating because their establishment usually releases soil carbon and so it takes 5-10 years before they become net carbon sinks, they are usually clearfelled on 10-30 year rotations for pulp therefore only providing temporary storage, and soil carbon losses may never be regained.

Mixed species regeneration and plantings are the most efficient and effective for capturing and storing atmospheric carbon, and local indigenous species provide the

greatest biodiversity benefits. Though to maximise benefits they need to be established for the long-term and appropriately protected. Rather than commercial plantations, the Government needs to encourage and support native forest regeneration as an urgent priority. The benefits of new regrowth for enhancing regional rainfalls, reducing temperatures and supporting biodiversity, needs to considered along with the effects on streamflows.

Globally, terrestrial ecosystems currently remove an amount of atmospheric carbon equal to one-third of what humans emit from burning fossil fuels, which is about 9.4 GtC/y (10^9 metric tonnes carbon per year). (Moomaw *et. al.* 2019). Forests cover about 30% of the Earth's terrestrial surface and store around 90% of terrestrial vegetation carbon (Besnard *et. al.* 2018).

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 2016 ratified Paris Climate Agreement declared a commitment to hold "the increase in the global average temperature to well below 2 °C above preindustrial levels" with a goal of limiting warming to 1.5^{o}C. The Intergovernmental Panel on Climate Change (IPCC 2018), identifies that to achieve this 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.*

Limiting global warming below the 2°C threshold set by the Paris Climate Agreement is contingent upon both reducing emissions and removing greenhouse gases (GHGs) from the atmosphere. There has been considerable emphasis on failed mechanical schemes for increasing carbon capture and storage when for millions of years trees have effectively performed this function. There is growing recognition that we need to utilise natural climate solutions to have any chance of limiting global heating to below 2°C. These include protecting remnant vegetation from further degradation, encouraging regrowth of natural ecosystems, widespread planting of trees. and restoring soil carbon on agricultural lands.

It has long been recognised that we need natural climate solutions (NCS) to have any chance of limiting the worst effects of climate change (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, Moomaw *et. al.* 2019, Goldestein *et. al.* 2020). As well as reducing atmospheric carbon, natural climate solutions have a multitude of environmental benefits including reducing flammability, enhancing rainfalls, reducing temperatures, enhancing streamflows (except for reforestation), protecting and enhancing natural habitats, restoring habitat linkages and improving soils.

Griscom *et. al.* (2017) calculate that natural climate solutions can provide 37% of cost-effective CO_2 mitigation needed through to 2030 for a >66% chance of holding warming to below 2°C, and 20% of cost-effective mitigation between now and 2050, further noting:

> *Thereafter, the proportion of total mitigation provided by NCS further declines as the proportion of necessary avoided fossil fuel emissions increases and as some NCS pathways saturate. Natural climate solutions are thus particularly important in the near term for our transition to a carbon neutral economy by the middle of this century.*

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*".

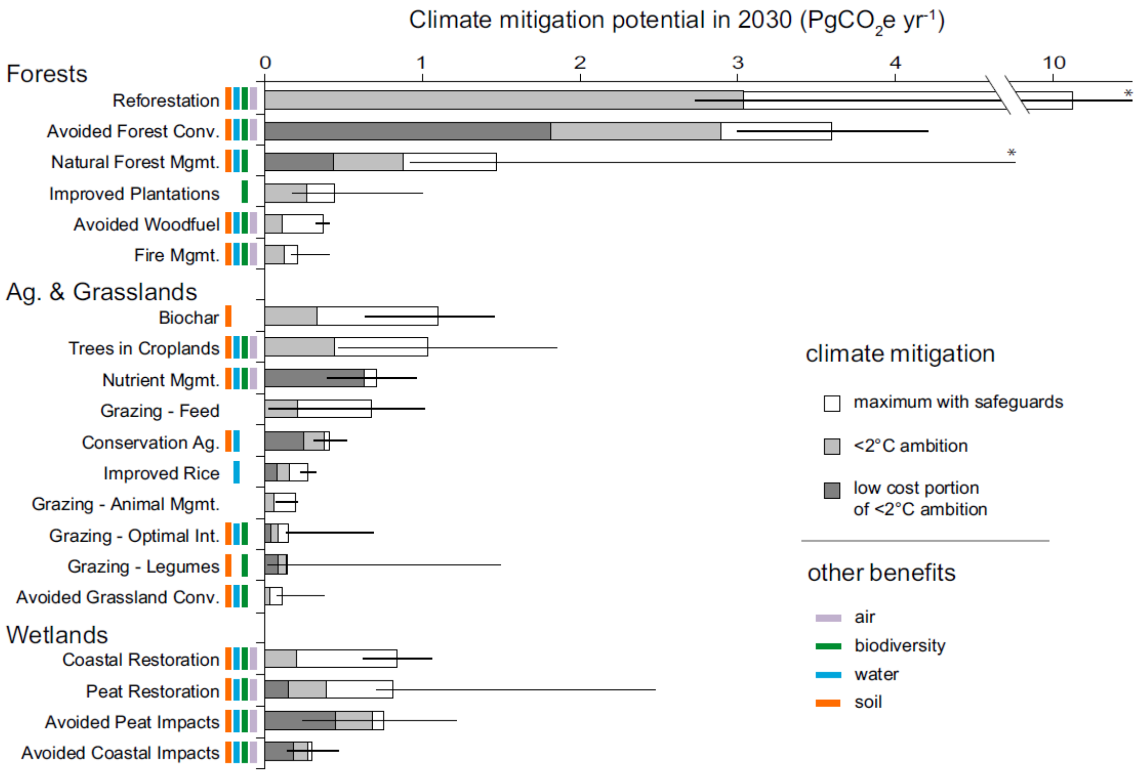


Fig. 1. from Griscom et. al. (2017): Climate mitigation potential of 20 natural pathways. We estimate maximum climate mitigation potential with safeguards for reference year 2030. Light

gray portions of bars represent cost-effective mitigation levels assuming a global ambition to hold warming to <2 °C (<100 USD $MgCO_2e^{-1}$ y^{-1}). Dark gray portions of bars indicate low cost (<10 USD $MgCO_2e^{-1}$ y^{-1}) portions of <2 °C levels. Wider error bars indicate empirical estimates of 95% confidence intervals, while narrower error bars indicate estimates derived from expert elicitation. Ecosystem service benefits linked with each pathway are indicated by coloured bars for biodiversity, water (filtration and flood control), soil (enrichment), and air (filtration). Asterisks indicate truncated error bars.

Fargione *et. al.* (2018) quantified the potential of natural climate solutions to increase carbon storage and avoid greenhouse gas emissions in the United States, finding "*a maximum potential of 1.2 (0.9 to 1.6) Pg CO_2e year^{-1}, the equivalent of 21% of current net annual emissions of the United States*", and concluding *"The conservation, restoration, and improved management of lands in the United States represent a necessary and urgent component of efforts to stabilize the climate".* Their solutions include reforestation of marginal farmland, extending logging cycles, increasing soil carbon, and avoiding emissions. They found that reforestation has the single largest maximum mitigation potential, followed by extending logging cycles on private lands, stopping forest and grassland clearing, improving farming practices and soil carbon, and restoring wetlands.

The first step has to be to stop deforestation. Goldestein *et. al.* (2020) observe "*From 2000–2012, the aggregate of thousands of local decisions drove the loss of 2.3 million km^2 of forest cover worldwide. Human-driven loss was attributable primarily to agricultural expansion in tropical regions and to forestry in boreal and temperate regions*".

While reforestation has the highest potential carbon benefits if undertaken on a large scale, it requires an enormous amount of additional land, and will take some decades after establishment before the carbon sequestration benefits begin to manifest. 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 contrast 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) consider:

> *... growing existing forests intact to their ecological potential – termed proforestation – is a more effective, immediate and low-cost approach that could be mobilized across suitable forests of all types. 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 produces natural forests as maximal carbon sinks of diverse species (while supporting and accruing additional benefits of intact forests) and can reduce significantly and immediately the amount of forest carbon lost to non-essential management. Because existing trees are already growing, storing carbon, and sequestering more carbon more rapidly than newly planted and young trees (Harmon et al., 1990; Stephenson et al., 2014; Law et al., 2018; Leverett and Moomaw, 2019), proforestation is a near-term approach to sequestering additional atmospheric*

carbon: a significant increase in "negative emissions" is urgently needed to meet temperature limitation goals.

Globally, existing forests only store approximately half of their potential due to past and present management (Erb et al, 2018), and many existing forests are capable of immediate and even more extensive growth for many decades (Lutz et al, 2018). During the timeframe while seedlings planted for afforestation and reforestation are growing (yet will never achieve the carbon density of an intact forest), proforestation is a safe, highly effective, immediate natural solution that does not rely on uncertain discounted future benefits inherent in other options.

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.

Moomaw et. al. (2019) "*conclude that protecting and stewarding intact diverse forests and practicing proforestation as a purposeful public policy on a large scale is a highly effective strategy for mitigating the dual crises in climate and biodiversity and ultimately serving the 'greatest good' in the United States and the rest of the world*".

Logging is the primary cause of carbon loss from forests, for example for the USA Moomaw et. al. (2019) consider "*Together, fires, drought, wind and pests account for ~12% of the carbon lost in the U.S.; forest conversion accounts for ~3% of carbon loss; and forest harvesting accounts for 85% of the carbon lost from forests each year*".

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*".

	Current average net emissions 2006–2015 (PgC/year)	Current average gross emissions 2006–2015 (PgC/year)	Net potential sink with a complete halt to deforestation and forest harvest 2016–2100 (PgC)
Temperate	−0.3	−1.1	−19
Tropics (Houghton & Nassikas, 2017) Simulation #2A	1.4	−0.5	−15
Tropics (with shifting cultivation) Simulation #2B	1.4	−3.3	−98
Global	1.1/1.1	−1.6/−4.4	−34/−117

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) cite one of their studies that "*showed that forests could account for approximately a third of total abatement over the next century*".

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 (Section 5.3). As shown by the 2019-20 fires we don't have any time to waste.

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,

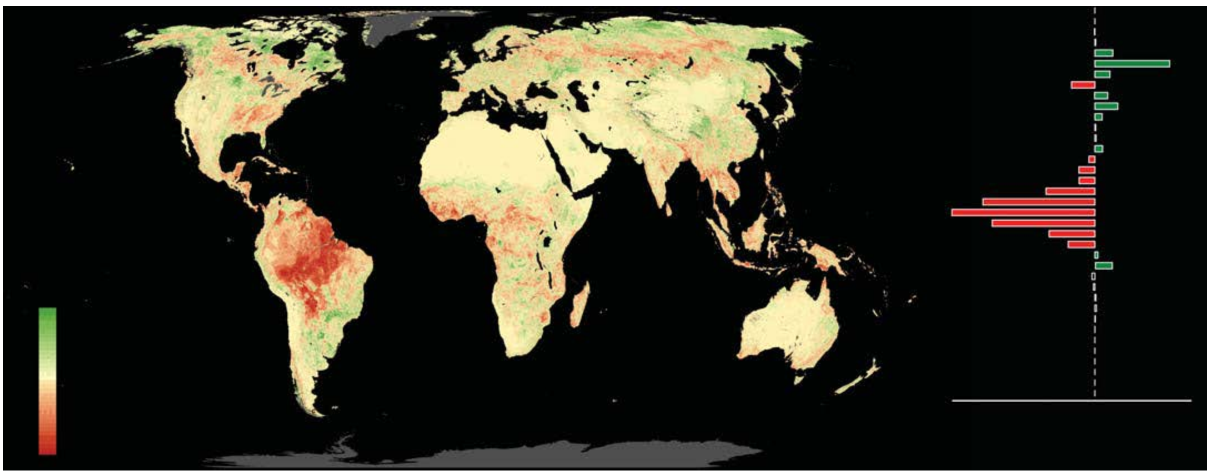


Fig. 3 from Bastin et. al. (2019): Risk assessment of future changes in potential tree cover. (A) Illustration of expected losses in potential tree cover by 2050, under the "business as usual"

climate change scenario (RCP 8.5), ... (B) Quantitative numbers of potential gain and loss are illustrated by bins of 5° along a latitudinal gradient.

Wardell-Johnson *et. al.* (2011) consider:

> *There is a need to establish effective financial and legislative mechanisms to safeguard current carbon stocks, and re-sequester carbon, while also providing positive biodiversity benefits. Furthermore, protected areas need to be increased and off-reserve conservation improved, including increasing the area of reforestation and improving the management of existing carbon stocks. A price on carbon emissions throughout Oceania can redirect energy use to less polluting forms.*

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

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.*

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).

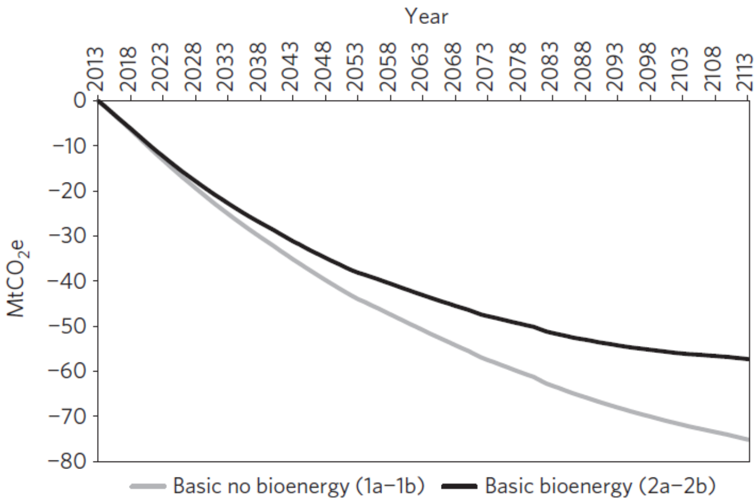


Fig 1 from Macintosh *et. al.* (2015). Basic scenarios—difference between the sustainable use reference case and the conservation scenario as cumulative net GHG emissions. Net emissions were calculated as the net flux difference (emissions less removals) between the sustainable use reference case and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

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*".

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.

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*".

5.2.1. Forests Carbon Carrying Capacity

Trees are essential elements of the earth's carbon cycle, essential for mopping up excess atmospheric carbon and putting it out of harm's way. Trees continue to take up CO_2 and store exponentially increasing volumes of carbon in their wood and soils as they age. The older trees and forests are the more carbon they store making them vital components of the solution to rapidly escalating climate heating.

Because of their extent fires can release significant volumes of carbon, largely as CO_2, though this is primarily carbon sequestered in dead biomass and a portion of it may end up as char sequestered in alluvial deposits or soils if fires are not too frequent. Some trees may be killed, though the dead standing trees may slowly release their carbon over decades.

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.

A significant part of the solution to the climate crisis is to protect native forests from clearing and logging to 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. 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.

Native forests play a crucial role in the storage of carbon and the sequestration of carbon dioxide from the atmosphere. Old growth forests are the most significant carbon storehouses, with most carbon stored in the oldest and biggest trees (Roxburgh *et.al.* 2006, Mackey *et. al.* 2008, Sillett *et.al* 2010, Dean *et. al.* 2012, Stephenson *et. al* 2014, Keith *et. al.* 2014b). Forests also remove carbon dioxide from the atmosphere and sequester it in live woody tissues and slowly decomposing organic matter in litter and soil. (Zhou *et. al.* 2006, Luyssaert *et. al.* 2008)

Forests accumulate carbon when their photosynthesis driven gross primary production (GPP), is greater than their carbon loss through ecosystem (plant and microbial) respiration (ER), giving them a positive net ecosystem production (NEP). These have diurnal variations, with photosynthesis dominant during the day and respiration at night.

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*

5.2.1.1. The Influence of Fire

Fires contribute significantly to global CO2 emissions, amounting to a third of current annual emissions from fossil fuel burning and from industry (Santin *et. al* 2012). Global fires are estimated to have emitted an average of 2.0 Petagrams of carbon into the atmosphere each year between 1997 and 2009, with carbon emissions from fire in Australia constituting approximately 7% of the global total (Surawski *et. al.* 2016).

The Climate Council (Hughes et. al. 2020) report Summer of Crisis notes regarding the 2019-20 fires:

> *The bushfires are estimated to have spewed between 650 million and 1.2 billion tonnes of carbon dioxide into the atmosphere. That is equivalent to the annual*

emissions from commercial aircraft worldwide and is far higher than Australia's annual emissions of around 531 million tonnes.

Keith *et. al.* (2015) assessed the release of carbon from an area of the Central Highland in the 2009 Victorian wildfires, finding:

> *The average carbon stock loss from biomass components was 40 tC ha^{-1} and 58 tC ha^{-1} in low- and high-severity fires, respectively, and this represented an estimated maximum amount (Table 4). As a proportion of the total biomass carbon stock (above- and below-ground), this loss represented 6–7% in low-severity fires and 9–14% in high-severity fires.*
>
> *... with an average of 8.5% across the landscape that was burnt. This is a relatively small proportion compared with impacts of human disturbance events, such as logging that removes biomass off-site*

Total Carbon Stocks (tC ha^{-1})

	Living Biomass	Litter	Course Woody Debris	Dead Standing Trees
Pre-fire	822	8	51	41
Post-fire	795.3	0	50.6	19.3

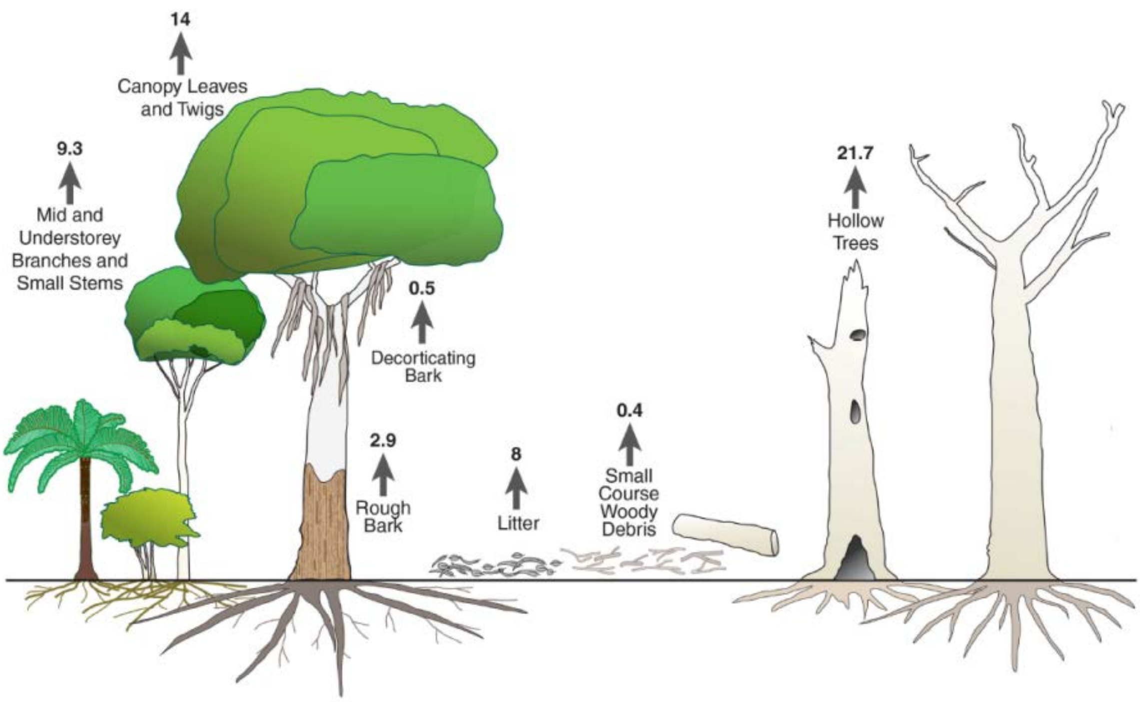


Figure 4 from Keith *et. al.* (2015): Schematic of carbon stocks in the forest ecosystem and stock changes resulting from fire.

Keith *et. al.* (2015) consider:

> *Mean residence time of the biomass components combusted is critical for determining the impact of wildfire on longer-term carbon dynamics. More than half the stock losses from combustion were derived from biomass components with short lifetimes; in the canopy, bark, litter layer and shrubs. These components are described as fine fuel, and this amount remains reasonably constant after about 10 years post-fire in a range of forest types ...*

> *The components combusted with longer mean residence times, such as CWD and large hollow trees, have variable stocks and proportions combusted depending on forest type, conditions for decomposition, logging and fire history. This coarse material contributed 18 to 45% of the carbon combusted in the montane ash forest, with an increasing proportion in older stands. The residence time of this coarse material is in the order of decades to centuries*

Surawski *et. al.* (2016) estimated greenhouse gases and particulate emissions from the 2009 100,000 ha Kilmore East fire in Victoria over a 12 hour period. The fire burnt not only through a range of sclerophyllous Eucalyptus vegetation types but also through grassland, woodland, temperate rainforest, and pine plantations. Their assessed carbon loss works out at about 27.7 tC ha^{-1}, which is significantly less than Keith *et. al.* (2015) found for the total carbon pool, much of which would have remained as surface ash and char. Surawski *et. al.* (2016) finding:

> *... 10,175 Gigagrams (Gg) of CO_2 equivalent (CO_{2-e}) emissions occurred, with CO2 (~68%) being the dominant chemical species emitted followed by CH4 (~17%) and black carbon (BC) (~15%). About 63% of total CO_{2-e} emissions were estimated to be from coarse woody debris, 22% were from surface fuels, 7% from bark, 6% from elevated fuels, and less than 2% from tree crown consumption.*

Bradstock *et. al.* 2012 assessed the prospects of using prescribed burning to reduce carbon emissions from wildfires in temperate forests. They identify that the average fuel consumption by prescribed fires was 40% of that of unplanned fires, concluding "*High rates of prescribed burning in temperate eucalypt forests may lead to either no change or a net increase in emissions, relative to a situation without prescribed burning, owing to the predicted trends in fuel consumption*".

Bradstock *et. al.* 2012 consider *"Strategic prescribed burning may therefore be best used in dry forest with low rates of fuel accumulation, rather than in restricted patches of wetter, more productive forests with inherently higher and more rapidly accumulating fuel loads".*

Fargione *et. al.* (2018) considered using control burning to limit canopy loss in wildfires a "*promising opportunity*", requiring more work:

> *The high uncertainty associated with the climate mitigation benefits of fire management would be reduced by additional research to quantify the carbon storage benefits of prescribed fire across a diversity of forest types, including the length of time that prescribed fire reduces the risk of subsequent high-severity fires.*

It needs to be recognised that increases in fire frequency in Australia's temperate forests will increase their carbon loss and decrease the crucial environmental service of carbon sequestration. Bradstock *et. al.* 2012 identify:

> *Estimates of Net Ecosystem Exchange (NEE) from temperate eucalypt forests (van Gorsel et al. 2008; Keith et al. 2009b) suggest that carbon is sequestered at a rate of 2 to 6 t $ha^{-1}year^{-1}$ in the interval between fires. Such sequestration is offset by a rate of carbon loss from fires of ,1.0 to 1.7 t $ha^{-1}year^{-1}$, ... Thus Net Biome Productivity ... in these forests may be of the order of 1 to 5 t $ha^{-1}year^{-1}$. High rates of burning from both prescribed (Fig. 7) and unplanned fires would tend to diminish NBP and sequestration capacity in these forests.*

The interaction between logging and burning is discussed in Section 2.

5.2.1.2. The Influence of Logging

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 has a far more significant impact on forest carbon stores than burning, generally logging has run down carbon stores by around 50% in affected forests (Noormets *et. al.* 2015).

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). During droughts forests can become carbon sources rather than sinks (Chen *et. al.* 2004, Falk *et. al.* 2004).

In fact 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).

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*".

There can be no doubt that it is the big old trees that store and sequester the most carbon. For example Roxburgh *et.al.* (2006) found:

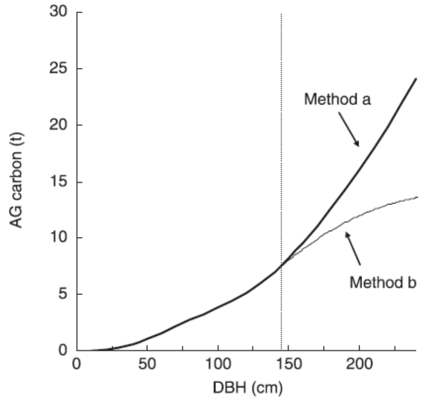
> *In mature forests, large diameter trees greater than 100 cm d.b.h. comprised 18% of all trees greater than 20 cm d.b.h. and contained 54% of the total above-ground carbon in living vegetation. ... The influence of large trees on carbon stock therefore increases with their increasing size and abundance.*

Similarly Moomaw *et. al.* (2019) identify

> *Each year a single tree that is 100 cm in diameter adds the equivalent biomass of an entire 10-20 cm diameter tree, further underscoring the role of large trees (Stephenson et al., 2014). 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).*

Keith *et. al.* (2014b) found large trees >100 cm diameter contributed 76% of the biomass in old growth sites, but only 43% of tree numbers, with remnant old trees also making significant contributions in predominately regrowth stands.

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.



Sillett *et.al* (2010) found that traditional ground-based measurements are inadequate to quantify whole tree wood production of tall tree species, finding that *"larger trees produce more wood annually than smaller trees",* and that *"annual aboveground wood production increased with size and age up to and including the largest and oldest trees"* they measured.

Similarly Stephenson *et. al* (2014) concluded:

> *Here we present a global analysis of 403 tropical and temperate tree species, showing that for most species mass growth rate increases continuously with tree size. Thus, large, old trees do not act simply as senescent carbon reservoirs but actively fix large amounts of carbon compared to smaller trees; 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.*

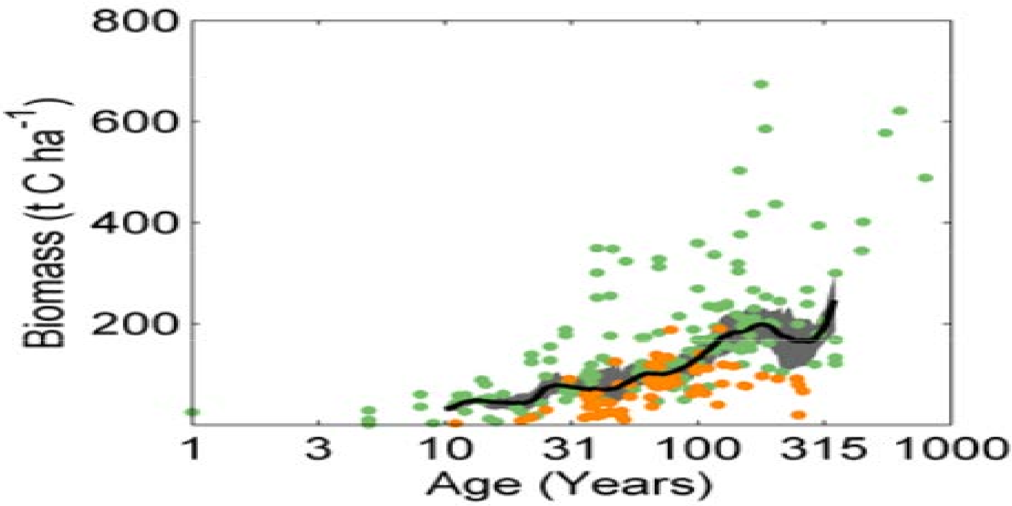


Figure S3 from Luyssaert *et. al.* (2008) showing Biomass accumulation as a function of stand age, shown as the relationship between aboveground biomass and the logarithm of stand age. The thick black line shows the weighted mean within a moving window of 15 observations. The grey area around this line shows the 95% confidence interval of the median. Each data point represents a forest stand (green is temperate, and orange is boreal), many of which have different growing conditions and species composition.

It is blatantly obvious that by removing the largest trees that logging dramatically reduces the carbon stored in forests (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). The accumulation of carbon with age is not limited to individual trees, but is also evident that oldgrowth forests can go on sequestering carbon indefinitely. It is only in oldgrowth forests that the maximum volume of carbon is stored, and forests reach their carbon carrying capacity.

In America Harmon *et. al.* (1990) found that during simulated harvesting carbon storage is reduced by 49-62% and does not approach old growth storage capacity for at least 200 years (even when storage in wooden buildings is accounted for).

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

Carey *et. al.* (2001) assessed 67 to 458 year old subalpine forests in the northern Rocky Mountains and found that net ecosystem production, assessed as aboveground net primary productivity (ANPP), increased over time, well above single species models indicated:

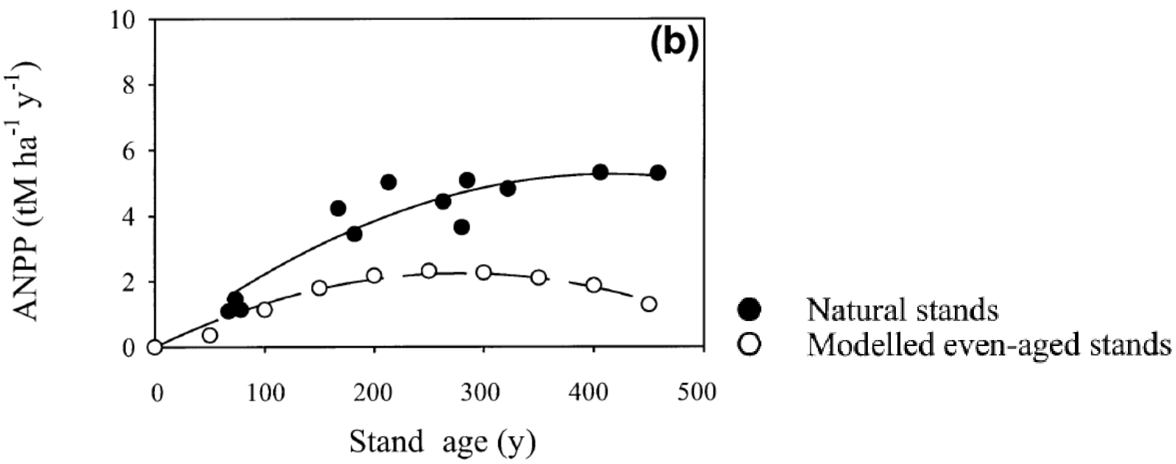


Fig 2(b) from Carey *et. al.* (2001), annual net primary productivity for natural subalpine forest stands of different ages in the northern Rocky mountains and simulated whitebark pine stands.

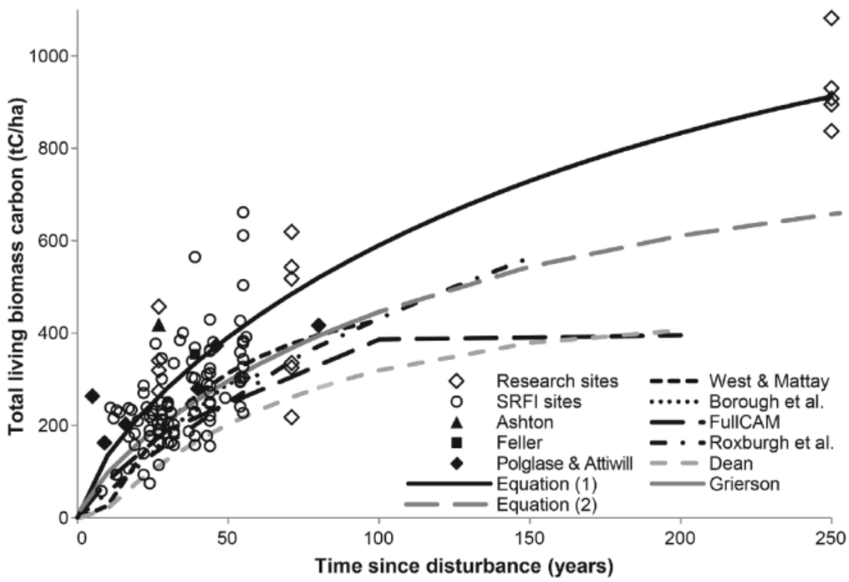
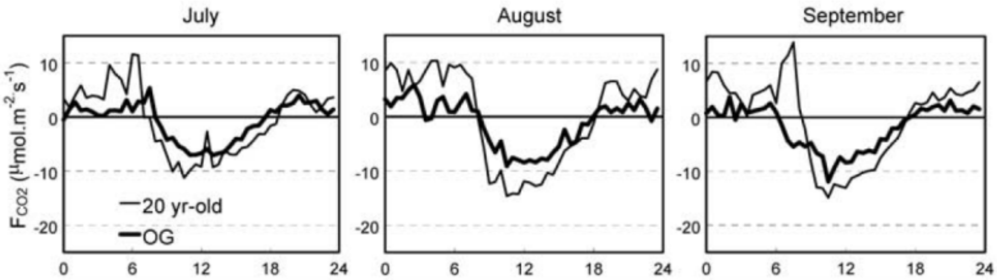


Fig. 7 from Keith et. al. (2014b): "Carbon accumulation in living biomass (above- and belowground) over time in E. regnans forest based on site data and equations from the

literature and current study". Details are provided in the paper, though the trends over time are clear.

Chen *et. al.* (2004) assessed 20, 40 and 450 year old Douglas-fir dominated forests in Washington, USA, finding that all three age classes were net carbon sinks during the dry warm summers, except in one year when the oldgrowth was affected by drought and became a carbon source.



Figures 2 and 3 from Chen *et. al.* (2004) showing average diurnal fluxes of carbon dioxide (CO2) in a 20- and a 450-year-old Douglas-fir forest in southern Washington, USA. Negative values indicate uptake (that is, sink); positive values indicate loss (that is, source). Note the significantly increased respiration of 20 yr old forest.

Chen *et. al.* (2004) conclude:

> *... our results strongly suggest that the old-growth forest may be a stronger carbon sink than previously believed. However, given its shift between a carbon source and sink in these two summers, the potential for long-term net carbon accumulation in the old-growth stand is uncertain. The 2 years of data for the summer season examined imply that these forests are sensitive to interannual weather conditions and thus will be sensitive to any directional climate change.*
>
> *The conversion of long-lived forests into young stands may change the system from a sink to a source of carbon for several decades because the lower leaf area in regenerating forests limits photosynthesis while the residual carbon in soils and woody debris contributes to respiration, whereas old-growth forests may continue to function as a net carbon sink, in addition to their many other important ecosystem functions (for example, critical habitat, aesthetic values, watershed protection). Stands younger than 20 years old are expected to be carbon sources because of low photosynthetic potential and substantial respiratory losses ...*

For oldgrowth forests, Luyssaert *et. al.* (2008) undertook a search of literature and databases for forest carbon-flux estimates, finding:

> *Old-growth forests remove carbon dioxide from the atmosphere at rates that vary with climate and nitrogen deposition. The sequestered carbon dioxide is stored in live woody tissues and slowly decomposing organic matter in litter and soil. Old-growth forests therefore serve as a global carbon dioxide sink ... forests between 15 and 800 years of age, net ecosystem productivity (the net carbon balance of the forest including soils) is usually positive. ... Old-growth forests accumulate carbon for centuries and contain large quantities of it. We expect, however, that much of this carbon, even soil carbon, will move back to the atmosphere if these forests are disturbed.*

Luyssaert *et. al.* (2008) consider

We speculate that 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).

Luyssaert *et. al.* (2008) emphasise:

In fact, young forests rather than old-growth forests are very often conspicuous sources of CO_2 (Fig. 1a) because the creation of new forests (whether naturally or by humans) frequently follows disturbance to soil and the previous vegetation, resulting in a decomposition rate of coarse woody debris, litter and soil organic matter (measured as heterotrophic respiration) that exceeds the NPP of the regrowth.

Curtis and Gough (2018) similarly found that a long held theoretical assumption of carbon neutrality in old-growth forests was not supported by their assessment of global data for northern deciduous forests, noting:

All stands older than 2 yr were net carbon sinks, including 12 forests > 100 yr old, and we found little evidence of declining carbon storage during mid-succession (100–200 yr) and more gradual declines than expected in late succession (> 200 yr, Fig. 3). On average, NEP was lower in very old forests, but the decline from peak annual carbon storage was gradual, falling to half the maximum value at 315 yr, well within late succession.

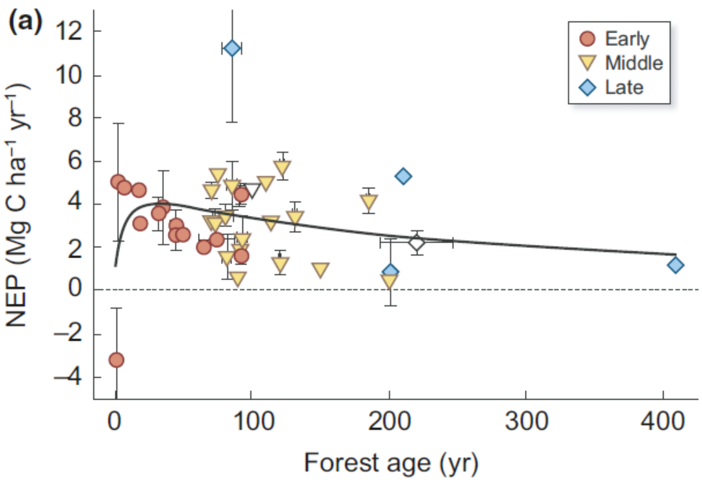


Fig 3(a) from Curtis and Gough (2018), showing no evidence for a steep decline in Net Ecosystem Productivity during mid-succession

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.*

From their consideration of global data, Besnard *et. al.* 2018 concluded that "*forest age was a dominant factor of NEP spatio-temporal variability in both space and time at the global scale as compared to abiotic factors, such as nutrient availability, soil characteristics and climate. These findings emphasize the importance of forest age in quantifying spatio-temporal variation in NEP using empirical approaches".*

In regards to logging Mackey *et. al.* (2008) note:

> *The carbon stock of forests subject to commercial logging, and of monoculture plantations in particular, will always be significantly less on average (~40 to 60 per cent depending on the intensity of land use and forest type) than the carbon stock of natural, undisturbed forests.*
>
> *...*
>
> *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. ..*

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.*

Keith *et. al.* (2015) demonstrate that changing native forest management from commercial harvesting to conservation "*results in an immediate and substantial reduction in net emissions relative to a reference case of commercial harvesting*":

> *Total carbon stocks were lower in harvested forest than in conservation forest in both case studies over the 100-year simulation period. We tested a range of potential parameter values reported in the literature: none could increase the combined carbon stock in products, slash, landfill and substitution sufficiently to exceed the increase in carbon stock due to changing management of native forest to conservation.*

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 (Section 4.1.). 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%).*

Hatanaka *et. al.* (2011) recommend:

> *There is a need to complement carbon crediting with biodiversity credits to avoid perverse investment outcomes ... If our results are widely applicable, then the preservation of old-growth forests is about a two-fold greater (bird) biodiversity benefit compared with even the oldest regrowth stands, notwithstanding comparable aboveground carbon storage levels. ...*
>
> *Mature vegetation simultaneously maximizes both avian biodiversity and above-ground carbon storage. These results bolster arguments for allocating highest priorities to the preservation of old-growth forest stands rather than alternative investments (e.g. reafforestation for carbon sequestration)*

When a tree is logged most of it is left behind in the forest to rot or burn. Of the logs removed, some 40-60% may end up as offcuts or sawdust in the production of sawntimber, or the whole logs may be chipped, with only the sawntimber component being used for longer-term products which may store the carbon for a few years or decades. It is apparent that most of the accumulated carbon stored in any tree logged is quickly released, and the relatively small volumes stored in products and landfill do not offset the lost carbon (Wardell-Johnson *et. al.* 2011, Dean *et. al.* 2012, Keith *et. al.* 2014b, Keith *et. al.* 2015).

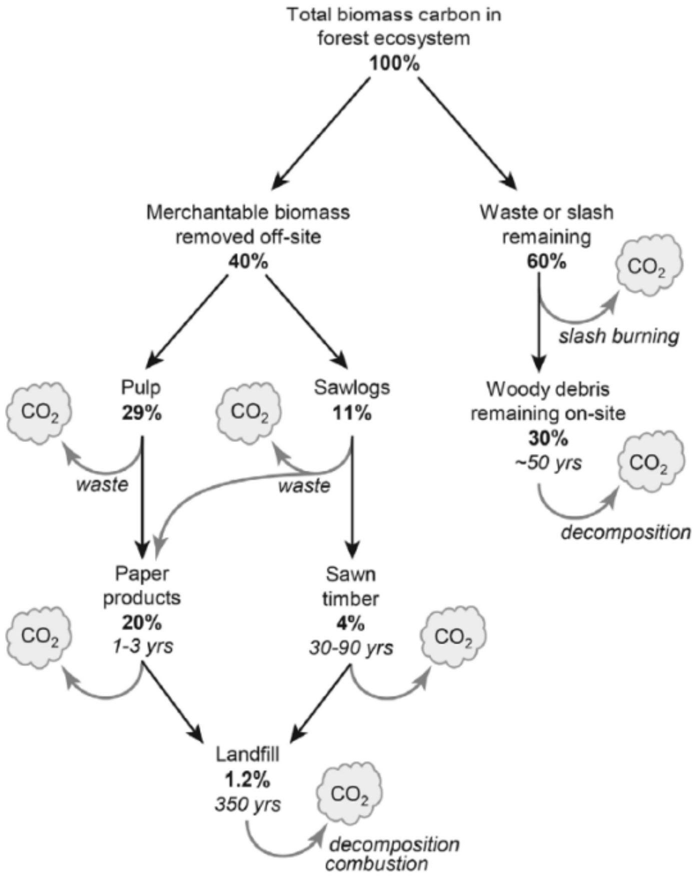


Fig. 8 from Keith *et. al.* (2014b). Transfer of biomass carbon during harvesting and processing of wood products. Numbers in bold represent the proportion of the total biomass carbon in the forest that remains in each component. Numbers in italics are the average lifetime of the carbon pool.

5.2.1.3. North East NSW Carbon Sequestration Potential

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

Allowing forests to recover and regain their lost carbon is termed proforestation. It is a significant and essential part of the measures needed to limit global warming to 1.5^{o} or 2^{o} C.

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. 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.

In NSW the average land clearing was 2,700 hectares per year between 2006/07 and 2016/17, with this increasing under the new rules to 45,553 hectares from June 2018 until May 2019, with over 140,000 ha also approved for clearing under the guise of 'invasive native species'. Increasing land-clearing in a climate emergency is akin to pouring petrol onto the flames. Land clearing increases regional temperatures, reduces rainfalls and releases large quantities of carbon into the atmosphere, as well as stopping that vegetation from sequestering carbon, we cannot afford for it to continue, let alone escalate.

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).*

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*

As noted by Keith *et. al.* (2014b) it is oldgrowth forests that are the baseline we need to measure change against:

> *Comparison of carbon stock change due to different disturbance types requires a baseline or initial condition. An appropriate baseline is the upper limit of carbon accumulation over time, or the potential maximum carbon stock. This maximum stock occurs where inputs and outputs of carbon in the growing forest are determined by natural environmental conditions and disturbance regimes at the landscape scale*

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}.*

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

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

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

...

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

...

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

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

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

† Woody debris refers to dead and downed woody debris.

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

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

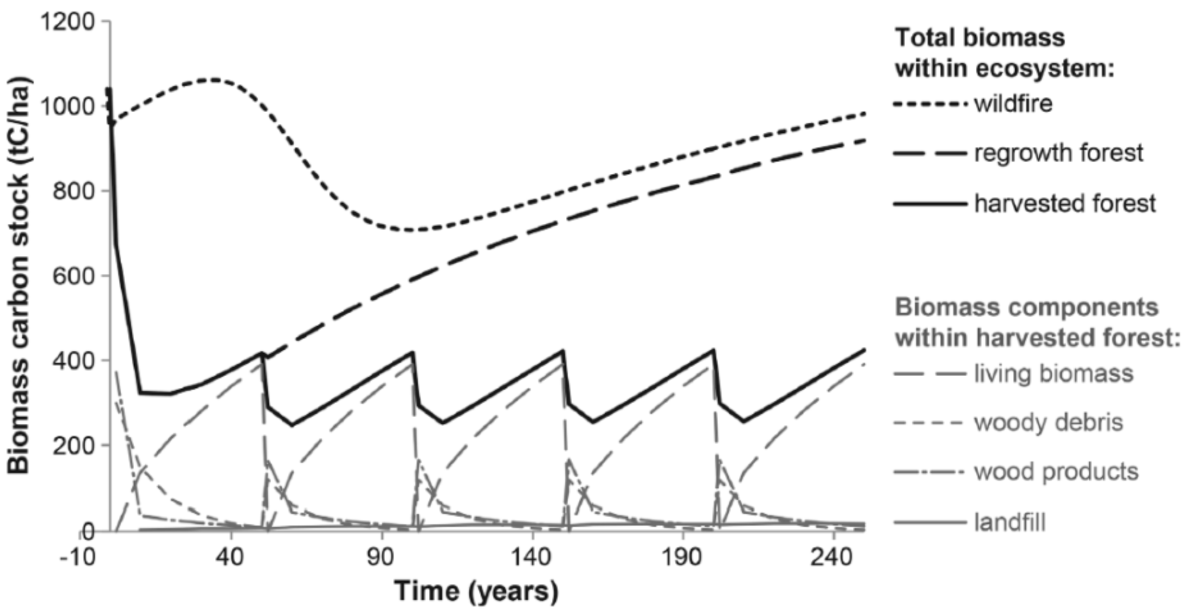


Fig. 10. from Keith *et. al.* (2014b): Changes in total biomass carbon stock of the ecosystem over time under three scenarios (shown as black lines) from an initial stock of a native forest: (1) wildfire that occurred at time 0 years and then the forest regenerated and dead biomass

decomposed over time, (2) regrowth forest after logging once and regeneration, and (3) harvested forest under a regime of repeated logging rotations consisting of clearcutting and slash burning on a 50 year cycle

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

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

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.

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.*

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

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

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

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

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

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

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

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

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

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 these are public lands and most Wood Supply Agreements expire in 2023, with Boral's expiring in 2028, the rapid phase-out of logging of public lands is readily achievable. Though 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.

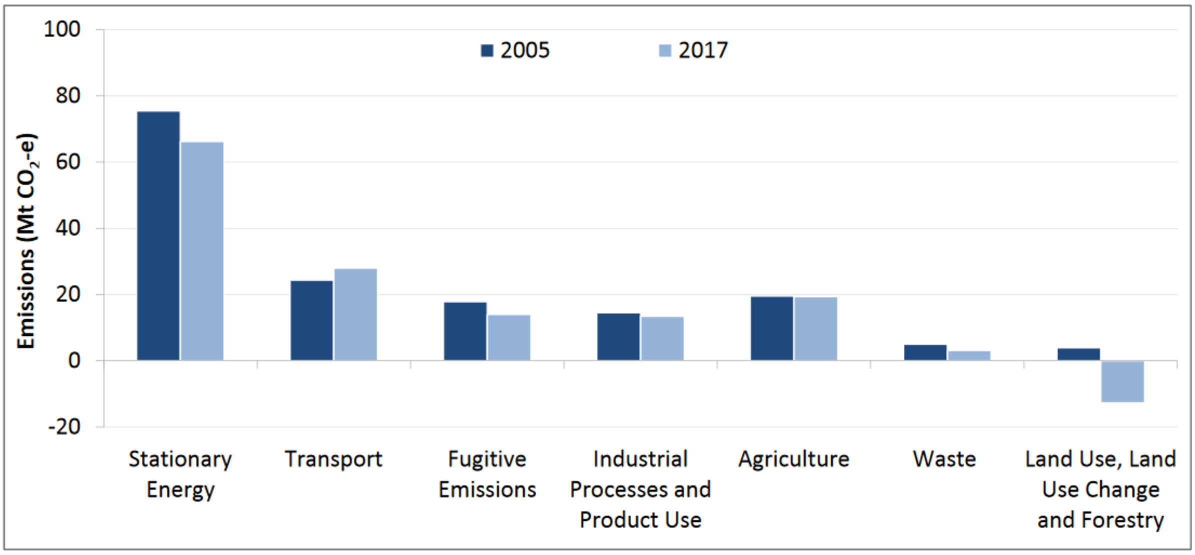
	Areas of degraded forests ha	Total Carbon Carrying Capacity[1] (t C)	Current Carbon Stock[2] (t C)	Carbon Sequestration Potential (t C)	Carbon Dioxide Sequestration Potential[3] (t CO_2)	Annual Sequestration potential[4] (t CO_2)	% of NSW Annual Emissions[5]
Protected, National parks and informal reserves	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.

Commonwealth of Australia (2019) claim "*The Land use change and forestry sector includes emissions from land clearing and deforestation with carbon sequestered from reforestation activities. Overall, the sector was a net sink of emissions, helping to reduce total NSW emissions by 10% in 2017*". Overall the Land Use Change and Forestry sector was counted as a net sink, though this is questionable.

Figure 4: New South Wales, annual emissions by sector, 2005 and 2017



The June 2019 Auditor General report on NSW's land clearing found:

> *The clearing of native vegetation on rural land is not effectively regulated and managed because the processes in place to support the regulatory framework are weak. There is no evidence-based assurance that clearing of native vegetation is being carried out in accordance with approvals. Responses to incidents of unlawful clearing are slow, with few tangible outcomes. Enforcement action is rarely taken against landholders who unlawfully clear native vegetation.*
>
> *There are processes in place for approving land clearing but there is limited follow-up to ensure approvals are complied with.*

The Natural Resources Commission's belatedly released July 2019 report on land clearing gives another damning assessment of NSW's land clearing free-for-all, revealing that from June 2018 until May 2019, was approved to be cleared under the Government's new Land Management (Native Vegetation) Code (the Code), excluding "invasive native species". This was a massive increase from the average of 2,700 hectares per year between 2006/07 and 2016/17. There was also over 140,000 ha approved for clearing in 2018/19 under the guise of 'invasive native species'. Land clearing will result in a massive spike in emissions from the Land Use Change and Forestry sector.

Land clearing increases regional temperatures, reduces rainfalls and releases large quantities of carbon into the atmosphere, as well as stopping that vegetation from sequestering carbon, we cannot afford for it to continue, let alone escalate. We need to be planting more trees to take up carbon, not bulldozing them.

5.2.2. Soil Carbon Carrying Capacity

Soils are the largest terrestrial carbon pools on earth, with labile carbon pools subject to rapid turnover and stable pools that change over centuries and millennia. Burning and logging of above-ground biomass can result in an immediate input to surface carbon, much of which may be lost by wind and water erosion.

The gross soil disturbances by logging machinery can significantly increase the loss of soil carbon by exposing labile carbon to oxidisation and erosion, and when coupled with the long term reduction in above ground biomass from repeated logging can progressively and significantly deplete soil stores of stable carbon over time.

A significant part of the biomass burnt in fires is not fully combusted resulting in charcoal which is resistant to further decay, and thus may persist in the landscape for considerable time if not subject to further combustion. Char can add to stable carbon pools when incorporated into soils, or deposited in stream sediments. Though if fire is too frequent it can reduce both labile and stable carbon pools.

There is a need to account for the loss of soil carbon from logging and too frequent burning, and its effect on increasing atmospheric carbon and climate change. Maintaining and restoring soil carbon is one of the benefits of stopping logging, with significant long term ramifications for climate change. The creation, fate and longevity of char from fires warrants consideration, particularly its loss under a frequent burning regime.

Soil is the largest terrestrial C pool on earth, storing an estimated 2300 Pg, of which forest soils account for 70%. Vegetation takes up about a third of our carbon emissions, of which about 10–15% ends up in the earth (Rumpel *et. al.* 2018). Rumpel *et. al.* (2018) consider:

> *Increasing the carbon content of the world's soils by just a few parts per thousand (0.4%) each year would remove an amount of CO_2 from the atmosphere equivalent to the fossil-fuel emissions of the European Union (around 3–4 gigatonnes (Gt)).*

Similarly Jandl *et. al.* (2007) identify:

> *The annual CO_2 exchange between forests and the atmosphere via photosynthesis and respiration is ≈50 Pg C/yr, i.e. 7 times the anthropogenic C emission. An increase in soil respiration would increase the CO_2 emissions from forest ecosystems. In order to mitigate climate change, more C should be sequestered in forest ecosystems*

Bowd *et. al.* (2019) identify:

> *Soils play key roles in (1) the demography, interspecific interactions and community structure of plant and microbial communities, (2) biogeochemical cycles, (3) biomass production and environmental filtering and buffering, and (4) climate change mitigation through the sequestration of carbon and other greenhouse gases*

Keith *et. al.* (2014b) recognise "*Disturbance events, such as logging and wildfire, affect soil carbon stocks through combustion, erosion, and changes in rates of soil respiration and litter inputs*".

Luyssaert *et. al.* (2008) found that 54% of the carbon stored by oldgrowth forests can be in roots and soil organic matter, indicating the importance for restoring forests to increase the sequestration of atmospheric carbon:

> *... old-growth forests accumulate 0.4 ± 0.1 $tCha^{-1} yr^{-1}$ in their stem biomass and 0.7 ± 0.2 $tCha^{-1} yr^{-1}$ in coarse woody debris, which implies that about 1.3 ± 0.8 $tCha^{-1} yr^{-1}$ of the sequestered carbon is contained in roots and soil organic matter.*

Soils have labile carbon pools derived from plant litter decomposition and root exudates that are subject to rapid turnover from months to years, and strongly mineral-bound and stable carbon pools that vary over timeframes of centuries and millennia. Disturbances such as logging and burning directly affect soil carbon and thus need to be constrained so as to limit emissions and increase storage if we want to stabilise atmospheric carbon.

Bowd *et. al.* (2019) quantified the impact of natural disturbance (fire) and human disturbances (clearcut and post-fire salvage logging) on soil measures in Victorian Mountain Ash forests, finding significant effects were evident up to at least eight decades post-fire and three decades post-clearcut logging in the 0–10 cm and 20–30 cm layers of soil. In relation to carbon they found:

- relative to sites burnt once, forest stands burnt twice (since 1850) were characterized by significantly lower levels of organic carbon
- relative to unlogged forest, clearcut logging resulted in significantly lower levels of organic carbon in the lower 20–30 cm layer of soil.

Bowd *et. al.* (2019) state:

> *Logging impacts observed in this study were highly significant in both the short and midterm (8 and 34 years), and result from the high-intensity combination of physical disturbance (clearing of forest with machinery) and post-logging 'slash' burning (of remaining vegetation). These disturbances can expose the forest floor, compact the soil, volatilize soil nutrients and redistribute organic matter, resulting in the release of large amounts of CO_2 into the atmosphere (Fig. 4). These impacts can alter plant–soil–microbial dynamics and subsequently decomposition rates and carbon storage, and result in the leaching of dissolved organic carbon and nitrogen, and the depletion of base cations, reducing overall site productivity. Given the long-lasting impacts of fire, we suggest that the logging-related depletion of key soil measures may act as a precursor for longer-term, and potentially severe changes in soil composition.*
>
> ...
>
> *To maintain vital soil nutrient pools and preserve the key functions that soils have in ecosystems, such as carbon sequestration and the regulation of plant and microbial community productivity, land managers should consider the impacts of current and future disturbances on soils in ecosystem assessments and land-use management and planning. Specifically, perturbations such as fire (outside the historical fire return interval of 75–150 years) and clearcut and post-fire salvage logging should be limited wherever possible, especially in areas previously subject to these disturbances.*

Retaining and protecting forests to restore lost soil carbon is part of the solution to climate heating, conversely continuing to reduce the carbon content of the world's soils through logging and frequent burning and is accentuating the problem.

5.2.2.1. The Influence of Fire

Soil temperatures can exceed 500 °C during high-intensity fires and result in the loss of soil nutrients, organic carbon and organic matter through volatilization and postfire erosion, which can reduce soil fertility (Bowd *et. al.* 2019).

Fires affect carbon by consuming biomass, with a proportion of the carbon being released to the atmosphere in smoke and the balance being added to litter and soil carbon. A proportion of the carbon added to the surface is as charcoal that has had incomplete combustion (i.e. char, charred organic materials, pyrogenic organic matter, black carbon) with increased resistance to degradation, which may persist for hundreds of years if not subject to further burning. The proportion of char produced in wildfires has been estimated to be 1–10% of the biomass combusted (Keith et. al. 2015). Much of this may be removed from burnt sites by water erosion and be deposited in streams and seas.

Krishnaraj *et. al.* (2016) assessed the effects of prescribed burns on carbon stocks pre and post fire in a Victorian Messmate forest, finding they:

> *... reduced total litter mass by 38% including a loss of 3.3 Mg ha^{-1} C from 2 to 25 mm litter. The results clearly show that total carbon stock of the top 2 cm of soil is significantly increased after fire, due to the incorporation of pyrogenic residues from the combusted litter and above ground biomass. The prescribed fire assessed in the present study did not change net litter + soil C stocks, but it did increase the proportion of PyC in litter and soil. Prescribed fire more than doubled litter PyC (measured as 2–25 mm charcoal), adding between 260 and 360 kg ha^{-1} C. Prescribed fire increased PyC in 0–2 cm soil by 370 kg ha^{-1} C. If we combine these data for litter + soil with the changes in aboveground biomass C reported in Volkova and Weston (2013) for the same forests, an emission of 6.1 Mg ha^{-1} C is calculated.*

Santin *et. al* (2012) assessed the impacts of the Victorian Black Saturday bushfires at eucalypt sites where there was almost the complete incineration of canopy, understorey and litter fuels resulting in substantial ash deposition of 81.9 t ha^{-1}, comprising 5.9 t ha^{-1} of C (mostly organic) being transferred from vegetation to the forest floor. A significant proportion of this carbon was char which would be resistant to further decay, leading Santin *et. al* (2012) to conclude "*it is feasible that some types of wildfire could be contributing to natural C sequestration similar to what it is hoped that biochar production can achieve artificially through industrial-scale C sequestration*".

Santin *et. al.* (2015) assessed the generation of char in a pine forest finding *"overall, 27.6% of the C affected by fire was retained in PyOM (4.8 _ 0.8 t C ha-1), rather than emitted to the atmosphere (12.6 _ 4.5 t C ha-1)",* and concluding *"Our findings suggest that PyOM production from boreal wildfires, and potentially also from other fire-prone ecosystems, may have been underestimated and that its quantitative importance as a C sink warrants its inclusion in the global C budget estimates".*

Jandl *et. al.* (2007) consider that:

> *The policy of fire suppression can delay but cannot prevent wildfires over the long term. It leads to an apparent net C accumulation that in fact increases the risk of large C release during catastrophic fires. The role of fire in ecosystem C changes is not straightforward. Several experiments showed that wildfire had caused increases in soil C, which may be driven by the incorporation of charcoal into soils and new C inputs via postfire N_2 fixation (Schulze et al., 1999; Hirsch et al., 2001; Johnson and Curtis, 2001; Johnson et al., 2004). However, N-fixing plants are not common to all fire-prone ecosystems.*

Sawyer *et. al.* (2017) assessed the impacts of 2 and 4 year fire regimes on carbon (C) and nitrogen (N) in surface soils (<10 cm), compared to long unburnt sites, in wet sclerophyll forest in south eastern Australia, finding the 4 year frequency had no significant effect but the 2 year burning treatment lowered soil total C by 44%, hydrolysable C by 48%, microbial biomass C by 42%, cumulative CO_2–C by 28%, non-oxidizable C by 41% and charcoal-C by 17%. They summarise "*in a wet sclerophyll forest, long-term more frequent prescribed fire (2yrB) led to lower soil labile, biologically active C and N pools",* and *"more frequent prescribed fire (2yrB) had lower soil recalcitrant C and N pools (except for charcoal N) compared with the no burning treatment*".

5.2.2.2. The Influence of Logging

Logging significantly affects soil carbon, as identified by Noormets *et. al.* (2015):

> *The physical disturbance of soil, and mixing of the litter layer with surface soil during harvesting and site preparation activities results in significant redistribution of C between different pools, and triggering accelerated carbon losses ...Mixing of litter layer with topsoil effectively removes this structural element and exposes it to diverse microbial communities ... whereas the breaking of the physical structure of soil aggregates exposes carbon that may previously have been protected*
>
> *...*
>
> *Harvesting influences soil carbon in two contrasting ways: harvest residues left on the soil surface increase the C stock of the forest floor and disturbance of the soil structure leads to soil C loss. In a comparative study, harvesting turned forests into a C source because soil respiration was stimulated, or reduced to a lesser extent, than photosynthesis (Kowalski et al., 2004)*

An Australian study by Rab (1996) of the effects of clearfell logging on the top 100 mm of soils in Mountain Ash forests in Victoria identified that 87% of the logging area had some soil disturbance, with snig tracks and log landings affecting 30% of the area, and:

> *.. that organic carbon and organic matter content in the litter disturbed areas was not significantly different from that of undisturbed areas. In contrast, organic carbon and organic matter content in the topsoil and subsoil disturbed areas was significantly lower than that of the undisturbed areas. Mean organic carbon content in the topsoil and subsoil disturbed areas decreased by about 33% and 66% respectively compared with undisturbed areas.*
>
> *Organic carbon and organic matter content in the snig tracks and the log landing was also significantly lower than that of undisturbed areas (Table 3). Organic carbon content decreased by about 53%, 27% and 42% respectively in the primary and*

tertiary sing tracks and the log landing respectively compared to undisturbed areas. Organic matter content decreased by about 42%, 27% and 33% respectively in the primary and tertiary snig tracks and the log landing respectively compared to undisturbed areas.

Despite the massive soil disturbance and loss of biomass, in the medium term there can be an increase in soil carbon from logging debris and freshly killed roots. The long term stability of sequestered soil carbon is a key issue, as identified by Jandl *et. al.* (2007) "*Once C is stabilized, the C pool does not change, even when marked differences in land use and climate occur*".

A variety studies have given conflicting assessments of the long-term effects of logging on soil C pools, in part because of high spatial variability and slow responses to change (Jandl *et. al.* 2007, Noormets *et. al.* 2015, Petrenko and Friedland 2015, Lacroix *et. al.* 2016, Dean *et. al.* 2017). From their review Dean *et. al.* (2017) concluded:

All modelling that includes major aboveground and belowground biomass pools shows a long-term (i.e. ≥300 years) decrease in SOC when a primary forest is logged and then subjected to harvesting cycles. The empirical longer-term studies indicate likewise. With successive harvests the net emission accumulates but is only statistically perceptible after centuries. Short-term SOC flux varies around zero. The long-term drop in SOC in the mineral soil is driven by the biomass drop from the primary forest level but takes time to adjust to the new temporal average biomass. ... Thus, conclusions that conventional harvests do not deplete SOC in the mineral soil have been a function of their short time frames. Forest managers, climate change modellers and environmental policymakers need to assume a long-term net transfer of SOC from the mineral soil to the atmosphere when primary forests are logged and then undergo harvest cycles.

Dean *et. al.* (2017) modelled the response of soil organic carbon in a Tasmanian Mountain Ash forest to an 80-year harvesting cycle, based on an averaged decrease of above ground biomass by 63% (from 740 to 275 Mg ha-1) they forecast a long-term (~1500 years) drop in soil organic carbon of 39%, without accounting for losses due to regeneration burns.

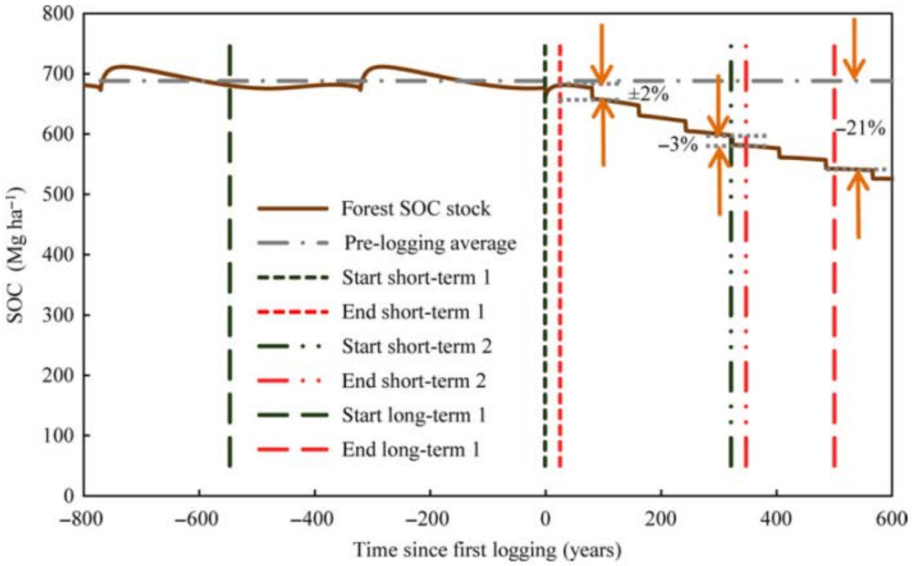


Fig. 3 from Dean *et. al.* (2017):Total SOC pool following conversion of primary forest to secondary forest on 80-year harvesting cycles with clearfell, burn and sow silviculture.

Individual changes with the initial logging or harvest may not be distinguishable but the accumulated change over several cycles should be detectable empirically.

Noormets *et. al.* (2015) conclude:

> *Long-term carbon sequestration potential in soils is assessed through the ratio of heterotrophic respiration to total detritus production, which indicates that (i) the forest soils may be losing more carbon on an annual basis than they regain in detritus, and (ii) the deficit appears to be greater in managed forests. While climate change and management factors (esp. fertilization) both contribute to greater carbon accumulation potential in the soil, the harvest-related increase in decomposition affects the C budget over the entire harvest cycle. Although the findings do not preclude the use of forests for climate mitigation, maximizing merchantable productivity may have significant carbon costs for the soil pool.*

Lacroix *et. al.* (2016) assessed differences in soil organic matter (SOM) in a north American hardwood stand, finding Mature and Cut stands contained similar amounts of C, though *"soils from Mature forest stands stored significantly more SOM in strongly mineral-bound and stable C pools than soils from Cut stands did*".

Across the north-eastern United States Petrenko and Friedland (2015) compared soil C pools in logged forests with forests that haven't been logged for over 100 years, finding "*no significant differences between soil C pools*", though did find " *a significant negative relationship between time since forest harvest the size of mineral soil C pools, which suggested a gradual decline in C pools across the region after harvesting*", leading them to conclude this "*suggested a gradual decline in C pools across the region after harvesting ... soil C pools have a gradual and slow response to disturbance, which may last for several decades following harvest*"

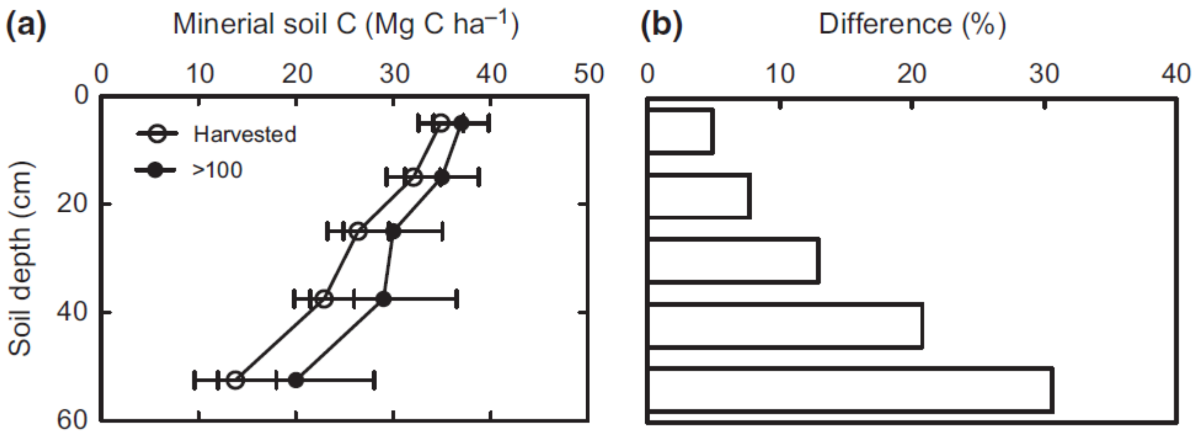


Fig. 4 from Petrenko and Friedland (2015): (a) Mean soil carbon pools by mineral soil depth increment in forests with different management histories, and (b) percent difference between >100-year-old forests and harvested forests. Number of stands varied between harvested (n = 15) and >100-year-old (n = 5) treatments. Error bars represent the standard error of the mean.

From their assessment of long-term declines in soil organic carbon (SOG) with each logging event, Dean *et. al.* (2017) consider:

> *One way to enable climate change mitigation is therefore to discontinue the logging of secondary forests, especially those with less than a few cycles since they were primary forests.*
>
> *...*
>
> *Forest managers, climate change modellers and environmental policymakers need to assume a long-term net transfer of SOC to the atmosphere when primary forests are logged then undergo harvest cycles. This includes calculations for primary forests that were logged and converted from decades to millennia ago, and whose emissions are now contributing to current climate change.*

5.2.3. Restoring Native Vegetation

The IPCC (2018) identify that if we want to limit global warming to below 1.5-2^{o}C then we need a 10 million km^2 increase in forests by 2050 relative to 2010. This is a massive undertaking, with only limited international commitments for implementation, and most of these are for commercial plantations rather than forest restoration.

While Australia, and north-east NSW in particular, has extensive areas of cleared and semi-cleared grazing land suitable for reforesting, the Government's only commitment to date has been to assist industry in establishing 400,000 hectares of new plantations for timber production over the next decade, while also facilitating loggers access to remnant forests on Aboriginal and freehold lands.

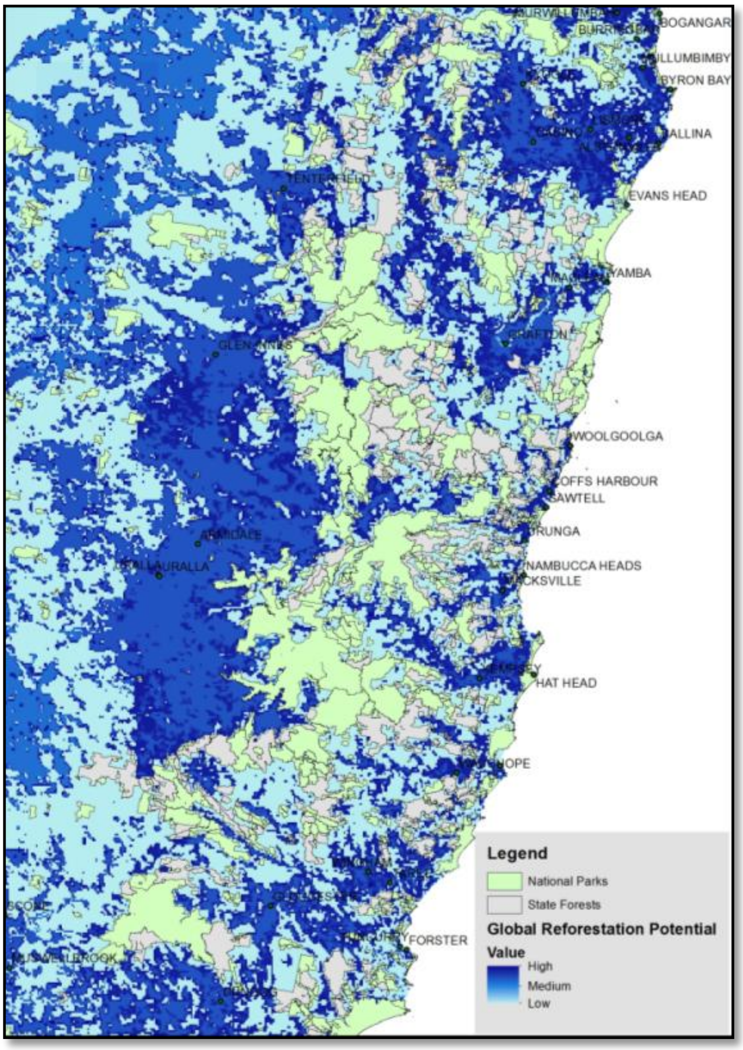
Plantations will be of little benefit to mitigate climate heating because their establishment usually releases soil carbon and so it takes 5-10 years before they become net carbon sinks, they are usually clearfelled on 10-30 year rotations for pulp therefore only providing temporary storage, and soil carbon losses may never be regained.

Mixed species regeneration and plantings are the most efficient and effective for capturing and storing atmospheric carbon, and local indigenous species provide the greatest biodiversity benefits. Though to maximise benefits they need to be established for the long-term and appropriately protected. Rather than commercial plantations, the Government needs to encourage and support native forest regeneration as an urgent priority. The benefits of new regrowth for enhancing regional rainfalls, reducing temperatures and supporting biodiversity, needs to considered along with the effects on streamflows.

Under the strategy Growing a better Australia – A billion trees for jobs and growth (DAWR 2018) the Australian Government committed to assisting industry to plant a billion new trees in 400,000 hectares of new plantations over the next decade to meet Australia's demand for wood. To their credit they did not pretend this was being undertaken to mitigate climate heating (which they have trouble even acknowledging), though do still claim this as a side-benefit, claiming an "*additional 18 megatonnes of carbon dioxide will be sequestered per year by 2030"* and that "*Australia's forest industries are part of the solution to climate change*".

Griscom et. al. (2017) identify reforestation as the "*largest natural pathway*" for climate change mitigation, noting "*reforestation has well-demonstrated cobenefits, including biodiversity habitat, air filtration, water filtration, flood control, and enhanced soil fertility*".

Griscom et. al. (2017)prepared a global spatial dataset of reforestation opportunities, allowing for "*no reduction in existing cropland area, but we assume grazing lands in forested ecoregions can be reforested, consistent with agricultural intensification and diet change scenarios*".



Global Reforestation Potential of North East NSW, from Griscom *et. al.* (2017)

Bastin *et. al.* (2019) also undertook a worldwide assessment to identify the extent of tree cover that could naturally exist in regions beyond existing forested lands, identifying that

> *Excluding existing trees and agricultural and urban areas, we found that there is room for an extra 0.9 billion hectares of canopy cover, which could store 205 gigatonnes of carbon in areas that would naturally support woodlands and forests. This highlights global tree restoration as our most effective climate change solution to date.*

Bastin's estimates of the land needed and available for replanting have attracted strong criticism, for example Skidmore *et. al.* (2019) consider:

> *We estimate that the global land area required to sequester human-emitted CO_2 is at least a factor of 3 higher than estimated by Bastin et al. As much as we would like to embrace the central conclusion of Bastin et al. that ecosystem restoration is "one of the most effective solutions at our disposal to mitigate climate change," we conclude that the emerging global political myth of massive tree planting and restoration as a*

> *panacea for global warming requires an unrealistically large area. Although tree planting should be welcomed, curbing emissions appears to be the key, albeit politically challenging, action.*

Wardell-Johnson *et. al.* (2011) consider:

> *Widespread reforestation provides an opportunity to reverse many of the threats associated with near-future climate change in terrestrial ecosystems (see Climate Commission 2011) but it needs to begin soon. Plantations on long-cleared land can increase biodiversity and carbon stocks (e.g., Kanowski et al. 2005) but may also depend on strategic land purchase, good land management, and corridor establishment.*

Harper *et. al.* (2012) compared 26 year old reforestation with four Eucalyptus species with agricultural sites in Western Australia. They note that reforestation is required for control salinity and wind erosion, with estimates that salinity due to land clearing and rising water-tables will affect up to 17 million ha of Australia by 2050, commenting:

> *it may therefore be possible to combine the parallel goals of carbon dioxide mitigation and landscape restoration, and in particular use investment in carbon dioxide mitigation as a means of financing the scale of reforestation needed*

They found there was no increase in soil carbon, though "*the reforested plots contained additional carbon in the tree biomass (23–60 Mg ha^{-1}) and litter (19–34 Mg ha^{-1})*", commenting:

> *Litter represented between 29 and 56% of the biomass carbon and the protection or utilization of this litter in fire-prone, semi-arid farmland will be an important component of carbon management.*

Moomaw *et. al.* (2019) identify

> *Managed plantations that are harvested periodically store far less carbon because trees are maintained at a young age (Harmon, 1990; Sterman et al., 2018). Furthermore, plantations are often monocultures, and sequester less carbon more slowly than intact forests with greater tree species diversity and higher rates of biological carbon sequestration (Liu et al., 2018). Recent research in the tropics shows that natural forests hold 40 times more carbon than plantations (Lewis et al., 2019).*

It is apparent that multi-species plantings (and regeneration) are more effective at sequestering and retaining carbon, while providing far greater ecosystem benefits. Osuri *et. al.* (2020) compared eucalypt and teak plantations to native forest in India, finding that:

> *Plantations had 4-9% higher average C capture rates (estimated using the Enhanced Vegetation Index – EVI) than natural forests during wet seasons, but up to 29% lower C capture during dry seasons across the 2000-18 period. In both seasons, the rate of C capture by plantations was less stable across years, and decreased more during drought years (i.e., lower resistance to drought), compared to forests. Thus, even as certain monodominant plantations could match natural forests for C capture and storage potential, plantations are unlikely to match the stability – and hence reliability – of C capture exhibited by forests, particularly in the face of increasing droughts and other climatic perturbations. Promoting natural forest regeneration and/or multi-species native tree plantations instead of plantation monocultures could therefore*

> *benefit climate change mitigation efforts, while offering valuable co-benefits for biodiversity conservation and other ecosystem services.*

Osuri *et. al.* (2020) conclude:

> *... our findings suggest that when assessed for both quantity and quality, in terms of reliability of C capture in the face of perturbation such as droughts, forests are superior to, and irreplaceable by, plantations as agents of terrestrial C sequestration. ... Our findings thus underscore the need for policy changes that increase focus on protecting and restoring natural forests and/or mixed plantations of native tree species – instead of promoting low-diversity plantations (Lewis et al., 2019) – as a more appropriate strategy for sequestering carbon in an increasingly variable and drought-prone climate. Apart from likely benefits for climate change mitigation, such policy changes would also generate valuable co-benefits for biodiversity conservation and other ecosystem services.*

Lewis *et. al.* (2019) identify that encouraging cleared and disturbed lands to naturally regenerate, with assistance as needed, is the cheapest and most effective means to recover to their previous high-carbon state, provided it is also appropriately protected. This also has the advantage of not involving the release of carbon from soil disturbance. They state:

> *We call on the restoration community, forestry experts and policymakers to prioritize the regeneration of natural forests over other types of tree planting*

5.2.3.1. Rorting Commitments

There has been some progress with the IPCC (2018) commitment to increase forests by10 million km^2 by 2050 relative to 2010 , though it is misguided as it is dominated by commercial interests after cheap resources. As identified by Lewis *et. al.* (2019) "*these efforts will remove sufficient carbon from the atmosphere only if forest restoration is taken to be what it means: the permanent re-establishment of largely natural and largely intact forest*".

For example in 2011, the German government and the International Union for Conservation of Nature launched the Bonn Challenge (www.bonnchallenge.org), which aims to restore 3.5 million km^2 of forest by 2030. Lewis *et. al.* (2019) identify that under this initiative and others, 43 countries across the tropics and subtropics where trees grow quickly, including Brazil, India and China, have committed nearly 3 million km^2 of degraded land, though:

> *A closer look at countries' reports reveals that almost half of the pledged area is set to become plantations of commercial trees (see Table S1). Although these can support local economies, plantations are much poorer at storing carbon than are natural forests, which develop with little or no disturbance from humans. The regular harvesting and clearing of plantations releases stored CO_2 back into the atmosphere every 10–20 years. By contrast, natural forests continue to sequester carbon for many decades[4].*

Agroforestry accounts for another 21%, meaning two-thirds of the area committed to global reforestation for carbon storage is slated to grow crops. Lewis *et. al.* (2019) consider:

> *policymakers are misinterpreting the term 'forest restoration'. Few conservationists, for example, think that this should include planting a monoculture of Eucalyptus trees for regular harvest. But by exploiting broad definitions and confused terminology, policymakers and their advisers are misleading the public.*

Lewis *et. al.* (2019) identify that just over one-third (34%) of the land allocated under the Bonn Challenge is intended to be naturally regenerated, considering this *"is the cheapest and technically easiest option",* allowing *"trees to return and forests to flourish, building carbon stocks rapidly to reach the level of a mature forest in roughly 70 years".*

Lewis *et. al.* (2019) compare the effectiveness of the 3 strategies:

> *In short, if the entire 350 Mha is given over to natural forests, they would store an additional 42 Pg C by 2100 ... Giving the same area exclusively to plantations would sequester just 1 Pg C or, if used only for agroforestry, 7 Pg C. Furthermore, we find, on average, that natural forests are 6 times better than agroforestry and 40 times better than plantations at storing carbon (sequestering 12, 1.9 and 0.3 Pg C per 100 Mha by 2100, respectively;*

They also identify the fourth strategy as 'bioenergy with carbon capture and storage' (BECCS) which is expected to remove 130 Pg C by 2100, commenting:

> *That technology would require a further 380–700 Mha of land by mid-century to grow crops for biofuel[7]. Eucalyptus, maize and switchgrass (Panicum virga-tum) would be burnt in power stations and the carbon emissions captured and stored underground. This huge extra demand for land could displace restored forests. We estimate that converting the planned new natural forests to bioenergy crops after 2050 slashes sequestration to a paltry 3 Pg C by 2100. This also delays by decades the time when BECCS becomes carbon-negative*

Osuri *et. al.* (2020) is concerned that even where countries, such as India, have committed significant areas to restoring natural forests they predominantly employ non-commercial monoculture/monodominant tree plantations comprising substantially lower tree diversity and carbon sequestration stability than native forests.

5.2.3.2. The Limitations of Soil Carbon

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}.

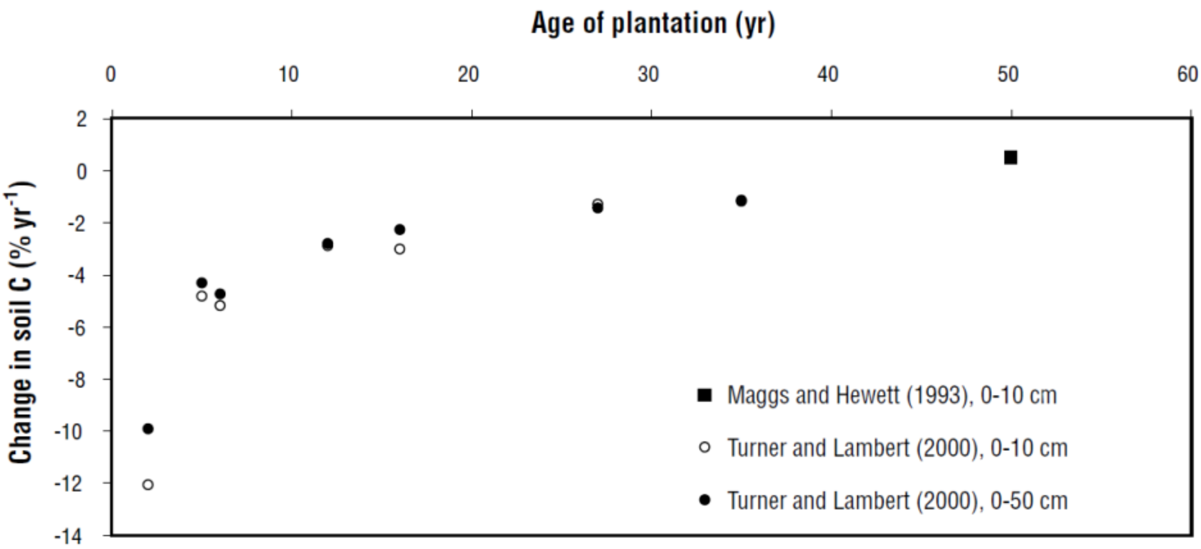


Figure 12.2. from Polgase *et. al.* (2000) Change in soil C in 0-10 cm or 0-50 cm layer under 2- to 50-year-old forest on ex-pasture land in the subtropical climatic regions of Queensland and the north coast of New South Wales.

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*".

Bastin *et. al.* (2019) warn that

> *However, climate change will alter this potential tree coverage. We estimate that if we cannot deviate from the current trajectory, the global potential canopy cover may shrink by ~223 million hectares by 2050, with the vast majority of losses occurring in the tropics. Our results highlight the opportunity of climate change mitigation through global tree restoration but also the urgent need for action.*

5.3. The Struggling Forests

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.

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*

Interactions of drought effects with biotic agents and their feedbacks can also significantly change the demographic patterns of tree mortality (Anderegg *et. al.* 2016)

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.

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 grazing. With increasing mortality of surviving trees, the need for adequate recruitment increases in significance.

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.

The consequences of increasing temperatures and more erratic rainfall due to climate change are more frequent droughts, extreme temperatures and heatwaves. 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.*

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.*

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*".

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)

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