REPORT: RECOGNISING THE CARBON SEQUESTRATION POTENTIAL IN NATIVE REGROWTH FORESTS

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Forest Resource Security

This report was commissioned by the North East NSW, South East NSW, South & Central Queensland and North Queensland Regional Forestry Hubs with funding from the Australian Government, Department of Agriculture, Fisheries and Forestry.

Recognising the Carbon Sequestration Potential in Native Regrowth Forests

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A report for the North East NSW, South East NSW, South & Central QLD and North QLD Regional Forestry Hubs

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Executive Summary

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E1 Introduction

The aim of this research was to investigate the carbon sequestration potential of commercially important private native forest regrowth[1] in the South East New South Wales (NSW), North East NSW, South and Central Queensland (QLD) and North QLD Forestry Hub regions (Figure E1). 'Commercially important forest' is forest with potential to contribute to national demand for domestically produced timber and carbon sequestration.

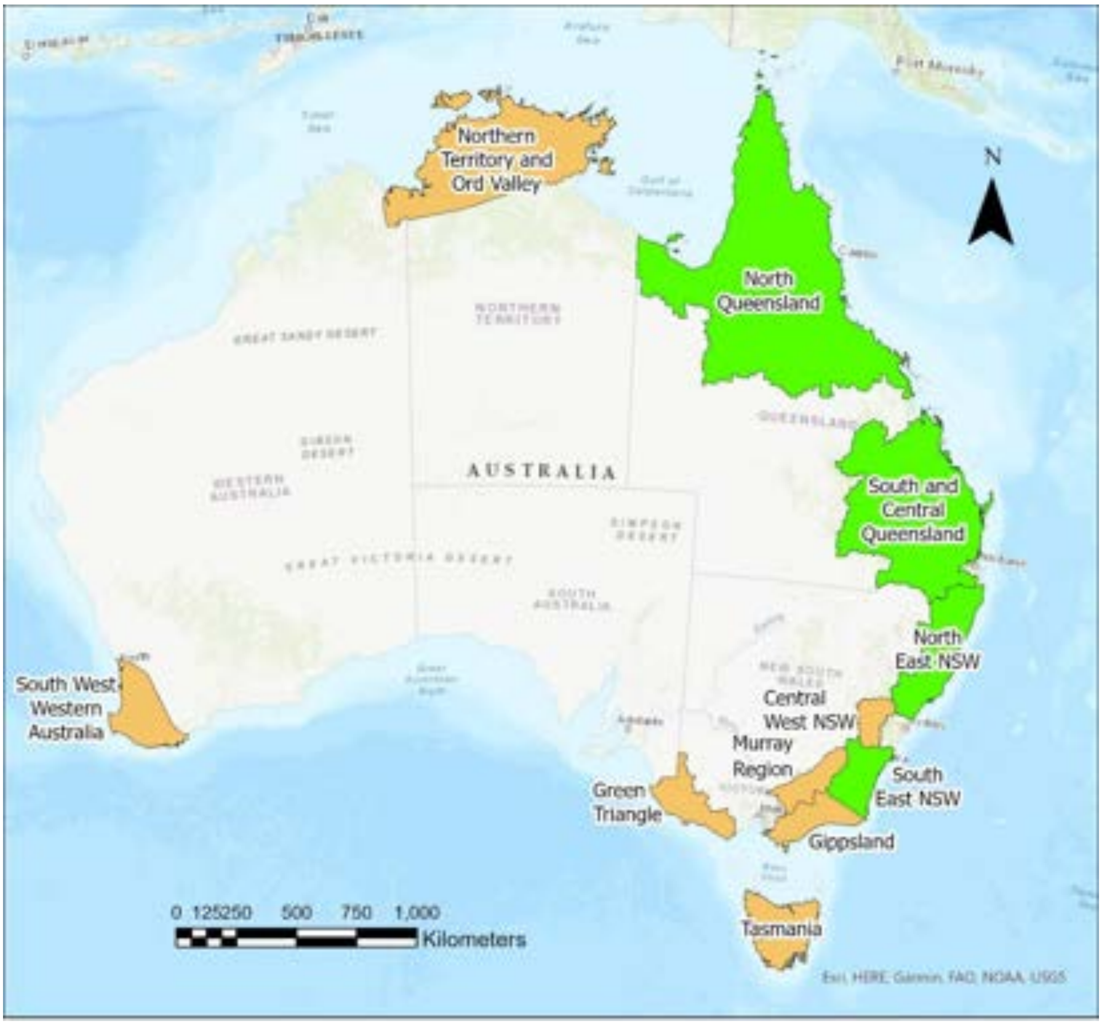

Figure E1. Location of Australia's Forestry Hub regions with the study area shaded green

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[1] While an overall perspective of the private native forest resource has been provided, the focus of the research was on post-1990 commercially important regrowth

The report includes a brief description of the international and national contexts for emissions reduction targets and carbon accounting, followed by a detailed description of Australia's National Carbon Accounting System (NCAS) and the Full Carbon Accounting Model (FullCAM), which are used to account for emissions and removals from the land use, land use change and forestry (LULUCF) sector. The contribution of forests under Australia's LULUCF sector has been summarised.

The report specifically examines the limitations of NCAS and FullCAM for estimating net carbon emissions from native forestry and for informing the design and evaluation of native forest carbon policy. A review of existing Australian Carbon Credit Unit (ACCU) methods and proponent-led ACCU methods in development is also provided.

Spatial analysis and FullCAM simulations have been conducted to estimate trends in area and the carbon sequestration potential of commercially important private native forest regrowth under alternative management scenarios. Vesta 2 wildfire simulation modelling was also conducted to estimate the effect of forest management on wildfire behaviour. Recommendations for improvement of NCAS and FullCAM, the development of a native forestry ACCU method and for further research are made.

E2 Key findings and recommendations

FullCAM and NCAS are compliant with United Nations Framework Convention on Climate Change (UNFCCC) and Intergovernmental Panel on Climate Change (IPCC) methods to account for emissions and removals from Australia's LULUCF sector. However, the partial carbon accounting framework, technical limitations and some questionable assumptions in these models mean that the full potential of native forestry to sequester carbon relative to strictly conserved forest is not recognised in Australia's carbon accounts. This research highlighted six important FullCAM and NCAS limitations and concerns that must be addressed before these tools can meaningfully support the design and evaluation of native forest carbon policy.

1. Revise estimates of rates of decay in old trees;
2. Revise estimates of biomass allocated to stems in commercially important forests;
3. Revise estimates of rates of decay of coarse dead roots;
4. Revise estimates of rates of decay of wood products in landfill;
5. Adopt a lifecycle analysis (LCA) of carbon framework; and
6. Change or provide a more rigorous scientific justification of the carbon accounting of 'natural' wildfire and forest fuel management.

Spatial analysis of commercially important private native forest regrowth in the South East NSW, North East NSW, South and Central QLD and North QLD Forestry Hub regions revealed 1.5 million ha of commercially important post-1990 standing regrowth and cleared areas with the potential to develop into commercially important regrowth stands. Queensland Government agencies recognise large additional areas of commercially important private native forest as regrowth, but these forests re-established before 1990.

Land use on properties with regrowth is dominated by livestock production, with management typically involving periodic re-clearing to increase pasture production. The current silvicultural condition of private native forest regrowth is generally poor, although it can be greatly improved with management.

FullCAM simulations revealed commercially important private native forest regrowth can sequester large volumes of carbon relative to periodic re-clearing. If 750,000 ha (50%) of the commercially important regrowth forests in the study area were retained as silvopastoral systems (livestock and timber production on the same land management unit), the landscape can sequester an additional 26.5 M tC (97.2 M tCO_2-e) over 100 years. A preliminary LCA of carbon highlighted the potential for regrowth to sequester more carbon in the long run when managed under a selection harvesting regime than when managed strictly for conservation.

Vesta 2 wildfire simulation modelling indicated standard native forestry silvicultural practices to improve forest silvicultural condition, including thinning and prescribed fire, have strong potential to reduce GHG emissions from wildfire, and the risk to human lives, livestock, infrastructure and other assets. This is possible because management decreases flame height, wildfire intensity and the potential for crown fire, while also increasing opportunities for direct attack to suppress wildfire.

Spatial analysis identified that tens of thousands of hectares of commercially important regrowth continues to be re-cleared annually, indicating existing ACCU methods have not incentivised retention. Proponent-led ACCU methods prioritised for development by the Federal Government in October 2024 are also unlikely to incentivise retention of regrowth forests in relatively productive agricultural regions. Development of a new native forestry ACCU method, such as the Forestry Australia proposed Enhancing Native Forest Resilience (ENFR), could overcome the opportunity costs of carbon farming in agricultural landscapes by facilitating ongoing income streams from livestock and timber, while also generating carbon credits. Improvement of forest policy to remove sovereign risk associated with sustainable private native forestry will also be essential to motivate retention of regrowth.

Several important recommendations arise from this research. First, Australia needs tools that can inform the design and evaluation of forest and carbon policy. In their current form, NCAS and FullCAM are unsuited to this purpose. The six limitations of these models outlined above likely result in a substantial underestimation of the carbon balance of native forestry relative to strict conservation and need to be addressed. This includes the development of a forest carbon accounting model within a LCA framework, and the review and revision of FullCAM model parameters. Presently, NCAS disincentivises investment in fire and forest management to protect carbon stocks, reduce wildfire emissions and improve resilience and recovery of ecosystems from fire. The NCAS definition and carbon accounting of ‘natural’ wildfire requires more rigorous scientific justification.

Second, the NCAS methods for determining carbon removals due to reduced native forest harvesting must be clearly articulated in future national carbon inventories, including spatially explicit reporting by forest type, avoided harvest regime and time since avoided harvest disturbance. Third, a native forestry ACCU method, such as ENFR, should be developed to reduce the opportunity costs of carbon farming in relatively productive agricultural landscapes to encourage the retention of private native forest regrowth.

Fourth, future research should also aim to produce more precise estimates of private native forest regrowth by forest type than was possible in this report to facilitate efficient decision making about regrowth management.

E3 Australia’s greenhouse gas emissions targets and carbon accounting system

Australia is a party to the UNFCCC treaties, initially under the Kyoto Protocol and now under the Paris Agreement. In 2022, Australia submitted an updated Nationally Determined Contribution (NDC) target to reduce greenhouse gas (GHG) emissions to 43% below 2005 levels by 2030 while reaffirming a commitment to reach net zero emissions by 2050. Australia reports its emissions and progress towards the NDC by submitting an annual National Inventory Report in compliance with UNFCCC reporting guidelines. To fulfill these reporting commitments, Australia has developed and maintained the NCAS to quantify GHG emissions and sinks across the country since 1990. NCAS is consistent with the requirements of the UNFCCC and uses methods consistent with those described by the IPCC.

Australia has produced its own UNFCCC approved country-specific methodology to account for emissions and removals from its LULUCF sector, the Full Carbon Accounting Model (FullCAM). FullCAM estimates carbon stock changes and greenhouse gas emissions by integrating spatially referenced data with an empirically constrained, mass balance, carbon cycling ecosystem model.

E4 Australia’s GHG emissions and the contribution of native forests

Australia’s total net GHG emissions across all sectors was 464.8 MtCO_2-e in 2020/21. This represents a decrease of 27% since 1990 (Kyoto Protocol baseline year), and 24.6% since 2005 (Paris Agreement baseline year). As indicated in Figure E2, Australia’s record of achieving its GHG reduction targets is almost entirely due to emissions reductions in the LULUCF sector, which have declined from a source of net emissions of 198.2 Mt CO_2-e in 1990 to a net carbon sink of 63.9 Mt CO_2-e in 2021. Net annual emissions from all other sectors of the economy have increased by 90.6 Mt CO_2-e since 1990.

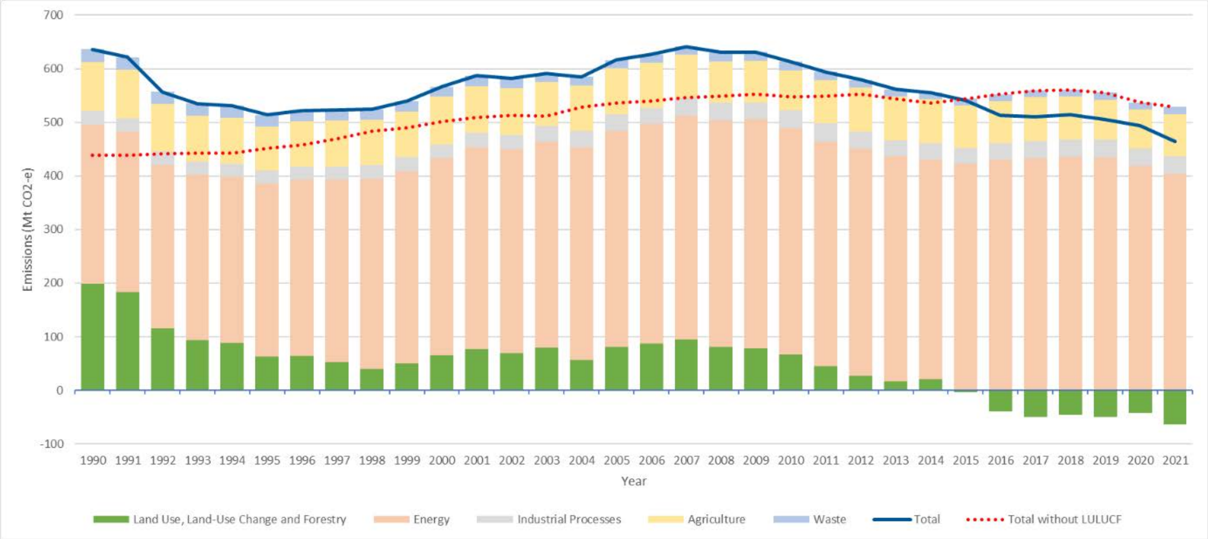


Figure E2. Australia's greenhouse gas emissions by sector

Emissions reductions in the LULUCF sector have been driven primarily by changes in forest management. This had been largely due to carbon sequestration in forest regrowth on previously cleared land and declining emissions from conversion of primary and secondary forest to other land uses. Figure E3 highlights that the cumulative total forest area cleared since 1990 is around 18 M ha (purple dotted line), with secondary re-clearing accounting for 65% (11.8 M ha) and primary forest conversions contributing the remaining 35% (6.2 M ha, the light blue dotted line). However, when the cumulative area of secondary forest regrowth since 1990 is also considered (10.3 M ha), Australia's net forest cover has declined by 7.8 M ha since 1990 (Figure E3 dark blue dotted line) and has remained relatively stable since around 2009. This is because the overall rates of forest conversion in Australia have been balanced by a similar extent of forest regeneration, with the total area of forest cover increasing between 2009 and 2015 and again in 2021 (Figure E3 red line below zero).

FigureE4 illustrates the annual carbon emissions and removals associated with forest conversion and regrowth in Australia since 1990. This includes the direct emissions and removals associated with the change in live biomass on-site (light green, dark green and yellow bars), as well as indirect emissions from the ongoing decay of debris and gradual loss of soil carbon that occur on cleared lands (grey bars). On average, one hectare of cleared primary forest has been modelled within FullCAM and NCAS to emit 5.6 times more carbon than re-cleared secondary forest. As the extent of primary forest clearing has declined and the cyclical re-clearing of previously cleared forest has become the dominant form of forest conversion, emissions and removals have trended towards parity (Figure E4 red line reaching zero in 2021).

Figure E3. The contribution of primary (dark green bars) and secondary (light green bars) forest conversion, and secondary forest regrowth (yellow) to Australia's annual net forest conversion area (red line). The following cumulative areas of forest clearing are also displayed – (i) dark blue line: change in forest cover, (ii) light blue line: primary forest clearing, and (iii) purple line: total forest clearing.

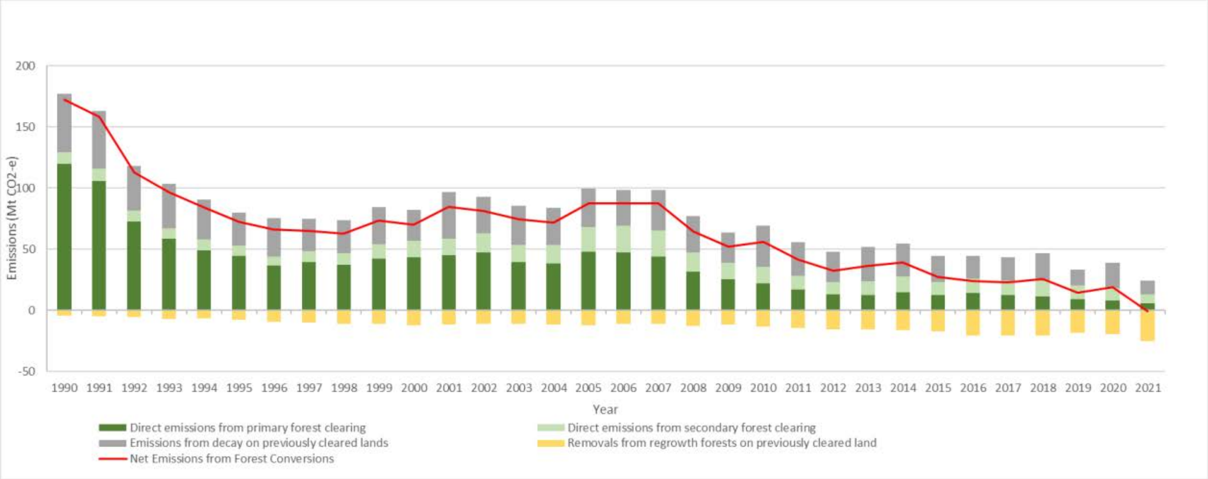


Figure E4. Annual GHG emissions and removals associated with forest conversions in Australia since 1990

The contribution that reduced land clearing can make to lowering Australia's GHG emissions has declined substantially, particularly since about 2007. However, as indicated in Figure E5, declining net emissions recorded by NCAS in the LULUCF sector since 2010 have been driven by historically low levels of native forest harvesting. As the annual area of native forest harvested fell by 71% between 1995 (124,354 ha) and 2021 (36,106 ha), NCAS has recorded an increase in carbon sequestered in harvested native forests due to less biomass being removed for processing into wood products and avoided decay of harvest debris (dark green bars in Figure E5). Reduced native forest harvesting sequestered an average of 35.4 Mt CO_2-e annually over the period 2016 to 2021, contributing 79% of the total GHG removals associated with the forest land remaining forest land category. In 2021, reduced native forest harvesting accounted for 55% of all GHG sequestration in the LULUCF sector, equivalent to offsetting 9% of Australia’s total annual emissions from the energy sector. Therefore, reduced native forest harvesting has become a significant contributor to Australia meeting its GHG emissions targets. However, Australia’s National Inventory Report is unclear about how the carbon removals due to reduced native forest harvesting are calculated.

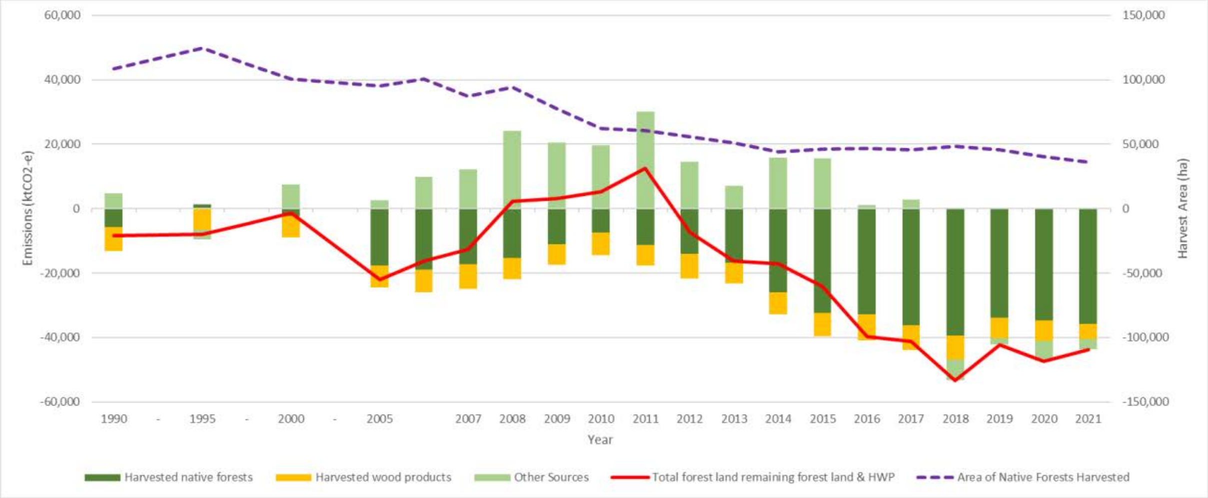


Figure E5. Contribution of harvested native forests to the net emissions in the forest land remaining forest land and harvested wood products category. The ‘Other Sources’ category (light-green bars) includes net emissions related to plantations, fuelwood, wildfires, prescribed burning and non-temperate forest fires. NOTE: Australia’s 2021 National Inventory Report provided data in 5 yearly increments from 1990 to 2005. Annual data is then reported from 2005 – 2021 (Australian Government, 2023a)

E5 FullCAM and NCAS should not be used to support the design and evaluation of native forest carbon policy in their current form

NCAS is consistent with the IPCC guidelines for carbon accounting and reporting, and is appropriate for tracking the nation’s progress towards meeting its carbon emissions reduction targets. However, NCAS has limited capacity to inform the development and evaluation of sector-specific policy in its current form. A review of literature revealed that technical limitations of FullCAM and NCAS lead NCAS to both overestimate the carbon storage potential of mature forests and underestimate the potential for sustainably managed production forests to sequester and store carbon on site, within wood products and through avoided consumption of substitutes. The limitations include:

1. Overestimation of the carbon storage potential of strict conservation forests because existing allometric equations used to infer biomass in mature trees fail to adequately account for increasing rates of decay as trees age;
2. Underestimation of the proportion of biomass allocated to the stems of trees in commercially important forest types (e.g. by 10.4% in spotted gum forests), which

overestimates the level of forest residue carbon that will rapidly decay following harvest and underestimates carbon stored in wood products;

3. Overestimation of the rate of decay of coarse dead roots by decades, thereby discounting their carbon storage potential within production forests;
4. Overestimation of the rate of decay of wood products deposited within landfill by about 8.6%, thereby discounting the climate mitigation potential of harvested wood products produced from sustainably managed production forests;
5. Failure to account for the carbon benefit of native forest wood products on avoided consumption of fossil fuel intensive substitutes (e.g. steel, concrete, brick, plastic and carpet), or imported wood from nations where forests are not as well managed as in Australia; and
6. Likely overestimation of the long-term average on-site carbon storage potential of strict conservation forests relative to native forestry due to a questionable NCAS definition of ‘natural’ wildfire, the exclusion of their emissions from the national GHG accounts, and an assumption that forest management makes little difference to wildfire-related carbon fluxes.

Point five refers to the fact that NCAS and FullCAM only provide a partial carbon accounting framework and cannot provide the more accurate approximation of actual atmospheric impacts of industries that can be produced with the lifecycle assessment (LCA) carbon accounting framework. Among the notable GHG accounting concerns with Australia’s partial accounting framework are that it does not track substitution of one product for another, and also excludes emissions from international consumption of exported goods and international production of imported goods. For example, Australia’s fossil fuel exports, which account for 90% of domestic coal production and 80% of domestic natural gas production, were responsible for 1.15 billion t CO_2-e emissions globally in 2023. These exported fossil fuel emissions are equivalent to 2.5 times Australia’s total annual domestic emissions from all sources and are not reported by NCAS. Australians are the world’s largest consumers of new clothing and our love of petroleum-based fashion is largely responsible for the nation’s 14 M tCO_2-e/y in fashion emissions. However, the majority of these emissions are excluded from NCAS accounting because of Australia’s dependence on imported clothing.

Similarly, NCAS does not capture the carbon benefits associated with using domestic wood products by avoiding consumption of imported wood product substitutes or the use of imported or domestically manufactured fossil fuel intensive substitutes. Avoided emissions from substitutes are large, often in the range of 1 tC to 2.5 tC (3.66 t CO_2-e to 9.15 t CO_2-e) per tonne of carbon stored in wood products. Therefore, NCAS and FullCAM have limited capacity to inform industry-specific or national climate policy; they are accounting tools only. The carbon benefits of avoided domestic native forest harvesting being reported by NCAS cannot honestly be interpreted as such without first subtracting estimates of the carbon emissions from Australian consumption of substitute products.

Point six refers to the fact that NCAS disincentivises investment in fire and forest management to protect carbon stocks, reduce wildfire emissions and improve resilience and recovery of ecosystems from fire, because there is no carbon penalty for ‘natural’ wildfire. There is little recognition that management can make a difference to wildfire risk and carbon emissions from fuel reduction treatments to reduce wildfire risk are recorded in the national accounts. The NCAS definition of natural wildfire in southern Australia is based on the distribution of wildfire carbon emissions over the period 1989-90 to 2019-20 – a period of declining government investment in proactive wildfire risk management, limited indigenous burning, and climate change. There is a strong likelihood of climate change-driven pyrogeographical changes in Australia, which will test the NCAS assumption that forests will fully recover from future wildfires in the absence of management. There is a substantial body of Australian literature with empirical and simulated data that highlights the potential for forest management to alter wildfire risk. Therefore, NCAS will likely overestimate the long-term average on-site carbon storage potential of strict conservation forests relative to forests in which fuels are more actively managed.

In its current form, NCAS cannot be used to design and evaluate forest and carbon policy aimed at increasing the contribution of Australia’s native forests to climate risk mitigation. The development of a forest carbon accounting model within a LCA framework is necessary to support policymakers. FullCAM model parameters need to be reviewed and revised where appropriate. Further research is required to improve our understanding of the carbon dynamics of managed and unmanaged forests. The NCAS definition of ‘natural’ wildfire and the exclusion of their GHG emissions from national accounts requires a more rigorous scientific justification.

E6 Review of historic, existing, and in development ACCU scheme methods for native forests

Several vegetation-based ACCU methods have been developed that together accounted for over 55% of all ACCUs generated between inception in 2012 and October 2023. None of the native vegetation-based ACCU methods allow the harvest of timber. Three percent of all ACCUs generated have been for establishment of new native forests from seeds or seedlings and timber plantation forests (the latter allows timber harvesting but excludes native forests). ACCU prices have not provided sufficient return on investment to incentivise planting trees on cleared land.

About 21% of all existing ACCUs were issued under the Avoided Deforestation Method, which credited landholders for emissions reductions if they refrained from clearing established native forests. Following the independent Chubb review, this method was discontinued because of concerns around the integrity of the ACCUs being generated. This method was popular in arid and semi-arid agricultural landscapes.

The Human-Induced Regeneration (HIR) method and Native Forest from Managed Regrowth (NFMR) method together accounted for another 31% of all ACCUs generated. The methods expired in September 2023 and March 2024, respectively. These methods allowed for the establishment of permanent native forests through assisted regeneration from in situ seed sources, remnant native plants, or rootstock already present and native to the site. Serious concerns were raised about these methods, as they have almost exclusively been adopted in uncleared arid and semi-arid rangelands where their capacity for increased carbon sequestration is likely to be limited. The Federal Government announced an intention to replace these two methods with the Integrated Farm and Land Management method, which had not been released as at December 2024.

In October 2024, the Federal Government announced it will prioritise four new proponent-led ACCU methods, including Improved Native Forest Management (INFM) in Multiple-use Public Forests, which was proposed by the NSW Government Department of Climate Change, Energy, the Environment and Water. This method has not been designed for application to private native forest, but aims to incentivise government forest management agencies to deliver carbon abatement by not harvesting public native forests or lengthening the rotation. At the time of writing, there is limited publicly available information about the proposed method. For example, it is not clear whether the method will account for domestic and international leakage arising from reduced harvesting in public native forests. The concerns outlined above about FullCAM and NCAS will need to be addressed to ensure the carbon sequestration estimates of forestry and strict conservation are robust. It appears that all additional carbon sequestered under the INFM method will be in the forest and thus exposed to climate change, drought, wildfire and cyclone risk.

The Federal Government also agreed to prioritise the Improved Avoided Clearing of Native Regrowth (IACNR) ACCU method proposed by the Queensland Government Department of Environment, Science and Innovation to incentivise retaining regrowth at high risk of re-clearing. It will focus on regrowth native forests up to 25 years of age on land on which landholders have a right to re-clear the regrowth. This new method could provide an incentive for landholders to retain regrowth and receive ACCUs for the carbon stored in regrowth forest. However, it is not yet clear how this method has been ‘improved’ over the discontinued Avoided Deforestation Method and whether it will overcome the opportunity costs of participation that were largely responsible for the lack of interest in that method from landholders outside the low-productivity arid and semi-arid zones (e.g. foregone rights to silviculturally thin, selectively harvest timber and maintain pasture for livestock). On the balance of probabilities, it is unlikely this method from the Queensland Department of Environment will permit thinning and native forest timber harvesting. If that is the case, then the method is unlikely to be of interest to landholders with regrowth forests in relatively productive agricultural landscapes. This is because of the high opportunity cost of foregone medium and long-term income (see Section E10).

E7 Extent of commercially important private native forest regrowth in New South Wales and Queensland

From existing literature, the total (regrowth and remnant) area of commercially important private native forest is approximately 4.6 M ha, consisting of:

- 233,466 ha in the South East NSW Forestry Hub region;
- 1,328,910 ha in the North East NSW Forestry Hub region;
- 1,886,400 ha in the South and Central QLD Forestry Hub region; and
- 1,160,500 ha in the North QLD Forestry Hub region.

The reported areas in the last three listed Hub regions are likely to be underestimates given that commercially important private native forest area has not previously been assessed for the entirety of these Hub regions. Research specifically on commercially important private native regrowth forests is scarce.

Recent Yield Association Group (YAG) mapping for most of the North East NSW Forestry Hub region and all of the South East NSW Forestry Hub region by the NSW Department of Primary Industries did not identify regrowth or age classes. Furthermore, the NSW Statewide Landcover and Trees Study (SLATS) program does not monitor regrowth, only clearing. Consequently, the National Forest and Sparse Woody Vegetation Data, Version 7.0 (2022 Release), was intersected with YAG mapping to estimate commercially important private native forest regrowth extent in NSW.

For QLD, mapping of commercially important private native forest regrowth with foliage projective cover of at least 15% on Category X land (where landholders retain rights to clear vegetation) was available and combined with QLD's SLATS data, which monitors annual changes due to clearing and regrowth. This indicated total standing regrowth areas in 2020 of 1.33 M ha in the South and Central QLD Forestry Hub region, and 0.06 M ha in the North QLD Forestry Hub region. This included 677,000 ha of ironbark, 314,900 ha of spotted gum and 270,200 ha of Queensland blue gum regrowth. However, about 852,500 ha in these regions was forest on Category X land and was estimated to be pre-1990 regrowth (>31 years old in 2020). Post-1990 commercially important regrowth amounted to 500,400 ha in the South and Central QLD Forestry Hub region and 28,400 ha in the North QLD Forestry Hub region. To provide Queensland regrowth estimates consistent with the NSW post-1990 regrowth estimates, the National Forest and Sparse Woody Vegetation Data, Version 5.0 (2020 Release) was intersected with commercially important private native forest on Category X land.

Table E1 reports a total potential area of private commercially important post-1990 native forest regrowth in the assessed Forestry Hub regions of 1.5 M ha. This comprises standing and cleared commercially important regrowth private native forest areas based on the National Forest and Sparse Woody Vegetation Data. The standing regrowth is reported as strictly and not strictly post-1990 regrowth. The former category was non-woody vegetation in 1991. The latter category was either sparse woody or forest vegetation in 1991 and was sparse woody vegetation in 2020 (QLD) or 2022 (NSW). The total area of commercially important private native forest regrowth was about 882,100 ha, of which 70% is in the South and Central QLD Forestry Hub region. The total cleared area in 2020 to 2022 with potential for development into commercially important private native forest regrowth was estimated to be about 604,600 ha, with 79% in the South and Central QLD Forestry Hub region.

Table E1. Standing private post-1990 regrowth and cleared area of commercially important regrowth private native forest by Hub region in 2020 for Queensland and 2022 for New South Wales

Regrowth forest category	**Area by Hub region (ha)**						
	S&C QLD	**N QLD**	**Total QLD**	**NE NSW**	**SE NSW**	**Total NSW**	**Total QLD and NSW**
Strictly post-1990 regrowth [a,b]	451,600	16,200	467,800	192,100	57,100	249,200	717,000
Not strictly post-1990 regrowth [b,c]	356,500	9500	366,000	167,900	33,500	201,400	567,400
Total regrowth	808,100	25,700	833,800	360,000	90,600	450,600	1,284,400
Percent commercially important (%) [d]	*76*	*82*	*76*	*62*	*26*	*55*	*69*
Total standing commercially important regrowth [e]	614,200	21,100	635,300	223,200	23,600	246,800	882,100
Total cleared area [f]	627,200	21,300	648,500	157,000	50,300	207,300	855,800
Total cleared with commercially important regrowth [e]	476,700	17,500	494,200	97,300	13,100	110,400	604,600
Total potential area of commercially important regrowth [g]	1,090,900	38,600	1,129,500	320,500	36,700	357,200	1,486,700

Notes: a. Consisting of land cover that (1) Changed from non-woody to sparse woody, (2) Changed from non-woody to forest, and (3) Changed from forest to sparse woody over the period 1991 to 2020 for QLD, or over the period 1991 to 2022 for NSW. Area estimates summarised from Tables 7.5, 7.6, 7.7 and 7.9.

b. In Queensland, the regrowth forest areas had to be harvestable under the *Managing a native forest practice accepted development vegetation clearing code*, which includes some forest types that are not considered commercially important by the timber industry. In New South Wales, the regrowth forest areas had to be mapped into one of the Yield Association Groups.

c. Consisting of land cover that (1) Remained sparse woody and (2) Changed from sparse woody to forest over the period 1991 to 2020 for QLD, or over the period 1991 to 2022 for NSW. Taken from Tables 7.5, 7.6, 7.7 and 7.9.

d. For QLD is 1 minus the percent of non-commercial forest in Table 7.2. For NSW is the total commercial forest YAG area divided by the total YAG area in Tables 7.3 and 7.4.

e. Total standing regrowth or cleared area multiplied by the percent commercially important.

f. Consisting of land cover that (1) Remained as non-woody vegetation, (2) Changed from sparse woody to non-woody vegetation, and (3) Changed from forest to non-woody vegetation over the period 1991 to 2020 for QLD, or over the period 1991 to 2022 for NSW. Area estimates summarised from Tables 7.5, 7.6, 7.7 and 7.9.

g. Sum of total standing and total cleared commercially important regrowth.

Further data analysis is required to estimate the regrowth areas from the National Forest and Sparse Woody Vegetation Data (Table E1) by forest type. From the SLATS analysis reported for Queensland (see main report Table 7.2), the distribution of the commercially important regrowth up to 31 years old by forest type in the South and Central QLD Forestry Hub is dominated by ironbark (55%), Queensland blue gum (19%) and spotted gum (18%). In the North QLD Forestry Hub region, the regrowth is dominated by ironbark (61%), mixed hardwood (14%) and Queensland blue gum (12%). Based on the area of sparse woody vegetation on private land in NSW from the National Forest and Sparse Woody Vegetation Data, Version 7.0 (2022 Release) intersected with YAG mapping (see main report Table 7.3), the regrowth in the North East NSW Forestry Hub region is dominated by coastal dry eucalypts (34%), tablelands dry and semi-moist eucalypts (29%), and viney scrub (17%). In South East NSW, the regrowth is dominated by ‘Negligible forest products’ (64%) and coastal dry hardwoods (17%) (main report Table 7.4).

The silvicultural condition of private native forest regrowth in NSW and QLD is generally poor. This appears to be a result of a history of poor harvest management (i.e. high grading) and the fact that many regrowth forests have high densities of small stems, which have not been silviculturally thinned. Published estimates of mean annual increment (MAI) in poorly managed private native forest in NSW and QLD are in the range of 0.15 m^3/ha/y to 1.7 m^3/ha/y, depending on forest type. The weighted (by forest type) average MAI in the South and Central QLD Forestry Hub region is about 0.26 m^3/ha/y. Several studies have highlighted the potential for MAI in the private native forest resource to be improved by a factor of three to five with silvicultural management. Native forests in the Forestry Hub regions assessed in this study generally cannot achieve growth rates exceeding 10 m^3/ha/y, which is common in intensively managed even-aged plantations (e.g. *Pinus radiata*) and even-aged native forests (e.g. Victorian *Eucalyptus regnans*) in Australia.

E8 Trends in area of commercially important private native forest regrowth in New South Wales and Queensland

Over the period 1991 to 2020-22, commercially important sparse woody and forest vegetation on private land increased in the South and Central QLD, North East NSW and South East NSW Forestry Hub regions, resulting in a net gain of 133,900 ha over the entire period (see main report Table 7.11). However, as indicated in Table E2, over the period 2011 to 2020-22, there was a net decrease in commercially important sparse woody and forest vegetation on private land of 57,000 ha. During that period, 409,400 ha of commercially important sparse woody and forest vegetation were cleared, versus 352,400 ha that regrew from non woody vegetation. It is clear that existing ACCU methods have not incentivised retention of commercially important private native forest regrowth in the Forestry Hub regions.

The level of commercially important regrowth clearing over the period 2011 to 2020-22 was greatest in the South and Central QLD Forestry Hub region at 238,800 ha, although net sparse woody and forest cover on private land increased in that region by 14,900 ha. Nevertheless, the clearing of advanced regrowth represents a large opportunity cost for hardwood timber production and carbon sequestration. The region with the second largest area of clearing was the North East NSW Forestry Hub, where 122,100 ha were cleared and only 65,700 ha regrew, resulting in a net loss of 56,400 ha. Smaller net losses of commercially important sparse woody and forest vegetation on private land occurred in the North QLD (8400 ha) and South East NSW (7100 ha) Hub regions.

Table E2. Trends in area of commercially important sparse woody and forest vegetation over time in Queensland and New South Wales

Vegetation statistic	**Area by Forestry Hub region and time period (ha)**				
	S&C QLD	**N QLD**	**NE NSW**	**SE NSW**	**Total**
	2011 to 2020	**2011 to 2020**	**2011 to 2022**	**2011 to 2022**	**2011 to 2020-22**
Non woody to sparse woody or forest vegetation [a]	253,700	4,300	65,700	28,700	352,400
Forest or sparse woody to non woody vegetation and forest to sparse woody vegetation [a]	238,800	12,700	122,100	35,800	409,400
Net increase in sparse woody and forest vegetation [b]	14,900	-8,400	-56,400	-7,100	-57,000
Average annual increase in sparse woody and forest vegetation [c]	25,400	400	5,500	2,400	33,700
Average annual loss of sparse woody and forest vegetation [c]	23,880	1,300	10,200	3,000	38,300
Average net annual increase in sparse woody and forest veg. [c]	1,500	-800	-4,700	-600	-4,600

Notes: a. These areas are from Tables 7.5, 7.6, 7.7 and 7.9.

b. Non woody to sparse woody or forest vegetation area minus forest or sparse woody to non woody vegetation and forest to sparse woody vegetation.

c. Each of these three rows have been calculated as the area estimate from the first three rows, respectively, divided by 10 (2011 to 2020) years for Queensland and 12 (2011 to 2022) years for New South Wales.

E9 FullCAM and lifecycle analysis of carbon sequestration in private native forest regrowth under alternative management scenarios

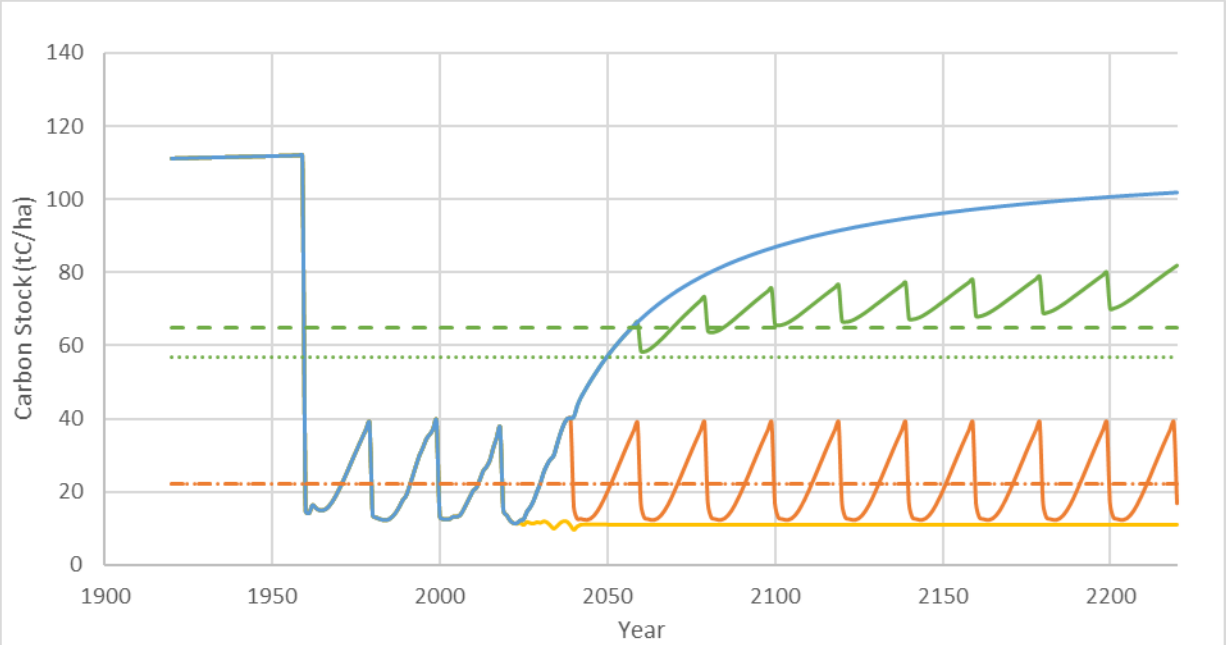
FullCAM (2023 Public Release Beta Version) was used to model the long-term carbon stocks on grazing land. Regrowth private native forest types examined were spotted gum in the South and Central QLD Hub region, ironbark in the North QLD Hub region, and coastal dry eucalypt forest in both NSW Hub regions. The scope of the analysis aligned with the carbon accounting framework of NCAS and existing ACCU methods, with the carbon abatement potential of each scenario based on the total carbon stocks of on-site biomass and harvested wood products. Four sites with these regrowth forest types were selected for FullCAM analysis in each Forestry Hub to accommodate some natural variation in climate, elevation, soils and other characteristics that can influence forest growth. The following four management scenarios were simulated for each forest type:

- Scenario 1: Business-as-usual (BAU)– a 20-year cyclical regrowth and re-clearing regime;
- Scenario 2: Native regrowth vegetation managed for selection timber harvesting (carbon stored both in biomass onsite and in harvested wood products, HWPs);
- Scenario 3: Native regrowth vegetation is permanently suppressed and the site is managed for livestock grazing; and
- Scenario 4: Native regrowth vegetation is preserved, and the site is managed for conservation.

Figure E6 illustrates the carbon stock for each management scenario averaged across the four sites for spotted gum in the South and Central QLD Forestry Hub and coastal dry eucalypts in the North East NSW Forestry Hub region. Table E3 reports the FullCAM-estimated 100-year average carbon stock for Scenarios 1 to 4 in all Forestry hub regions. For example, Scenario 2 for spotted gum in South and Central Queensland exceeded the 100-year average of Scenario 1 by 34.5 tC/ha, but was 8.6 tC/ha less than the 100-year average for Scenario 4. Table E3 highlights that, relative to BAU (Scenario 1) and permanent suppression of regrowth (Scenario 3), selection forestry (Scenario 2) generated substantial increases in carbon sequestered across all four forest types. However, FullCAM simulations found that strict conservation (Scenario 4) maximised carbon storage for all forest types. This result must be interpreted cautiously, because FullCAM and NCAS are not lifecycle assessment models and do not account for emissions from substitute products consumed when timber from the regrowth forests is not harvested.

When substitute product carbon emissions were included in a preliminary lifecycle of carbon analysis, the carbon abatement associated with management of regrowth for selection forestry exceeded that of strict conservation in the South and Central QLD and both NSW Hub regions. Figure E7 presents the results for South and Central QLD and North East NSW. In the comparatively low productivity ironbark woodlands of the North Queensland Hub region, the average carbon abatement associated with selection forestry over 100 and 200 years was 5% and 3% lower, respectively, than strict conservation.

(a) South and Central Queensland Forestry Hub region spotted gum forest



(b) North East New South Wales Forestry Hub region coastal dry eucalypt forest

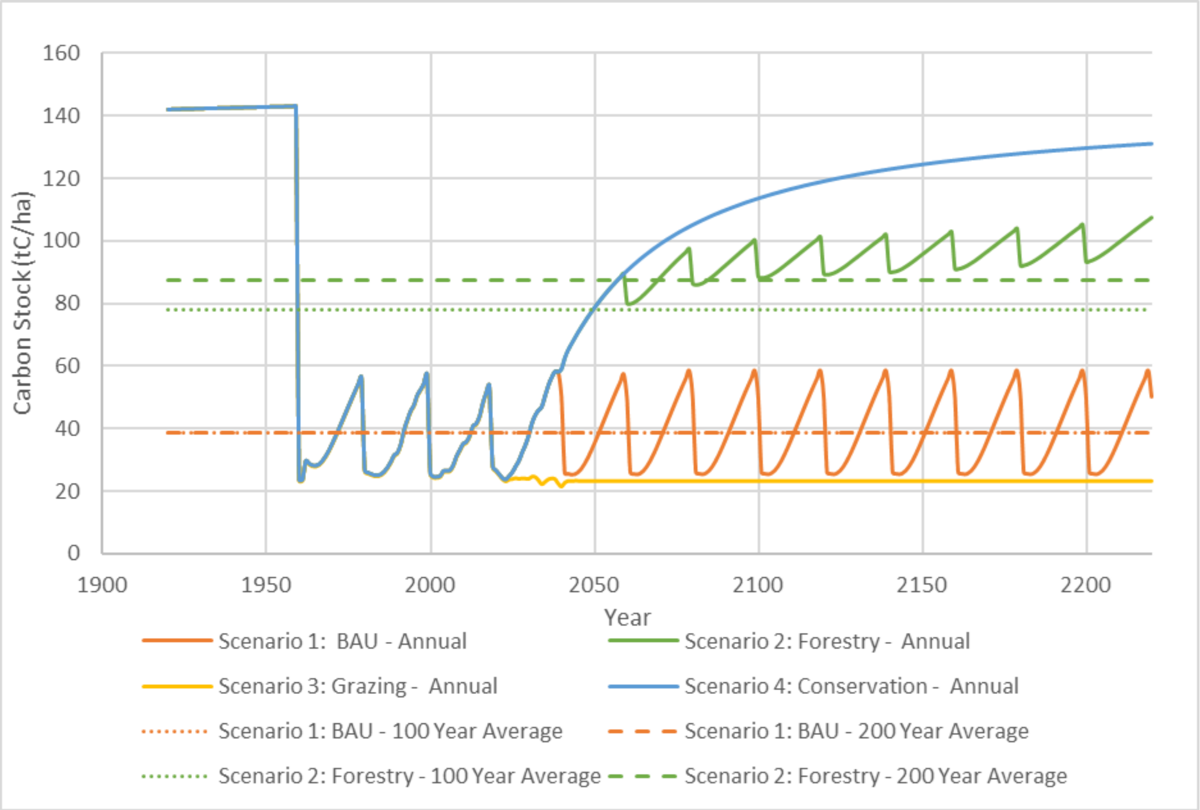


Figure E6. FullCAM estimated carbon stock over time for four forest management scenarios averaged across four sites for each forest type (a and b). The 100-year and 200-year long term average carbon stock for scenarios 1 and 2 are also depicted.

Table E3. Long term (100-year) average carbon stock for each private native forest regrowth management scenario by Forestry Hub region

Forestry Hub region and forest type	Long term (100-year) average carbon stock by regrowth management scenario (tC/ha)			
	1. Business as usual	2. Selection timber harvesting	3. Permanent clearing for livestock grazing	4. Strict conservation
SE NSW – coastal dry eucalypts	44.6	107.9	20.2	124.5
NE NSW – coastal dry eucalypts	38.7	77.8	23.6	88.1
S&C QLD – spotted gum	22.2	56.7	11.1	65.3
N QLD – ironbark	24.8	40.5	18.6	45.7

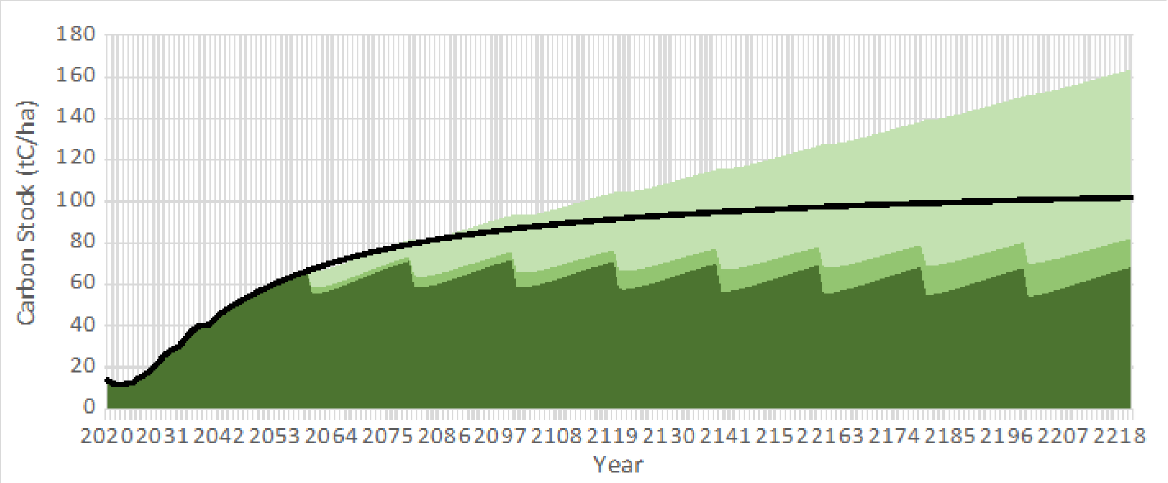
The 1.5 M ha of standing post-1990 and cleared areas with commercially important private regrowth potential in 2020 to 2022 (Table E1) indicates the existence of a substantial carbon abatement opportunity. Assuming 50% of this total potential area is managed for forestry and silvopastoral systems (Scenario 2) rather than business as usual (Scenario 1), and multiplying these areas by the additional carbon that can be sequestered per hectare in Scenario 2 relative to Scenario 1 (from Table E3), reveals that 750,000 ha of managed private native forest regrowth can sequester an additional 26.5 M tC (97.2 M tCO_2-e) over 100 years. This carbon sequestration potential is dominated by South and Central QLD (71%) and North East NSW (24%).

The 100-year sequestration potential of 750,000 ha of Scenario 2 regrowth is equivalent to less than three years of NCAS-reported increased sequestration due to reduced native forest harvesting in recent years. This provides another perspective of the magnitude of the carbon benefit Australia has been reporting for reduced native forest harvesting. The 97.2 M tCO_2-e potentially sequestered in regrowth managed under Scenario 2 is also equivalent to 24% of the annual emissions produced by Australia’s energy sector in 2021 (404.03 M tCO_2-e).

If the 750,000 ha of regrowth was instead managed for strict conservation (Scenario 4), the FullCAM simulations suggested 25% more carbon could be sequestered on site (33.3 M tC or 121.9 M tCO_2-e). However, FullCAM modelling of Scenario 4 does not account for emissions from Australians consuming substitute products instead of the 975,000 m^3/y timber that could be produced. Furthermore, this management regime would generate no timber income, and livestock income will decline to zero. Therefore, this management regime is unlikely to generate interest among landholders who aim to maintain or increase the profitability of their business over time.

If a native forestry ACCU method was developed, the undiscounted value of 97.2 M tCO_2-e sequestered in 750,000 ha of native forestry (Scenario 2) regrowth, estimated at the June 2024 ACCU spot market price of \$33.47/t CO_2-e, would be \$3.25 billion. Assuming the long-term average additional level of carbon per hectare in the managed regrowth is reached over 20 years, this is equivalent to an average gross carbon revenue (excluding all costs of participation in the carbon market) of $217/ha/y until payments end in year 20[2]. If Australia chooses to adopt a LCA approach in its national carbon accounts, avoided emissions from substitute products could also be accommodated in a future forestry ACCU method, and the creditable potential for carbon abatement in managed forests will be higher. Carbon payments could reduce the opportunity cost of foregone livestock production while the timber producing silvopastoral systems are developing. While carbon could become an important income stream for some landholders, it is important to recognise that any carbon credits sold can no longer be counted towards reducing the net carbon emissions of their own business.

(a) South and Central Queensland Forestry Hub region spotted gum forest



(b) North East New South Wales Forestry Hub region coastal dry eucalypt forest

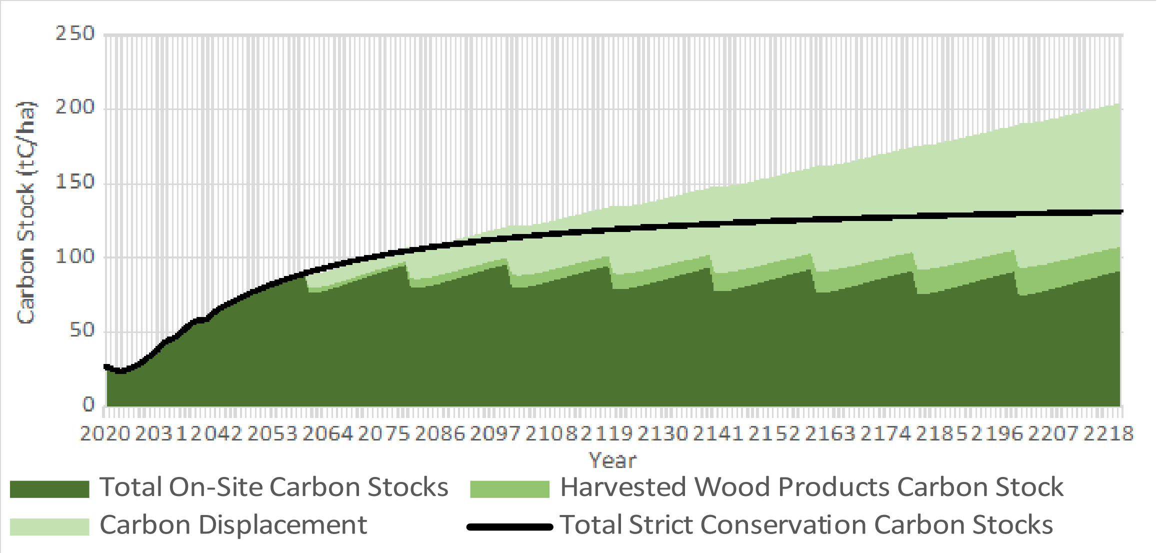


Figure E7. Lifecycle analysis of carbon under selection forestry (Scenario 2; sum of all shaded areas) and strict conservation (Scenario 4; the back line). The sum of the two darkest shaded areas is the FullCAM carbon stock for Scenario 2 from Figure E1. The black line is the FullCAM carbon stock for Scenario 4 from Figure E1.

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[2] Average annual gross carbon revenue over 20 years = 97.2 M tCO2-e / 750,000 ha / 20 years x $33.47

E10 Wildfire risk mitigation benefits of private native regrowth management

The Vesta 2 fire model was applied to model fire behaviour within privately managed spotted gum and blackbutt regrowth forests in the South and Central Queensland Forestry Hub region at the ages of approximately 15 and 25 years, with and without silvicultural management under one 24-hour period of fire weather scenarios with a return interval of 1 in 1 year and 1 in 25 years. The managed forest scenarios had lower tree and shrub density, potentially increasing wind interaction with flames. However, surface and elevated fuel loads were considerably lower than in unmanaged forests, resulting in lower hazard ratings within the managed forests. Lower and less connected fuels in managed regrowth forests can reduce wildfire risk to life, assets and forest carbon stocks by decreasing: (a) flame height; (b) radiant heat flux (which determines safe setback distances of assets from potential fire fronts); (c) fire intensity; and (d) the potential for and duration of crown fire.

Table E4 summarises the simulated wildfire behaviour and wildfire direct attack management implications of silvicultural treatments in regrowth. Across all scenarios, maximum flame height and wildfire intensity in managed regrowth forests was at least 56% and 35% lower, respectively, than in unmanaged regrowth forests. The potential for crown fire in managed spotted gum regrowth was reduced by 73% to 100% relative to unmanaged regrowth. In blackbutt regrowth forests, the potential for crown fire was reduced by 0% to 29% relative to unmanaged regrowth. Managed spotted gum increased the window for direct attack of the simulated wildfire front by 13% to 26%. In 25-year-old blackbutt regrowth, silvicultural treatments increased the opportunity for direct attack of the simulated wildfire front by 69%. However, in all other blackbutt scenarios, management of regrowth provided negligible benefit for direct attack. Through reducing flame height, fire intensity and the potential for crown fire, and by increasing opportunities for direct attack of wildfire, managed regrowth forests reduce the risk of wildfire on carbon stocks, human lives and other assets, relative to unmanaged regrowth forests.

These Vesta 2 wildfire simulations have provided evidence of the potential for forest management to reduce wildfire risk. This adds to the weight of existing literature that contradicts the NCAS assumption that management makes little difference to wildfire outcomes and their associated carbon emissions. In this context, the exclusion of GHG emissions of ‘natural’ wildfires from the national accounts, coupled with the inclusion of GHG emissions from fuel reduction treatments is questionable and incentivises neglect of Australia’s forests.

Table E4. Simulated wildfire behaviour and direct attack implications for spotted gum and blackbutt regrowth forests in the South and Central Queensland Forestry Hub region

Forest type and fire weather scenario	Regrowth age (y)	Regrowth management	Max. flame height (m)	Max. wildfire intensity (kW/m)	Crown fire potential (hours)	Direct attack potential (hours)
Spotted gum; 1 in 1 year	15	No	13.2	13,802	5.5	16
		Yes	5.6	8,028	1.5	19.5
	Improvement with management (%)		*58*	*42*	*73*	*22*
	25	No	14.5	14,329	5.5	17.5
		Yes	3.6	5,238	0	22
	Improvement with management (%)		*75*	*63*	*100*	*26*
Spotted gum; 1 in 25 years	15	No	14.9	16,420	4	18
		Yes	6.6	10,145	1	20.5
	Improvement with management (%)		*56*	*38*	*75*	*14*
	25	No	16.6	17,248	4	19
		Yes	4.5	7,082	0	21.5
	Improvement with management (%)		*73*	*59*	*100*	*13*
Blackbutt; 1 in 1 year	15	No	28.7	34,512	11.5	11.5
		Yes	12.4	22,314	8.5	11.0
	Improvement with management (%)		*57*	*35*	*26*	*-4*
	25	No	46.4	44,698	15.5	6.5
		Yes	17.2	24,494	11.0	11.0
	Improvement with management (%)		*63*	*45*	*29*	*69*
Blackbutt; 1 in 25 years	15	No	40.1	54,898	22.5	2.5
		Yes	17.4	35,918	17.5	3.5
	Improvement with management (%)		*57*	*35*	*22*	*4*
	25	No	62.8	67,899	21.5	0
		Yes	24.0	38,929	21.5	0
	Improvement with management (%)		*62*	*43*	*0*	*0*

E11 The need for a native forestry ACCU method

As a large net importer of solid wood products, Australia has a substantial carbon and ecological footprint in forests around the world. For example, as native forest log production fell from 4.0 million m^3/y in 1996 to 1.8 million m^3 in 2018, and Australia's plantation forest area has contracted, annual solid wood imports have increased from 2.9 million m^3 of roundwood equivalent (RWE) to 6.5 million m^3 of RWE. Imports from developing countries accounted for 53% of that increase, where unsustainable harvesting practices are common and associated with deforestation, forest degradation and biodiversity loss. With a large landmass and small population, domestic forest and carbon policy settings that are supportive of native forestry can substantially reduce the impacts of Australian consumers on domestic and international carbon emissions, as well as threats to the conservation of domestic and international biodiversity.

Spatial analysis and FullCAM simulations in the Forestry Hub regions have revealed substantial potential for commercially important private native forest regrowth to store carbon and increase domestic wood production. The dominant land use in these regions is livestock grazing. More than a decade of carbon market evidence, coupled with continuing high levels of re-clearing of commercially important regrowth, indicates the existing native forest ACCU methods do not provide sufficient returns to overcome the high opportunity costs of foregone agricultural and timber income streams in these relatively productive agricultural landscapes. This is because potential carbon income streams from native forest regrowth continue only until the 100-year average additional (compared to business as usual) carbon stock level is reached, which is typically within 15 to 25 years. By prohibiting thinning and timber harvesting, existing native forest ACCU methods will reduce livestock income to zero as the regrowth ages and decrease the medium and long-term income earning potential of a farm. Furthermore, lower farm income streams will be capitalised into lower property values, particularly in areas where there is not strong demand for 'rural lifestyle' blocks.

The limited information available about proponent-led INFM and IACNR ACCU methods prioritised for development by the Federal Government in October 2024 indicates they are not applicable to private forests managed for timber and may be incompatible with landholder opportunity costs and interests to maintain or improve the profitability of their business. Therefore, these methods in development are unlikely to incentivise retention of commercially important private native forest regrowth in NSW and QLD.

Increasing carbon sequestration on private land is likely to be most efficiently achieved by producing a suite of ACCU methods so that landholders can select a method that best suits their circumstances. A native forestry ACCU method that recognises most business owners aim to maintain or improve their financial performance over time is far more likely to attract landholder interest. An opportunity to sustainably manage private native forest regrowth for timber and livestock production, as well as carbon sequestration, could encourage retention of regrowth as silvopastoral systems. In the long-term, the combined income streams in a silvopastoral system are often higher than can be achieved in open pasture grazing (livestock only) and conservation (carbon only). The sale of carbon credits could assist landholders overcome some of the short and medium-term opportunity costs of foregone livestock and other agricultural income while the timber production forest is developing.

Expansion of private native forestry represents a substantial opportunity for carbon sequestration, farm income diversification, increased farm resilience to drought and climate change, and to reduce Australia's impacts on international forests. With an MAI of 1.3 m^3/ha/y and an average stumpage price of \$120/m^3, a selection harvest timber income stream equivalent to \$3100/ha every 20 years is possible, with the first harvest when the regrowth reaches about 25 to 40 years (depending on site quality). If 750,000 ha (50%) of commercially important regrowth in the Hub regions was managed as silvopastoral systems, this could increase sawlog and electricity distribution pole production by about 975,000 m^3/y in the long-term. To put this timber production potential in perspective, it is equivalent to 15% of Australia's annual imports of solid wood RWE volume in 2018. From FullCAM simulations reported above, native forestry will also sequester an additional 97.2 M tCO_2-e relative to BAU.

Forestry Australia submitted a proponent-led method for review, Enhancing Native Forest Resilience (ENFR), but this was not prioritised for development by the Federal Government in October 2024. This method aims to restore forests across all land tenures to improve habitat values, carbon stocks and resilience to droughts, wildfires and climate change through a broad suite of active and adaptive management activities including assisted regeneration, cultural and prescribed fire, thinning for ecological and cultural values, protecting old and big trees, weed and feral animal control, and improved utilisation of forest products. This method has the potential to develop a diversified carbon portfolio that includes wood products (in use and in landfill), as well as avoided emissions from substitutes, which are less exposed to climate change, drought, wildfire and cyclone risk than carbon stored by existing native vegetation ACCU methods and the INFM and IACNR methods that are in development at the time of publication. ENFR could be developed to accommodate management of private native forest regrowth, and thereby encourage greater forest cover in productive agricultural landscapes. Nevertheless, improvement of forest policy to remove the sovereign risk associated with private native forest management will also be essential to motivate adoption.

1. Introduction

Tyron Venn

All global modelled pathways that limit warming to 2°C require large-scale sequestration and storage of atmospheric CO_2, in addition to rapid, deep and immediate reductions of GHG emissions across all sectors (Shukla et al., 2022). Currently, the only approach with immediate capacity to remove greenhouse gasses (GHGs) from the atmosphere at scale is plant-based photosynthesis (Chubb et al., 2022). Globally, the carbon sequestration potential of forests is large, and the Intergovernmental Panel on Climate Change (IPCC) has long argued that management aimed at maintaining or increasing forest carbon stocks, while producing an annual sustained yield of timber, fibre and energy, will generate the largest sustained climate risk mitigation benefit from forests (Metz et al. 2007).

There are four main carbon benefits of forests managed for timber (Lippke et al., 2014; Williams et al., 2016; Köhl et al., 2020). First, the harvested logs can be transformed into wood products that store carbon off-site for many decades in use (e.g. electricity distribution poles, structural timber and engineered wood products), while freeing up growing space within the forest for regeneration to sequester more carbon. Furthermore, at the end-of-their useful life, wood products can store substantial volumes of carbon for long time periods if disposed in landfills (Ximenes et al., 2015; Ximenes et al., 2019). Second, wood products from sustainably managed forests can displace high embodied carbon substitutes (e.g. steel and concrete) and avoid carbon emissions from unsustainably managed forests that would otherwise supply substitute wood products. Third, thinned trees from silvicultural treatments, harvest residues in the forest, and residues at the mill and can potentially be utilised to help meet energy needs by recycling biosphere carbon and avoiding fossil fuels that transfer geologic carbon to the biosphere. Fourth, there are climate risk mitigation benefits of having a diversified portfolio of forest carbon sinks, including wood products, displaced substitute products and energy, which are less susceptible to disturbances such as wildfires and cyclones than carbon stored on-site only.

Despite the carbon sequestration benefits of forests managed for timber, as Australia’s population grew by 39% between 1996 and 2018, production of native forest hardwood timber declined by 55% and the timber plantation estate area declined by 13% (Australian Government 2023a; Venn 2023). The reason behind declining native forest timber production has been the transfer of publicly owned timber production native forests to protected area status by state governments (Queensland CRA/RFA Steering Committee, 1999; Victoria State Government, 2023; West Australia Government, 2023). The decline in plantation area has been due to poor financial returns to the private sector, even with timber plantation carbon market opportunities being available in Australia since 2012.

Unsurprisingly, Australia’s reliance on imported solid wood products has grown by 124% since 1996 to 6.5 M m^3/y of roundwood equivalent (RWE) volume to satisfy Australian consumers (Venn 2023). Most of the increase in timber imports has been sourced from developing countries, particularly China. China does not harvest its own forests and sources a high proportion of their wood from countries with high risk of poor governance and corrupt institutions that are associated with high levels of illegal logging and broader land clearing, including Papua New Guinea, Solomon Islands, Cambodia, Myanmar, Laos, Malaysia, Indonesia, Thailand, Republic of Congo, and Ghana (Forest Trends, 2017; Yi, 2019; Guan et al., 2020). Illegal logging is responsible for up to 30% of global timber production, 50 % to 90 % of harvesting in many tropical countries, and remains common throughout tropical Africa, Asia and South America (Linkie et al., 2014; INTERPOL, 2019; Piabuo et al., 2021). Demand for wood products made in China is positively correlated with loss of forest cover in the low and middle-income countries from which China sources its wood (Fuller et al., 2018; Shandra et al., 2019).

Merbau (*Intsia* spp.) is an example of a popular imported substitute for Australian native forest hardwood that is widely available (e.g. Bunnings Warehouse), regularly advertised in Australian media, and commonly associated with illegal and unsustainable harvesting in Indonesia, Malaysia, Papua New Guinea, and Pacific Island nations (Tong et al., 2009; Shearman et al., 2012; Riddle, 2014; Anon., 2020; Ng et al., 2020). Australia's high and increasing consumption of internationally traded timber encourages illegal logging, deforestation, and reduction in the carbon stock and biodiversity conservation potential of forests globally (Lenzen et al., 2012; Taylor et al., 2016; Kitzes et al., 2017; Moran and Kanemoto, 2017; Chaves et al., 2020; Shigetomi et al., 2020) regardless of whether Australian imports are reported as sustainably and legally sourced. However, Australia's national carbon accounts do not consider the carbon emissions (nor the biodiversity loss) associated with the production of imported goods.

Materials consumed within the construction sector account for 11% of global GHG emissions (Adams et al., 2019). Australian research that has shown substantial carbon emissions reduction can be achieved by using more wood products in construction (Yu et al., 2017), including halving the lifecycle emissions of detached houses (Carre, 2011; Ximenes and Grant, 2013) and reducing the lifecycle emissions of midrise residential buildings by one-third (Jayalath et al., 2020). In forest-poor Asian nations, including Taiwan, Japan and South Korea, Australian wood products for construction are considered among the most sustainable, and as having lower embodied carbon than equivalent wood products from the USA, China, Malaysia, Brazil and Russia (Li et al., 2018). However, Australia's carbon accounts do not track these GHG emissions reduction benefits of substituting products with high embodied carbon with sustainably grown domestic wood.

The critical role that retention of native forest regrowth can play in meeting Australia's net zero emissions targets has been recognised by the Australian government through the development of several Australian Carbon Credit Unit (ACCU) methods. Most areas best suited for these approaches are located in agricultural landscapes where large scale uptake will require adequate compensation to overcome the opportunity cost of increased forest cover on the profitability of agribusinesses (Evans, 2018). However, to date, few vegetation-based ACCU projects have been established outside the arid and semi-arid zones of Australia, and the uptake of the plantation forestry ACCU method has been minimal (Australian Government 2023a). No ACCU methods have been developed to encourage native forestry to increase forest cover, carbon sequestration and farm incomes.

The aim of this research was to investigate the carbon sequestration potential of commercially important private native forest regrowth, and the limitations of the National Carbon Accounting System (NCAS) in supporting the design and evaluation of carbon policy. A study area was defined comprising the South East New South Wales (NSW), North East NSW, South and Central Queensland (QLD) and North QLD Forestry Hub regions illustrated in Figure 1.1. ‘Commercially important forest’ is forest with potential to contribute to national demand for domestically produced timber and carbon sequestration. While an overall perspective of commercially important private native forest has been provided, the focus was on the potential for native forestry to encourage retention of post-1990 regrowth. Findings inform the potential for development of an ACCU method for native forestry.

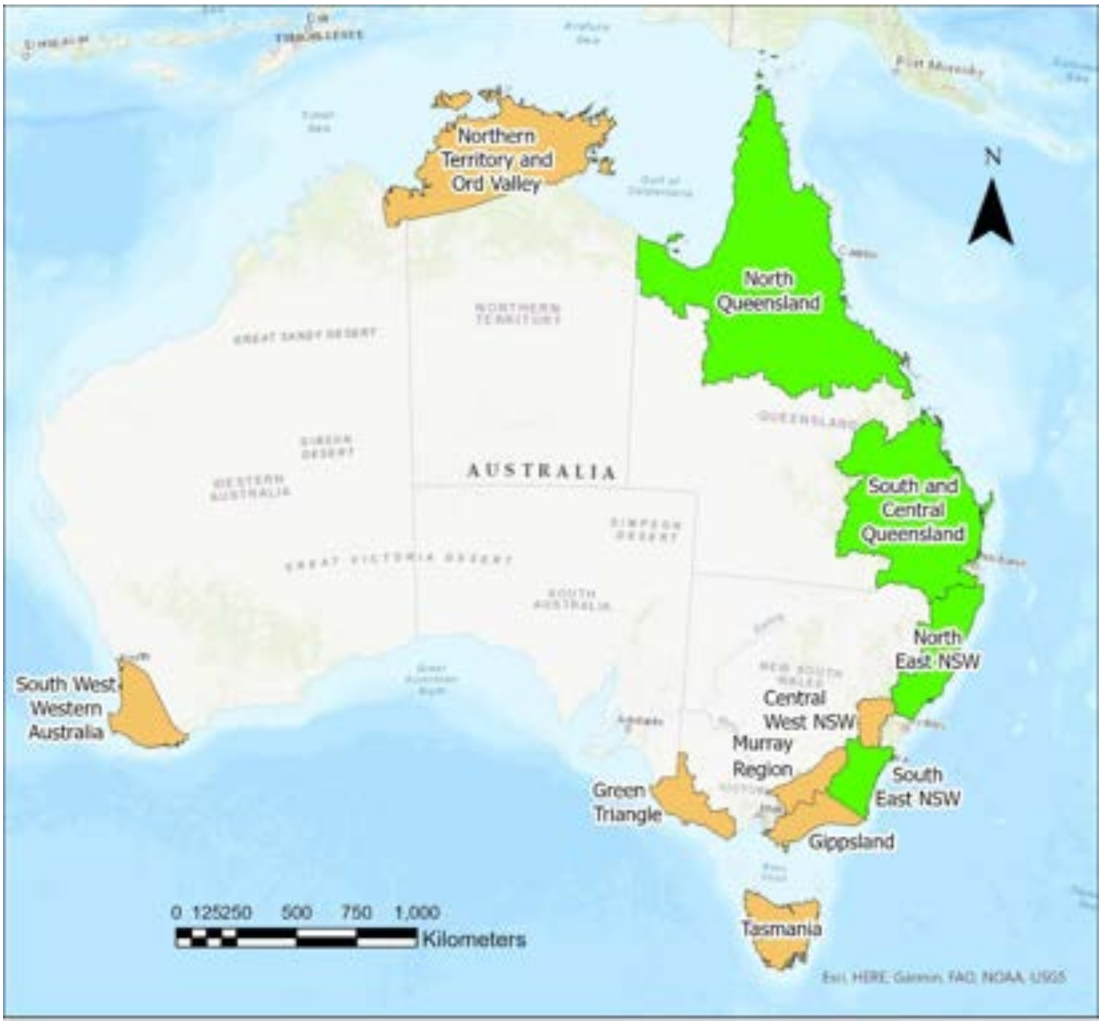

Figure E1. Location of Australia’s Forestry Hub regions with the study area shaded green

The report proceeds as follows. Chapter 2 summarises Australia’s greenhouse gas (GHG) emissions targets and reporting commitments according to international agreements. Australia’s national carbon accounting system (NCAS) and the Full Carbon Accounting Model (FullCAM) used to estimate changes in carbon in the land use, land use change and forestry (LULUCF) sector are introduced in Chapter 3 with an emphasis on native forests. Chapter 4 expands on Chapter 3 by summarising the contribution of the LULUCF sector to Australia’s carbon accounts and carbon describing limitations of NCAS and FullCAM for estimating net carbon emissions from native forestry and informing carbon policy. Chapter 5 reviews historic, existing, and in-development (as at October 2024) ACCU methods relevant to native vegetation management. The need for development of a native forestry ACCU method is also outlined.

Chapter 6 provides a description of the private native forest resource from published sources without focussing on regrowth forests, as few publications have distinguished between regrowth and mature forests. Chapter 7 uses the best available spatial datasets to estimate the private native forest regrowth resource and changes in regrowth extent over time. This highlights the failure of existing ACCU methods to incentivise retention of regrowth. Chapter 8 reports FullCAM simulations of net carbon storage in private native forest regrowth under alternative management regimes, including native forestry and strict conservation. Chapter 9 reports Vesta 2 wildfire simulation analyses in managed and unmanaged spotted gum and blackbutt native forest regrowth to examine how native forestry can affect wildfire behaviour. Readers are referred to Appendix D for the complete write-up of this research. Chapter 10 concludes the report with a summary and recommendations.

2. Australia’s Greenhouse Gas Targets and Reporting Obligations

Martin Timperley and Tyron Venn

2.1 Australia’s Greenhouse Gas Reduction Targets

By becoming party to the United Nations Framework Convention on Climate Change (UNFCCC) in 1992, Australia committed to participate in international efforts to stabilise greenhouse gas concentrations at a level that would prevent dangerous anthropogenic interference with the climate system (UNFCCC, 1992). This convention established expectations for industrialised countries, including Australia, to report on climate change policies and mitigation measures, as well as issue inventories of GHG emissions and removals across their economies, including the land use, land use change and forestry (LULUCF) sector. Australia has since signed successive UNFCCC treaties pledging to reduce GHG emissions to limit the effects of climate change – first under the Kyoto Protocol and then under its successor, the Paris Agreement.

The Kyoto Protocol was signed by Australia in 1997, with parliament later ratifying it in 2007 (Power, 2017). Australia went on to meet and exceed its obligations under this treaty, which was to limit emissions to 108 per cent of 1990 emissions levels by 2012 (the first commitment period) and to 99.5% of 1990 emissions levels by 2020 (the second commitment period) (Loynes, 2016). Notably, Australia successfully lobbied the UNFCCC to include a clause in the agreement that permitted nations where the LULUCF sector was a net source of GHG emissions to include net emissions from land-use change in their 1990 base year estimate of national carbon emissions. This concession was particularly favourable towards Australia due to land clearing emissions being especially high in 1990. By the time the agreement was being negotiated in 1995, emissions from this sector had fallen by 30%. This effectively gave Australia an exceptionally high baseline emissions level and allowed emissions from other sectors to continue to rise while still achieving its targets under the treaty.

The Paris Agreement came into force in 2016 and builds upon the international climate commitments set by the Kyoto Protocol. It aims to strengthen the global response to climate change by holding the increase in global average temperatures to well below 2°C above pre-industrial levels and pursuing efforts to limit temperature increase to 1.5°C (UNFCCC, 2015). While the Kyoto Protocol only set emissions reduction targets for industrialised (Annex I) countries, all signatories to the Paris Agreement are expected to submit emissions reduction commitments known as Nationally Determined Contributions (NDCs). Each country’s NDC is developed independently, with emissions reduction targets and policy measures expected to reflect the highest possible ambition in line with the principle of common-but-differentiated responsibilities and respective capabilities (UNFCCC, 2015). While the Kyoto Protocol set emissions reductions targets against a 1990 baseline year, countries were free to choose their own baselines under the Paris Agreement.

Australia’s first NDC was submitted in 2015 with a commitment to reduce emissions by 26-28% by 2030, relative to 2005 levels. In 2021, Australia announced a commitment to achieve ‘net zero emissions by 2050’. In 2022 Australia submitted an updated NDC, revising its 2030 target to reduce emissions by 43% below 2005 levels while reaffirming the 2050 net zero commitment (Australian Government, 2022).

2.2 Australia’s Emissions Reporting Commitments

Under the Paris Agreement’s transparency framework (UNFCCC, 2015) Australia reports on its emissions and progress towards its NDCs by submitting National Inventory Reports annually. These inventories are compiled in compliance with UNFCCC Reporting Guidelines and provide detailed information on Australia's GHG emissions and removals, broken down by sector and activity (Australian Government, 2023a). To fulfill these reporting commitments as well as provide a basis for tracking progress towards and assessing compliance with its NDCs, Australia has developed and maintained a National Carbon Accounting System (NCAS). This system enables emissions sources and sinks across the country to be identified, quantified and traced over time from 1990 onward (Australian Government, 2023c).

To ensure that emissions estimates are consistent and comparable between countries, Australia’s National Greenhouse Gas Inventory is produced in accordance with the standardized requirements set out by the UNFCCC and using methods consistent with those described by the IPCC (UNFCCC, 2009). Based on this guidance, the inventory has been developed to cover sources of GHG emissions, and removals by sinks, that result from human (anthropogenic) activities for the major greenhouse gases: carbon dioxide (CO2), methane (CH4), nitrous oxide (N2O), perfluorocarbons (PFCs), hydrofluorocarbons (HFCs), sulphur hexafluoride (SF6) and nitrogen trifluoride (NF3)(Australian Government, 2023a). These emissions and removals are then reported under 5 sectors defined by the IPCC to represent the main human activities that contribute to the release or capture of greenhouse gases, and include (Australian National Greenhouse Accounts, 2011):

- Energy;
- Industrial processes and product use (IPPU);
- Agriculture;
- Land use, land use change and forestry (LULUCF), and
- Waste.

The contribution of the LULUCF sector to Australia’s annual GHG emissions, are described in Chapter 4.

3. Australia’s National Inventory System for the LULUCF Sector

Martin Timperley and Tyron Venn

Australia has produced its own UNFCCC approved country-specific methodology to account for emissions and removals from its LULUCF sector (Australian National Greenhouse Accounts, 2013), which is consistent with Intergovernmental Panel on Climate Change (IPCC) guidelines for national GHG inventories (IPCC, 2019a). Given the size of Australia’s land area and absence of extensive forest inventory or measurement systems, the direct estimation methods proposed by the international guidelines were considered impractical to measure Australia’s LULUCF emissions and abatement (Australian Government, 2023b). Instead, Australia was the first country to integrate remote sensing techniques to detect and quantify emissions associated with forest loss and land clearing for its national GHG inventories (Richards & Evans, 2004). This has been achieved through modelling undertaken using the Full Carbon Accounting Model (FullCAM), which estimates carbon stock changes and greenhouse gas emissions by "integrating spatially referenced data with an empirically constrained, mass balance, carbon cycling ecosystem model” (Australian Government, 2023a, p. 272).

3.1 IPCC Guidance on Greenhouse Gas Accounting Methodologies and Land-Use Categorisation Approaches for National Inventory Systems

3.1.1 Greenhouse Gas Accounting Methods

The IPCC has developed a series of methodological guidelines of varying complexities for estimating GHG emissions and removals across all economic sectors. ‘Tier 1’ methodologies are the simplest approach, with the ‘Tier 2’ and ‘Tier 3’ methods becoming increasingly more elaborate. The selection of a particular tier of method depends on the degree of accuracy required as well as the availability of the data and resources needed to complete the inventory (UNFCCC, 2009). As an Annex I country, Australia is expected to report on its GHG inventory to a high degree of accuracy using the Tier 3 method wherever practicable. This demands the use of complex methodologies based on very high resolution and disaggregated datasets (IPCC, 2019e).

In line with these requirements, GHG accounting for Australia’s LULUCF sector is undertaken primarily using Tier 3 methods through the application of FullCAM, which provides a fully integrated approach to estimating carbon stock changes and emissions across the country (Richards & Evans, 2004). The foundation of this methodology is based on the following two principles (UNFCCC, 2009):

- The flux of CO2 between terrestrial sinks and the atmosphere is equal to the change in carbon stocks in the existing biomass and soils, and
- The changes in carbon stocks are determined by establishing the rate of change in land use as well as the practices used to bring about the change.

Under this approach, FullCAM accounts for the exchange of all relevant IPCC recognised GHGs (carbon dioxide CO2, methane CH4 and nitrous oxide N2O) from each terrestrial carbon pool (above and below ground biomass, standing and decomposing debris, wood products and soil) by linking spatially referenced data with a mass-balance, carbon-cycling ecosystem model (Australian Government, 2023a). Figure 3.1 illustrates the FullCAM modelling framework and depicts the flows of carbon between each pool. Black arrows indicate the flow of GHGs between terrestrial carbon pools while grey arrows depict where emissions are exchanged between these pools and the atmosphere.

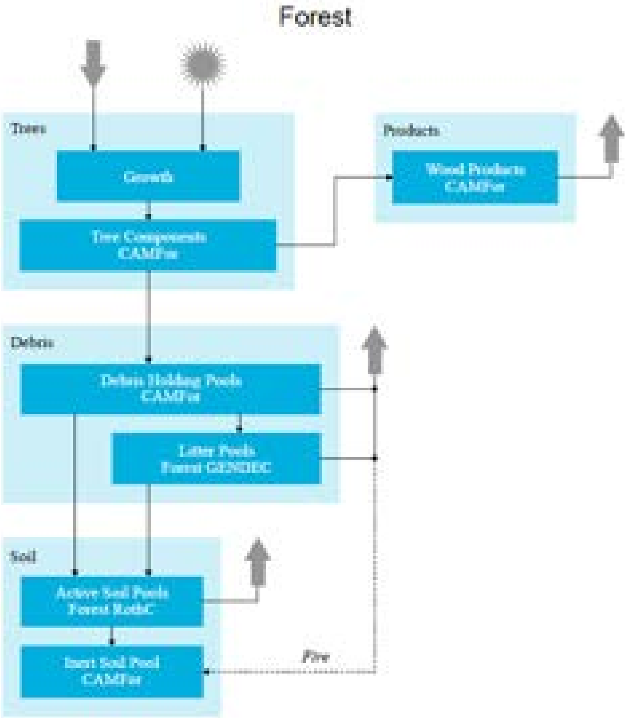

Figure 3.1. The FullCAM model pool structure. Arrows depict the flows of carbon between each pool (Australian Government, 2023b)

3.1.2 Land Use Categorisation

To effectively account for changes in carbon stocks, all terrestrial areas must be assigned a land use category based on its biophysical coverage (known as land-cover) and socioeconomic uses (known as land uses) (IPCC, 2019d). In doing so, the ongoing conversion of land between categories can then be tracked by identifying the extent and cause of land cover disturbances across the country. These disturbances are then used to estimate the GHG emissions and removals associated with the land sector.

Six broad land-use categories have been defined by the IPCC and form the basis of estimating and reporting greenhouse gas emissions and removals from land-use and land-use conversions. These include (IPCC, 2019d):

- Forest land;
- Cropland;
- Grassland;
- Wetlands;
- Settlements; and
- Other lands.

Specific definitions for each of these categories can be found in Section 6.2.2 of Australia's 2021 National Inventory Report (Australian Government, 2023a).

Each year, land cover is assessed and classified as either:

- Land remaining in a land-use category (i.e., it remains in the same use over the assessment period); or
- Land converted to a new land use category (i.e., a change in land-use has been identified).

In instances where land conversion has been identified, the area is reclassified into a land conversion category based on its current land-use, with additional sub-categorisation taking place if the prior land use category is known. For example, the 'Land Converted to Forest Land' conversion category can be sub-divided into sub-categories including 'Grassland Converted to Forest Land', 'Cropland Converted to Forest Land' etc. (IPCC, 2019d).

The IPCC specifies three approaches of increasing complexity that can be used to categorise areas of land-use. These are (IPCC, 2019d):

- Approach 1: The change in area of each land use category within a country is identified but no information is provided on the nature and area of conversions between land-use categories.
- Approach 2: Land-use conversions between specific land use categories are recorded; however, no allowance is made to track these changes through time.
- Approach 3: Land-use conversions between specific land use categories are recorded and the ability to track land use conversions through time on a spatially explicit basis is also introduced.

Decisions on which approach to use is determined by factors such as data availability and quality, as well as the specific ecosystem characteristics. Therefore, a nation can adopt a mix of approaches for application across different regions and land uses based on their unique circumstances.

3.2 Estimating GHG Emissions and Removals from Australia’s Native Forests and their Conversion to and from Grassland

Australia predominantly utilises a Tier 3, Approach 3 methodology to estimate GHG emissions from the LULUCF sector by combining spatially referenced data (Approach 3) with the FullCAM carbon cycling ecosystem model (Tier 3). However, other methods and approaches are applied to estimate the carbon stock exchange of lands in instances where it is not practicable to utilise spatial imagery and high resolution and disaggregated datasets. Table 6.1.1 of Australia’s 2021 National Inventory Report outlines the methods used to estimate emissions associated with all sinks within Australia’s LULUCF sector (Australian Government, 2023a).

Emissions and removals associated with Australia’s native regrowth forests are primarily associated with the clearing of established forests for agriculture (predominantly grasslands for pastures) as well as the regeneration and subsequent re-clearing of vegetation on previously cleared land. These disturbance events generally occur on land classified under the following land use categories:

- Forest land remaining forest land;
- Land converted to grassland; and
- Land converted to forest land.

Table 3.1 summarises the accounting methods and land use categorisation approaches used to estimate the carbon flux associated these land use categories for Australia’s national inventory.

Table 3.1. Summary of methodologies and approaches used to estimate carbon flux from forests and their conversion to and from grasslands (Australian Government, 2023a)

Land-Use Categories	Conversion Sub-Category	GHG Inventory Methodology	Land Use Categorisation
Forest land remaining forest land		Tier 3	Approach 2 - For both public and private harvested native forests in Queensland and Western Australia, and for private native forests only, in Victoria, New South Wales and Tasmania
			Approach 3 - For all other native forests
Land converted to forest land	Grassland converted to forest land	Tier 3	Approach 3
Land converted to grassland	Forest land converted to grassland	Tier 3	Approach 3

Note: for the Forest Land Remaining Forest Land category, a tier 3 method is primarily applied. However, a tier 2 method is applied to prescribed burning in Western Australia and fires in arid and semi-arid central Australian forests.

The FullCAM Tier 3 modelling system is used across all categories related to native forests. Furthermore, the spatially explicit Approach 3 process for land-use categorisation is applied in all areas other than where this data is not available, such as for public and private harvested native forests in some states. In these instances, FullCAM operates in a non-spatially explicit Approach 2 mode known as the 'Estate' module (Australian Government, 2023a). The following sections will outline the process used by FullCAM to estimate GHG emissions and removals using the spatially explicit (Tier 3, Approach 3) approach for Australia's native forests and their conversion to and from grasslands. Details of the non-spatially explicit (Tier 3, Approach 2) method is outlined in Appendix A.

3.2.1 Spatially Explicit Greenhouse Gas Accounting Methodology (Tier 3, Approach 3)

The workflow associated with estimating GHG emissions and removals associated with Australia's native forests and their conversion to and from grasslands using the spatially explicit process is outlined in **Error! Reference source not found.**.2. Details of each stage of the process are outlined in the following sections.

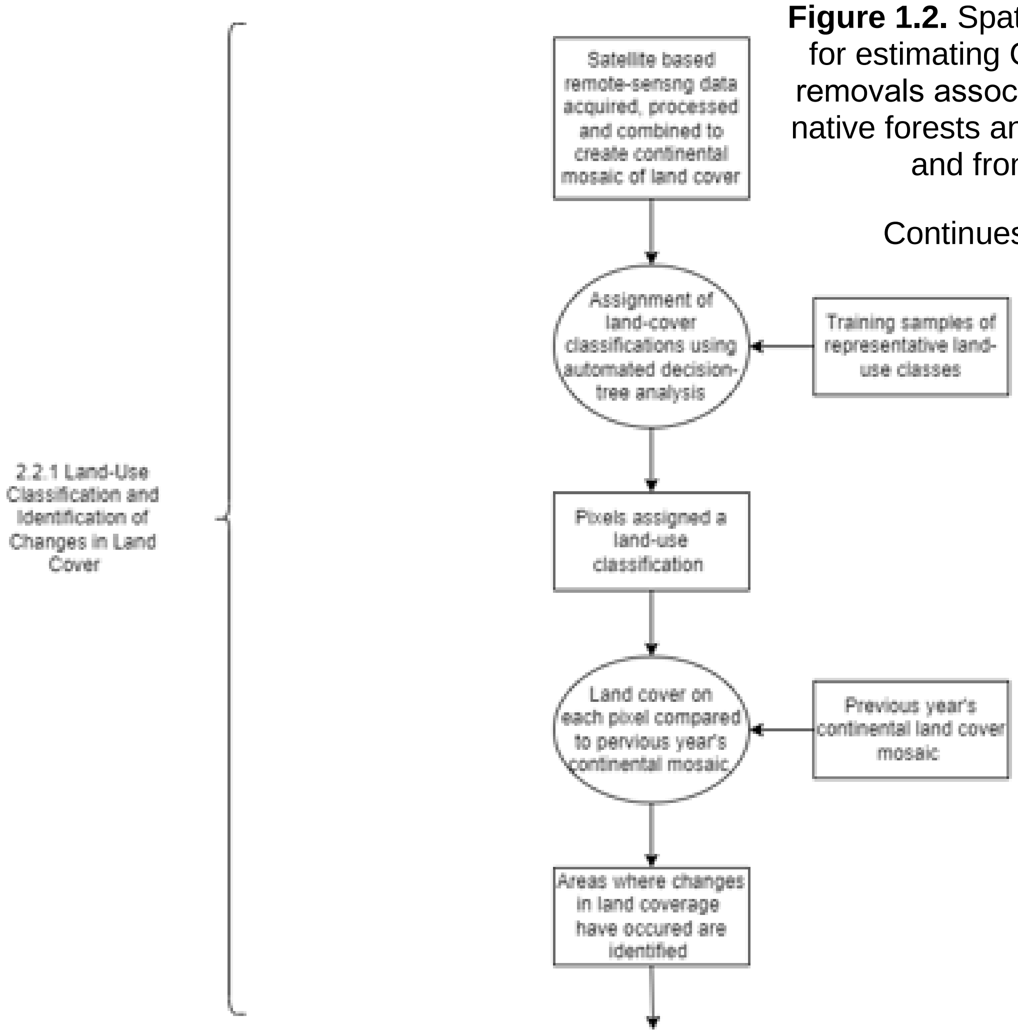

Figure 1.2. Spatially explicit workflow for estimating GHG emissions and removals associated with Australia's native forests and their conversion to and from grassland.

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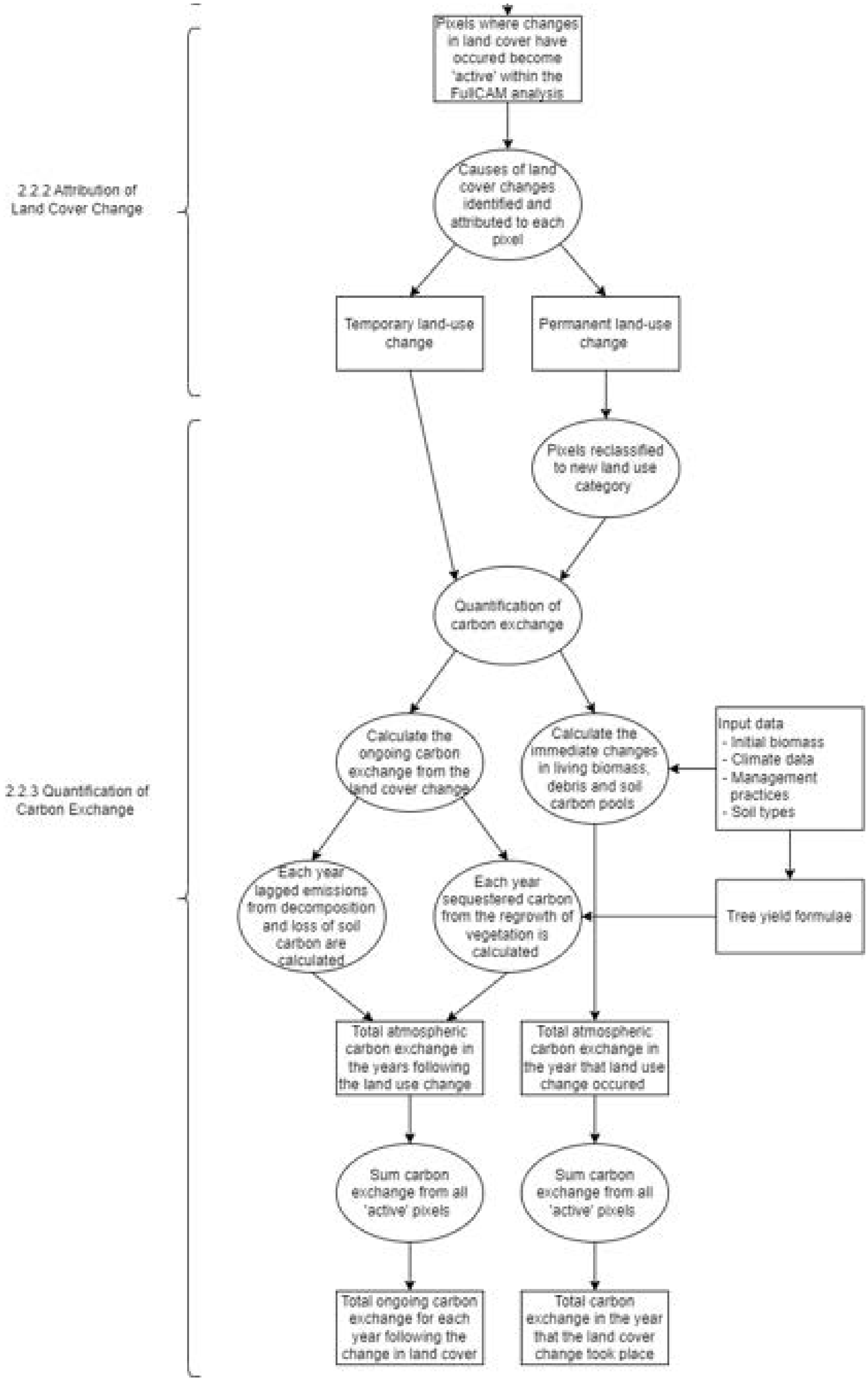
2.2.2 Attribution of Land Cover Change
Pixels where changes in land cover have occured become 'active' within the FullCAM analysis
Causes of land cover changes identified and attributed to each pixel
Temporary land-use change
Permanent land-use change
2.2.3 Quantification of Carbon Exchange
Pixels reclassified to new land use category
Quantification of carbon exchange
Calculate the ongoing carbon exchange from the land cover change
Calculate the immediate changes in living biomass, debris and soil carbon pools
Input data
- Initial biomass
- Climate data
- Management practices
- Soil types
Tree yield formulae
Each year lagged emissions from decomposition and loss of soil carbon are calculated
Each year sequestered carbon from the regrowth of vegetation is calculated
Total atmospheric carbon exchange in the years following the land use change
Total atmospheric carbon exchange in the year that land use change occured
Sum carbon exchange from all 'active' pixels
Sum carbon exchange from all 'active' pixels
Total ongoing carbon exchange for each year following the change in land cover
Total carbon exchange in the year that the land cover change took place

3.2.1.1 Land-Use classification and identification of changes in land cover

Satellite-based remote sensing data is derived from the Landsat program[3] and is used to classify land uses and identify change in land cover over time. These images are processed annually and combined to create a nation-wide mosaic at a 25 m x 25 m grid resolution, with the dataset extending back over 50 years to 1972 (Australian National Greenhouse Accounts, 2013). This extensive temporal coverage is critical, as it allows historical land use of a site to be tracked and used as the basis for calculating GHG emissions from current activities[4] (Australian National Greenhouse Accounts, 2013).

Once satellite data has been acquired and processed, each 25 m2 pixel is then assigned a land use classification. To do so, different vegetation types are identified using an automated decision tree analysis which compares each pixel to training samples of representative land-use classes (Australian Government, 2023a). The annual extent and location of land use change can then be determined by identifying which pixels have been reclassified from the previous year.

3.2.1.2 Attribution of land cover change

The cause of the land cover change is then determined to distinguish between permanent land use change events (such as land clearing for agriculture, mining and urban development) and temporary forest cover loss events (such as timber harvesting or wildfire). To do so, qualified technical staff cross-check remote sensing data against high-resolution imagery, ground data and national land use databases to separate temporary forest loss from permanent conversions. Seasonal and inter-annual variability in vegetation is also identified and excluded through the application of automated, rule-based monitoring systems (Australian National Greenhouse Accounts, 2013).

In instances where permanent land-use change is identified, the pixel is reclassified into the ‘land conversion’ subcategory (e.g. If established forests within the ‘forest land remaining forest land’ category are cleared for grazing, the land is reclassified into the ‘land converted to grassland’ category). Once reclassified, ongoing monitoring of the area will occur to detect subsequent changes in regrowth and re-clearing (Australian Government, 2023a). If after 50 years no further land use changes are identified in the converted areas then it will be moved into the relevant ‘land remaining’ subcategory (e.g. ‘land converted to grassland’ will be moved into the ‘grassland remaining grassland’ category).

When the disturbance is considered to be temporary, the pixel’s classification remains unchanged (e.g. established forest burned by wildfire will remain in the ‘forest land remaining forest land’ category). Ongoing monitoring of these areas will also occur to identify any areas of permanent disturbance – which will then be reclassified to the relevant ‘land conversion’ subcategory (Australian Government, 2023a). The land use classification process following the identification of a change in land cover is outlined in Figure 3.3.

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[3] The Landsat program is comprised of a series of Earth observing satellite missions jointly managed by NASA and the U.S. Geological Survey.

[4] For example, a current conversion activity will likely produce fewer emissions if the forest cleared is secondary forest rather than a primary forest.

3.2.1.3 Quantification of carbon exchange

Once the location, extent and cause of changes in land cover have been determined, the exchange of carbon between the atmosphere and terrestrial biological systems can then be determined. As outlined in Figure 3.4, the FullCAM model splits pixels into separate classes based on the land use change identified within them (Australian Government, 2023a).

Pixels where no land use change has occurred since 1972 (pink cells) are not considered within the model as the carbon exchange within these areas is considered to have reached an equilibrium. However, once a land use change event is detected on a pixel for the first time (e.g. dark blue cells in time period T1), the pixels become ‘active’ within the model and trigger the initiation of FullCAM for the quantification of emissions. Therefore, for each year after 1972, additional ‘active’ pixels are added into the model as new land use change events occur on previously undisturbed land. The GHG emissions and removals on these pixels will then be calculated from the moment they become active. Tracking will also continue each year to identify whether the land remains cleared (light blue cells in T2) or regrowth occur over time (green cells in T2) (Australian Government, 2023a).

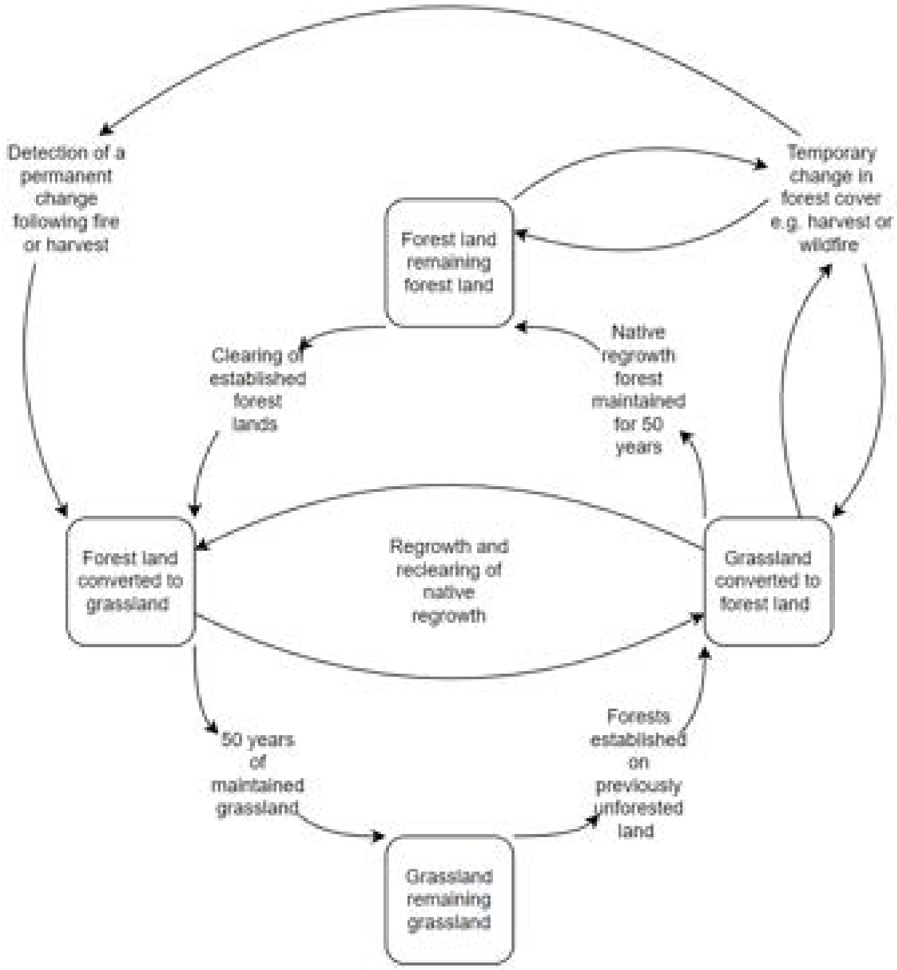

Figure 3.3. Land-use classification process associated with changes in land cover between forests and grasslands

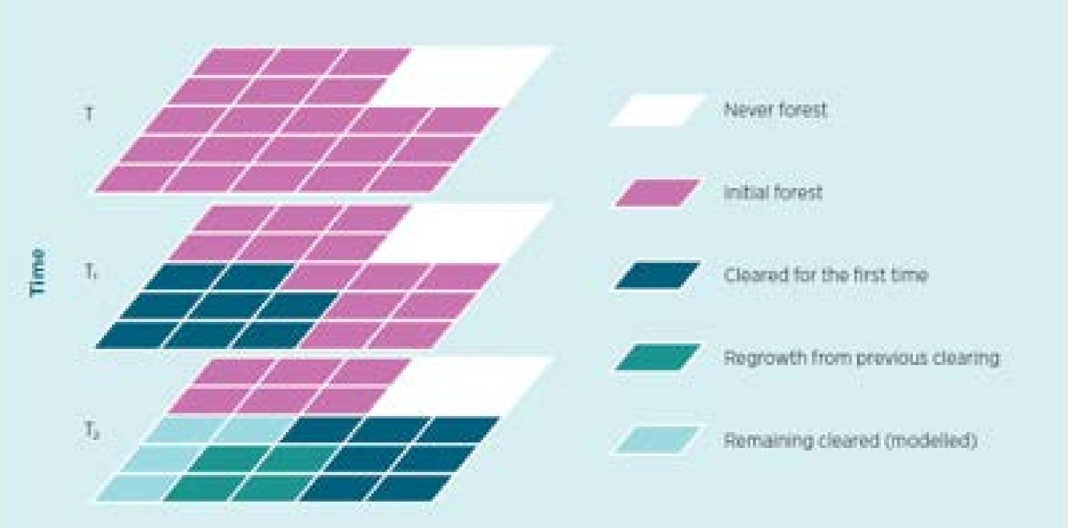

Figure 3.4. Diagram representing the approach for estimating forest land conversion (Australian Government, 2023a)

Immediate emissions and removals arising from a change in land cover within a pixel are modelled in FullCAM as follows (Australian Government, 2023a):

1. The date that the disturbance event occurred is allocated randomly between the date of the satellite images from this year and last year.
2. Key information related to the pixel is obtained including climate data, local land management practices, soil types and the assumed initial biomass[5] on site.
3. Changes in living biomass, debris and soil carbon pools associated with the disturbance event are estimated.
4. The carbon exchange associated with the carbon pools for each pixel are then summed together to estimate the total immediate impact associated with the disturbance event for each pixel.

3.2.2 The FullCAM Forest Growth Model

In the years following the change in land cover, FullCAM will model the ongoing emissions and removals associated with the disturbed pixel. In instances where vegetation regenerates, FullCAM will employ a forest growth model to estimate the ongoing accumulation of biomass for that given land unit. These calculations are based on the application of relevant Tree Yield Formulae (TYF) which have been informed from above ground biomass measurements attained from calibration sites of different types of tree stands across the country (Australian Government, 2023a). Using this approach, annual increments in the growth of biomass is determined as a function of:

- the age of the tree stand;

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[5] The assumed initial biomass of vegetation prior to a first-time clearing event is determined based on the forest productivity index (FPI) and is also a measure of the growth potential of vegetation across the country at a 1 km scale and in 1 month increments since 1970. These site-based, multi-temporal indices allow for the total biomass to be established based on empirical growth models.

- the maximum aboveground biomass M, predicted by the model for a mature forest at each location; and
- an estimated constant that determines the rate of biomass accumulation towards M.

The TYF models the accumulation of aboveground biomass as a forest stand grows towards a theoretical maximum (M) as a function of both the ecosystem's structural characteristics as well as the environmental productivity of the site, as in Figure 3.5 (Roxburgh et al., 2019).

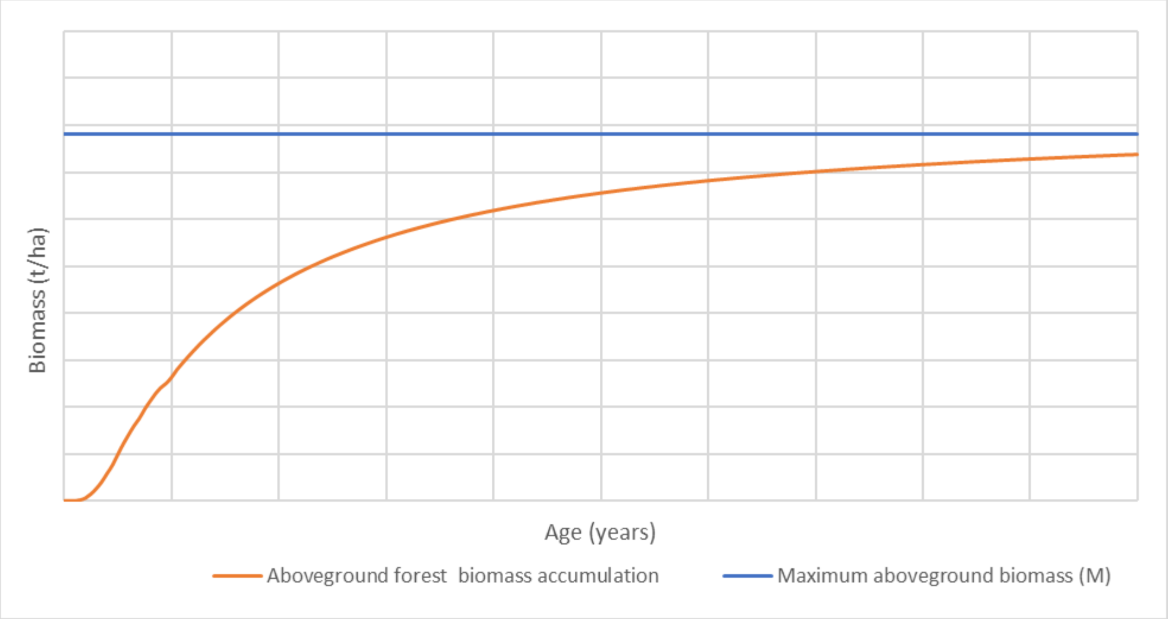

Figure 3.5. Indicative representation of the incremental accumulation of a forest's aboveground biomass towards its maximum value (M)

The sigmoidal nature of this growth curve reflects the growth characteristics of both individual trees and the forest at the stand level including:

- the growth rate of individual trees slowing as they reach maturity;
- the mortality of mature tree balancing with the growth of new stems; and
- increasing competition for limited resources such as light, water and nutrients decreases the stand growth rates and overall stand density. For example, the enclosure of the forest canopy by mature trees restricting sunlight access to understory vegetation and new stems.

These factors all contribute to forest growth and loss rates balancing over time and results in total biomass trending towards the steady-state maximum value of M.

A critical limitation identified with FullCAM's forest growth modelling is its failure to account for the impact of decay in living trees (Ximenes et. al. 2018), which is discussed in Chapter 4.

3.2.2.1 FullCAM partitioning of biomass

For each year of growth determined by the TYF, FullCAM will partition the accumulated biomass into six separate tree components: stem, branches, bark, foliage, coarse roots and fine roots. The need for accurate partitioning of biomass to each tree component is important, as it dictates how the forest's carbon stocks are affected by various management or disturbance activities such as fire, pruning, thinning or harvesting. The proportion of biomass allocated to each component is determined empirically based on large datasets of measured tree and shrub data collated across Australia (Australian Government, 2023b). This enables unique partitioning ratios to be applied across different vegetation groups while also varying as the stand matures (Australian Government, 2023a).

However, studies have indicated that FullCAM may be underestimating the proportion of biomass allocated to the woody components of trees as they mature (Ximenes et al. 2005), resulting in overestimation of the carbon exchange due to of forest disturbances, such as the harvesting. This is discussed further in Chapter 4.

3.2.2.2 FullCAM biomass recovery from disturbance function

Following disturbance events that leave a component of the living biomass in place, such as a partial harvest (e.g. selection harvest) or fire, a biomass recovery function is employed in FullCAM to calculate the rate of regrowth. Biomass recovery is determined as a function of the proportion of biomass lost due to the disturbance, with the incremental regrowth then added back into the system in addition to the annual growth predicted by the TYF of the existing stand, as illustrated in Figure 3.6**Figure**). Further details of this method are outlined in Annex 5.6.2 of Australia's 2021 National Inventory Report Volume 2 (Australian Government, 2023b). The associated carbon removals related to this regrowth can then be accounted for over time as the vegetation matures. Emissions from any subsequent change in land cover can then be determined based on the actual age of the regenerated vegetation and the estimated accumulation of biomass in that area (Australian Government, 2023a).

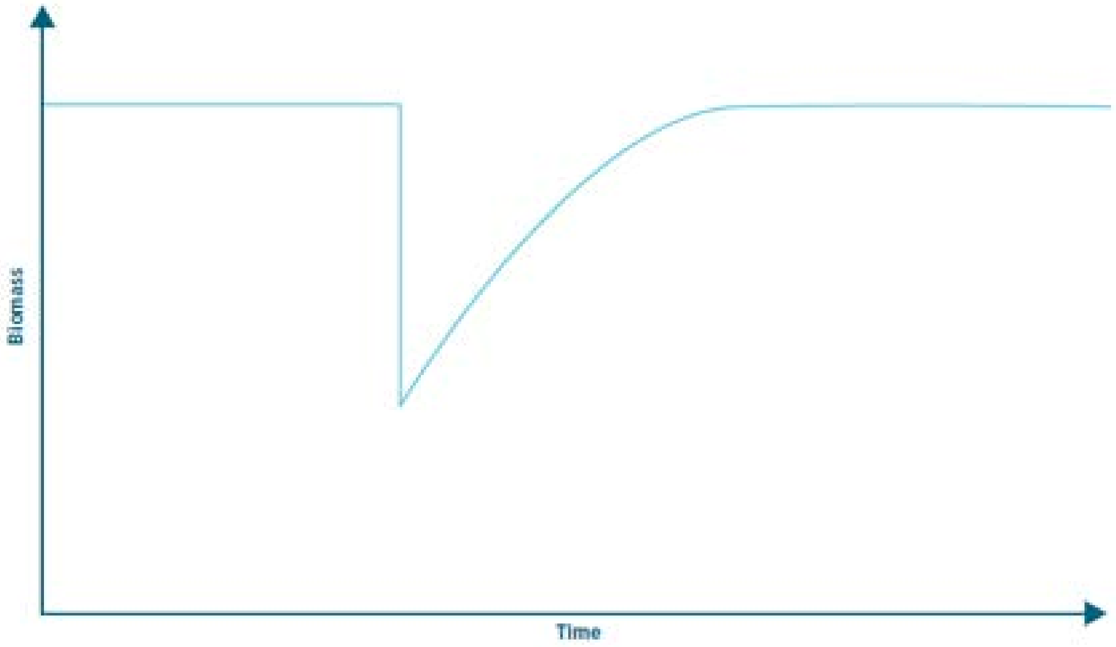

Figure 3.6. Biomass recovery function (Australian Government, 2023a)

FullCAM will also account for the lagged emissions associated with a previous disturbance event due to the decay of dead organic matter and loss of soil carbon (Australian Government, 2023a). These emissions are dependent on the ongoing use of the land after its disturbance and will continue to be reported in the years following the disturbance.

3.3 Carbon Accounting Methodology for Wildfires and Natural Disturbances

For national inventories to quantify and report on the anthropogenic GHG emissions and removals associated with the land use sector, changes in land cover that are specifically related to human influence and activity must be identified. To do so, the IPCC has determined that anthropogenic effects on land cover occur predominantly on ‘managed lands’ where “human interventions and practices have been applied to perform production, ecological or social functions”(IPCC, 2019b, p. 5). Based on this rationale, all direct human-induced GHG emissions and removals must occur on managed lands only, with disturbances on unmanaged lands being primarily the cause of natural effects. This is defined as the Managed Land Proxy (MLP) and acts as the IPCC’s universally applicable approach to distinguishing natural disturbances from human impact within the LULUCF sector (IPCC, 2019b).

While the MLP provides a consistent, comparable, and transparent approach to identifying human influence on land cover, it is recognised that these emissions and removals are characterised by a high degree of interannual variability (IAV) due to both anthropogenic (direct and indirect) and natural causes (IPCC, 2019c). Notably, the three main causes of the IAV in carbon flux on managed land include (IPCC, 2019c):

- **Natural disturbances**: This includes events which are beyond the control of, and not influenced by humans, such as wildfire initiated by lightning, damage from extreme weather or insect and disease infestations. Chapter 4 details concerns about how NCAS defines and accounts for GHG emissions from 'natural' wildfire.
- **Climate variability**: This relates to non-human induced conditions that exacerbate natural disturbances and influence the growth and decay of vegetation. This includes interannual variability in fire conditions, drought, and rainfall. Note that climate variability is also influenced indirectly by human induced factors such as climate change as well as alterations in local conditions due to deforestation.
- **Variation in the rate of human activity**: This includes variations in land use (such as forest harvesting), and land-use change, as well as changes in management activities such as prescribed burning.

A key assumption of the MLP methodology is that emissions and removals associated with natural causes will average out over space and time. That is, it is expected that the GHGs emitted from natural disturbances will be balanced by the subsequent removals from vegetation regrowth at some future point in time[6]. This then leaves human activities as the dominant trend in terrestrial carbon stock over the long run (IPCC, 2019b).

While a balance is eventually achieved between emissions and removals from natural causes, their IAV in emissions and removals can be substantial, and make it difficult to identify the influence of human activities. To account for this, the IPCC has developed a voluntary approach that countries can apply to disaggregate the emissions and removals from natural causes within the MLP. This disaggregation can provide improved insight into the trends in carbon exchange in the land sector that are due to human activities and identify the effect that mitigation measures are having in reducing anthropogenic emissions and maintaining carbon stocks (IPCC, 2019c). Figure shows what types of emissions can be identified through disaggregation, with details about Australia's approach to the disaggregation of interannual variability due to natural disturbance fires outlined in Appendix B.

3.4 Carbon Accounting Methodology for Harvested Wood Products

3.4.1 The Stock-Change Method for Measuring Carbon Flux from Harvested Wood Products

Harvested wood products (HWP) are wood-based materials harvested from forests to serve a variety of functions including paper, utility poles, flooring, furniture or fuel (UNECE, 2008). These materials represent a carbon reservoir, with the carbon sequestered during the growth of the biomass being retained throughout the lifecycle of the product. This carbon is eventually emitted back to the atmosphere via oxidation, either through

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[6] The timing around when this balance is achieved is site specific, being highly dependent on local conditions and the type of vegetation that is affected by the disturbance

combustion or gradual decay when deposited in solid waste disposal sites (SWDS). Nevertheless, wood products can store substantial volumes of carbon for long time during their useful life and when deposited in landfill (Ximenes et al., 2015; Ximenes et al., 2019).

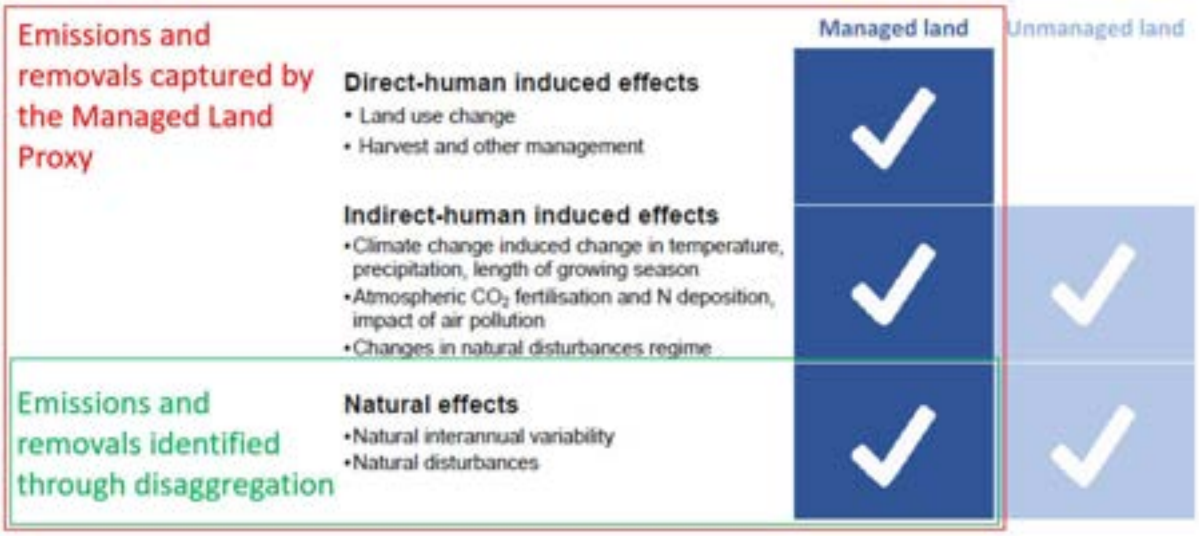

Figure 3.7. Summary of how various anthropogenic (direct and indirect) and natural factors affect land-related GHG emissions and removals in managed and unmanaged lands (IPCC, 2019c)

The time that GHGs are stored within HWPs varies considerably based on the product and its uses. This means that the total oxidation from this reservoir within a given year will not necessarily align with the total annual quantity of wood that is harvested. This storage time must therefore be considered when estimating HWPs contribution to a country's national GHG inventory.

To determine the carbon stocks associated with its HWP, Australia applies the stock-change method as outlined by the IPCC (2019f). This approach involves tracking the changes of carbon stocks from a nation's HWP pool from one year to the next and focuses on assessing carbon-stock changes associated with the country who uses the HWP (known as the consuming country) (IPCC, 2019f). The annual HWP consumed by a country is calculated as the domestic HWP production, plus the international imports of HWP, minus the international exports. Therefore, exported HWP are excluded while imported HWP are included, making the system boundary of the analysis consistent with the national boundary, as outlined in Figure (IPCC, 2019f).

Based on this assessment, an increase in a country's HWP carbon stocks correspond to net GHG removals from the atmosphere, while annual decreases in HWP carbon stocks corresponds to net GHG emissions.

Australia has developed a National Wood Products Model to track the changes in its HWP stocks each year (Australian Government, 2023a). The model is based on a database of detailed time-series data since the 1940s, which is used to monitor the incoming and outgoing quantities of HWP at various life cycle stages, including (Australian Government, 2023a):

- forest harvest data that tracks log flows of various species and product classes (sawlogs, veneer logs, pulp logs, roundwood etc);
- fibre processing data that tracks the quantity of HWP produced annually. This includes the total intake of raw materials as well as the outputs of various classes of products and by-products;
- import and export quantities of HWP; and
- waste disposal data of HWP lost from service.

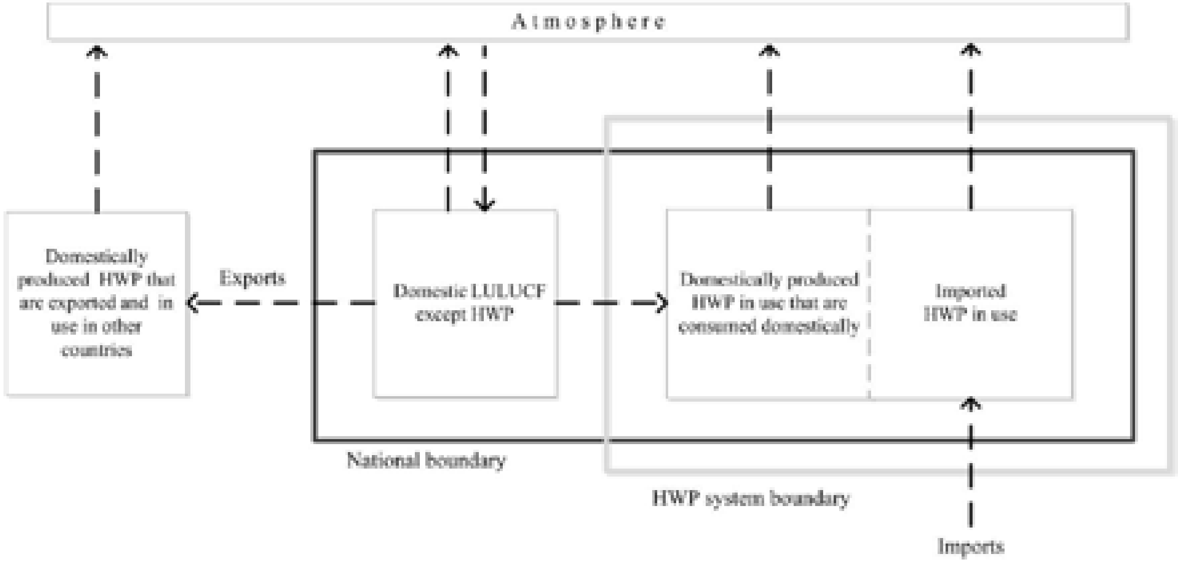

Figure 3.8. System boundary of the stock-change method for assessing the carbon flux of a nation’s HWP pool. Note that the dashed lines indicate fluxes that are inferred from changes in carbon stocks in pools in LULUCF and HWP in use. For the estimation of CO2 emissions and removals arising from HWP, only those fluxes crossing the HWP system boundary are covered under the ‘stock-change’ approach. This figure has been adapted from Figure 12.A.2 in the IPCCs Refinement to the 2006 IPCC Guidelines for the National Greenhouse Gas Inventories - Volume 4, Chapter 12 (IPCC, 2019f).

By quantifying the total HWP stocks within Australia, the total carbon stored within the reservoir can be determined by applying the known wood densities, and moisture and carbon content associated with the various wood products in use (as outlined in Table 6.10.2 of Australia’s 2021 National Inventory Report) (Australian Government, 2023a).

3.4.2 FullCAM Accounting for the Life Span of Harvested Wood Products

Using the HWP time series data, the National Wood Products Model assesses the year-on-year stock changes associated with distinct pools of wood products within the total HWP inventory. As it is crucial to understand a product's life span in order to quantify the overall carbon flux of the HWP reservoir, pools have been compiled by grouping together products based on the duration that they are expected to remain in service. This allows the model to track the expected entry and exit of products from each pool, with a specified proportion of material allocated to be lost each year based on the age of the product.

The model assumes that a product will become increasingly more likely to reach the end of its service life as it ages. To account for this, three age classes are established within each product pool (young, medium and old), with a specified proportion of material to be lost annually for products that fall within each age class (Australian Government, 2023a). The cutoff year and product loss rate assigned to each age class is dependent on the characteristics of products within each pool, as summarised in Table 2.2.

Table 2.2. Details of wood product pools within the National Wood Products Model including the type of products included in each pool, the duration age class and proportion of products lost within this period (Australian Government, 2023a)

Pool	Example Products	Age Classes (Years)	Proportion of Material Lost Within the Age Class (%)
Pool 1: Very short-term products	• Paper and paper products • Woodchips and pulp logs	Young (1)	0.60
		Medium (2)	0.65
		Old (3)	0.90
Pool 2: Short-term products	• Hardwood – pallets and palings • Plywood – form board	Young (2)	0.30
		Medium (6)	0.50
		Old (10)	0.90
Pool 3: Medium-term products	• Particleboard and MDF – kitchen and bathroom cabinets, furniture • Preservative treated softwood – decking and palings	Young (10)	0.15
		Medium (20)	0.65
		Old (30)	0.45
Pool 4: Long-term products	• Softwood – furniture • Roundwood logs	Young (20)	0.25
		Medium (30)	0.65
		Old (50)	0.80
Pool 5: Very long-term products	• Hardwood – green framing, dried framing, flooring and boards • Softboard and Hardboard – weathertex, lining, bracing, underlay	Young (30)	0.20
		Medium (50)	0.55
		Old (90)	0.95

Products that reach the end of their useful life are assigned to an end-of-life stream (SWDS, recycled or burnt), with the total quantity allocated to each based on historical waste reporting data, as illustrated in Figure (Australian Government, 2023a). HWP transferred to landfill is captured as a transfer of carbon stock from the HWP pool to the SWDS pool. From this point, HWP in SWDS is tracked based on methodologies from the waste sector (see Chapter 7 of Australia's 2021 National Inventory Report). Notably, the rate of decay of HWP in SWDS will vary based on the waste type (as in table 7.6 in the National Inventory Report), with half of the carbon losses assumed to result in the generation of methane (the IPCC default value) (Australian Government, 2023a). This approach ensures that the average age of products within each pool will vary based on the rate at which materials enter the system (through domestic production or imports). Therefore, by tracking the rate that products enter service and determining their expected lifespan, the total GHGs stored within HWPs can be established, along with the annual carbon flux associated with the reservoir (Australian Government, 2023a).

Figure 3.9. Illustration of the National Wood Products Model depicting the annual proportion of products lost from each age class and designation of end-of-life streams (Australian Government, 2023a)

3.4.3 FullCAM Estimated Emissions from the Decay of Harvest Residues and Products in Solid Waste Disposal Sites

3.4.3.1 Harvest residues

The annual change in dead organic matter (DOM) in harvested native forests is the net result of additions to the debris pool through the natural turnover of forest materials as well as the production of harvest residues, and losses from ongoing decay and harvest management techniques such as residue burning. To account for the ongoing decay of DOM, NCAS applies decomposition rates to different forest debris pools based on the findings from various studies conducted within Australia (Australian Government, 2023a). While these decomposition rates are based on the best available information, it is acknowledged that limited research has been conducted within this field. As such, default values are applied across all forest types and locations, with each pool segregated into ‘decomposable' and ‘resistant’ components, and separate rates applied to each. Decomposition rates also vary between FullCAM’s 'spatially explicit’ and ‘estate’ accounting methodologies, although NCAS does not state the reason for this distinction.

Table outlines the time required for each debris pool to fully decay based on the FullCAM decomposition rates.

Table 3.3. Time for debris components to fully decay based on NCAS default decomposition rates (Australian Government, 2023a)

Debris Component	Time for debris to fully decay (years)			
	Spatially Explicit Method		**Estate Method**	
	Decomposable	**Resistant**	**Decomposable**	**Resistant**
Deadwood	-	6.67	20.00	20.00
Bark litter	-	5.79	2.00	2.00
Leaf litter	0.10	3.09	1.25	1.25
Coarse dead roots	-	2.84	2.50	10.00
Fine dead roots	0.10	0.10	1.00	1.00

Note: For the spatially explicit method, deadwood, bark litter and coarse dead roots are classified as resistant.

However, there is evidence that the decay of course dead roots occurs at a much slower and varied rate than the default factors employed by the NCAS (Ximenes and Gardner 2006). This suggests that the generalised root decomposition values employed by NCAS do not sufficiently account for the carbon storage potential of dead course roots within production forests, which is discussed in greater detail in Chapter 4.

3.4.3.2 Solid waste disposal sites

Wood products have the potential to store substantial volumes of carbon indefinitely while disposed in landfill. NCAS accounts for the storage potential of HWPs deposited in SWDS through the use of decay values that represent the total fraction of organic carbon that is expected to dissimilate from the product while in landfill (known as the dissimilated organic carbon value, DOC_f). These values have been determined based research conducted for various waste types and are reflective of the fact that carbon in waste does not degrade or degrades very slowly under anaerobic conditions (Australian Government, 2023a). The DOC_f for wood products employed by Australia’s national carbon inventory has decreased over time, initially assuming a DOC_f of 50%, in line with generic IPCC factors, prior to being reduced to 20% as per US EPA guidance. The factor has now been reduced to 10% (in total, not per annum) to reflect observations of DOC_f values from various wood species used for wood products in the USA (Australian Government, 2023a). The current default landfill decay factor in NCAS appears to substantially over-estimate HWP decay in Australia (Ximenes et al. 2019), which is discussed further in Chapter 4.

4. Limitations of the National Carbon Accounting System for Estimating Net Carbon Emissions from Native Forestry and Informing Forest and Carbon Policy

Tyron Venn and Martin Timperley

4.1 The LULUCF Sector's Contribution to Australia's National Greenhouse Gas Inventory

Australia's total net GHG emissions across all sectors since 1990 is illustrated as the blue line in Figure 4.1, and was 464.8 MtCO_2-e in 2020/21. This represents a decrease of 27% since 1989/90, the Kyoto Protocol baseline year, and 24.6% since 2004/05, the Paris Agreement baseline year. Since 1989/90 the LULUCF sector has changed from being a net source of GHGs to a net sink, with net emissions decreasing by 132.2% from producing 198.2 MtCO_2-e in1990 to removing 63.9 MtCO_2-e from the atmosphere in 2020/21 (green bars in Figure 4.2). The LULUCF sector's decrease in net emissions is the primary driver of Australia's overall long-term GHG reductions. In fact, when the LULUCF sector is excluded from analysis, Australia's net annual emissions have actually increased by 90.6 MtCO2-e since 1989/90 (dotted red line in Figure 4.2). Therefore, Australia's record of achieving its GHG reduction targets to date is almost entirely due to the LULUCF sector.

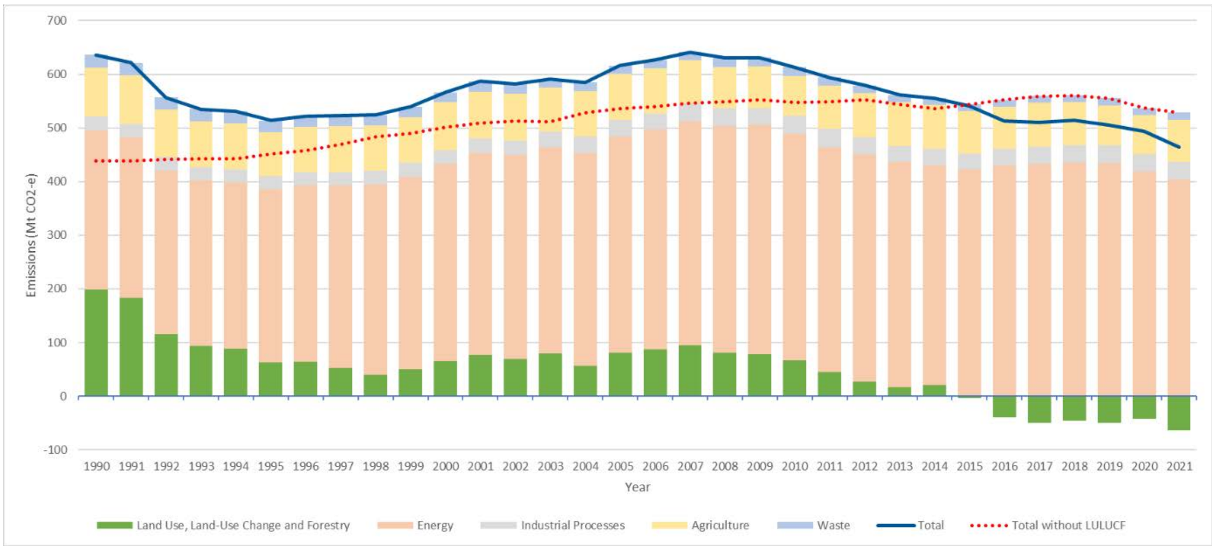

Figure 4.2. Australia's greenhouse gas emissions by sector (Source: Australian Government, 2023a)

The reduced net emissions in the LULUCF sector have been driven primarily by changes in the forest land subsectors. Historically this has largely been a result of declines in emissions associated with the conversion of primary and secondary forests to other land uses, as well as the relative increase in removals through forest regrowth on previously cleared land. However, declining net emissions in recent years has also been driven by historically low native forest harvesting, which has led to increased GHG removals as forests have been allowed to regenerate (Australian Government, 2023a). Hence, the management, conversion, and regrowth of native forests have played a crucial role in defining Australia’s GHG emissions and achieving its climate commitments. The following section provides a technical overview of the methods employed by the NCAS to estimate the net emissions associated with forests and their conversion to and from other land uses. The key drivers that have shaped the emissions trends associated with the LULUCF sector since 1990 will be explored.

4.2 Emissions Trends from Forests and their Conversion to and from Other Land Uses

As highlighted in Section 4.1, the primary driver of the decline in Australia’s GHG emissions since 1990 has been the decrease in net emissions from the LULUCF sector. Figure4.2 highlights that these trends are chiefly a result of two key factors.

1. Changes in native forest management practices, specifically a decline in the area of native forests harvested for timber production (the primary contributor of net emissions in the green bars of Figure 4.2).
2. Changes in forest conversion practices. Specifically, declines in the rate of primary and secondary forest clearing (grey bars) and the relative increase in native forest regrowth on previously cleared lands (blue bars Figure 4.2).

This section will explore how these changes in the management and conversion of native forests have shaped GHG emissions trends associated with the LULUCF sector since 1990, based on data provided in Australia’s 2021 National Inventory Report.

4.2.1 Net Emissions from Native Forestry (Forest Land Remaining Forest Land)

The annual area of harvested native forest has decreased by 71% since its peak in 1995 (124,354 ha) to only 36,106 ha in 2021. The sharpest decline occurring between 2008 and 2014, where the annual harvested area fell by almost 51,000 ha. This has resulted in a net increase in the carbon sequestered on-site, with less biomass being removed from the native forests to be processed into HWPs and consumed domestically (included in the national inventory) or exported abroad (excluded in the national inventory), as well as avoiding the decay of debris created from harvesting activities.

Trends in the annual area of native forest harvesting (dotted purple line) and its contribution to the net emissions of forest land remaining forest land category (dark green bars) are outlined in Figure4.3.

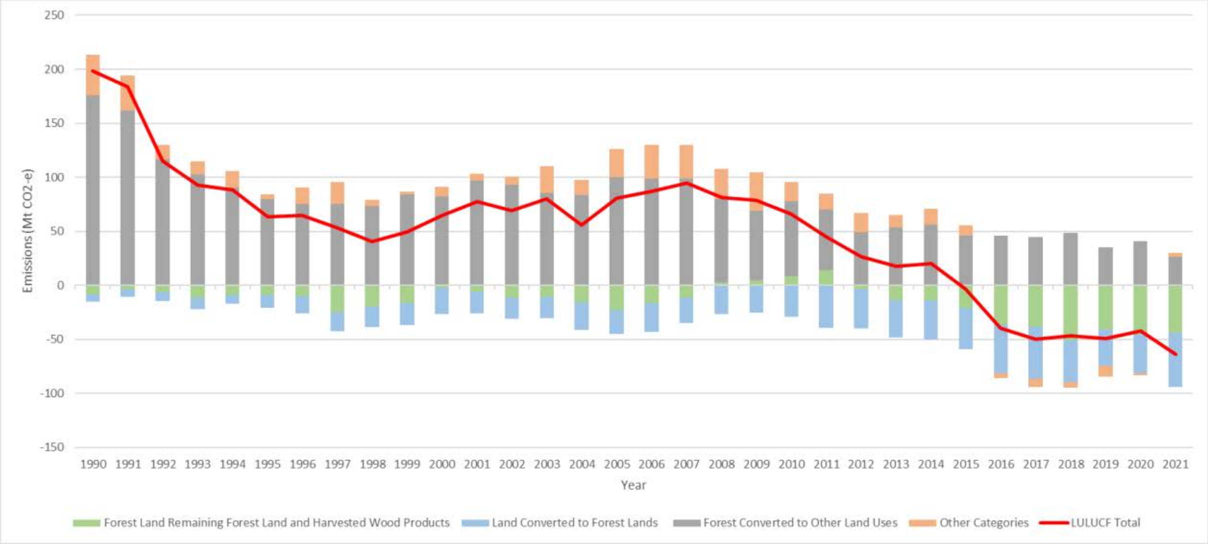

Figure 4.2. Net GHG emissions from the LULUCF sector noting the contribution of forest and forest conversion categories. Note that the ‘Other categories’ includes net emissions from (i) cropland and non-forested land converted to cropland, (ii) grassland and non-forested land converted to grassland and wetland, and (iii) non-forested land converted to wetlands and settlements (Source: Australian Government, 2023a).

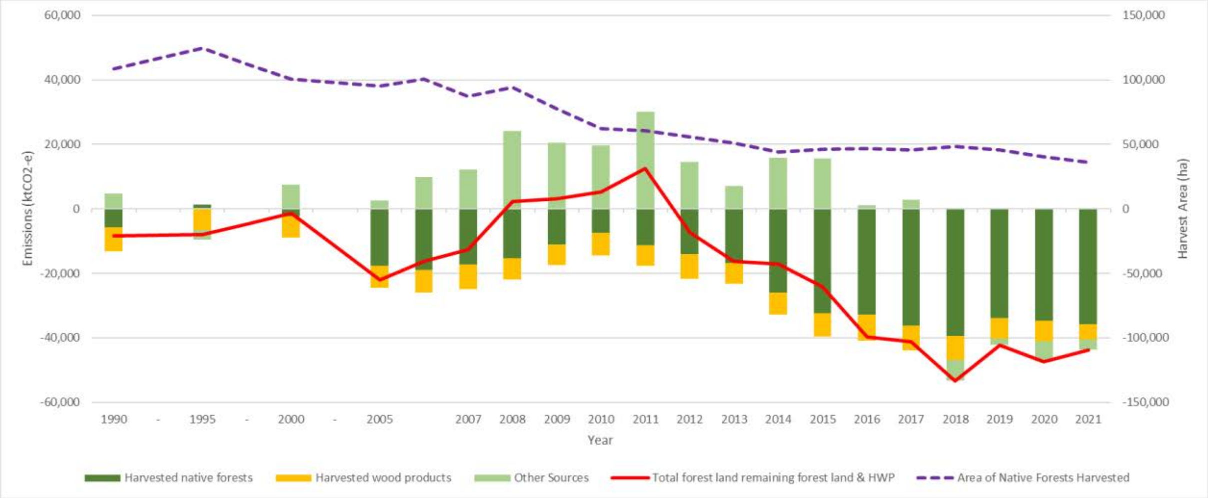

Figure 4.3. Contribution of harvested native forests to the net emissions from forest land remaining forest land and HWP. The ‘Other Sources’ category (light-green bars) includes net emissions related to plantations, fuelwood, wildfires, prescribed burning and non-temperate forest fires. NOTE: Australia’s 2021 National Inventory Report provides data in 5 yearly increments from 1990 to 2005. Annual data is then reported from 2005 – 2021 (Source: Australian Government, 2023a)

The decrease in annual area of native forests harvested has contributed 79% of the total GHG removals associated with the forest land remaining forest land category over the period of 2016 to 2021. In fact, the decline of Australia's native forestry industry was responsible for 55% of net carbon sequestration in the LULUCF sector in 2021, removing a quantity of GHGs from the atmosphere equivalent to 9% of Australia's total annual emissions from the energy sector (see Figure 4.2). However, the description in Australia's National Inventory Report of how the carbon removals due to reduced native forest harvesting were calculated is unclear. It is recommended that these methods be clearly articulated in future national GHG inventory reports, including spatially-explicit reporting by forest type and time since avoided harvest disturbance.

4.2.2 Net Emissions from Forests Converted to and from Other Land Uses

While the decline in the annual area of native forests harvested has been a key contributor to LULUCF emissions reduction in recent years, the carbon flux associated with the conversion of forests to and from other land uses has historically driven trends in the sector (as per the grey and blue bars in Figure 4.2). Figure depicts the annual area of forest land converted to other land uses both from the clearing of mature primary forests (dark green bars) and re-clearing of secondary forest cover (light green bars). The area of identified forest regrowth emerging on previously cleared lands is also illustrated (yellow bars). These trends indicate that the annual area of forest conversion has fallen significantly since 1989/90, with total yearly clearing rates declining by 81% by 2020/21. Specifically, the extent of primary forest conversion during 2020/21 is now only 4% of the level in 1989/90, with clearing rates falling sharply in the early 2000's due in part to the implementation of more restrictive state and national vegetation management regulations.

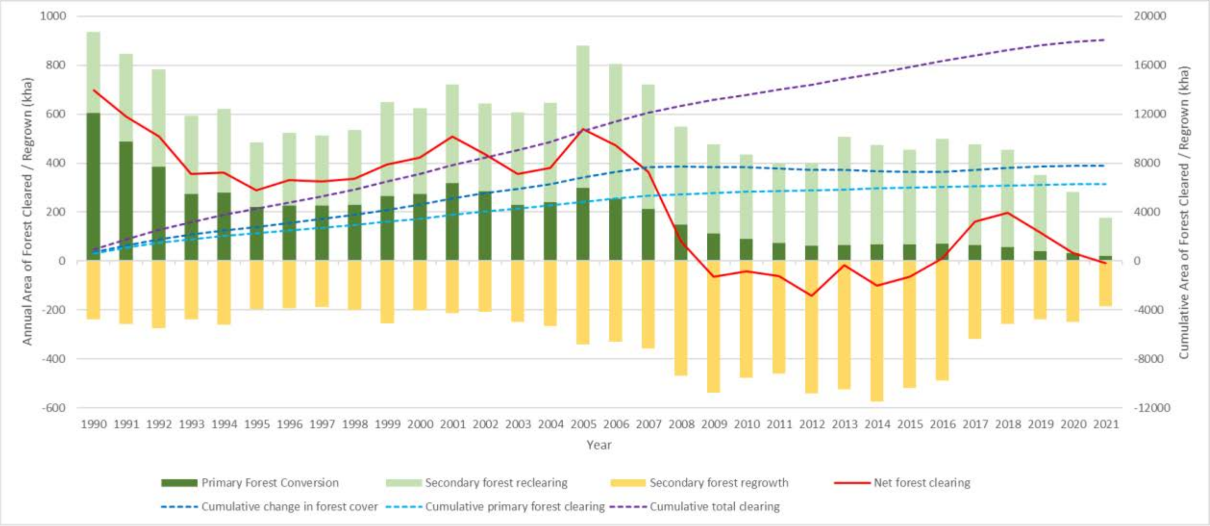

Figure 4.4. The contribution of primary (dark green bars) and secondary (light green bars) forest conversion, and secondary forest regrowth (yellow) to Australia's annual net forest conversion area (red line). The following cumulative areas of forest clearing are also displayed – (i) dark blue line: change in forest cover, (ii) light blue line: primary forest clearing, and (iii) purple line: total forest clearing. (Source: Australian Government, 2023a)

Forest land conversion is now dominated by secondary forest re-clearing which accounted for 88% of all forest clearing in 2020/21, compared to only 35% in 1989/90. Secondary forest re-clearing is largely the periodic re-clearing of regrowth on private land to maintain pasture production for cattle (Australian Government, 2023a). Since 2009, the overall rates of forest conversion in Australia have been balanced by a similar extent of forest regeneration, with the total area of forest cover increasing between 2009-2015 and again in 2021 (red line in Figure 4.4). The authors note that FAO (2024) reported Australia had an average annual net gain in forest area between 2010 and 2020 of 446,000 ha. This may have been a misrepresentation of the secondary forest regrowth data in Figure 4.4.

Figure 4.4 also highlights that the cumulative total forest area cleared since 1989/90 is around 18 M ha (purple dotted line), with secondary re-clearing accounting for 65% (11.8 M ha) and primary forest conversions contributing the remaining 35% (6.2 M ha, as per the light blue dotted line). However, when the cumulative area of secondary forest regrowth since 1989/90 is also considered (10.3 M ha) Australia's net forest cover has declined by 7.8 M ha since 1989/90 (the dark blue dotted line), with the cumulative change in forest cover remaining relatively stable since around 2009.

Figure illustrates the annual CO_2-e emissions and removals associated with forest conversion and regrowth in Australia since 1989/90. This includes the direct emissions and removals associated with the change in biomass on-site (light green, dark green and yellow bars), as well as indirect emissions from the ongoing decay of debris and gradual loss of soil carbon that occur on cleared lands (grey bars). Net emissions due to forest conversion and regrowth have decreased by 100.4% since 1989/90, declining from 172.5 $MtCO_2$-e, to now removing 0.6 $MtCO_2$-e from the atmosphere in 2020/21 (red line in Figure 4.5).

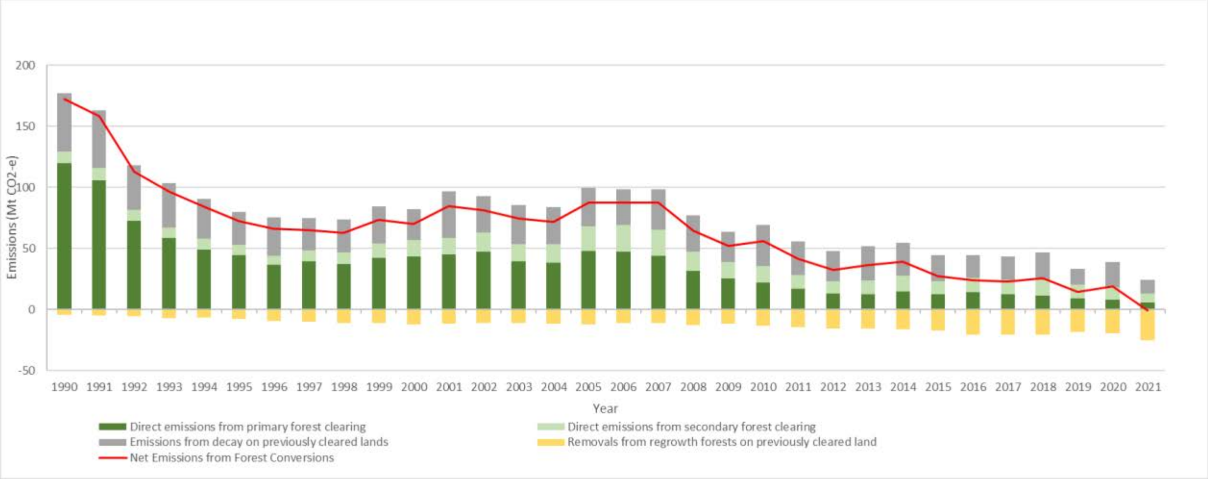

Figure 4.5. Annual GHG emissions and removals associated with forest conversions in Australia since 1990. (Source: Australian Government, 2023a)

A key driver behind this trend is the shift in the balance between primary forest clearing and secondary forest re-cleaning. On average, one hectare of cleared primary forest emits

5.6 times the direct emissions of re-cleared secondary forest (Australian Government, 2023a) due to the biomass of re-cleared forest being significantly less than that of a mature forest cleared for the first time. Therefore, as the extent of primary forest clearing has declined and the cyclical clearing and re-clearing of previously cleared forest has become the dominant form of forest conversion, emissions and removals have trended towards parity over time.

Comparison of Figure and Figure4.5 reveal that the avoided carbon emissions associated with reduced native forest harvesting between 2019 and 2021 was equivalent to the carbon emissions from clearing about 680,000 ha of primary and regrowth forests over the same time period, plus indirect emissions from decay on previously cleared lands.

4.3 Limitations of FullCAM and the National Carbon Accounting System for Estimating Net Carbon Emissions from Native Forestry

As highlighted in Chapter 3, there are a number of technical limitations of FullCAM, which limits NCAS' ability to effectively account for the carbon abatement potential of native forests managed for timber production. Furthermore, the NCAS disincentivises investment in management of forests and fuels to reduce wildfire risk. Six ways in which FullCAM and NCAS are likely to underestimate the net carbon sequestration potential of native forests managed under selection harvesting regimes are discussed:

1. Overestimation of the carbon storage potential of mature trees by failing to account for increasing rates of decay as trees age (Ximenes et al., 2018);
2. Underestimation of the proportion of biomass allocated to the woody components (stems) of trees in commercially important forest types, which overestimates the level of forest residue carbon that will rapidly decay following a selection harvest (Ximenes et al., 2005);
3. Overestimation of the rate of decay of coarse dead roots, thereby discounting their carbon storage potential within production forests (Ximenes & D.Gardner, 2006);
4. Overestimation of the rate of decay of wood products deposited within landfill, thereby discounting the climate mitigation potential of HWPs produced from sustainably managed production forests (Ximenes et al., 2019);
5. Failure to account for the carbon benefit of native forestry of avoided consumption of fossil fuel intensive substitutes (e.g. steel, concrete, brick, plastic and carpet), or imported wood from nations where forests are not as well managed as Australia's (Venn 2023); and
6. Likely overestimation of the long-term average on-site carbon storage potential of strict conservation forests relative to forests managed for selection timber harvesting due to a questionable NCAS definition of 'natural' wildfire and exclusion of their emissions from the national GHG accounts, coupled with the inclusion of emissions from fuel reduction treatments in the national GHG accounts.

4.3.1 Overestimation of the Carbon Storage Potential of Mature Trees

The extent of decay in tree boles tends to increase with age and can result in the formation of hollow regions of trunks, segments and branches that are not visible, making their full extent difficult to determine and quantify (Sillett et al., 2010). Ximenes et. al. (2018) assessed the reliability of existing allometric equations used to infer the biomass of mature trees in native eucalypt forests within New South Wales and Victoria by comparing the outputs of these equations with direct weight measurements of numerous felled mature trees. Overall, it was determined that existing allometric equations were unreliable and generally poor at estimating biomass for mature trees across all sites. The study also noted that allometric equations that did not rely on direct weighing tended to significantly overestimate the total aboveground biomass (and therefore carbon) within mature forests, with their inability to account for internal decay identified as a primary reason for the overestimation (Ximenes et al., 2018). Therefore, FullCAM and NCAS are overestimating the carbon storage potential of conservation forests relative to production forests.

4.3.2 Underestimation of the Proportion of Biomass Allocated to the Stems of Trees in Commercially Important Forest Types

Ximenes et al. (2005) performed destructive sampling to determine the allocations of biomass to log products and other aboveground components from mature spotted gum trees within eucalypt forests located on the NSW south coast. Table4.1 compares the aboveground biomass partitioning of mature spotted gum trees based on Ximenes et al. (2005) to FullCAM defaults for the comparable ‘Eucalypt Open Forest’ vegetation group. Findings from Ximenes et al. (2005) suggest that FullCAM underestimates the proportion of biomass allocated to the woody components (stems) of trees as they by more than 10%. Therefore, by over-allocating biomass to leaves, bark and branches (which decay at a faster rate than HWPs), FullCAM overestimates the carbon exchange that occurs due to forest disturbances, such as selection harvesting. This will lead to FullCAM underestimating the climate mitigation potential of native forests managed sustainably for wood products.

4.3.3 Overestimation of the Rate of Decay of Coarse Dead Roots

Ximenes and Gardner (2006) excavated 45 stumps of harvested trees of various species across three sites in southern NSW to determine the extent of decay since harvesting in order to specify specific decomposition rates for each species. Root systems of trees were found to decay much more slowly than previously thought, and that the rate of decomposition is dependent on several factors including the wood type, species, tree age at time of harvest, climate and the presence of different biological decomposers (Ximenes and Gardner, 2006). Table 4.2 outlines the percentage of coarse root biomass remaining 20 to 25 years, 50 years and at least 85 years after a harvest for various tree species and locations.

Table4.1. Comparison of aboveground biomass portioning between FullCAM's Eucalypt Open Forest vegetation group and mature spotted gum trees as determined by Ximenes (Australian Government, 2023a; Ximenes et al., 2005).

Source	Fraction of biomass allocated to aboveground tree components (%)		
	Stems (both the bole and stump)	**Branches and leaves**	**Bark**
FullCAM - Eucalypt Open Forest	52.4%	33.7%	13.9%
Ximenes et. al. (2005) - Spotted gum forest	62.8%	30.1%	7.2%
Difference	10.4%	-3.6%	-6.7%

Note: While FullCAM partitions biomass across both above and belowground tree components, only the aboveground proportions have been listed to maintain consistency with the outputs of the Ximenes et. al. study (2005).

Table 4.2: Estimates of coarse root biomass remaining over time since harvest (Ximenes and Gardner, 2006)

Tree Species	NSW region	Coarse root biomass (%) remaining after:		
		20-25 years	**50 years**	**At least 85 years**
Cypress Pine (*Callitris glauca*)	Narrandera	100*	80	60*
Ironbark (– possibly *E. paniculata*)	Moss Vale	90*	70*	50
Spotted Gum (*Corymbia maculata*)	Batemans Bay	75	50	25*
Grey Box (*E. microcarpa*)	Narrandera	75	40	10*
Stringybark (- possibly *E. baxteri*)	Moss Vale	70*	50*	25
Radiata Pine (*Pinus radiata*)	Moss Vale	20	0*	0*

Note: Values marked with an * have been extrapolated by Ximenes and Gardner (2006).

All native species examined retained at least 70% of their coarse root biomass 20 to 25 years after harvest. Radiata pine only retained 20% of coarse root biomass after 20-25 years. Some highly decay resistant species such as ironbark and cypress pine can retain at least 50% of course root biomass for at least 85 years post-harvest (Ximenes and Gardner, 2006). In contrast, NCAS assumes that resistant coarse dead roots will fully decay within 10 years using the estate method, and only 2.84 years using the spatially explicit method (see Table 3.3) (Australian Government, 2023a). Ximenes and Gardner (2006) suggested that the generalised root decomposition values employed by NCAS do not sufficiently account for the carbon storage potential of dead coarse roots within production forests, while also failing to capture the variability of decomposition rates between species and across different regions. Consequently, FullCAM and NCAS underestimate the climate mitigation potential of native forests managed sustainably for wood products.

4.3.4 Overestimation of the Rate of Decay of Wood Products Deposited Within Landfill

Ximenes et al. (2019) sought to refine DOC_f factors by using data derived for a range of species (radiata pine, blackbutt, spotted gum and mountain ash) that cumulatively represented approximately 60% of the total volume of wood produced in Australia. The study used microscopic analysis to assess the level of carbon loss within each wood type under optimal anaerobic decay conditions intended to replicate those within actual landfills. Results indicated that the expected carbon loss of wood products deposited in landfills in Australia is 1.4%, which is significantly smaller than the 10% decay values currently employed by NCAS (Ximenes et al., 2019). NCAS's decay rate significantly discounts the carbon storage potential of HWPs in landfill and therefore underestimates the climate mitigation potential of HWPs produced from sustainably managed production forests.

4.3.5 Failure to Account for the Carbon Benefit of Avoided Consumption of Fossil Fuel Intensive Substitutes and Imported Wood

NCAS and FullCAM only provide a partial carbon accounting framework and cannot provide the more accurate approximation of actual atmospheric impacts of industries that can be produced with the lifecycle assessment (LCA) carbon accounting framework. Among the notable GHG accounting concerns with Australia's partial accounting framework are that it does not track the substitution of one product for another, and excludes emissions from international consumption of exported goods and international production of imported goods.

Australia's fossil fuel exports provide a notable example of the limitation of the partial accounting framework. Australia exports about 90% of domestic coal production and 80% of domestic natural gas production (Campbell et al., 2023). Australia's main energy sector climate policy, the Safeguard Mechanism, does not apply to fossil fuel exports (Campbell et al., 2023). Australian exported fossil fuels were responsible for 1.15 billion t CO_2-e emissions globally in 2023 (Climate Analytics, 2024), which are excluded from the national accounts, and equivalent to 2.5 times the annual level of emissions reported by NCAS for the entire Australian economy. Furthermore, there are more than 114 fossil fuel development projects in the pipeline in Australia that will emit billions more tonnes of CO2-e (Campbell et al., 2023).

On a per capita basis, Australia is the world's largest consumer of new clothing and our love of petroleum-based fashion is largely responsible for the nation also having the world's highest fashion emissions at 503 kg CO_2-e per capita per year (Coscieme et al., 2022; Gbor and Chollet, 2024); equivalent to 13.6 M tCO_2-e/y or 3% of national annual GHG emissions. However, the majority of these emissions are excluded from NCAS GHG accounting because of Australia's dependence on imported clothing. The Australia Institute found 54% of Australians are unaware that much of their clothing is petroleum-based and ultimately also contributes to the world's microplastic problem (Gbor and

Chollet, 2024). While successive Federal Governments have proposed policies intended to create a ‘circular economy’ to address Australia’s textile waste problem, the industry remained effectively unregulated in 2024 (Gbor and Chollet, 2024).

With respect to native and plantation forestry, NCAS and FullCAM do not account for the carbon benefit associated with using domestic wood products and avoiding the use of domestically manufactured or imported fossil fuel intensive substitutes (e.g. steel, concrete, brick, plastic and carpet), or imported wood from nations where forests are not as well managed as our own. Avoided emissions from substitutes are large, often in the range of 1 tC to 2.5 tC (3.66 t CO_2-e to 9.15 t CO_2-e) per tonne of carbon stored in wood products (Sathre & O’Connor, 2010). Australia annually imports large volumes of solid wood products from nations known to participate in illegal and unsustainable harvesting that leads to deforestation, forest degradation, large emissions from decaying forest biomass and biodiversity decline (Venn 2023). NCAS also does not take into account the GHG benefits associated with the use of wood biomass in the generation of bioenergy to displace the use of fossil fuels (Ximenes et al., 2016).

The importance of minimising imported wood products to Australia was highlighted by a June 2024 study of 140 imported wood products by the Federal Government Department of Agriculture, Fisheries and Forestry, which found 25% had inaccurate species and origin claims (https://www.abc.net.au/news/2024-11-06/timber-industry-leader-calls-country-origin-labeling-imports/104536952, accessed 13 November 2024). Notable findings included undeclared ‘conflict’ sawnwood and veneers from Russia, products declared as Burmese teak that were of actually of unknown species and origins, and ‘oak’ that was incorrectly declared as originating from Europe and the United States.

The failure of NCAS to accommodate avoided emissions from substitutes is exacerbated by the fact that NCAS does explicitly report carbon benefits of avoided domestic forest harvesting in terms of increased biomass on-site. However, these reported carbon benefits of avoided domestic forest harvesting cannot honestly be interpreted as such without first subtracting estimates of the carbon emissions from Australian consumption of substitute products.

The fossil fuel export, fashion import and domestic forestry examples highlight serious limitations of NCAS and FullCAM to inform industry-specific and national climate policy design and evaluation. In contrast to the partial accounting framework of NCAS and FullCAM, the lifecycle assessment (LCA) framework provides the most accurate approximation of actual atmospheric impacts of forestry activities by considering all relevant carbon stocks and flows from the forest and HWP interface (Ximenes et al., 2016). The scope of LCA and NCAS are compared in Table 4.3**Error! Reference source not found.**. International and Australian researchers who have adopted a partial carbon accounting framework, such as NCAS, have typically determined that forests managed for strict conservation will generate superior climate outcomes (Colombo et al., 2012; Frontier Economics & Macintosh, 2021; Mackey et al., 2022). Researchers adopting the LCA approach have typically found managing forests to produce a sustained yield of timber generates increased carbon sequestration benefits compared to strict conservation (Gustavsson et al., 2017; Morrison Vila et al., 2021; Suter et al., 2017). An LCA study in northern New South Wales found selection harvested forests sequester more carbon over time than forests managed for strict conservation (Ximenes et al., 2016; Ximenes et al., 2012). The LCA studies favouring forestry management are consistent with the long-standing recommendation of the IPCC that forest management aimed at maintaining or increasing forest carbon stocks, while producing an annual sustained yield of timber, fibre and energy, will generate the largest sustained climate risk mitigation benefit from forests (Metz et al., 2007).

Table4.3: Comparison of scope of accounting frameworks (Ximenes et al., 2016)

Parameters	Life Cycle Assessment	National Carbon Accounting Framework
Carbon in trees	Yes	Yes
Carbon in coarse woody debris	Yes	Yes
Emissions due to harvest machinery	Yes	Yes
Emissions due to fire	Yes	Yes
Emissions due to decay	Yes	Yes
Carbon storage in HWP in service	Yes	Yes
Carbon storage in HWP in landfill	Yes	Yes
Emissions due to log transport and product manufacture	Yes	Yes
HWP substitution impact (including international leakage)	Yes	No
Fossil fuel displacement benefits – biomass for bioenergy	Yes	No

4.3.6 Likely overestimation of the long-term average on-site carbon storage potential of strict conservation forests relative to native forestry due to a questionable NCAS definition of ‘natural’ wildfire, the exclusion of their emissions from the national GHG accounts, and an assumption that forest management makes little difference to wildfire-related carbon fluxes

Wildfire can result in enormous periodic carbon fluxes in Australian landscapes. For example, Bowman et al. (2021a) estimated bootstrapped mean emissions from 7.2 M ha of *Eucalyptus* forests and woodlands burned by the Black Summer Bushfires in eastern Australia in 2019-20 at 670 M t CO_2-e, or 93 t CO_2-e/ha. That was equivalent to 144% of Australia’s total GHG emissions in 2021. Australia classifies large wildfire events such as this as ‘natural’ wildfires caused by non-anthropogenic events and circumstances beyond the control of, and not materially influenced by, Australian authorities that occur despite costly and on-going efforts across regional and national government agencies and emergency services organisations to prevent, manage and control them. The carbon impacts of ‘natural’ wildfires are modelled in NCAS to average out over time (regrowth offsets emissions) and these GHG emissions and removals do not count toward Australia’s net emissions. An explicit and transparent explanation of the methods used by the Australian Government to quantify wildfire emissions is not available (Bowman et al., 2023).

NCAS identifies natural wildfires in two steps.

1. First, at the national level, emissions from the area burned are assessed on a year-by-year basis for extreme fire events where outcomes at the national level were beyond the control of authorities to manage. This is done by comparing each year's data with a threshold level or 'margin' based on two standard deviations above the mean of gross annual emissions from all fires and after iteratively excluding outliers. The national natural disturbance threshold has been calculated for the calibration period of 1989-90 to 2019-20. This threshold is 62.57 M t CO_2-e, and six years over the time period exceeded the threshold: 2002-03; 2006-07; 2013-14; 2015-16; 2018-19; and 2019-20. However, this is also a period of declining levels of government resources applied to natural resource management, including reductions in the field workforces by 50% to 67% (see below).
2. Second, once natural disturbance years are identified at a national level, natural disturbances are spatially identified and the area burnt tracked at the sub-national level. Natural disturbances at the State and Territory level were identified where the area burned during their local fire season exceeded a State or Territory natural disturbance threshold equal to the average area of the calibration period plus one standard deviation of the non-natural disturbance years.

Wildfire years that do not pass the threshold at the national and sub-national levels are classified as anthropogenic wildfire and do count towards Australia's annual emissions. Emissions and removals from known anthropogenic fires, including prescribed fire to reduce wildfire risk, also count towards Australia's annual GHG emissions.

The NCAS definition of 'natural' wildfire in 2024, and the exclusion of their emissions from the national carbon accounts, disincentivises investment in fire and forest management to protect carbon stocks, reduce wildfire emissions and improve resilience and recovery of ecosystems from fire, because there is little recognition that management can make a difference and no carbon penalty associated emissions (Ndalila et al., 2022; Bowman et al., 2023). In contrast, the savanna burning programs in northern Australia provide an example of how wildfire management has been incentivized by government. Two major concerns with NCAS assumptions about natural wildfire GHG emissions and removals are that:

1. Australia's forests will fully recover carbon emissions from present and future natural wildfires;
2. All large, high severity wildfires, such as those that burned during the Black Summer Bushfires of 2019-20, are 'natural' and beyond the ability of government agencies and emergency services organisations to influence, prevent, manage or control.

These concerns are discussed in turn below.

4.3.6.1 Concern with assumption 1: Can Australia's forests fully recover carbon emissions from present and future natural wildfires?

Climate change is increasing wildfire risk (Abram et al., 2021; Canadell et al., 2021) and the strong likelihood of climate change-driven pyrogeographical changes in Australia suggests the NCAS assumption that forests will fully recover from future wildfires will be tested (Bowman et al., 2023; Cunningham et al., 2024). Therefore, management activities that increase forest resilience to future climate and wildfire need to be considered. Bowman (2021b) indicated that research involving empirical measurements, modelling and a mix of large-scale management intervention is urgently required to determine what interventions can maximise carbon storage in the face of climate change-driven fires.

4.3.6.2 Concern with assumption 2: In the cultural landscapes of Australia, are all large, intense wildfires beyond the ability of government agencies and emergency services organisations to influence, prevent, manage or control?

Fletcher et al. (2024) argued that the use of words like 'wilderness' to describe Australian conservation areas makes it difficult for policymakers and managers to recognise their long-neglected obligations to care for cultural landscapes. Much discussion of Australian wildfire ignores the fact that Australian landscapes were very different under indigenous management (Fletcher et al., 2024). From this perspective, change in forest structure, and increased fuel loads and fuel connectivity to historically high levels that have contributed to larger and higher intensity wildfires is at least partly a direct consequence of government policy (Murphy et al., 2013; Williams, 2013; Fletcher et al., 2021a; Mariani et al., 2024).

Depictions of Australian landscapes being bountiful with large trees free from underwood and reminiscent of a 'gentleman's park' are numerous in the ethnographic and ethno-pictorial record in the early settlement period (Ryan et al., 1995; Florence, 1996; Benson and Redpath, 1997; Jurskis, 2000; Gammage, 2011; Mariani et al., 2024). Patchwork mosaics of vegetation at different stages of post-fire development, from recently burned to long unburned were maintained by indigenous burning practices for thousands of years prior to the arrival of Europeans (Burrows and McCaw, 2013; Jurskis et al., 2020). Cultural burning may not have been prodigiously applied throughout Australia (Egloff, 2017); however, Gammage (2011) asserted that, while some areas would have burned only infrequently due to terrain and moisture, most of Australia was burned about every one to five years by small, low-intensity fire. Thus, the forest landscape of 1788 was very different from that of the 21st century.

A growing body of research examining charcoal and pollen records in south eastern Australia (NSW, VIC and TAS) show low levels of biomass burned before colonisation and that levels of biomass burned after colonisation increased markedly (Adeleye et al., 2021; Fletcher et al., 2021b; Adeleye et al., 2022; Mariani et al., 2022; Fletcher et al., 2024). Mariani et al. (2024) found that the cessation of cultural burning since European colonization, coupled with wildfire suppression, has facilitated the build-up of fuel loads in Australia's forests resulting in shrub cover increasing to a mean of 35% of land cover, which is higher than at any time in the last 130,000 years. All of these papers concluded that Indigenous peoples maintained open vegetation with grassy understories through ubiquitous application of low-intensity and patchy cultural burning. European suppression of Indigenous land management amplified biomass accumulation and fuel connectivity in southeast Australian forests, resulting in infrequent, high-intensity fire regimes since 1788.

In the literature, there are two broad schools of thought about forest fuels management to reduce wildfire risk in southern Australia:

1. Fuel management offers an effective approach to proactively reduce wildfire risk; and
2. Fuel management exacerbates wildfire risk, and greater emphasis needs to be placed on technology for early wildfire detection and rapid wildfire suppression.

Interestingly, neither school of thought explicitly supports the NCAS definition that ‘natural’ wildfires are beyond the ability of government agencies and emergency services organisations to influence, prevent, manage or control. The paradigms are described below.

Proactive management of wildfire risk and associated carbon emissions

Many managers and scientists have argued that increased application of prescribed fire and cultural burning in the landscape could ameliorate wildfire risk and associated carbon emissions, as well as support the conservation of biodiversity, cultural and other ecosystem services (Jurskis et al., 2020; Adeleye et al., 2021; Williams et al., 2022; Williams, 2023; Fletcher et al., 2024; Partridge et al., 2024). There are numerous datasets throughout southern Australia that clearly highlight an inverse relationship between the extent of prescribed fire and wildfire (Attiwill and Adams, 2013; Burrows and McCaw, 2013; Ximenes et al., 2017; AFPA, 2020; Doherty et al., 2024). However, large reductions in Australian government field workforces (by 50% to 67%) and forest access since the 1980s have reduced opportunities for wildfire risk management in Australia’s forests, including prescribed fire (Queensland CRA/RFA Steering Committee, 1998b; McAlpine et al., 2005; Whiteman et al., 2015; Queensland Department of Agriculture and Fisheries, 2016; Kanowski, 2017; NSW DPI Forestry, 2018; Morgan et al., 2020).

An international meta-analysis performed by Hunter et al. (2020) found that both empirical and modelling studies overwhelmingly show that increasing application of prescribed fire can result in wildfire regimes of lower extent and intensity. Landscape fire modelling in southeastern Australia by Carey at al. (2016) revealed that, within practical operational limits, fuel treatments explained less than 7% of variation in total area burned and area burned by moderate to high intensity wildfire. However, Price et al. (2015) found the leverage (the reduction in unplanned area burnt resulting from recent previous area burnt) of prescribed fire was 0.086 for the Australian Alps / South Eastern Highlands, 0.163 for the Sydney Basin, 0.285 for the NSW North Coast and 0.363 for the New England Tablelands. Therefore, 1 ha of wildfire was avoided in NSW North Coast for every 3.5 ha (=1/0.285) of prescribed fire. Leverage estimates have also been estimated at 0.19 for prescribed fire in forest and shrubland communities in Tasmania (King et al., 2013), 0.25 for southwest Western Australia (Boer et al., 2009), and similar values in the Sydney region (Price and Bradstock, 2011).

Empirical data examined by Hislop et al. (2020) revealed fuel reduction burns from 2015 to 2019 significantly reduced wildfire severity during the 2019-20 Black Summer Bushfires on 48% of the 307 fuel-reduction burn sites evaluated in Victoria and New South Wales.

Likewise, Nolan et al. (2021) found that prescribed fires up to five years before the Black Summer wildfires were effective in reducing wildfire severity, but particularly prescribed fires within 2 years of Black Summer.

Vesta 2 wildfire simulations described in Chapter 9 (and Appendix D) of this report have provided new evidence of the potential for native forestry silvicultural practices to reduce wildfire risk in spotted gum and blackbutt native forest regrowth. Relative to forests where silviculture was not performed, managed regrowth forests had lower and less connected fuels that will reduce wildfire risk to life, assets and forest carbon stocks by increasing opportunities for wildfire suppression and decreasing: (a) flame height; (b) radiant heat flux; (c) fire intensity; and (d) the potential for and duration of crown fire. This finding is at odds with the NCAS assumption that management makes little difference to wildfire behaviour and their associated carbon emissions.

From a carbon emissions reduction perspective, more prescribed fire on the landscape is beneficial if periodic low emissions from prescribed fire are less than infrequent large emissions from wildfire. Hunter et al. (2020) found the effects of prescribed fire on ecosystem carbon dynamics internationally were unclear, with results varying considerably across studies. Possell et al. (2015) found planned fires in a temperate Eucalyptus forest in south-east Australia released between 20 t CO_2-e/ha and 139 t CO_2-e/ha, with variability a consequence of different burning efficiencies among investigated fuel types. Price et al. (2015) cautioned that there may be limited scope for active fuel management to increase carbon stocks in the south-eastern Australian mainland forests. For example, based on the prescribed fire leverage they estimated for Northern NSW, a wildfire would have to emit at least (depending on the probability of wildfire) 3.5 times more carbon per hectare than a prescribed fire in order for prescribed fire to be effective at maintaining or increasing long-run carbon stocks. Volkova et al. (2021) developed a full ecosystem carbon model for southeastern Australia to investigate the implications of prescribed fire management on net ecosystem carbon and found that prescribed fires applied on a 5- to 15-year cycle were successful at increasing net ecosystem carbon for scenarios of two or more high intensity wildfire events per 100 years.

Reactive management of ignitions to suppress wildfires and their associated carbon emissions

The other perspective on fuel management is that the wildfire crisis in Australia is exacerbated by active management of landscapes through prescribed fire and timber harvesting. This paradigm recommends minimising forest disturbance, coupled with rapid suppression of wildfires when they threaten to burn areas too frequently. It is based on the idea that natural forests can become less flammable with increasing time since disturbance (Lindenmayer and Zylstra, 2023). However, Lindenmayer et al. (2023) do regard prescribed fire, thinning and pruning as appropriate to reduce wildfire risk in timber plantation forests. Confusing wildfire risk management recommendations for southern Australian forests have also been published in the field of biodiversity conservation, with a paper by more than 100 authors advocating cultural burning as important for wildfire management and biodiversity conservation, while also arguing prescribed fire (not cultural fire) exacerbates species decline (Driscoll et al., 2024).

Lindenmayer et al. (2020) asserted that the temperate mountain ash forests of Victoria have become more fire prone with harvesting, and Lindenmayer et al. (2020; 2022b) argued that harvested areas in Victoria and New South Wales burned with higher likelihood or significantly increased severity, respectively, during the 2019-20 fire season. However, other researchers have disputed the assertion that forestry has increased flammability in Victorian mountain ash forests (Price and Bradstock, 2012; Attiwill et al., 2014; Adams et al., 2020), and empirical literature about the 2019-20 bushfire season (Davey and Sarre, 2020; Bowman et al., 2021a; Bowman et al., 2021b; Natural Resources Commission, 2021), and state and federal government inquiries made no link between the 2019–20 fires and forestry practices (Bowman et al., 2022). There is considerable evidence from Australia and internationally that forestry practices including prescribed fire, thinning, maintaining fire breaks and maintaining skills and capacity to manage prescribed fires and wildfires in difficult forest terrain can improve the resilience of landscapes to wildfire (Jurskis et al., 2003; Stephens, 2010; Tucker and Wormington, 2011; Stephens et al., 2012; Burrows and McCaw, 2013; Florec et al., 2013; McCaw, 2013; AFAC, 2015; Petrokofsky et al., 2015; United States Department of Agriculture, 2015; Ximenes et al., 2017; Evans, 2018; Montreal Process Implementation Group for Australia and National Forest Inventory Steering Committee, 2018; AFPA, 2020; IFA / AFG Board, 2020; Keenan et al., 2021; Tolhurst and Vanclay, 2021; Lukpat, 2022).

Lindenmeyer et al. (2022a; 2023) contended that improving early fire detection is a promising strategy to protect forests from wildfire, which would facilitate crews arriving sooner to perform suppression activities. They recommended investment in rapid detection and suppression, such as cameras in fire towers, ground-based sensor networks, mathematical modelling of lightning strikes, fleets of wildfire detection drones coupled with uncrewed, autonomous vehicles that can rapidly access ignitions and extinguish fires, and the installation of watering systems in areas of high conservation value. However, it is not clear how such an approach would be resourced. Owing to the high cost of wildfire policy that emphasised 'reactive' wildfire suppression, the United States began a transition in the early 2000s towards 'proactive' fuels management with prescribed fire and mechanical thinning, while allowing wildfire to play its natural ecological role (Venn and Calkin, 2011; Barnett et al., 2016; Schoennagel et al., 2017).

4.3.6.3 Summary of concerns with the NCAS definition and accounting of 'natural' wildfire

The NCAS definition of natural wildfire in southern Australian, which is based on the distribution of wildfire carbon emissions over the period 1989-90 to 2019-20 – a period of declining government investment in proactive wildfire risk management, limited indigenous burning, and climate change – is questionable given that Australia is a cultural landscape shaped over millennia by indigenous burning.

NCAS disincentivises investment in fire and forest management to protect carbon stocks, reduce wildfire emissions and improve resilience and recovery of ecosystems from fire, because there is no carbon penalty for 'natural' wildfire and little recognition that management can make a difference. However, there is a strong likelihood of climate change-driven pyrogeographical changes in Australia, which will test the NCAS assumption that forests will fully recover from future wildfires in the absence of management. Furthermore, the two highly conflicting wildfire risk management paradigms discussed above contradict a key element of the NCAS definition of ‘natural’ wildfire in forests of southern Australia; that ‘natural’ wildfires cannot be materially influenced by management.

There is much more published evidence supporting increased investment in fuel reduction treatments to mitigate wildfire risk than increased investment in wildfire suppression.

The absence of a carbon penalty for ‘natural’ wildfire, coupled with the inclusion of GHG emissions from fuel reduction treatments in the national accounts will likely overestimate the long-term average on-site carbon storage potential of strict conservation forests relative to forests in which fuels are more actively managed, including timber production forests.

The NCAS definition of ‘natural’ wildfire and the exclusion of their GHG emissions from national accounts requires a more rigorous scientific justification.

4.4 FullCAM and NCAS are Likely to Substantially Underestimate the Carbon Abatement Potential of Native Forestry

Australia’s NCAS is consistent with the IPCC guidelines for carbon accounting and reporting. NCAS is appropriate for tracking the nation’s progress towards meeting its carbon emissions reduction targets, but it has limited capacity to inform the development and evaluation of sector-specific policy in its current form.

The limitations described above lead NCAS to both overestimate the carbon storage potential of mature, primary forests and underestimate the potential for sustainably managed production forests to sequester and store carbon on site, within wood products and through avoided consumption of substitutes. Therefore, NCAS and FullCAM cannot be used to inform forest policy and evaluate carbon outcomes associated with the management of domestic forests for wood products.

Further research is necessary to improve our understanding of the carbon dynamics of forests, particularly those managed for wood products, to refine the GHG emissions and removals estimates associated with Australia’s LULUCF sector. The development and evaluation of forest policy that increases the contribution of Australia’s forests to mitigation of climate risk can be supported by development of a forest carbon accounting model with a LCA framework.

5. Review of ACCU Methods and the Potential for a Native Forestry Method

Martin Timperley and Tyron Venn

5.1 Australian Carbon Credit Unit Scheme Overview

The Australian Carbon Credit Unit Scheme (the ACCU Scheme) - formally known as the Emissions Reduction Fund - has been Australia's primary climate mitigation policy since its establishment under the Carbon Credits (Carbon Farming Initiative) Act 2011 and the Carbon Credits (Carbon Farming Initiative) Rule 2015 (Clean Energy Regulator, 2023a). The Scheme offers financial incentives to businesses, landholders, and communities who adopt new practices and technologies to that avoid the release of greenhouse gas emissions or remove and sequester carbon from the atmosphere.

Eligible projects taking part in the scheme can earn Australian Carbon Credit Unit (ACCUs) for every tonne of carbon dioxide equivalent emissions that are stored or avoided. These ACCUs can then be either held by the project proponent or sold to generate additional income streams. ACCUs may be purchased by the Australian Government through publicly funded reverse auctions or private buyers seeking to voluntarily offset their own emissions or meet compliance requirements (DCCEEW, 2023a). Alternatively, ACCUs can be voluntarily retired (surrendered) by the project proponent to meet their own GHG reduction obligations (DCCEEW, 2022b). The lifecycle of a typical ACCU project is outlined in Figure.1.

Figure 5.1. Lifecycle of an ACCU project (DCCEEW, 2023a)

To participate in The Scheme, projects must be conducted according to approved methodology determinations (known as methods) which set out the rules for how the activity should be carried out, as well as how to measure emissions reduction or carbon sequestration. Eligible methods can include activities such as (DCCEEW, 2022b):

- installing new technology;
- upgrading equipment;
- changing land or business practices to improve productivity or energy use; and
- changing the way vegetation is managed to store more carbon.

The extent of greenhouse gas abatement achieved by the project is calculated as the difference between the emissions or removals that result from the activity and those that would have occurred under a relevant baseline scenario in which the project did not take place. To ensure the Scheme delivers real emissions abatement, all methods have been designed to comply with the following legislated Offsets Integrity Standards (Emissions Reduction Assurance Comittee, 2021).

- **Additional**: A method should result in carbon abatement that is unlikely to occur in the ordinary course of events.
- **Measurable and verifiable**: A method involving the removal, reduction or emissions of greenhouse gases should be measurable and capable of being verified.
- **Eligible:** A method should provide abatement that is able to be used to meet Australia's international mitigation obligations.
- **Evidence based:** A method should be supported by clear and convincing evidence.
- **Account for project emissions**: Material greenhouse gas emissions emitted as a direct result of the project should be deducted.
- **Conservative:** Where a method involves an estimate, projection or assumption, it should be conservative.

5.2 Independent Review of the ACCU Scheme and Future Updates

In July 2022, the Australian Government issued an independent review of the integrity of carbon credits created through the ACCU Scheme (Chubb et al., 2022). The review was commissioned as a response to assertions that projects operating in accordance with the ACCU Scheme were overstating the quantity of GHG emissions that they avoided or sequestered. To abate these concerns, the review sought to "advise on ways to strengthen the integrity of Australia's carbon crediting framework in contributing to Australia's emissions reduction targets, and to ensure the scheme maintains a credible and strong reputation supported by participants, purchasers and the broader community"(Chubb et al., 2022, p. 1). The review examined key features of the scheme including its governance structure, information transparency and review processes, as well as the effectiveness of various methods along with their compliance with offset integrity standards.

In December 2022 the independent expert panel issued their findings to the Minister for Climate Change and Energy (Chubb et al., 2022). They concluded that "the ACCU scheme arrangements are essentially sound", while also making 16 recommendations centred around "clarifying governance, improving transparency, facilitating positive project outcomes and co-benefits, and enhancing confidence in its integrity and effectiveness" (Chubb et al., 2022, p. 2). The Australian Government accepted in principle all 16 recommendations and in June 2023 issued an Implementation Plan setting out the proposed timing and approach for incorporating these improvements into the scheme(DCCEEW, 2023b).

The key findings and recommendations that have a direct bearing on the vegetation-based methods have been noted in the following sections where relevant.

5.3 ACCU Scheme Governance Structure

To ensure confidence in the scheme's integrity and to manage conflicts of interest, the Independent Review made recommendations to improve the scheme's governance arrangements, including to clearly identify and separate the key functions of integrity assurance, regulation and administration. This included (DCCEEW, 2023a). At time of writing, the Scheme's existing governance structure remains in place with most revisions expected to be enacted in 2024 (DCCEEW, 2023b). The existing and future governance framework of the ACCU Scheme is outlined in Table 5.1.

Table 5.1. Existing and amended governance structure of the ACCU Scheme (DCCEEW, 2023a)

Responsibility	**Responsible Entity**		**Comments**
	Existing Structure	**Amended Structure**	
Management of The Scheme's overarching policy and legislation	Department of Climate Change, Energy, the Environment and Water (DCCEEW)		
Scheme administration	An independent statutory authority known as the Clean Energy Regulator (CER)	Clean Energy Regulator (CER)	
Methodology development			
Purchase of ACCUs on behalf of the Australian Government		Another government body (TBC)	Responsibility of government purchases reallocated from the CER to avoid actual or perceived conflicts of interest
Oversight of method development to ensure Offsets Integrity Standards are maintained	An independent expert committee known as the Emissions Reduction Assurance Committee (ERAC)	The ERAC will be re-established as the Carbon Abatement Integrity Committee (CAIC)	The CAIC will have adjusted terms of reference, membership, and functions to be supported by an independent secretariat

5.4 Vegetation-Based ACCU Scheme Methods

A number of methods have been developed for the ACCU Scheme to incentivise land-based sequestration activities, such as (Clean Energy Regulator, 2023b):

- reforestation;
- regeneration;
- plantation forestry; and
- protecting existing forests at risk of clearing.

Collectively, vegetation-based methods have produced the majority of ACCUs issued under the scheme, accounting for over 55% of all credits generated between its inception in 2012 and October 2023 (all green slices in **Figure**). Methods facilitating emissions reductions through landfill and alternative waste treatments (grey slice in **Figure**) have been the next largest contributor of ACCUs, accounting for 31% of all credits.

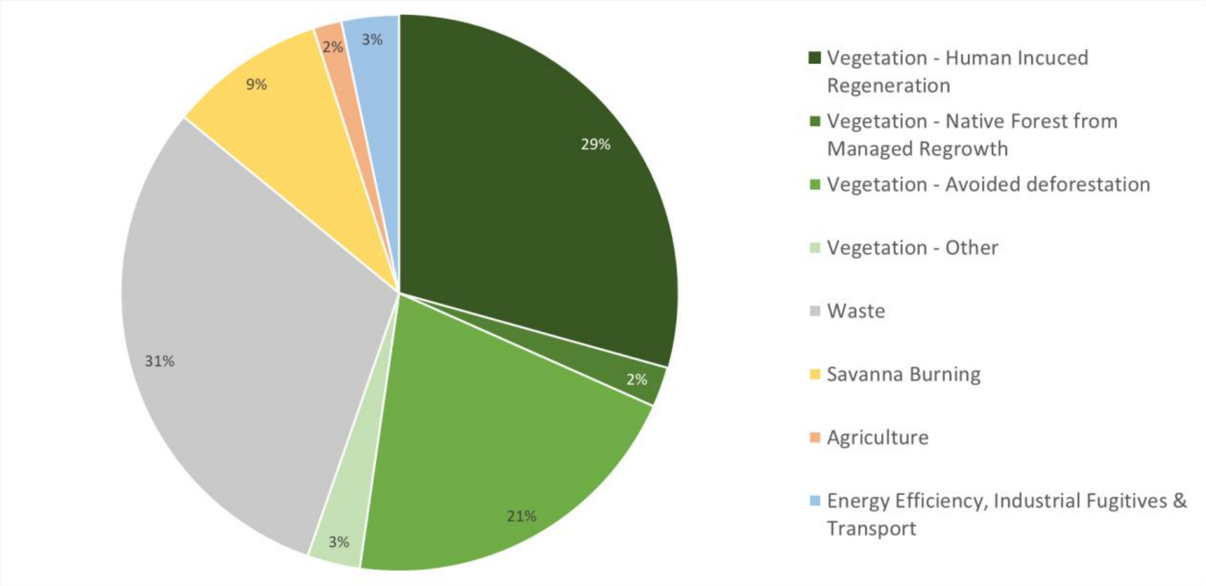

Figure 5.2. Contribution of approved methodologies to total ACCUs issued between inception in 2012 and October 2023. Note that methods comprising the 'Vegetation – Other' category include environmental plantings to reforest previously cleared land and plantation forestry (Clean Energy Regulator, 2023c)

Of the approved vegetation-based methods currently in place, two approaches enable ACCUs to be issued by sequestering carbon through the regeneration of native forests[7]:

- Human-Induced Regeneration (HIR), and
- Native Forest from Managed Regrowth (NFMR).

These methods are known as assisted natural generation (ANR) projects, have been widely adopted in southwest Queensland and far western New South Wales (DISER,

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[7] For these methods the term 'native forest' is determined to be native trees more than 2m tall with a crown cover of 20% or more.

2022), and together account for almost one third of all ACCUs issued under the scheme[8] (the two darkest dark green slices in Figure5.2).

A further 21% of all existing ACCU's have been created through the Avoided Deforestation Method (lime green slice of Figure), which credits emissions reductions to landholders who refrain from clearing established native forests. Projects are eligible to register under this method if landholders hold a clearing consent issued under certain conditions, limiting the scope of this approach to properties in particular regions of western New South Wales (Australian Academy of Science, 2022). This approach thereby uses the existing clearing consent to act as a proxy for additionality, with ACCUs awarded based on the intention of the landholder to clear all forest they are legally able to under a baseline scenario.

However, following the Independent Review this method has now been discontinued based on concerns regarding the additionality of ACCUs being generated in its current form (Chubb et al., 2022). Claims have been made that some landholders are being credited ACCUs for forests they either never intended to disturb or had limited capital to finance a clearing operation (Australian Academy of Science, 2022). This has been supported by evidence highlighting that the historic clearing rates would need to increase dramatically to execute all existing clearing permits prior to their expiry (Australian Academy of Science, 2022). As a result, the independent panel recommended that "no new project registrations be allowed under the current avoided deforestation method" (Chubb et al., 2022, p. 24).

The remaining 3% of vegetation based ACCUs (the light green 'Vegetation – Other' slice of Figure) are produced predominantly through two project types. First, from reforestation methods developed to promote the establishment of permanent forests on previously cleared agricultural lands through the planting of seeds or seedlings (Clean Energy Regulator, 2022a). Second, methods that promote increasing the carbon sequestration potential of plantation forests by incentivising activities such as (Clean Energy Regulator, 2023f):

- establishing a new plantation forest;
- converting a short-rotation plantation to a long-rotation plantation;
- continuing rotational harvest cycles in a plantation forest; and
- transitioning a plantation forest to a permanent forest.

ACCUs were first issued for vegetation based methods in financial year (FY) 2012/13, and after a short period of rapid growth in project registrations, have consistently produced between 7.2 and 9.5 million ACCUs annually since FY2016/17, accounting for 55% of credits issued until October 2023 (all green bars in **Figure**).

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[8] The HIR method has produced 29% of all ACCUs while the NFMR is responsible for 2%.

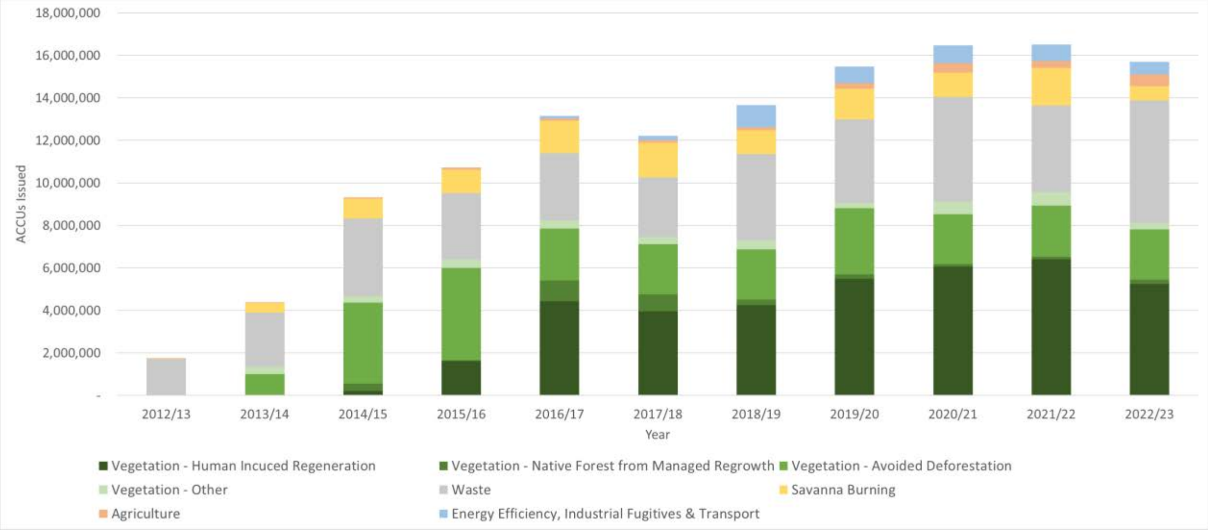

Figure 5.3. Annual quantity of ACCUs issued by methodology. Vegetation based methods have been represented by different shades of green. Note that methods comprising the ‘Vegetation – Other’ category include environmental plantings to reforest previously cleared land and plantation forestry (Clean Energy Regulator, 2023c)

While the ACCU Scheme currently accommodates methods that encourage the regrowth of native vegetation as well as increasing the carbon sequestration potential of plantation forests, no method has been developed to account for the potential GHG removal associated with native regrowth forests managed for sustainable timber harvesting. Details regarding the scope and crediting processes of existing native vegetation and plantation methods are outlined in Sections 5.4.1 and 5.4.2. Sections 5.5 to 5.7 discuss the need for new ACCU methods, the strengths and limitations associated with existing approaches as well as the potential to introduce methods that incentivise sustainable native forestry management practices.

5.4.1 Assisted Native Regeneration Project Methods

ANR project methods allow for the establishment of permanent native forests through assisted regeneration from in situ seed sources, remnant native plants, or rootstock already present and native to the site. In areas where natural regeneration of forest is possible, ANR is often far more cost-effective compared to reforestation approaches, as they utilise low-cost techniques to re-establish naturally occurring tree and shrub species. Additionally, ANR projects often deliver improved co-benefit outcomes to landholders through the provision of improved agricultural productivity, biodiversity and land resilience (Butler & Halford, 2015). These factors have resulted in ANR activities offering the greatest potential to enable forest restoration at scale under existing carbon prices (Evans, 2018), making them the most widely adopted methods under the ACCU Scheme (Clean Energy Regulator, 2023c).

Both the HIR and NFMR methods expired 30 September 2023 and 31 March 2024, respectively. Rather than renew them, the Government's Implementation Plan sets out the intention to replace them with the Integrated Farm and Land Management method. This new method is currently in development and will consolidate both of these approaches along with similar activities to enable landowners to maximise the carbon abatement potential of their lands without having to register them under separate projects (DCCEEW, 2023b).

While the HIR and NFMR methods both enable the creation of ACCUs through the regeneration of vegetation on previously cleared land, they each had notable characteristics which set them apart. These are outlined below.

5.4.1.1 Human-induced regeneration

The HIR method can be applied to areas where land has been cleared of native vegetation and where regrowth has been suppressed for at least 10 years prior to project commencement (Clean Energy Regulator, 2023e). Regeneration is enabled by undertaking activities that manage or remove external pressures that prevent regrowth from occurring, these can include (Clean Energy Regulator, 2023e):

- keeping livestock out of the area;
- managing the timing and the extent of grazing;
- managing, in a humane manner, feral animals;
- managing plants that are not native to the project area; and
- ceasing mechanical or chemical suppression activities.

Under this method, native vegetation is modelled to regenerate from a 'zero baseline' scenario where all regrowth commences at the time of the project establishment.

Independent Review Findings

The Independent Review undertook an assessment of whether this method adhered to the Offsets Integrity Standards. The panel concluded that the HIR method was sound in that it fulfilled the offsets integrity standards and was administered by robust regulatory frameworks (Chubb et al., 2022). However, several improvements were identified to improve its effectiveness. The primary concern related to this method was the difficulty in attributing carbon sequestration to human activities as opposed to natural factors such as rainfall. Most HIR projects have been established in low rainfall, semi-arid regions of Australia where variable rainfall patterns are the primary drivers of woody biomass growth and decay (Australian Academy of Science, 2022). Under these circumstances it can be challenging to convincingly confirm whether vegetation suppression mechanisms (grazing, feral animals, mechanical suppression etc.) were the dominant factor preventing vegetation regrowth during the baseline period.

While the panel "did not accept that a correlation between rainfall and vegetation growth undermines the method" (Chubb et al., 2022, p. 21), it did recommend that additional evidence be provided to ensure projects conform to its current intent. To do so, projects will now be required to demonstrate a causal relationship between the HIR activity and the dominant suppression mechanism that occurred through the baseline period, as well as demonstrate that these suppressors are directly addressed by the HIR activity (Chubb et al., 2022). This evidence will be submitted alongside the existing legislative requirement to conduct 5-yearly gateway checks to ensure that vegetation is regrowing as predicted and required. The combination of these two requirements was considered sufficient to ensure ‘evidence-based’ carbon sequestration is achieved for HIR projects.

The panel also noted that while FullCAM modelling was a suitable basis for estimating carbon storage in native vegetation, stakeholders should be allowed to develop direct measurement-based approaches to estimating sequestration as part of the proponent-led method development process (Chubb et al., 2022).

Macintosh et al. (2024) argued that the findings of government reviews of the HIR method, including Chubb et al. (2022), contrast sharply with peer-reviewed research. HIR projects are almost exclusively located in uncleared arid and semi-arid rangelands, where their capacity for increased carbon sequestration is likely to be limited. In addition to supporting the findings of previous research that has found most of the observed changes in tree cover are attributable to factors other than HIR project activity, Macintosh et al. (2024) found that most HIR projects are non-compliant with key regulatory requirements that are essential to protect project integrity.

5.4.1.2 Native forest from managed regrowth

Like the HIR method, NFMR projects sequester carbon by stopping activities that suppress native vegetation, while implementing new management practices that promote regeneration. The key difference of this method relative to HIR is that it covers areas that (at the time of project establishment) have young but established native regrowth with potential to achieve forest cover, but have not yet achieved it (Clean Energy Regulator, 2023d). Under these circumstances, the project regenerates from a ‘non-zero baseline’ with the project being credited for the new sequestration from the existing vegetation that occurs after the project commencement date (Butler & Halford, 2015). As these young forests are already established, projects can expect to initially generate ACCUs faster than ‘zero baseline’ regrowth projects using the HIR method.

5.4.1.3 Crediting carbon sequestration for assisted native regeneration project methods

The Clean Energy Regulator has produced guides that outline the rules and procedures relating to the development of ANRs and how their carbon abatement outcomes can be quantified (Clean Energy Regulator, 2023d, 2023e). Key concepts and processes associated with these methods are outlined below.

Calculating Total Carbon Abatement

These methods have been developed to enable changes in forest carbon stocks to be modelled directly using FullCAM, with no direct field measurements of site vegetation needed. Once all relevant inputs are gathered, the project’s net abatement over the reporting period is determined based on the following calculations (Clean Energy Regulator, 2023d).

1. FullCAM is used to determine the total carbon stock change for the project area (tC). This is calculated as the difference between the long-term average baseline carbon stock for the project area and the project area carbon stock at the end of the reporting period (tC). The total carbon stock change is then converted to the equivalent quantity of atmospheric carbon dioxide sequestered from vegetation regrowth (tCO_2-e).
2. The total methane and nitrous oxide emissions associated with biomass burning which occurred during the reporting period are calculated (tCO_2-e).
3. The total GHG emissions from fuel used during the reporting period is calculated.
4. Total abatement is calculated as a) minus the sum of these b) and c).

Permanence

In recognition that the carbon sequestered and stored within the regenerated forests can be lost due to natural or anthropogenic disturbances, the Clean Energy Regulator has subjected all vegetation-based projects to ‘permanence obligations.’ This obliges projects to choose a permanence period in which is obligated to maintain the project’s carbon stores for which ACCUs have been issued. Permanence periods can be set at either 25 or 100 years, however if the former is chosen there will be a 20% reduction in the quantity of ACCUs issued to the project. This deduction is to account for the potential costs incurred to the government to replace the lost carbon stores that may result at the end of the project. Therefore, if a fire or other disturbance occurs within the project area during the permanence period, lost vegetation must be managed to allow carbon stocks to return to pre-disturbance levels, prior to additional ACCUs being issued for the project. Alternatively, the ACCUs equivalent to the quantity of carbon lost to the disturbance can be relinquished to the Clean Energy Regulator (Clean Energy Regulator, 2021).

Additionally, all vegetation-based project methods are also subject to a 5% discount in ACCU’s issued known as the risk of reversal buffer. This is intended to protect the ACCU’s scheme from temporary losses of carbon emissions that cannot be accounted for though the permanence obligation (Clean Energy Regulator, 2018).

Exclusions

No commercial harvesting is permitted within the NFMR project areas other than the removal of up to 10% of fallen timber for personal use.

5.4.2 Plantation Forestry Project Methods

5.4.2.1 Overview

Between 2014 and 2020 Australia’s total commercial plantation estate contracted by 10% with almost 200,000 ha being converted to other land uses (red line in Figure 5.4). In addition, due to changing economic circumstances, the rate of new plantation establishment in Australia has been declining since 2006, with only a negligible area being developed since 2012 (dashed blue line in Figure). Under current market conditions and without the provision of government support or incentives, these trends are expected to continue in the near to medium term, (DCCEEW, 2022a). As unviable plantation estates are overwhelmingly converted to non-forested land for agriculture or pastoral use (Clean Energy Regulator, 2022b), the industry's decline will have a negative impact on Australia's efforts to reduce greenhouse gas emissions as the terrestrial carbon stock within these areas decrease.

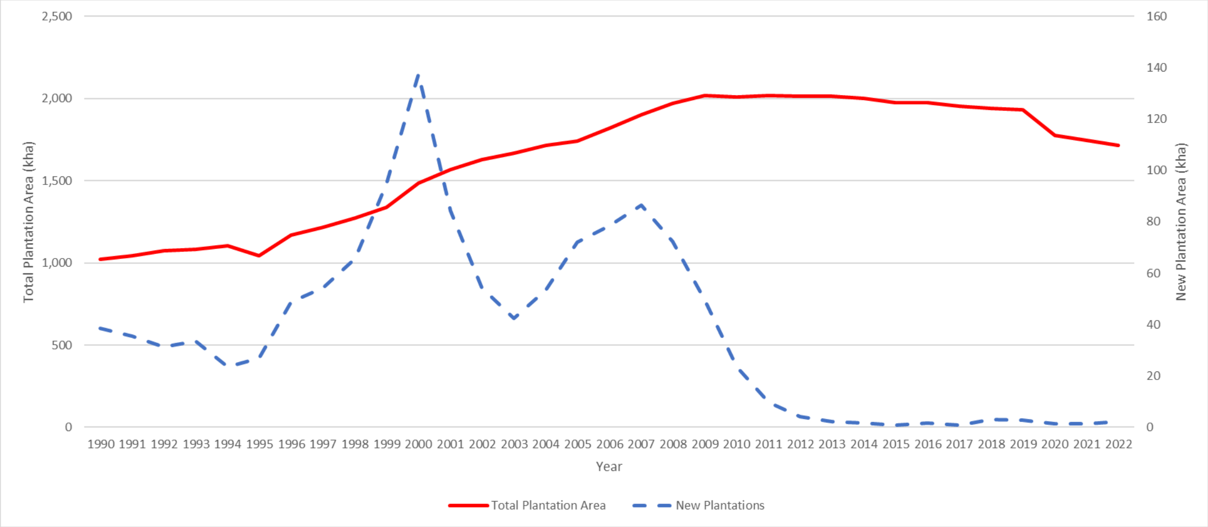

Figure 5.4. Australia's total plantation estate area (red) and year-on-year area of new plantings (dashed blue line) (ABARES, 2023b)

This has prompted the development of the Plantation Forestry method under the ACCU Scheme which "credits increased carbon sequestration through the establishment of new plantation forests, the transition of existing plantation forests from short rotation to long rotation plantation forests, and the avoided conversion of existing plantation forests to non-forested land" (DCCEEW, 2022a, p. 1). Under this approach, projects generate ACCUs by accounting for the changes in carbon stock of trees and debris within the plantation as well as the associated harvested forest products that are produced (Clean Energy Regulator, 2022b). The project's total carbon abatement over the crediting period is determined by modelling the forest growth over time while factoring in emissions from management activities and disturbances such as harvesting, thinning, pruning and controlled burning (Clean Energy Regulator, 2022b).

5.4.2.2 Crediting carbon sequestration in plantation forestry project methods

Calculating Total Carbon Abatement

Similar to ANR Methods, Plantation Forestry Project Methods estimate carbon abatement over the crediting period through the use of FullCAM. ACCUs are generated by undertaking one of four eligible activities under the method (DCCEEW, 2022a):

- **Schedule 1:** Establishment of a new plantation forest on land that has had no plantation forest for seven years;

- **Schedule 2:** Conversion of a short-rotation plantation to a long-rotation plantation, where the conversion might occur either part-way through the short-rotation plantation cycle, or following harvest of a short-rotation plantation;
- **Schedule 3:** Continuing plantation forestry under circumstances where the land would have otherwise converted to non-forested land; or
- **Schedule 4:** Transitioning from plantation forestry to a permanent forest (i.e. timber not harvested) under circumstances where the land would have otherwise been converted to non-forested land.

Carbon abatement is calculated as the difference in carbon stored as a result of the eligible project activities and that of a baseline scenario where no actions were taken.

For approaches that result in ongoing plantation activities (Schedules 1, 2 and 3), carbon stocks will fluctuate over the crediting period due to tree growth and harvesting cycles. To account for this, ACCU's are issued based on the long-term average carbon stock for the project. This is calculated as the net abatement resulting from the project calculated over 100 years of operations (Clean Energy Regulator, 2022b). For example, Figure 3 displays an illustrative example of an abatement profile for a Schedule 2 project where a short-rotation plantation (the baseline scenario – yellow lines) is converted to a long-rotation plantation (the project activity – blue lines). The year-on-year carbon stock of each scenario (solid lines) along with its long-term average calculated over the 100 year period (dashed lines) are depicted (Clean Energy Regulator, 2022b). The quantity off ACCUs issued for this project can then be determined as the difference between these long-term averages.

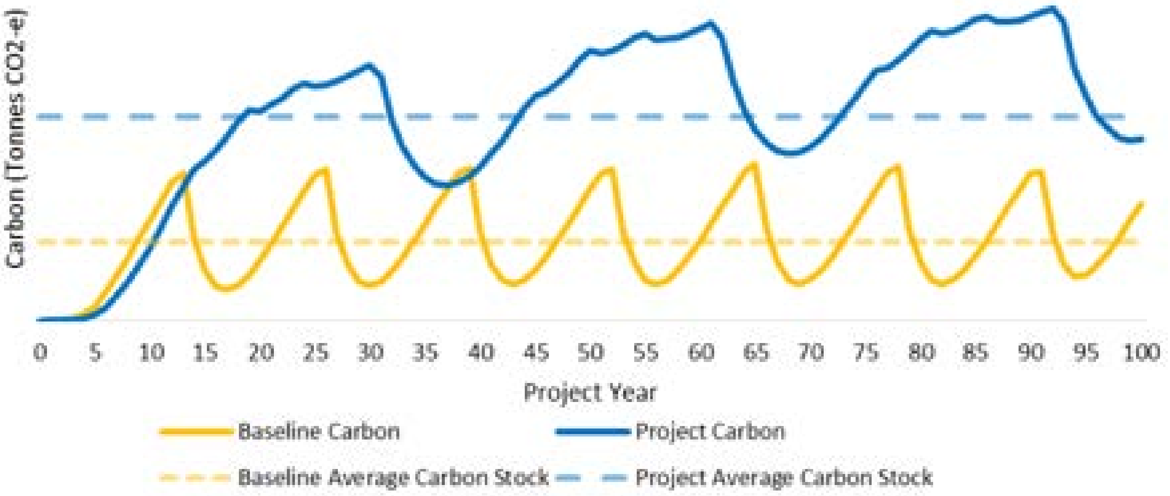

Figure 3. Carbon stored by the project scenario (blue lines) and baseline scenario (yellow lines) for a Schedule 2 project (Clean Energy Regulator, 2022b)

As Schedule 4 activities involve transitioning plantations to a permanent forest, carbon stock fluctuations from planting harvesting does not need to be considered within the modelling. As such rather than calculating the long-term average carbon stock, total abatement is modelled as the carbon stocks present in the forest at the end of the 25-year crediting period (Clean Energy Regulator, 2022b).

Table 5.2 summarises the key aspects associated with calculating the total carbon abated from each eligible activity under the Plantation Forestry Project Method.

Table 5.2. Summary of the baseline and project activities associated with the four eligible project types under the Plantation Forestry Project Method (Clean Energy Regulator, 2022b)

Schedule	Baseline Activity	Project Activity	Credit Entitlement
Schedule 1: Establishment of a new plantation forest on land that has had no plantation forest	The carbon stored is assumed to be zero, as the land would have continued to be managed as non-forested land in the absence of the project.	The long-term average carbon stock associated with the establishment of a new plantation forest.	ACCUs issued each year based on the increases in carbon that accumulate from forest growth. Crediting continues until the 100 year long-term average carbon stock is achieved on-site.
Schedule 2: Conversion of a short-rotation plantation to a long-rotation plantation	The long-term average carbon stock associated with the plantation continuing to implement short-rotation harvest cycles.	The long-term average carbon stock associated with the plantation converting to long-rotation harvest cycles.	The project is entitled to ACCU’s associated with the difference in the long-term average carbon stocks of the baseline and project activities. Credit entitlement is then split into equal apportionments over the first 15 years of the crediting period.
Schedule 3: Continuing plantation forestry where the land would have otherwise converted to non-forested land	The long-term average carbon stock associated with a single harvest event, followed by conversion to a non-forested land use. This ensures that the ongoing carbon stored in the debris and harvested wood product pools are accounted for.	The long-term average carbon stock associated with continuing the plantation forest.	The project is entitled to ACCU’s associated with the difference in the long-term average carbon stocks of the baseline and project activities. Credit entitlement is then split into equal apportionments over the first 15 years of the crediting period.

Schedule 4: Transitioning a plantation forestry to a permanent forest where the land would have otherwise converted to non-forested land	The long-term average carbon stock associated with a single harvest event, followed by conversion to a non-forested land use. This ensures that the ongoing carbon stored in the debris and harvested wood product pools are accounted for.	The total carbon stocks present in the permanent forest at the end of the 25-year crediting period.	The project is entitled to ACCU's associated with the difference in the long-term average carbon stocks of the baseline scenario and the carbon stocks of the permanent forest after 25 years. Credit entitlement is then split into equal apportionments over the first 15 years of the crediting period.

Permanence

Similar to the ANR project methods, participants can choose either a 25 or 100-year permanence period. For projects that elect a 25-year permanence period a 25% discount in the number of ACCU's issued for activities involving:

- Establishing a new short-rotation (20 years or less) plantation; or
- Continuing plantation forestry.

A 20% discount is applied to all other activities under this method that elect a 25-year permanence period (Clean Energy Regulator, 2023f). An additional discount of 25% applies to plantations that transition to a permanent forest that is not an environmental planting and choose a 25-year permanence period (Clean Energy Regulator, 2023f). Plantation forestry projects are also subject to a 5% risk of reversal buffer.

Exclusions

All harvested native forests are outside the scope of the Plantation Forestry Project Methods. Additionally, projects are ineligible for this method if the land has been cleared of native vegetation or drained of a wetland in the past 7 years[9] (Clean Energy Regulator, 2022b). Projects may also be declined if they are determined to cause an undesirable impact on agricultural production in the region in which the project is to be located (Department of Agriculture and Water Resources, 2017).

Plantation forests and international trade in carbon credits

At COP29 a decision was made to allow two countries to establish bilateral carbon trading agreements, and to establish a new UN-operated international carbon market with standardised methodologies for trade in credits between countries (Why UN-Operated Carbon Market Will Have Major Impact on Forests | Wood Central, accessed 15 November 2024). However, there is a strong push from Europe for plantation forests to be

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[9] This requirement is reduced to 5 years if there has been a change in ownership of the land after the clearing or draining event.

excluded from the international carbon market and limit the market to natural forests and natural restoration projects only.

5.5 Evaluation of Existing Vegetation Based ACCU Scheme Methods

Collectively known as assisted natural generation (ANR) projects, the Human-Induced Regeneration (HIR), and Native Forest from Managed Regrowth (NFMR) methods are the only methods that have enabled ACCUs to be issued by sequestering carbon in the regeneration of native forests[10], and together account for 31% of all ACCUs issued from inception of the program to October 2023. The adoption of these methods has been geographically constrained, with over 90% of the ACCUs issued located in the semi-arid Mulga Lands and Cobar Peneplain bioregions of far west New South Wales and southwest Queensland (Clean Energy Regulator, 2023c; Evans, 2018), as illustrated by the green shading in **Figure 5.6**5.6b. These areas are considered to have inherently low agricultural productivity (Bowen & Chudleigh, 2021) and are characterised by Mulga (*Acacia aneura*) dry forest ecosystems that are typically re-cleared on a 15-year cycle to maintain pasture for low intensity grazing (Evans, 2018).

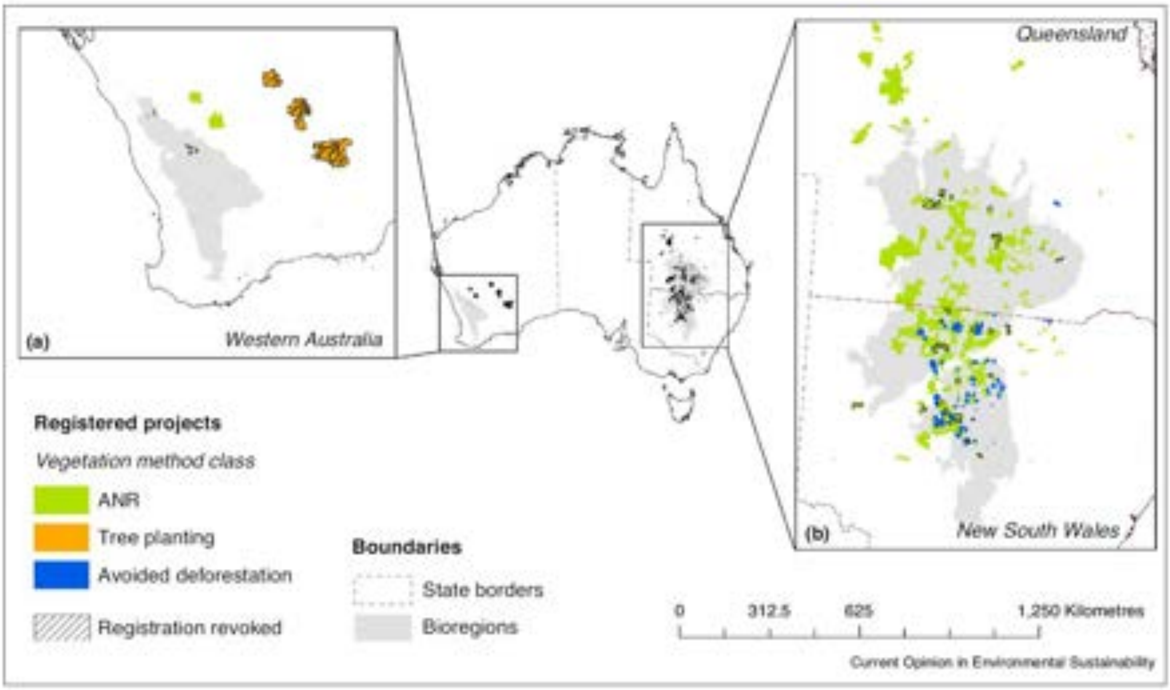

Figure 5.6. Distribution of vegetation projects (broken down by method class: ANR, tree planting, and avoided deforestation) registered under Australia's ACCU Scheme up until 2018. Specifically, exert (b) indicates that the majority of ANR projects (green zones) are located in the Mulga Lands bioregion crossing the Queensland state border, and the Cobar Peneplain bioregion south of the border in the state of New South Wales (Evans, 2018).

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[10] For these methods the term 'native forest' is determined to be native trees more than 2m tall with a crown cover of 20% or more.

A property's relative productivity can be conveyed based on its long-term carrying capacity (LTCC), which defines the number of livestock (measured as total adult equivalents - AE) that it can support without causing land degradation (The Long Paddock, 2023). The LTCC of rural properties across Queensland can be determined based on modelling undertaken using the FORAGE[11] tool developed by the Queensland Government (The Long Paddock, 2023). This has been used to compare the LTCC a property currently generating ACCUs using the HIR method in southwest Queensland to one located in an area of higher agricultural value (the Wide Bay-Burnett region of Queensland). The details of this assessment are outlined in Table 5.3.

Table 5.3. Long-term carrying capacity of projects implementing HIR activities in two regions of Queensland (Clean Energy Regulator, 2023c; The Long Paddock, 2023)

Property Location, Postcode	State Region	ERF Project ID	Assessment Area (ha)	LTCC (AE)	Grazing Area / AE (ha)
Quilpie LGA, 4480	South-West	ERF101800	12,562	144	87.2
North Burnett LGA, 4630	Wide Bay–Burnett	ERF141164	4,660	733	6.4

The property located in South-West Queensland requires 87.2 ha/AE to maintain productive pasture, while the property in the more productive Wide Bay-Burnett region needs only 6.4 ha/AE. That is, the Wide Bay-Burnett property is 13 times more productive than southwest Queensland. ANR project methods have only been implemented at scale in low productivity areas where the revenue gained from generating ACCUs from vegetation restoration is comparable with or exceeds the opportunity cost of forgone grazing income. Low productivity areas have lower carbon sequestration potential than higher productivity areas. Chubb (2022) also expressed concern about the integrity of some ANR projects in these arid landscapes.

There has also been minimal uptake of Plantation Forestry Project Methods, with ACCUs from these activities responsible for less than 1% of the total generated using vegetation-based methods (Clean Energy Regulator, 2023c). ACCU methods have had little impact on arresting the decline of the national plantation estate. Since the establishment of the initial version of the Plantation method in 2014, the total plantation estate area has fallen by 13% (257.36 kha), with very few new plantings being established (14.4 kha), as illustrated in Figure (ABARES, 2023b). Additional revenue created through the generation of ACCUs has not been sufficient to encourage new investment in plantations in the face of their poor financial performance given the high opportunity costs of 25 to 30 years of forgone grazing or cropping income (Venn, 2023). This suggests that the existing methods within the ACCU Scheme are not providing sufficient incentives to encourage large-scale

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[11] FORAGE is an online system that generates and distributes, in customised PDF reports, information for rural Lots on Plan greater than 1 hectare in area. FORAGE incorporates a number of products such as SILO climate data, satellite imagery and modelled pasture growth, to help decision-making in grazing land and environmental management.

vegetation-based carbon sequestration in planted forests to secure domestic supplies of harvested wood products.

There is currently no method that awards ACCUs to landholders who sequester carbon through the regeneration of native regrowth forests managed for sustainable timber production. The development of such a method has the potential to overcome the impediments that have limited the effectiveness of existing vegetation-based ACCU methodologies to encourage the expansion of native and plantation forests on private land, and increase domestic timber production. Further description of the need for a native forestry ACCU method is provided in Section 5.7.

5.6 Concerns About ACCU Methods Prioritised by the Federal Government for Development in October 2024

In October 2024, the Federal Government announced it had agreed to prioritise four new proponent led ACCU methods (https://www.dcceew.gov.au/about/news/priorities-accu-scheme-proponent-led-method-development-announced, accessed 13 November 2024):

1. Improved native forest management (INFM) in multiple-use public forests;
2. Improved avoided clearing of native regrowth (IACNR);
3. Extending savanna fire management to the northern arid zone; and
4. Reducing disturbance of coastal and floodplain wetlands by managing ungulates.

Methods 1 and 2 are relevant to commercially important native forests and are discussed below. Although publicly available information about the proposed methods is scarce, concerns are described below based on the limited information available.

INFM was proposed by the NSW Government Department of Climate Change, Energy, the Environment and Water to incentivise government forest management agencies to deliver carbon abatement by not harvesting native forests or lengthening the rotation. This method has not been designed for application to private native forest. The Emissions Reduction Assurance Committee (2024) indicated *there are complex matters that would require careful consideration if the proposal were prioritised for development including establishing a high integrity baseline harvest scenario* [to estimate additionality] *and developing protocols to monitor and address leakage from project activities* (https://www.dcceew.gov.au/sites/default/files/documents/proponent-led-method-development-2024-eoi-assessment-summaries.pdf, accessed 26 November 2024)). It appears that all additional carbon sequestered under this method will be in the forest and thus exposed to climate change, drought, wildfire and cyclone risk.

To ensure INFM delivers additional emissions abatement, all the limitations of FullCAM and NCAS described in Section 4.3 need to be clearly addressed, and convincing evidence produced to support the method.

IACNR was proposed by the Queensland Government Department of Environment, Science and Innovation to incentivise retaining regrowth at high risk of re-clearing. It will be focussed on regrowth native forests up to 25 years in age on land where landholders have a right to re-clear the regrowth. In higher rainfall areas, this regrowth will include commercially important forest types. It is not clear exactly how this proposed method has been improved over the discontinued Avoided Deforestation method. It is also unclear what incentives may be included relative to discontinued vegetation management methods (Human-Induced Regeneration and Native Forest from Managed Regrowth) being incorporated into the (yet to be released) Integrated Farm and Land Management method to overcome the lack of interest in these methods from landholders because of the high opportunity costs of participation outside the low-productivity arid and semi-arid zones. For example, will selection timber harvesting be permitted? Please see Sections 5.4 and 5.5 for a description and evaluation of the discontinued vegetation-based ACCU methods.

5.7 The Need for a Native Forestry ACCU Method

Evidence presented in this chapter on more than a decade of carbon market evidence and spatial analysis of continuing high rates of re-clearing reported in Chapter 7 suggests that, at current prices, the available suite of ACCU methods do not provide sufficient returns on investment to overcome the high opportunity cost of regenerating native forests and the direct costs of establishing plantation forests on relatively productive agricultural land. The failure of existing ACCU methods to overcome the opportunity cost of native forest regrowth is largely due to:

a) carbon income streams from regrowth only continuing until the 100-year average additional (compared to business as usual) carbon stock level is reached, which is typically within 15 to 25 years; and

b) the prohibition of thinning and timber harvesting, which will reduce livestock production to effectively zero as the regrowth ages.

The dominant land use in regions with commercially important native forest regrowth is livestock grazing. Existing native vegetation ACCU methods will decrease the medium and long-term income earning potential of a farm. Lower farm income streams will be capitalised into lower property values, particularly in areas where there is not strong demand for ‘rural lifestyle’ blocks. The business case for existing native vegetation ACCU methods in relatively productive agricultural landscapes is poor.

The limited information available about proponent-led INFM and IACNR ACCU methods prioritised for development by the Federal Government in October 2024 indicates they are not applicable to private forests or are incompatible with landholder opportunity costs and interests to maintain or improve the profitability of their business. Therefore, these methods in-development are unlikely to incentivise retention of commercially important private native forest regrowth in NSW and QLD.

In contrast, there is increasing evidence that silvopastoral systems, which produce timber and livestock income streams from the same unit of land, generate higher farm income in the long-run than either grazing or forestry on their own (Ryan and Taylor, 2006; Francis et al., 2020; Venn, 2020; Francis et al., 2022; Lewis et al., 2022; Venn et al., 2022). In addition, they represent a substantial opportunity for carbon sequestration (please see modelling in Chapter 8), increase farm income diversification, increase farm resilience to drought and climate change, and reduce Australia’s impacts on international forests.

Assuming a timber mean annual increment (MAI) of 1.3 m^3/ha/y and an average stumpage price of \$120/m^3, a selection harvest timber income stream equivalent to about \$3100/ha every 20 years is possible, with the first harvest when the regrowth reaches about 25 to 40 years (depending on site quality). However, the opportunity cost of foregone grazing income cannot be overcome until trees reach merchantable size and income from timber can complement livestock earnings. This opportunity cost could be overcome by the addition of a carbon income stream facilitated by a native forestry ACCU method, which would encourage retention of regrowth as silvopastoral systems and expand forest cover in agricultural landscapes while improving the financial performance of agribusinesses.

In 2024, Forestry Australia submitted a proponent-led method to Federal Government for review, entitled Enhancing Native Forest Resilience (ENFR), but it was not prioritised for development. ENFR can include management of commercially important private native forests regrowth for timber production. The method aims to restore forests across all land tenures to improve habitat values, carbon stocks and resilience to droughts, wildfires and climate change through a broad suite of active and adaptive management activities including assisted regeneration, cultural and prescribed fire, thinning for ecological and cultural values, protecting old and big trees, weed and feral animal control, and improved utilisation of forest products. This method has the potential to develop a diversified carbon portfolio that is less exposed to climate change, drought, wildfire and cyclone risk than INFM and IACNR. For example, this method will encourage storage of carbon off site in wood products for decades in use, and then in landfill after use. The harvest of wood products provides growing space for the forest to sequester more carbon, and facilitates permanent displacement of emissions from avoided consumption of substitute domestic and imported wood products, and non-wood products with high embodied carbon emissions (e.g. steel, concrete, plastic and carpet).

However, sovereign risk has constrained private investment in native forestry activities (Venn, 2023). For instance, in Queensland, where privately owned native forests supply over 50% of the state's native hardwood timber, there have been 40 amendments to vegetation management laws since 2000 (AgForce, 2021). This has resulted in landholders exhibiting a severe lack of trust in the Queensland Government (Brown et al., 2021), discouraged investment in forest management and caused periods of expedited planned and unplanned clearing to generate less risky income streams from cattle or cropping (Queensland CRA/RFA Steering Committee, 1998a, 1998b; Bureau of Rural Sciences, 2004; Dare et al., 2017; Simmons et al., 2018; Downham et al., 2019; Francis et al., 2020a). Addressing sovereign risk will be crucial to provide landowners with assurance that they can realise future benefits of investing in regenerating and managing native regrowth forests.

6. Description of the Private Native Forest Regrowth Resource in Queensland and New South Wales Based on Existing Literature

Tom Lewis and Tyron Venn

6.1 Aim

The aim of this chapter was to describe the private native regrowth forest resources in Queensland and NSW Forestry Hub regions using existing literature. Specifically we aimed to summarise information on forest types, silvicultural condition, growth rates, forestry potential and limitations regarding the available information. Chapter 7 will present a contemporary analysis of regrowth extent in the hub-regions and changes in regrowth extent over time.

6.2 Queensland Forest Types and Extent Based on Earlier Studies

Private native forestry in Queensland is regulated by the 'Managing a native forest practice accepted development vegetation clearing code' (NFP ADVCC). Some of the forest regulated by the NFP ADVCC is considered regrowth, e.g. Category C vegetation (https://www.cabinet.qld.gov.au/documents/2009/sep/vegetation%20mgt%20amendment%20bill%202009/Attachments/regrowth%20vegetation%20code.pdf), which includes (a) regional ecosystems that are either 'endangered', 'of concern' or 'least concern'; (b) areas that have not been cleared since 31 December 1989; and (c) areas shown on a Queensland Government regrowth vegetation map. However, most private native forest regrowth in Queensland is referred to as 'Category X' regrowth, which is not regulated by the NFP ADVCC. This regrowth is of most interest to the current project, as it is regrowth that can be re-cleared by a landholder. Hence the greatest potential to sequester carbon in privately owned native forest in Queensland is in areas mapped as Category X. Incentives are needed to ensure landholders retain Category X forest in the landscape (e.g. carbon methodologies that consider native forest timber management). Lewis et al. (2022) discussed the potential of such regrowth forests to be managed as silvopastoral systems.

Regional ecosystems have been mapped in Queensland using a combination of satellite imagery, aerial photography and on-ground investigation (see: https://www.qld.gov.au/environment/plants-animals/plants/ecosystems/about). Regional ecosystems are the vegetation communities in an area (bioregion) that are consistently associated with a particular combination of geology, landform and soils. The regional ecosystem mapping provides a reference for the likely forest types at a site. Regional ecosystems can be categorised into different 'broad vegetation groups' (BVGs), at different scales (https://www.qld.gov.au/environment/plants-animals/plants/ecosystems/broad-vegetation). A study by Lewis et al. (2020) reported the five most common potentially harvestable (under the current NFP ADVCC) private native forest types, based on broad vegetation groups (BVGs; Neldner et al. 2017). These are listed in Table 6.1. The study region of the

Lewis et al. (2020) study was broadly equivalent to the south and central Queensland Forestry Hub region (the South and Central Queensland Forestry Hub region extends a little further north and west of the region that was considered by Lewis et al. (2020)). Spotted gum forests and woodlands were the most common vegetation types, representing 34.5% of private native forest in the region. It was estimated that there was around 2.1 million ha of potentially harvestable private native forest in this region, of which around 30% were mapped as regrowth forest (Lewis et al. 2020).

Table 6.1. The most common broad vegetation groups that were potentially harvestable ecosystems (under the current NFP ADVCC) in the southern Queensland study region adopted by Lewis et al. (2020) and based on the broad vegetation grouping (BVG) mapping of Neldner et al. (2017).

Potentially harvestable forest type	Area	% of area
Corymbia citriodora (spotted gum) dominated open forests to woodlands on undulating to hilly terrain (BVG 10)	715,900	34.5
Dry to moist eucalypt woodlands and open forests, mainly on undulating to hilly terrain (BVG 13)	637,300	30.8
Moist to dry eucalypt open forests to woodlands usually on coastal lowlands and ranges (BVG 9)	235,500	11.4
Dry eucalypt woodlands to open woodlands, mostly on shallow soils in hilly terrain (BVG 12)	219,500	10.6
Eucalyptus spp. dominated open forest and woodlands drainage lines and alluvial plains (BVG 16)	123,700	6.0
Other forest types (BVGs 8, 11, 15, 17, 18 and 22)	140,100	6.8
Total	2,072,000	100

Across the State of Queensland, private native forest extent is estimated to be 14.2 M ha (ABARES, 2022) of which 9.7 million ha were native eucalypt forest, representing 27.7% of native eucalypt forest in Queensland according to the State of the Forest Report mapping (Montreal Process Implementation Group for Australia and National Forest Inventory Steering Committee, 2018). Although approximately 91% of this was greater than 10 m in height, it is not clear what proportion of the total Queensland private native eucalypt forest area contains commercially important forest. State and private native forests outside the southern Queensland region defined by Lewis et al. (2020) accounted for 11% of the total native forest harvest in Queensland in 2021, and only 6.7% of hardwood mill throughput (BDO EconSearch, 2022, 2023a). This suggests there are substantial resource, market and other impediments to native forestry outside the South and Central Queensland Forestry Hub region.

Using the regional ecosystem mapping, the vegetation at a site can also be more broadly categorised into commercial forest types. These are forest types that may contain species that are valued for the timber products they produce. The key eucalypt-dominated commercial forest types in the southern and central Queensland have been classed by Lewis et al. (2020) and Francis et al. (2023) as:

- **Moist tall** forests, with dominant species including *Eucalyptus pilularis* (blackbutt), *E. grandis* (flooded gum), *E. saligna* (Sydney blue gum), *E. acmenoides* (white mahogany), *E. cloeziana* (Gympie messmate), *Syncarpia glomulifera* (turpentine).
- **Mixed hardwood** forests, with dominant species such as *E. propinqua* (grey gum), *E. siderophloia* (grey ironbark), *E. acmenoides* (white mahogany).
- **Spotted gum** forests, with dominant species including *Corymbia citriodora subsp. variegata* and *citriodora* (spotted gum), and *E. crebra* (narrow-leaved ironbark).
- **Queensland blue gum** forests with common species including *E. tereticornis* (Queensland blue gum / forest red gum), E. crebra (narrow-leaved ironbark), *E. siderophloia* (grey ironbark).
- **Gum-topped box** forests with *E. moluccana* (gum-topped box) as the dominant species.
- **Ironbark** forests with dominant species including *E. fibrosa* (broad-leaved red ironbark), *E. crebra* (narrow-leaved ironbark), *E. decorticans* (gum-topped ironbark), *E. siderophloia* (grey ironbark).

As indicated in Table 6.2, the South and Central Forestry Hub region has 1.89 M ha of harvestable commercially important forests. The remaining forest types in the region, including 204,700 ha that are harvestable under the NFP ADVCC (but not considered commercially important by industry), are referred to as non-commercial forest types. Of the commercial forest types, spotted gum forests and ironbark forests are the most common in southern Queensland, each contributing around 30% of harvestable private native forests (Figure 6.1, Table 6.2, Lewis et al. 2020; Francis et al. 2023). The regional ecosystems associated with each commercial forest type are listed in Lewis et al. 2020, Appendix 4). The commercial forest type classification was based on a simplified classification of commercial forest types developed by Private Forestry Service Queensland (PFSQ), which contained 19 commercial native forest types for southern inland and south east Queensland (PFSQ 2015; https://www.pfsq.org.au/resources/) that are meaningful to the timber industry and landholders.

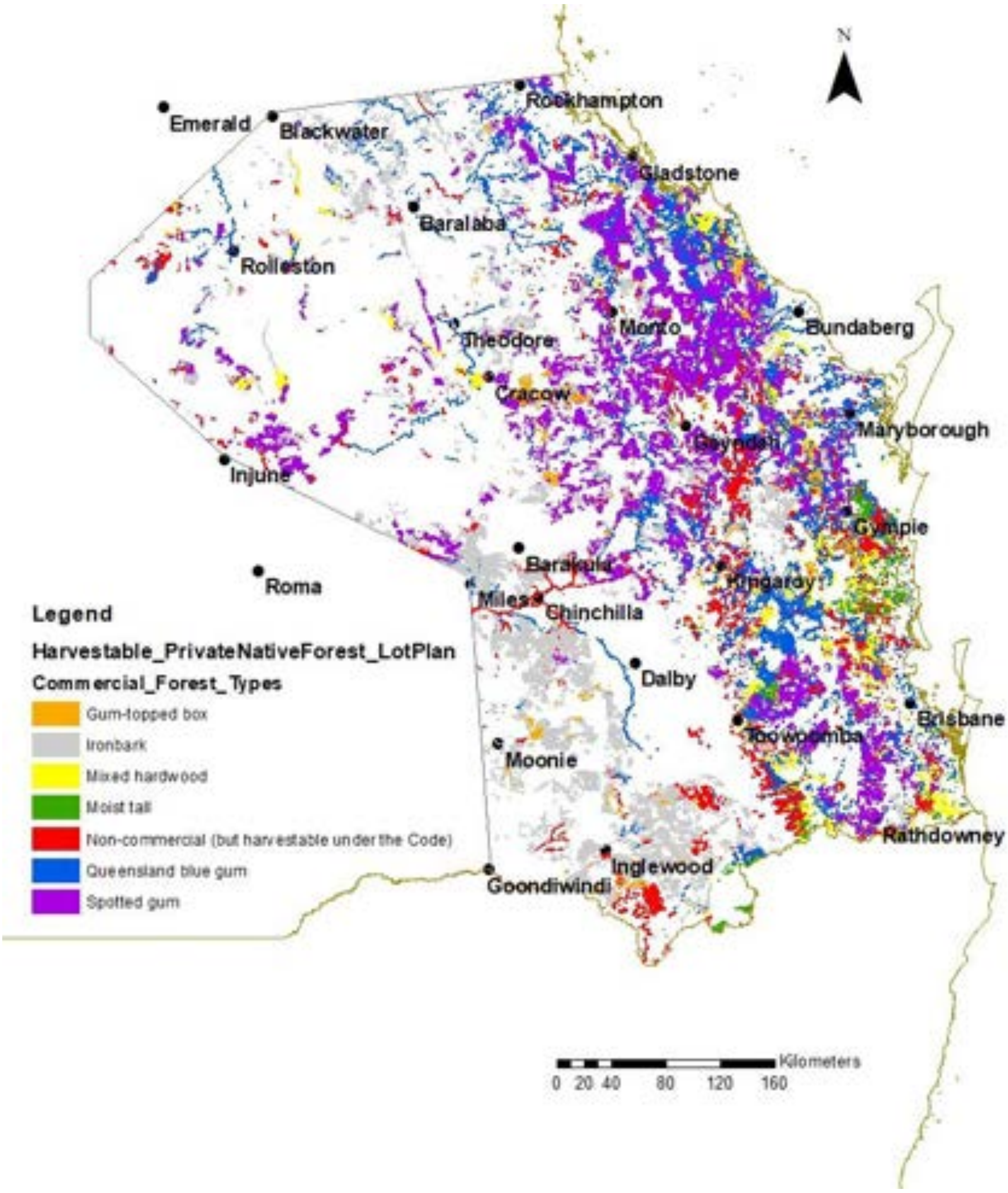

Figure 6.1. The spatial distribution of commercial private native forest based on the study area defined in Lewis et al. (2020) in the Queensland. Source: Lewis et al. (2020), Francis et al. (2023).

Table 6.2. Area of commercially important private native forest types, based on the Lewis et al. (2020) study area (see Figure 6.1) that partially covers the South and Central Queensland Forestry Hub region, and the BDO EconSearch (2022) assessment of QLD DAF Central and Northern Supply Zones, which partially covers the North Queensland Forestry Hub region.

Forest type	Lewis et al. (2020) ~S & C QLD Forestry Hub region harvestable area (ha)[b, c]	BDO EconSearch (2022) ~ N QLD Forestry Hub region harvestable area (ha)[b, c]	Total area (ha)
Moist tall	33,400	1,400	34,800
Mixed hardwood[a]	159,600	84,100	243,700
Spotted gum	693,000	109,600	802,600
Queensland blue gum	253,300	131,400	384,700
Gum-topped box	105,600	25,500	131,100
Ironbark	641,500	763,500	1,405,000
North eastern hardwoods		26,700	26,700
Savanna woodlands		18,300	18,300
Total	1,886,400	1,160,500	3,046,900

Notes:

a The mixed hardwood forest type is so named because relative to the other forest types: (i) the number of commercially important canopy species on any hectare is higher; (ii) the most common commercial species on any hectare varies considerably throughout the study area; and (iii) the relative frequency of the most common commercially important canopy species on any given hectare is lower than in the other listed forest types. The dominant species listed are the three most common in this forest type; however, there are at least 14 additional commonly associated commercial species in this forest type.

b Total forest area of each forest type excluded areas with slopes exceeding 25 degrees and was reduced by an additional 6.2% to account for stream buffers.

c Hectares refer to potentially harvestable areas available according to the NFP ADVCC. These are estimates of potentially harvestable forest only and do not reflect actual areas harvested.

Table 6.2 also provides an estimate of the commercially important private native forest area in north Queensland. This was based on work performed by BDO EconSearch (2022) with forest data provided by the Queensland Department of Agriculture and Fisheries (DAF) for the DAF Central and Northern Supply Regions. Two additional eucalypt forest types have been added to the list: savannah woodlands (with dominant species such as *Eucalyptus tetrodonta* (Darwin stringybark), *Corymbia nesophila* (Melville Island bloodwood), *C. clarksoniana* (grey bloodwood)); and northern mixed hardwood forests, which are similar to the moist tall forests in southern Queensland, with dominant species such as *Eucalyptus resinifera* (red mahogany), *E. acmenoides*, *C. intermedia*, *E. tereticornis*, *Syncarpia glomulifera*, *E. grandis*, *E. drepanophylla* (grey ironbark), and *E. pellita* (large-fruited red mahogany)). Cypress pine (*Callitris glaucophylla* (white cypress pine) or *C. intratropica* (northern cypress pine)) dominated forests are also important to the timber industry in Queensland. Cypress pine dominated REs may be classified as a separate forest type, but has not been reported here. Mixed cypress and eucalypt forest REs were included in the ‘ironbark’ commercial forest type in Figure 6.1 and Table 6.2.

The North Queensland Forestry Hub region also includes Cape York Peninsula (CYP), but this area was not considered by BDO EconSearch (2022). Hence, the estimate of commercially important private native forest in the North Queensland Forestry Hub region is likely to be an underestimate. Timber resources on CYP, particularly the Darwin stringybark (*Eucalyptus tetradonta*) forests, have long been recognised by the Queensland Government as the largest timber resource in Queensland with potential to substantially contribute to future timber supplies (Wannan, 1995). Darwin stringybark forests cover 1.9 M ha of CYP, and 1.7 M ha of these forests were outside national parks in the early 1990s (Wannan, 1995). Nevertheless, with the exception of operations by the Australian and United States Air Forces during World War II, large-scale sawmilling has never been attracted to the region. There have been ‘on-again’, ‘off-again’ small-scale native forest milling operations in several indigenous communities since at least the 1950s (Venn, 2004a, 2004b). In the 2000s, small-scale commercial milling of timber from mining leases was performed by the Nanum Tawap sawmill, which processed up to 1600 m^3/y before closing in 2012 due to resource insecurity, and Wik Timber commenced salvage harvesting operations ahead of mining in 2018 (Annandale et al., 2021). However, large volumes of commercial logs continue to be windrowed and burned every year prior to bauxite mining.

6.3 New South Wales Forest Types and Extent Based on Earlier Studies

In the State of NSW, Combe et al. (1998) estimated the private native forest estate included 6.83 million ha of medium open eucalypt forest (10-30 m in height) and 672,000 ha of tall open eucalypt forest (heights >30 m). These figures conflict somewhat with more recent estimates; the State of the Forest Report (Montreal Process Implementation Group for Australia and National Forest Inventory Steering Committee, 2018) reported 5.58 million ha of privately owned eucalypt forest across the state of NSW, 70% (3.9 M ha) of which is medium open forest.

Most published information on private native forest extent in NSW is relevant to the North East Forestry Hub region. Few studies on private native forests in southern NSW were found for this review, despite the importance of forestry in the region. However, there is less privately owned forest in southern NSW, relative to the north of the state. For example, Parsons and Pritchard (2009) reported that in the Eden region of southern NSW, 23% (125,000 ha) of forest was privately owned and in the Southern NSW Comprehensive Regional Assessment region, private native forest area was 34% (819,000 ha) of the total native forest area. In contrast, in the Upper and Lower North East regions (equivalent to the North East Forestry Hub region) 55% (1,193,000 ha) and 43% (1,435,000 ha) of the native forest area was privately owned (Parsons and Pritchard 2009). This included 56% of the dry spotted gum/blackbutt, 50% of the dry sclerophyll and 46% of the dry tableland associations (Ryan et al. 2002).

Jay (2017) reported the most common species based on 840 private native forest plots in North East NSW. The ten most common commercial species encountered in order of decreasing frequency were spotted gum (*Corymbia. maculata*), pink bloodwood (*C. intermedia*), white mahogany (*Eucalyptus acmendioides* or *E. umbra*), messmate (*E. obliqua*), blackbutt (*E. pilularis*), tallowwood (*E. microcorys*), grey gum (*E. propinqua* or *E. punctata*), ironbarks (Eucalyptus species grouped), and forest red gum (*E. tereticornis*).

The Upper North East Comprehensive Regional Assessment region (https://datasets.seed.nsw.gov.au/dataset/og-fe-crafti-cra-une) mapped the distribution of old-growth forest ecosystems that were privately owned. While this was not regrowth, the mapping does provide an indication of the privately owned forest types in north-eastern NSW, as reported in Table 6.3.

Table 6.3. Old growth forest types of the Upper North East Comprehensive Regional Assessment region of NSW.

Forest type	% of private native forest	Area of forest (ha)
Blackbutt-moist	2	13,160
Blackbutt-dry	8	71,724
Flooded gum	1	8,369
Brushbox	2	14,199
Moist coastal eucalypts	6	50,402
Semi-moist and taller dry eucalypts	13	110,576
Spotted gum - moist	1	4,897
Spotted gum - dry	19	166,213
Dry sclerophyll and woodlands	21	178,769
Tableland eucalypts-moist	11	91,132
Tableland eucalypts-dry	9	74,928
Tablelands stringybarks	9	76,960

More recently, the north coast NSW yield association groups (YAG) reported by NSW Department of Primary Industries (2018, https://www.dpi.nsw.gov.au/__data/assets/pdf_file/0004/849199/YAG-classification-guide-and-mapping-accuracy-report.pdf) also mapped private native forest. The yield association groupings are reported in Table 6.4. Definitions of these YAGs are provided in NSW Department of Primary Industries (2021b Appendix A). The YAG mapping utilised LiDAR, climatic, soil type, Sentinel and topographic variables to develop a model of yield groups. Overall accuracy (% of cases correctly allocated) was predicted to be 65.1% (NSW Department of Primary Industries 2021b).

Lewis et al. (2020) also reported on forest types in north-east NSW, based on an earlier version of the YAG data supplied by NSW Department of Primary Industries. The area of this study extended from the Queensland border, south to Coffs Harbour and to just west of Glen Innes, covering an area of 3.9 M ha. The total private forest area in this region was 1,020,800 ha. Estimates suggested there were approximately 525,600 ha of potentially harvestable private native forest in this north-eastern NSW region, after excluding rainforest vegetation and areas considered to be non-commercial or low productivity. Dry eucalypt forests and woodlands, including those dominated by spotted gum, were common, making up more than 49% of the potentially productive private native forests in the region, as reported in Table 6.5. The proportion of these forest types that are regrowth forests was not reported.

Table 6.4. Forest yield association groups of the north coast region of NSW. NSW Department of Primary Industries (2018).

Yield Association Group	% of private native forest
Rainforest	9
Viney scrub	3
Moist coastal eucalypts	8
Blackbutt	1
Semi-moist and taller dry eucalypts	20
Spotted gum	6
Dry sclerophyll forest	28
Swamp sclerophyll	3
Tableland eucalypts - moist	11
Tablelands eucalypts - dry	11

Table 6.5. Common forest types in potentially harvestable private native forest in northern NSW. Source: Lewis et al. (2020).

Potentially harvestable forest type	Area (ha)	% of area
Semi-moist and tall dry eucalypt forest	109,800	20.9
Dry eucalypt forest and woodland	104,500	19.9
Dry eucalypt forest and woodland occurring on the tablelands	90,300	17.2
Dry eucalypt dominated by spotted gum	64,800	12.3
Semi-moist eucalypt forest occurring on the tablelands	46,900	8.9
Other, mixed forest types (6)	109,300	20.8

The New England - North West Forestry Investment Group (2002) and McDonald and Brandis (2001) reported potentially large areas of privately owned regrowth in the New England region of NSW. They reported an area of 154,000 ha of potentially productive private forest in a 100 km radius of Walcha.

6.4 Forestry Potential of Private Native Forest in Queensland

6.4.1 Silvicultural Condition

Lewis et al. (2020) reported there were approximately 2,091,000 hectares of potentially harvestable private native forest in the Queensland study region (extending from the NSW border to Rockhampton and west to Injune, which is representative of the South and Central Queensland Forestry Hub Region). Across all plots measured (284 plots) in private native forest in that study, average stocking was 268.6 (± 7.36) stems per hectare and average basal area was 14.4 (± 0.45) m^2/ha. A large proportion of trees were considered unmerchantable, particularly in the 10–20 cm DBH class. Regrowth forests had a particularly high stocking in the 10–20 cm DBH class, where approximately 76% of stems were assessed as unmerchantable, as indicated in Figure 6.2. Unsurprisingly, regrowth forests had a lower density of trees in the larger size classes (30 cm plus DBH, Figure 6.2) relative to remnant forest, reflecting their previous clearing history. The private native forest inventory plots used in the analysis by Lewis et al. (2020) showed that this resource is in poor productive condition, with a high proportion of unmerchantable trees.

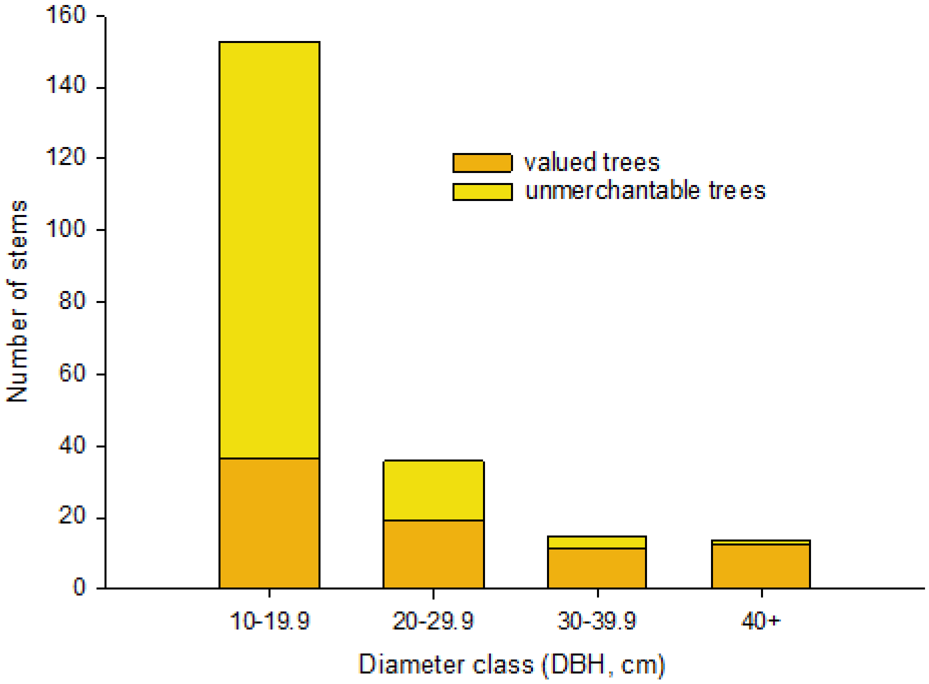

Figure 6.2. Stocking in regrowth private native forests in southern Queensland (stems / ha) in different size classes. Different coloured bars represent the stems that are valued (for current or future timber resource, or required for environmental purposes) or were considered unmerchantable, and would ideally be thinned to improve productivity of the retained stand. Source: Lewis et al. (2020).

MBAC Consulting Pty Ltd (2003a) estimated the average total standing volume of all commercial log types in private native forests of the SEQ region (a region extending from the NSW border, north to Gladstone and west to Toowoomba) to be 20.4 m^3/ha; however, 63% of this volume was small rounds and fence posts, with only 7.5 m^3/ha being conventional log volume (compulsory and optional sawlogs, poles and girders). This is consistent with the estimated merchantable volume for the south-east Queensland sub-region (Lewis et al. 2020 study) of 24.6 (± 2.58) m^3 for trees with any potential product with a DBH of ≥ 30 cm. Volumes in western and central Queensland are likely much lower. MBAC (2003b) reported estimated volumes in private native forest in the Western Hardwoods region of Queensland – a large region extending from the NSW border to Charters Towers in the north, and from Gladstone and Toowoomba in the east to Charleville in the west. They reported a recoverable volume (including sawlogs, poles, piles, small rounds and fencing material) to be 14.2 m^3/ha for this region. The volume of sawlogs and poles/piles was estimated to be 3.1 m^3/ha, with 2.8 m^3/ha being sawlogs (compulsory and optional). In the western region of the Lewis et al. (2020) study, potentially merchantable volumes of 5.8 m^3/ha on trees with a DBH ≥30 cm were reported. Assuming that 36% of this is sawlog (based on MBAC 2003b) this suggests around 2.1 m^3/ha would be available for sawmills in this region (which is similar to the MBAC 2003b estimated for the Western Hardwoods region). In the Wide Bay-Burnett sub-region of the Lewis et al. (2020) study, potentially merchantable volumes of 20.3 m^3/ha on trees with a

DBH ≥30 cm were reported. This equates to around 6.3 m^3/ha of sawlog, assuming 31% of the merchantable volume is sawlog.

The MBAC Consulting Pty Ltd (2003a) study did investigate areas of non-remnant (I.e. regrowth) woody vegetation. They reported total areas of non-remnant woody vegetation of 180,000 ha of commercially available regrowth forest in the SEQ region. An average gross volume of 51.5 m^3/ha was reported for regrowth forest in this region with 17.4 m^3/ha considered potentially recoverable, and 5.3 m^3/ha considered sawlog. The MBAC Consulting Pty Ltd (2003b) study reported a total net area of non-remnant woody vegetation of 176,630 ha in the Western Hardwoods region, but this study did not report volumes for non-remnant woody vegetation.

6.4.2 Growth Rates

The Bureau of Rural Sciences (2004) estimated growth rates (mean annual increment, MAI) for private native forests based on modelling using plot data from State Forests. MAI estimates were provided for moist and dry forests for four product categories: (1) compulsory sawlogs; (2) optional sawlogs; (3) girders and poles; and (4) post, round and utility products. The MAI of all four product categories was estimated to be 0.8 m^3/ha/yr in moist forests and 0.33 m^3/ha/yr in dry forests.

Lewis et al. (2020) used data from 203 plots to assess growth rates of treated and untreated stands mostly dominated by spotted gum in the South and Central Queensland Forestry Hub region. Most of these plots were located on private land (158) and forty-five plots were located in State Forest. The private native forest plots were established between 2010 and 2014 with repeated measures between 2010 and 2017. Average volume growth rates of potentially merchantable timber in this assessment ranged from 0.35 (SE ±0.05) m^3/ha/yr in unmanaged stands in State Forest to 1.67 (SE ±0.17) m^3/ha/yr in silviculturally treated regrowth forest, with an average of 1.2 (SE ±0.07) m^3/ha/yr across all silviculturally treated plots. The Lewis et al. (2020) study reported that regrowth forest was growing at a significantly faster rate than remnant forest in Queensland. For example, in areas without recent silvicultural management, regrowth forest was growing at a rate of 0.37 cm per year in diameter at breast height (DBH) compared to just 0.16 cm DBH per year in remnant forest. In areas that had received silvicultural treatments, regrowth forest was growing at a rate of 0.95 cm (DBH) per year compared to 0.59 cm per year in remnant forest. As such the growth model (decision support tool) developed in the Lewis et al. (2020) study has separate growth functions for these different forest states. Regrowth forests are likely grow at a faster rate due to higher resource availability (sunlight, moisture, nutrients), and less competition amongst trees. It is well known that regeneration can become suppressed in remnant forests, where large trees slow the growth of trees beneath the canopy (Florence 1996).

Table 6.6 presents a consensus of experts regarding MAI of sawlog and pole volume in the six commercial forest types with and without silvicultural treatment (for details see Francis et al. 2023). Average growth rates in well-managed private native forests range from 0.6 m^3/ha/y in ironbark forests to 3.5 m^3/ha/y in moist tall forests. The reality is that very few private native forests in the South and Central QLD Forestry Hub region are managed and the weighted (by forest type) average MAI is about 0.26 m^3/ha/y (Francis et al. 2023).

The available literature and expert opinion have provided a range which reflects variation in site quality, historic management and species composition. These growth rates consider both remnant and regrowth forests, with regrowth forests expected to be at the 'high' end of the range in growth rates. Although there is little information available on private native forest growth rates in NSW, it is likely that they are similar to the levels reported in Table 6.6, at least for private forest in the north-east NSW hub region.

Table 6.6. Estimated mean annual increment (MAI) in the South and Central Queensland Forestry Hub region (Francis et al. 2023).

Forest type	Silviculture	MAI of stands (m^3/ha/yr)		
		Mean	Low	High
Moist tall	Untreated	1.7	0.50	3.0
	Treated	3.50	2.00	7.0
Mixed hardwood	Untreated	0.30	0.10	1.0
	Treated	1.30	0.50	4.0
Spotted gum	Untreated	0.30	0.05	2.0
	Treated	1.30	0.50	2.0
Blue gum	Untreated	0.30	0.20	1.0
	Treated	1.00	0.50	2.0
Gum-topped box	Untreated	0.15	0.05	0.4
	Treated	0.80	0.40	1.5
Ironbark	Untreated	0.15	0.05	0.4
	Treated	0.60	0.30	1.2

It should be noted that the MAI values reported in Table 6.6 are considered low relative to intensively managed, even-aged plantations, where volume growth of 10–35 m^3/ha/yr is possible (Florence 1996). The MAI of private native forests in Queensland is strongly influenced by the competitive influence of 'useless' stems that can be silviculturally thinned in managed forest (Table 6.6). Yields reported for different native forest types and plantations also vary according to markets for the products of the forest. Intensively managed even-aged forests incorporate sawlogs, pulpwood, mining timber, posts and poles. However, in extensively managed uneven-aged forest, the products are mainly sawlogs and poles.

6.5 Forestry Potential of Private Native Forest in New South Wales

6.5.1 Silvicultural Condition

In NE NSW, the NSW Department of Primary Industries (2019) modelled timber production values of private native forest. Approximately 10% of properties were predicted to have very high suitability for timber production, 60% of properties were predicted to have high suitability, 27% of properties had moderate timber suitability, while only 2% of modelled properties were considered to have low suitability. Further to this, the NSW Department of Primary Industries (2021a) reported on the suitability of private native forest for timber production in northern NSW based on harvestable area, distance to processing facilities, slope, terrain roughness, yield association group and forest site quality. They found that there were nearly ten thousand properties, covering 670,724 ha of native forest, identified as being available and suitable for private forestry. Over two thirds of the properties assessed had less than 50 ha of harvestable forest and were rated as ‘low’ suitability; these properties accounted for 187,077 ha or 28% of the total net harvestable area of 670,724 ha. Eight percent of properties were classified as ‘very high suitability’ with at least 200 ha of harvestable forest, which accounted for 35% of the total net harvestable area. The combined ranking, based on all variables considered found that 59% of properties (with 61% of the harvestable area) were of ‘medium’ suitability for private native forestry. Seventeen percent of properties (with 28% of the harvestable area) were found to have ‘high’ suitability and 22% of properties (with 11% of the harvestable area) had ‘low’ suitability for forestry (Figure 6.3).

NSW Department of Primary Industries (2022) mapped private native forest commercial and non-commercial extent using LiDAR data in both the NE and SE NSW Forestry Hub regions. This mapping showed strong agreement with reference data, with an overall accuracy of 86%. In the North Coast region where LiDAR data was available, there was 2,462,607 ha of private native forest, of which 54% (1,328,910 ha) was of commercial value (i.e. capable of producing logs that could be harvested by the forest industry) and the remaining 46% was considered non-commercial (Figure 6.4). In the South Coast region of NSW where LiDAR data was available, there was 1,066,741 ha of private native forest, of which 21.9% (233,466 ha) was of commercial value and the remaining 78.1% was considered non-commercial (Figure 6.5).

A study by Dare et al. (2017) investigated landholder attitudes to private native forest management in northern NSW. This study reported that 20% of landholders, managing 31% of the private forest area, were likely to harvest their forest in the next 10 years. Properties with larger areas of native forest (>50 ha) were more likely to have a commercial forest management focus and be actively managed. Despite this potential for timber production on private land, studies have shown that the silvicultural condition of private native forest in NSW is poor.

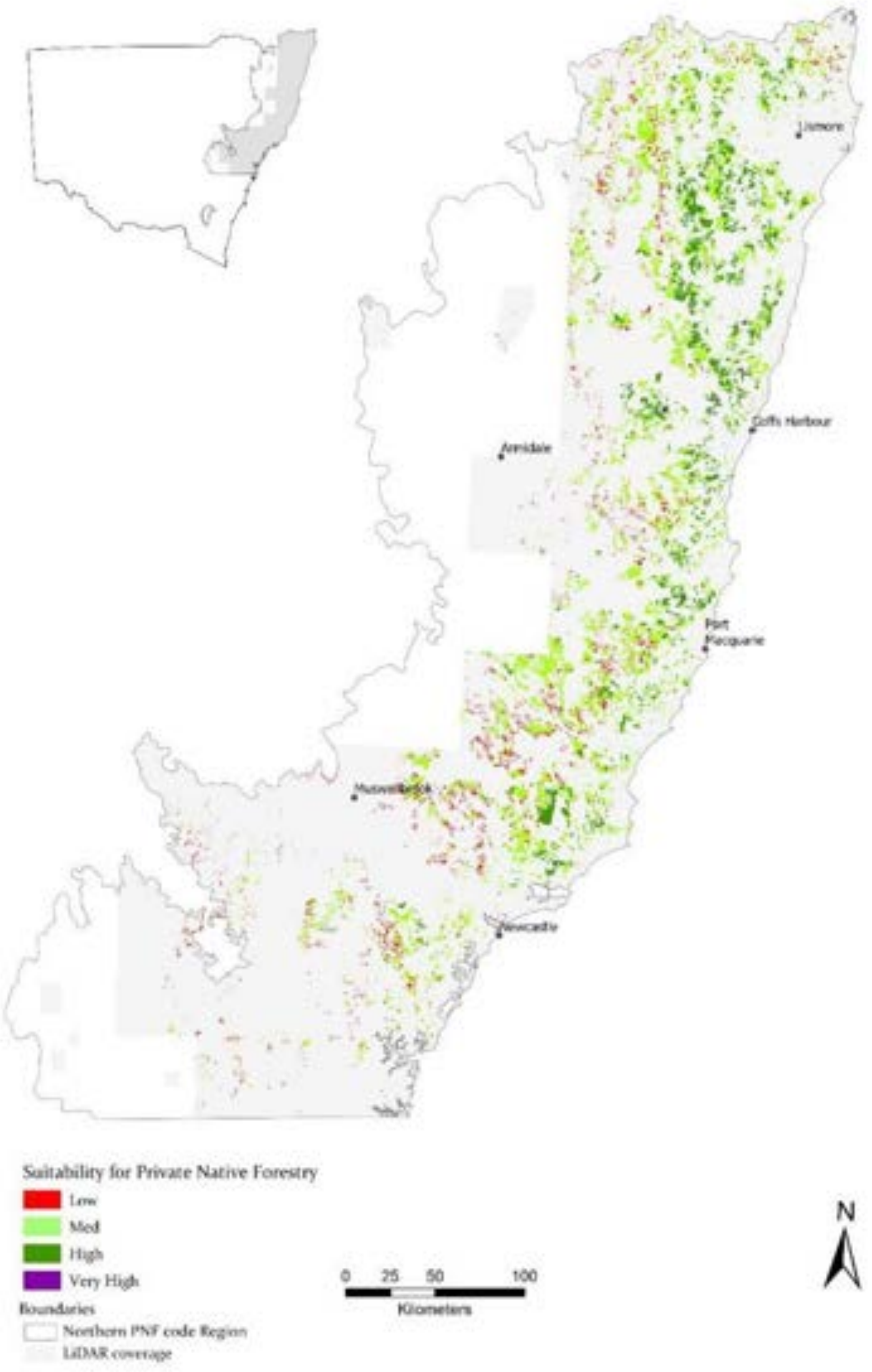

Figure 6.3. Suitability of private property for private native forestry in Northern NSW based on all model parameters (harvestable area, distance to processing facilities, slope, terrain roughness, yield association group and forest site quality). The grey shading represents the area with LiDAR coverage for analysis. Source: NSW Department of Primary Industries (2021a).

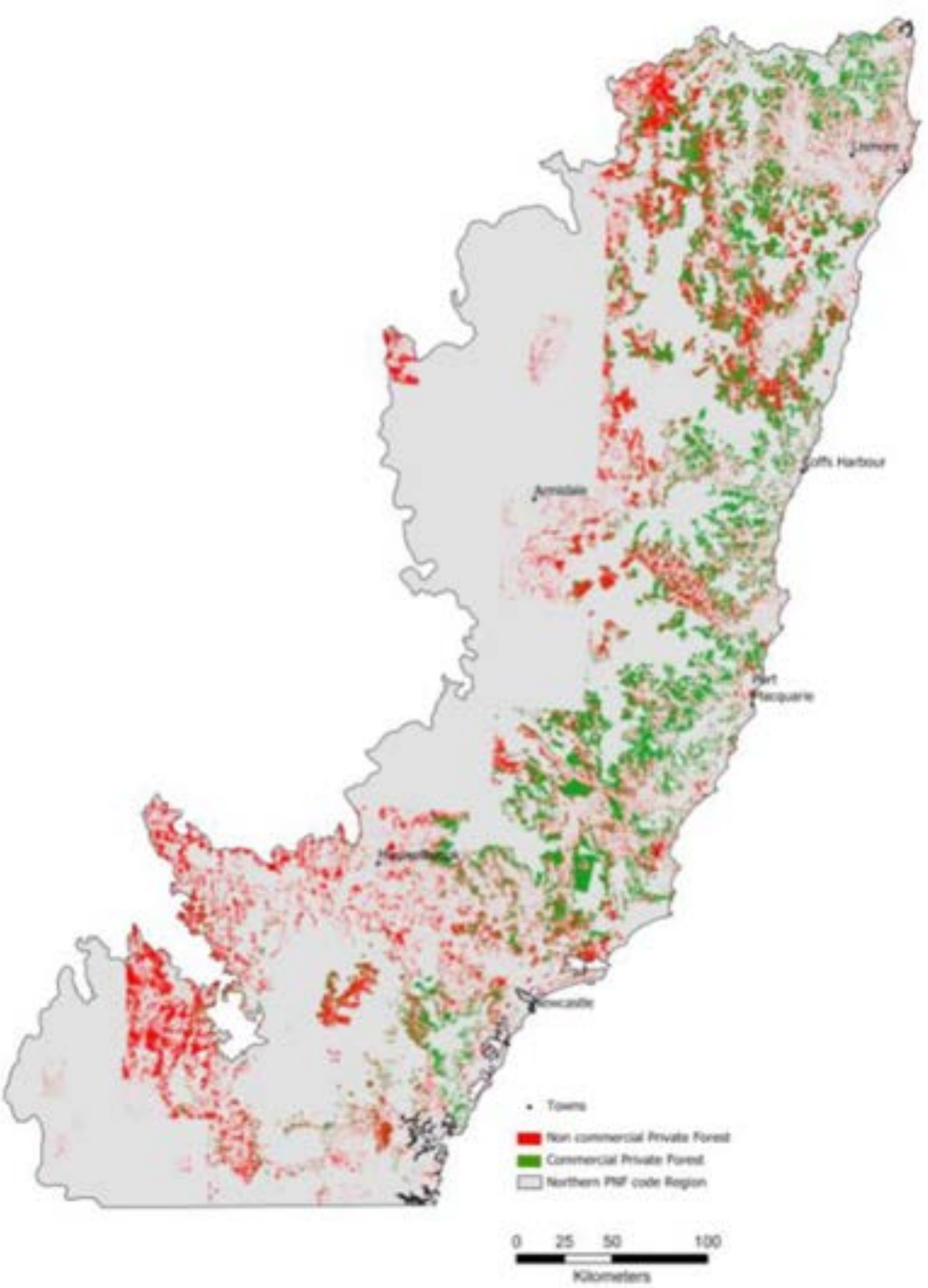

Figure 6.4. Map showing the commercial and non-commercial private native forest extent in the North Coast of NSW. Source: NSW Department of Primary Industries (2022).

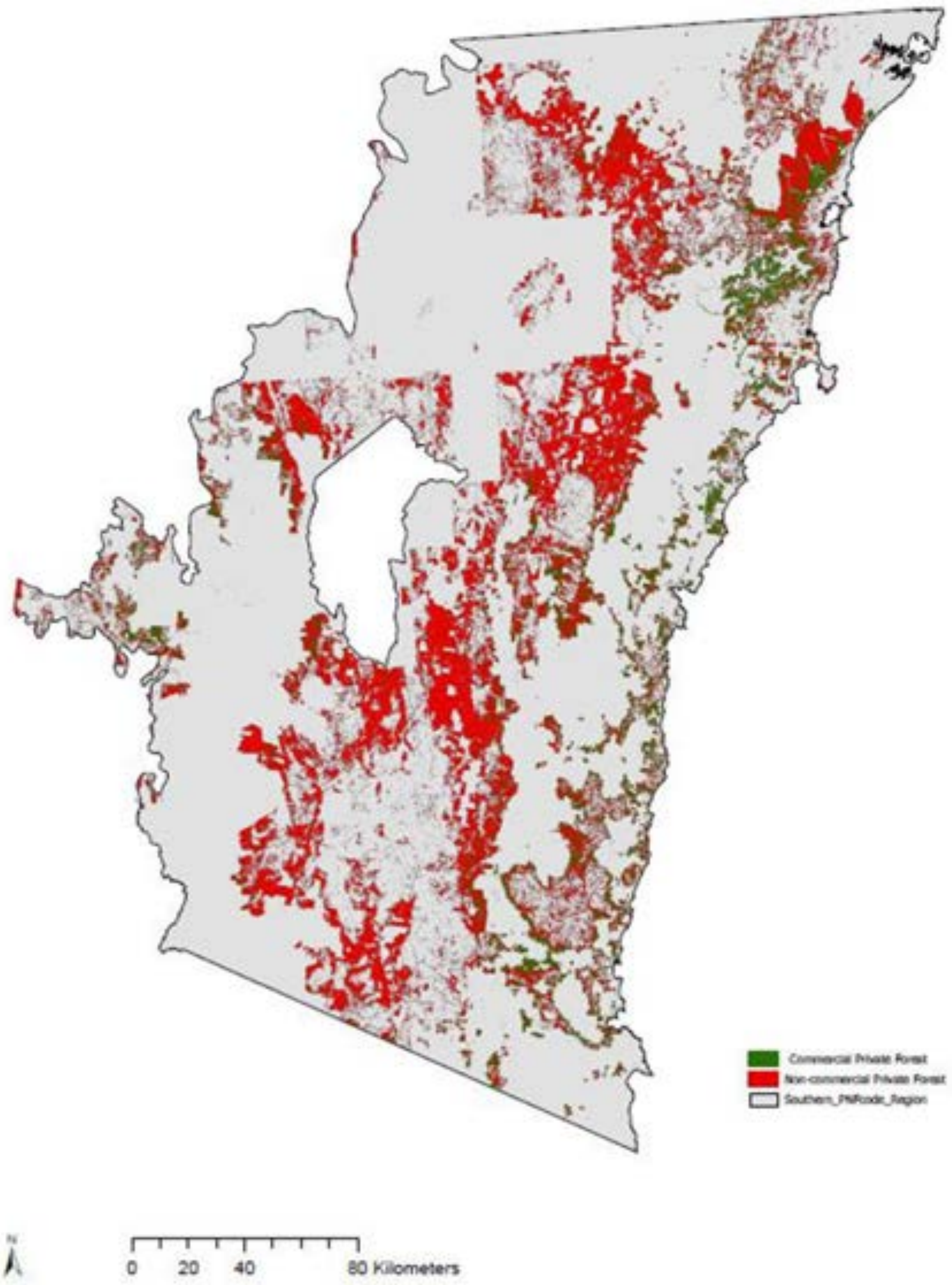

Figure 6.5. Map showing the commercial and non-commercial private native forest extent in the South Coast of NSW. Source: NSW Department of Primary Industries (2022).

A study by Jay (2017) for the NSW Department of Primary Industries, investigated the stand condition of private native forest in the North Coast region of NSW, based on field surveys at 840 plots assessed in the region between 2004 and 2013. While this project did not specifically focus on regrowth forest, it is likely that many of the plots assessed in this study could be considered regrowth, based on the diameter distributions presented. The study concluded that private native forest in this region was characterised by stands dominated by trees that were <40 cm in DBH. The most common size class was 25–40 cm DBH (approx. 33% of the total estate basal area), with trees 10–25 cm DBH being the next most common size class (approx. 28% of the estate basal area). Approximately 15% of the estate basal area was comprised of trees with a DBH ≥40 cm with high value logs and vigorous crowns – although most of these were < 55 cm DBH. Jay (2017) attributed the poor silvicultural stand condition in NSW to a long history of high grading.

Lewis et al. (2020) sampled a relatively small number of plots in upper north east NSW (32 plots), but reported similar findings to the Jay (2017) study. There were a high proportion of unmerchantable stems in these forests, particularly in the 10–19.9 cm DBH class and to a lesser extent in the 20–29.9 cm DBH class, as indicated in Figure 6.6. Across all plots in the north-eastern NSW region of the Lewis et al. (2020) study, average stocking was 286.3 (± 17.92) stems per hectare and average basal area was 20.1 (± 0.73) m2/ha. Potentially merchantable volume was 43.4 (± 3.91) m^3/ha with 37.9 (± 3.72) m^3/ha on trees with a DBH ≥30 cm. This equates to around 11.8 m^3/ha of sawlog, assuming 31% of the merchantable volume is sawlog (both optional and compulsory in MBAC 2003a). No studies were found that specifically reported timber volumes of private native regrowth forests in the NSW hub regions.

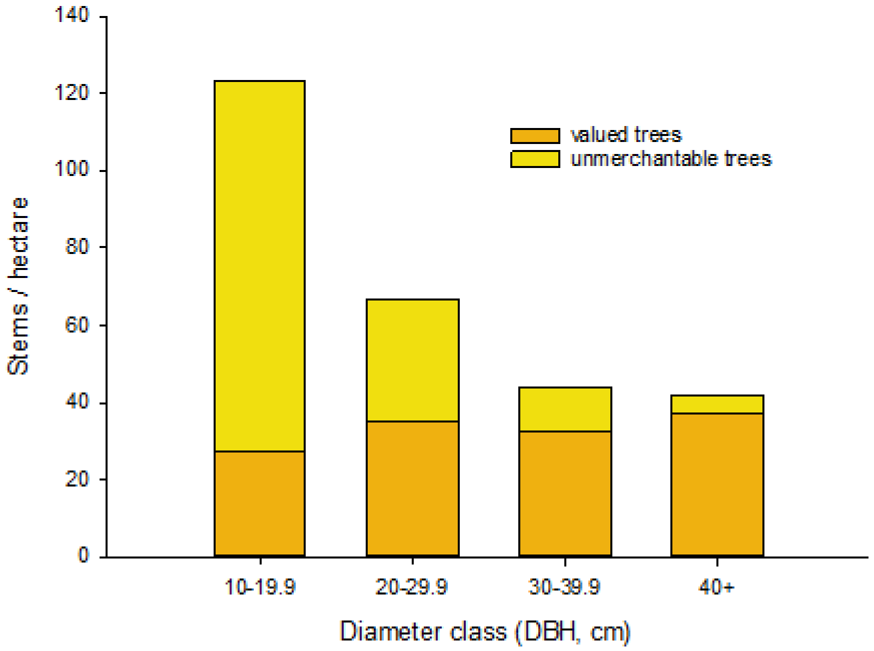

Figure 6.6. Stocking in private native forests (stems / ha) in different size classes in the north-eastern NSW region. Different coloured bars represent the stems that are valued (for current or future timber resource, or required for environmental purposes) or were considered unmerchantable, and would ideally be thinned to improve productivity of the retained stand. Source: Lewis et al. (2020).

6.5.2 Growth Rates

McDonald and Brandis (2001) reported that the silvicultural condition was poor in potentially commercial private native forest of the New England region of NSW. In their analysis they adopted growth rates varying from 0.5 m^3/ha/year in western forest types, to 4.5 m^3/ha/year for high site quality tableland forest. Most of the forests in the New England region were mature or uneven aged, with generally less than 5% of forest categorised as regrowth or early mature forest. Thompson (2007) and Jay and Dillon (2016) reported actual mean annual increment (MAI) in private native forests on the north coast of New South Wales of between 0.5 m^3/ha/y and 1.0 m^3/ha/y, compared to a potential of 5 m^3/ha/y to 30 m^3/ha/y.

The Forestry Commission of NSW (1982-1989) provided silvicultural notes on the most important commercial forest types in State Forest in NSW, including information on growth rates. They reported on 11 different broad forest types (Table 6.7). Those of commercial importance that are relevant to the NSW Forestry Hub regions vary greatly in productivity; spotted gum and dry coastal hardwoods with lower productivity, while moist tableland hardwoods, dry sclerophyll ash, blackbutt, flooded gum and alpine ash forests having higher productivity. Volume growth for these forest types was considerably higher than that for the Queensland forest types reported in Table 6.6, reflecting higher levels of site productivity (e.g. greater moisture availability) associated with some of the NSW forest types, and different markets available (e.g. pulpwood). The range in volume growth rates in Table 6.7 also includes some plantation forests, where productivity is improved.

Florence (1996) reported data from Curtin (1970) on coastal uneven-aged eucalypt forest, with net volume increments varying from 0.2 m^3/ha/yr in a mixed hardwood forest in Yarrat State Forest to 2.4 m^3/ha/yr in a blackbutt forest at Coopernook State Forest. Other forests with a large component of blackbutt reported volume increments of 0.9–1.6 m^3/ha/yr, with total standing volumes of 88 to 123 m^3/ha. Horne and Carter (1992) reported on long-term yield of blackbutt forest in the Kendall Management Area of northern NSW. Similar stand volumes were reported for 1960 and 1990, of 128 and 122 m^3/ha, but over this same period stand stocking increased from 212 to 354 stems per hectare. Standing volume of logged plots in 1960 was 104 m^3/ha compared to 160 m^3/ha in unlogged plots, reflecting an ‘overcut’ of the forest prior to 1960 (Horne and Carter 1992).

Bauhus et al. (2002) reported on basal area growth of uneven aged spotted gum forests on the south coast of NSW. They reported a great increase in basal area from 1959 to 1989 (from 15.8 to 29.8 m^2/ha) due to low levels of harvesting and natural mortality, which was only a fraction of the growth increment. Combe et al. (1998) also reported on growth of spotted gum and dry hardwood forests of NSW. They used inventory plot data for the ‘dry sclerophyll spotted gum league’ and the ‘dry mixed hardwoods league’. Average standing volume for the spotted gum forest was 187 m^3/ha (standard error of 2.1) across 106 plots, with a MAI of 2.3 m^3/ha/yr (standard error of 0.049) based on 77 plots. Average standing volume for the mixed hardwoods was 189 m^3/ha (standard error of 3.3) across 136 plots, with a MAI of 2.1 m^3/ha/yr (standard error of 0.074) based on 94 plots.

Table 6.7. Forests types, common species, stand volumes and basal areas, and growth rates for key forest types on State Forest in NSW, recognised by the Forestry Commission of NSW.

Forest type	Main species	Hub region relevance to this study	Stand volumes (m^3/ha) and basal areas (m^2/ha)	Growth rates (MAI, m^3/ha/yr)
Moist coastal hardwoods	Sydney blue gum, tallowwood, turpentine, Dunn's white gum, brushbox, white-topped box, white mahogany, flooded gum, New England blackbutt, silvertop stringybark	NE NSW	32–390 m^3/ha (varying with age and stocking) Basal areas not reported.	5–8 upper (50-60 year old) 2–2.5 for natural regeneration.
Moist tableland hardwoods	Brown barrel, messmate, silvertop stringbark, silvertop ash, yellow stringybark, southern blue gum, mountain/manna gum, roundleaved gum, white ash, New England blackbutt, peppermint	NE NSW SE NSW	Planted plots: Messmate – 416 m^3/ha Flooded gum – 577 m^3/ha Silvertop stringybark – 472 m^3/ha Brown barrel – 294 m^3/ha Sydney blue gum – 433 m^3/ha New England blackbutt – 168 m^3/ha Basal areas 11–94 m^2/ha.	Planted plots: Messmate – 19.8 Flooded gum – 27.5 Silvertop stringybark – 22.5 Brown barrel – 14.0 Sydney blue gum – 20.6 New England blackbutt – 8.0 Natural forest: Messmate – 9.7 Silvertop ash – 10–11.4

Dry sclerophyll ash	Silvertop ash, peppermint, stringybark, scribbly gum, blue-leaved stringybark, southern stringybarks, Blue Mountains ash, white ash	SE NSW	56–601 m^3/ha (varying with age and stocking) Basal areas 9.8–81 m^2/ha.	3.5 (175 stems per ha) to 15.2 (unthinned)
Blackbutt	Blackbutt, large-fruited blackbutt, tallowwood, white mahogany, red mahogany, grey gum, turpentine, Sydney blue gum, Sydney peppermint, bloodwoods, scribbly gum, rough-barked and smooth-barked apples	NE NSW SE NSW	52–610 m^3/ha (varying with age and stocking) Basal areas 10–44 m^2/ha in even-aged stands and 34–61 in virgin stands.	0.5–16 (8.8–11 at around age 30 years)
River red gum	River red gum, boxes (black box, yellow box and western grey box), carbeen, forest red gum	Not relevant to SE or NE NSW hubs. Inland distribution	13–520 m^3/ha (varying with age and stocking) Basal areas up to 68 m^2/ha (10–28 m^2/ha in managed stands)	Up to 5 at better quality sites
Spotted gum	Spotted gums, stringybarks, woollybutt, silvertop ash, red bloodwood, grey gum, ironbarks, forest red gum, grey box, Sydney blue gum, blackbutt, turpentine, tallowwood	NE NSW SE NSW	3–200 m^3/ha (varying with age and stocking) Basal areas 7–28 m^2/ha	0.39–2.93 (values around 1 commonly reported)
Flooded gum	Flooded gum, Sydney blue gum, blackbutt,	NE NSW	25–197 m^3/ha (varying with age	Mean 8.8. Plantations in

	tallowwood, brushbox, turpentine, Dunn's white gum		and stocking) Basal areas 3–22 m^2/ha (up to 41 m^2/ha in NSW plantations at age 29 years)	NSW 16. Plantations overseas up to 50.
Dry coastal hardwoods	Ironbarks, white mahoganies, grey gums, coastal boxes, red mahogany, rough-barked apple, woollybutt, forest red gum, tallowwood, bloodwoods, brushbox, blackbutt	NE NSW SE NSW	55–99 m^3/ha (varying with age and stocking) Basal areas 7–49.3 (7–9 m^2/ha in managed forest)	0.45–3.4 (values around 1 commonly reported).
Alpine ash	Alpine ash, manna gum, mountain gum, mountain grey gum, narrow-leaved peppermint, snow gum	SE NSW (limited to alpine regions)	92–1000 m^3/ha (varying with age and stocking) Basal areas of 64 m^2/ha (age 130 years)	9–26
Cypress pine	Black Cypress pine, white Cypress pine, ironbarks, red gum, boxes	NE NSW. Inland distribution	Stand volume not reported. Basal areas up to 20 m^2/ha (6–10 m^2/ha more common)	Stand volume increments not reported. Merchantable volume increments of 1.4 m^3/ha/yr. Basal area increments of 0.2–0.4 m^2/ha/yr
Rainforest	A range of rainforest types and species. Common timber species	NE NSW SE NSW (limited	64–892 m^3/ha (hoop pine plantations)	6.4–16.8 (hoop pine plantations)

	have included red cedar, white beech, hoop pine, coachwood, quandong, rosewood, bollywood, yellow and red carabeen, sassafras, black and white booyong, silky oak, crows ash	distribution)	Stand volumes for native stands not reported, but basal areas of >100 m^2/ha possible.	Volume increments for native stands not reported, but gross increments ‘well in excess of 1 m^3/ha/yr’

6.6 Limitations of existing datasets

A major limitation is a lack of mapping of forest regrowth area for the NSW Hub regions. Estimates of regrowth extent, based on existing, available datasets in NSW is likely to be indicative only, and further studies using remote sensing datasets should focus on developing a regrowth forest dataset for the State. In both Queensland and NSW, further work is needed to verify private native forest mapping with field surveys.

A lack of empirical growth data for most forest types in Queensland and NSW that are specifically relevant to private native regrowth forests is another limitation. Data based on expert opinion, existing datasets for private native forest and existing datasets for State Forest can help guide likely forest growth rates. Such datasets will be used in future sections of this report to estimate regional volume estimates for different forest types.

6.7 Conclusions

There are significant areas of private native regrowth forest that occur in NSW and Queensland. Updated estimates of these areas are provided in Chapter 7. Private native forests are generally in poor silvicultural condition. This appears to be a result of a history of poor harvest management (high grading) and the fact that many private native forests are regrowth forests, with high densities of small stems, and no silvicultural thinning. Previous studies (e.g. Lewis et al. 2020; Lewis et al. 2022; Francis et al. 2023) have highlighted the potential for the private native forest resource to be improved with silvicultural management, which will result in faster tree growth rates, and concentration of growth on stems with the greatest commercial value.

7. A Snap-shot of the Private Native Forest Regrowth Resource and Changes in Regrowth Extent Over Time Based on Datasets Available to the Project

Tom Lewis, Jack Baynes, Tyron Venn, and Amrit Kathuria

7.1 Aim

The aim of this chapter was to provide a contemporary estimate of regrowth extent and changes in regrowth extent over time using existing datasets available to the project. Specifically, we focused on regrowth forests that might be of commercial value to the timber industry in the Hub regions.

7.2 Mapping Datasets to Determine Regrowth Extent and Change

7.2.1 Queensland

The Department of Agriculture and Fisheries (DAF) with the assistance of the Queensland Herbarium, undertook a GIS analysis between July 2020 and November 2022 to map the extent of private native forest potentially available under the NFP ADVCC (i.e. 'Managing a native forest practice accepted development vegetation clearing code'). This work extended on the mapping work done during the Lewis et al. (2020) study; using updated datasets and ensuring coverage of the entire state, and mapping of Category X regrowth with an FPC of at least 15% (rather than 30%). The analysis focused on specific requirements under the NFP ADVCC and considerations of commercial viability that can be spatially represented. These were:

- Tenure – The NFP ADVCC applies only to freehold and indigenous land.
- Vegetation categories – The NFP ADVCC applies only to Category B and Category C areas on the Regulated Vegetation Management Map.
- Regional ecosystems (RE) – A native forest practice can only occur in the REs specified in the NFP ADVCC.
- Slope – A native forest practice cannot occur on slopes greater than 25 degrees (47 per cent).
- Foliage project cover (FPC) – FPC greater than 15 per cent.
- Commercial forest types – Forest types that produce timber that is most commonly processed by sawmills and for which there is the greatest market demand (see Section 6.2).
- Property size – Properties 20 hectares or greater in size are considered the minimum threshold to be viable for forestry on a commercial scale.

- Patch size within a property – Patches 20 hectares or greater within a property are considered the minimum threshold to be viable for forestry on a commercial scale.

The current project focuses on private native forest in Category X areas that are exempt from clearing work under the *Vegetation Management Act 1999.* Fortunately, these areas were included in the recent DAF analysis because they are an important resource for the native hardwood timber industry. However, it should be noted that Category X areas were only included if they were mapped as an RE (using pre-clearing mapping) which can be harvested under the NFP ADVCC. Although this is a limitation of the mapping, it should be noted that most REs that are currently harvestable under the NFP ADVCC are those with some commercial value.

The Statewide Landcover and Trees Study (SLATS) monitors the extent of woody vegetation and annual changes due to clearing and regrowth using Sentinel-2 satellite imagery as its primary monitoring tool. The SLATS data are directly comparable for the 2018–19, 2019–20 and 2020–21 reports. Earlier SLATS datasets from 1988 to 2017–18 are not directly comparable to datasets from 2018-19 due to a change in methodology. These earlier SLATS datasets used Landsat imagery to assess vegetation change. For this investigation, SLATS 2021 data was used to determine the age of the regrowth. By overlaying the DAF Category X regrowth layer with the SLATS 2021 data, age of regrowth was classified for the Queensland Forestry Hub regions. For the purposes of our analysis, the 10 m cell size in the SLATS dataset created a file that was too large to deal with, so it was aggregated to a 50 m raster. The DAF private native forest Category X layer was also aggregated to a 50 m raster. The two rasters (both with 50 m cells) were overlaid to ascertain the age distribution of the Category X private native forest. The SLATS 2021 age data is described in the Metadata description as follows:

“The 2021 woody extent is attributed with an estimated age in years since the last significant disturbance. The method uses a sequential Conditional Random Fields classifier applied to 1988-2021 Landsat time series to predict woody cover over the 33-year period. A set of heuristic rules is used to detect and track regrowing woody vegetation in the time series of woody probabilities and record the approximate start and end dates of the most recent regrowth event. Regrowth detection is combined with the SLATS Landsat historic clearing data to provide a preliminary estimate of age since disturbance for each woody pixel in the 2021 woody extent. The 'last disturbance' may be due to a clearing event or other disturbance such as fire, flood, drought-related death etc. Note that not all recorded disturbances may result in complete loss of woody vegetation, so the estimated age since disturbance does not always represent the age of the ecosystem. The age since disturbance product is derived from multiple satellite image sources and derived products which represent different scales and resolutions: Landsat (30m), Sentinel-2 (10m) and Earth-i (1m).”

7.2.2 New South Wales

Area of private native forest in NE NSW has been mapped by the NSW Department of Primary Industries. The process of mapping forest types involved the use of forest yield association groups, or YAGs, which are assemblages of forest types that share common biophysical attributes and timber properties. This classification system has primarily been applied to publicly managed State forests in New South Wales (NSW), with no corresponding mapping on private lands applied until recently. The development of forest YAG maps represents a significant advancement in the mapping of timber values. To create these maps, a data mining technique called k-Nearest Neighbor (k-NN) was utilised to establish a spatially explicit model for yield association groups at a resolution of 25 m for the North Coast region of NSW (Kathuria, 2023). This method utilised LiDAR, climatic, soil type, Sentinel and topographic variables to develop a model of yield groups. The model demonstrated strong agreement with reference data, achieving an overall accuracy of 80%. As a result, a map of YAGs for Private Native Forest NSW North and South Coast was generated. The YAG mapping does not identify areas of regrowth or age class of the forest.

A separate ‘commerciality’ layer was also made available by Local Land Services and NSW Department of Primary Industries to provide an indication of the YAG areas that were of commercial value from a forestry perspective (i.e. forest capable of producing high-quality logs that can be utilised by the forest industry). Non-commercial forests are native forests that are incapable of producing high-quality logs based on their height and form. In contrast, commercial forests are those parts of the forest that have large enough trees to be harvested by the forest industry. To develop a model for classifying forests, a machine learning technique called Random Forest was utilized using spatial services airborne laser scanner (ALS) data (Kathuria, 2022). The model demonstrated a good agreement with reference data, achieving an overall accuracy of 86.1%. Maps of commercial versus non-commercial forests were generated at a resolution of 20 m for the North and South Coast regions of New South Wales. It should be noted that this layer, while useful for mature forest, will not give an indication of potential commercial regrowth forest that is yet to attain mature forest height.

The aim of the NSW SLATS Program is to map the location and extent of woody vegetation loss each year (https://www.environment.nsw.gov.au/topics/animals-and-plants/native-vegetation/landcover-science/statewide-landcover-tree-study). As such, the extent of regrowth vegetation was not available for NSW using the SLATS data and this dataset was not utilised in the current study. The NSW SLATS Program was based on the work methodology developed and implemented in Queensland. Woody change is detected through a combination of automated and manual interpretation of the differences between images captured during summer of each year. Landcover classes reflect the interpreted cause of woody vegetation change. Each change year had a single statewide point and polygon layer derived from approximately 310 SPOT scenes covering NSW.

The National Forest and Sparse Woody Vegetation Data, Version 7.0 (2022 Release), was used to estimate private native forest regrowth extent in NSW (https://data.gov.au/dataset/ds-dga-69d09a6c-df77-439f-8bc7-87822cd520fd/details, Australian Government Department of Climate Change, Energy, the Environment and Water). In this dataset, Landsat satellite imagery was used to derive woody vegetation extent products that discriminate between forest, sparse woody and non-woody land cover across a time series from 1988 to 2022. Forest and sparse woody vegetation data were derived from satellite imagery sourced from Landsat TM, ETM+ and OLI sensors. A forest is defined as woody vegetation with a minimum of 20 per cent canopy cover, potentially reaching 2 metres (m) in height and with a minimum area of 0.2 hectares. Sparse woody vegetation is defined as woody vegetation with a canopy cover between 5-19 per cent. The three-class classification (forest, sparse woody and non-woody) superseded the two-class classification (forest and non-forest) from 2016. This classification uses time-series processing (conditional probability networks) to detect woody vegetation cover.

Combining private native forest mapping for NSW with the areas mapped as 'sparse woody vegetation' using National Forest and Sparse Woody Vegetation Data, provided some estimate of regrowth extent in the NSW hub regions. The National Forest Tenure layer (https://www.agriculture.gov.au/abares/forestsaustralia/forest-data-maps-and-tools/spatial-data/forest-tenure) was used to determine private native forest extent in NSW. It should be noted that 'sparse woody vegetation' is not always equivalent to regrowth forest. For example, mature paddock trees in a grazing landscape, that comprises more than 5% canopy cover would be considered regrowth using this methodology. It is likely that areas of regrowth, that had already reached 20% canopy cover, were included in the YAG mapping.

7.3 Method to Estimate Change in Regrowth Extent Over Time in Queensland and New South Wales

The National Forest and Sparse Woody Vegetation Data, Version 5.0 (2020 Release for Queensland) and Version 7.0 (2022 Release for NSW) time series data was used to investigate changes in privately owned forest cover over time in all Hub regions. Changes in the cover of private native forest were calculated for the entire period 1991-2020 or 2022 (29 or 31 years) and over the last 9 or 11 years (2011-2020 or 2022). This dataset allowed investigation of changes in forest cover. The dataset was restricted to the Category X private native forest layer in Queensland and to the private native forest extent in NSW. For each pixel (~25 m cell) of private native forest in the Hub regions, change was detected when non-woody vegetation (0 value) changed to woody vegetation (either sparse with a value of 1, or woody with a value of 2), or vice versa, over each time period. For each time period it was possible to report on estimated areas (calculated from pixel numbers) based on private native forest that:

1. Changed from non-woody to sparse woody vegetation.
2. Changed from non-woody to forest vegetation.
3. Remained as non-woody vegetation.
4. Changed from sparse woody to non-woody vegetation.
5. Changed from sparse woody to forest vegetation.
6. Remained as sparse woody vegetation.
7. Changed from forest to non-woody vegetation.
8. Changed from forest to sparse woody vegetation,
9. Remained as forest vegetation.

The 'extract by mask' function in ArcGIS Pro was used to complete this analysis. For each Forestry Hub region, this function allowed the area of land (as pixels) with crown cover of values 0, 1 and 2 in 1991 or 2011 to be extracted and then used as mask files for the area of land with crown cover values of 0, 1 and 2 in either 2020 or 2022, as indicated in Figure 7.1. In this way, the area of harvestable forest types on Category X land in Queensland was extracted. Using the raster mask overlay procedures, we were also able to determine the area of potentially commercial forest based on the NSW forest commerciality layer. This was applied based on forest cover (i.e. woody vegetation with a minimum of 20 per cent canopy cover) in 1991 and 2022, to determine the area of new ‘commercial’ forest appearing between these years. All areas estimated through GIS analysis were rounded to the nearest 100 ha for reporting, given the errors and assumptions associated with the GIS procedures.

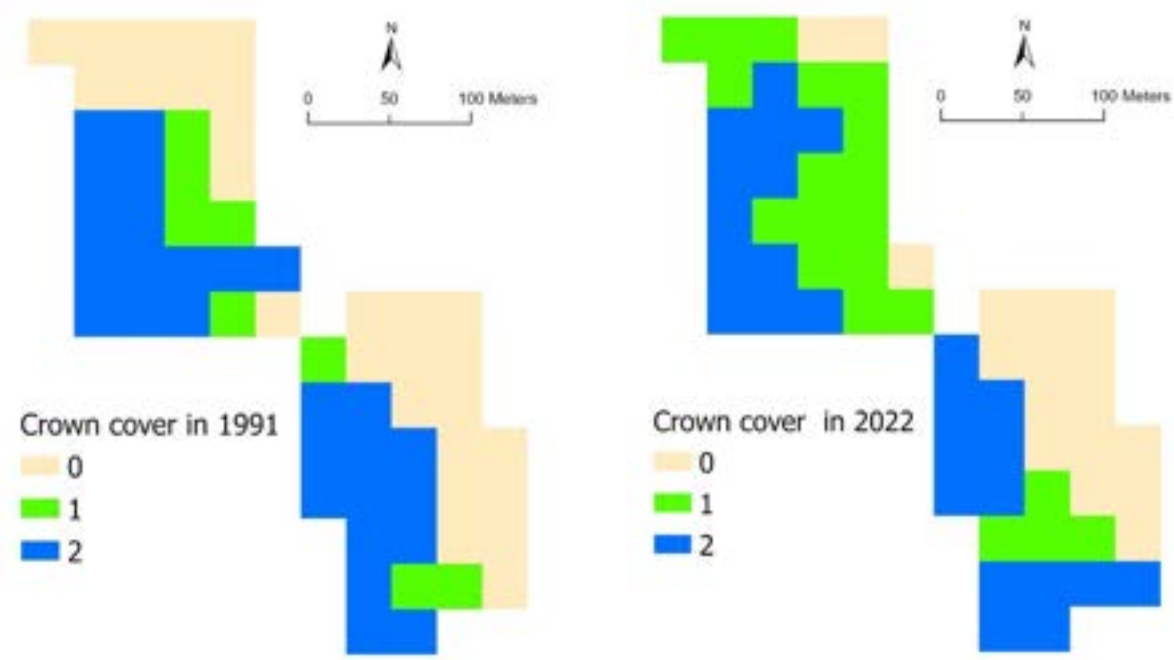

Figure 7.1. Illustration of the change detection method used to determine areas of regrowth forest that appeared between 1991 and 2022. Where pixels with 0 value represent non-woody vegetation, pixels with a value of 1 represent sparse woody vegetation and pixels with a value of 2 represent forest vegetation.

7.4 Queensland Private Native Forest Regrowth Extent in the Hub Regions

The total area covered by the Forestry Hub regions in Queensland was 91.8 M ha, of which 59.9 M ha was in the Northern Hub region and 31.9 M ha was in the Southern and Central Hub region. Latest mapping, completed by DAF in 2022 (with forest cover data from 2016-17), suggested that there were approximately 2,225,000 ha of Category X regrowth across both hub regions in Queensland in regional ecosystems that are potentially harvestable under the current NFP ADVCC. As indicated in Table 7.1, 1,669,000 ha of this regrowth was in forest types considered commercial by the timber industry. The commercial forest types with the largest areas were ironbark, spotted gum and blue gum, which together accounted for 91% of the total area of commercial regrowth. Non-commercial forest types that were still harvestable under the NFP ADVCC comprised 556,200 ha. Table 7.1 also reports that most of the commercially important Category X regrowth (2,141,300 ha) was located in the Southern and Central Forestry Hub region, where ironbark, blue gum and spotted gum forest contributed the largest areas. The total area of Category X regrowth in the Northern Forestry Hub region was 84,400 ha, of which 67,800 ha was commercially important forest types. Ironbark forest types were again the most common commercial forest type, accounting for approximately 40,700 ha. Mixed hardwoods, blue gum and northern hardwoods commercial forest types were also important contributors in terms of area in the Northern Forestry Hub region.

Table 7.1. Area of Category X regrowth private native forest in Queensland by forest type and forestry hub region, based on regional ecosystems considered harvestable under the current NFP ADVCC. Area figures were rounded to the nearest 100 ha from mapping completed by DAF in 2022.

Forest type	Both hub regions (ha) [and % of total]	Southern and Central (ha) [and % of total]	Northern (ha) [and % of total]
Moist tall	11,000 [0.5%]	10,900 [0.5%]	100 [0.2%]
Mixed hardwood	61,900 [2.8%]	51,700 [2.4%]	10,200 [12.1%]
Spotted gum	366,100 [16.5%]	365,800 [17.1%]	300 [0.3%]
Queensland blue gum	347,100 [15.6%]	338,100 [15.8%]	9,000 [10.6%]
Gum-topped box	67,000 [3.0%]	66,700 [3.1%]	300 [0.4%]
Ironbark	809,100 [36.4%]	768,400 [35.9%]	40,700 [48.2%]
Northern hardwood	4,500 [0.3%]	0 [0%]	4,500 [5.3%]
Savannah woodland	2,700 [0.2%]	0 [0%]	2,700 [3.2%]
Non-commercial	556,200 [25.0%]	539,600 [25.2%]	16,600 [19.6%]
Total	2,225,700	2,141,300	84,400

Figures 7.2 and 7.3 display the geographic locations of these forest types in the Southern and Central and Northern Forestry Hub regions, respectively. The ironbark forest type had a widespread distribution, from coastal regions to the west of the Southern and Central Hub region. Moist tall, mixed hardwoods and northern hardwoods forests tended to be

located closer to the east coast, in higher rainfall zones. Queensland blue gum forests often followed watercourses, where they naturally occur on floodplains and alluvial soils, but generally had a widespread distribution towards the east of the Southern and Central Hub region, and in the south of the Northern Hub region. Spotted gum forests also had a widespread distribution in the Southern and Central Hub region, but tended to be located closer to the east coast than the ironbark forest type and were not common in the Northern Hub region. Savannah woodlands tended to have a patchy distribution towards the north of the Northern Hub region (i.e. Cape York Peninsula). The non-commercial forest types had a widespread distribution across the Southern and Central Hub region, and in the south of the Northern Hub region

The private native forest Category X regrowth layer was used to determine the age class of regrowth mapped in Figures 7.2 and 7.3, using the 2021 SLATS data. As indicated in Table 7.2 and Figure 7.4, in the Southern and Central Forestry Hub region, a total of 401,200 ha (18.7%) was classified as non-growth (age zero) in 2020-21. Thus, total standing commercially important regrowth forest area on Category X land in 2021 in the Southern and Central Forestry Hub region was 1,740,100 ha (2,141,300 ha minus 401,200 ha). About 285,200 ha (13.3%) was classified as being between 1 and 15 years of age, 406,100 ha (19%) was classified as being between 15 and 31 years in age, and 1,048,800 ha (49%) was classified as being greater than 31 years in age. It might be assumed that the regrowth mapped in the DAF mapping that was no longer regrowth in the SLATS 2021 data (age zero) had been cleared in the period between 2016-17 and 2021[12]. Nevertheless, the methodologies for determining regrowth did differ between the two datasets, so caution is needed in interpreting these outputs (e.g. differing levels of FPC for determining forest cover and differing spatial resolutions). This estimated area of recently cleared private native forest is not mapped separately from all non-regrowth vegetation in Figure 7.4.

The area breakdown for the different forest types is presented in Table 7.2. In the Southern and Central Forestry Hub region, total area in Table 7.2 (2,141,300 ha) aligns with total area in Table 7.1. However, 22% of blue gum, and 23% of non-commercial forest had an age of zero in the 2021 SLATS data and may have been cleared after the 2016-17 foliage projected cover layer used in the DAF 2022 mapping was created. Only 14% of spotted gum and 16% of ironbark forest had an age of zero in the 2021 SLATS data. Acknowledging the need for cautious interpretation of change in forest cover given the differences in methods for determining regrowth between the datasets, the analysis suggests that, over the 5 years from 2016-17 to 2021, the average annual rate of re-clearing of regrowth forest ranged from 4.7% for non-commercial forests to 2.8% for spotted gum. This suggests an average re-clearing cycle of between 21 and 36 years, which is ‘in the ballpark’ of anecdotal information about grazing land management in southern Queensland. A consistently large proportion of regrowth was classified as >31 years old, varying between 41% for non-commercial forest to 61% for spotted gum forest, and 49% across all forest types (Table 7.2).

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[12] Although it is legal in Queensland to clear 15-year-old native forest regrowth on Category X land to immediately establish a timber plantation, this would not be eligible for ACCUs under the plantation methodology. The land would have to be cleared of vegetation for seven years before establishment of a timber plantation would be eligible for ACCUs.

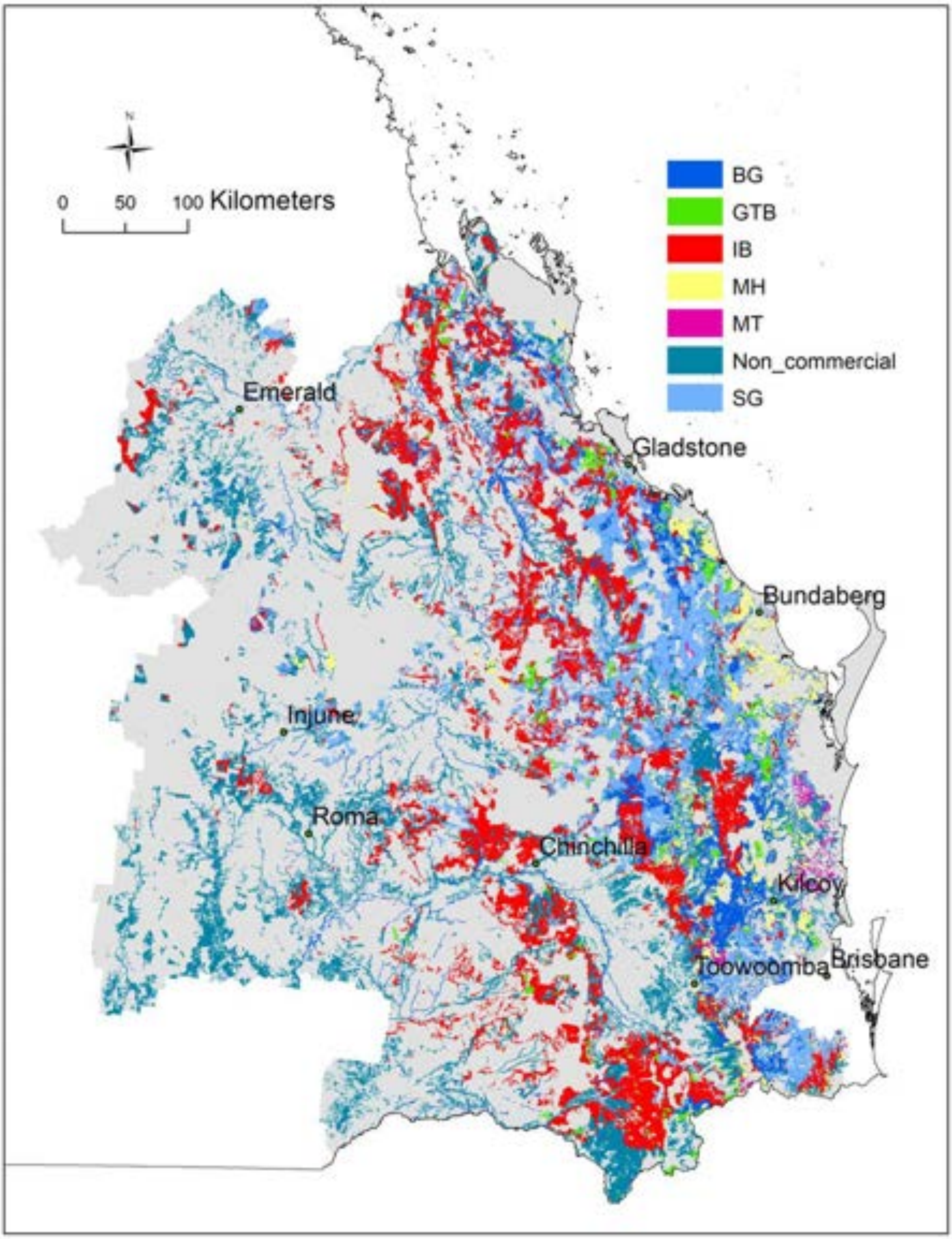

Figure 7.2. Private native regrowth forest (Category X) in the Southern and Central Forestry Hub region of Queensland, showing the different commercial forest types in the region.

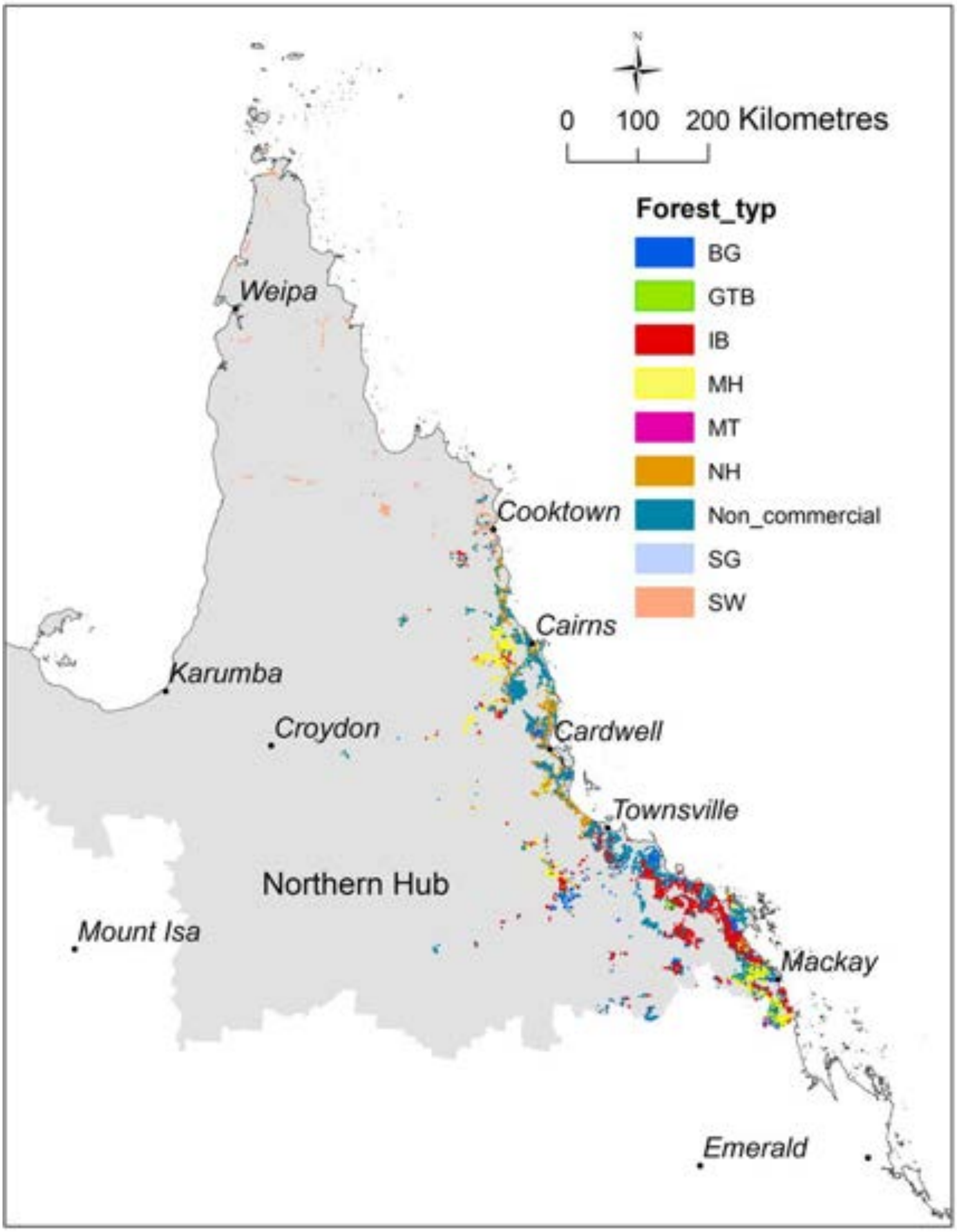

Figure 7.3a. Private native regrowth forest (Category X) in the Northern Forestry Hub region of Queensland, showing the different commercial forest types across the entire region

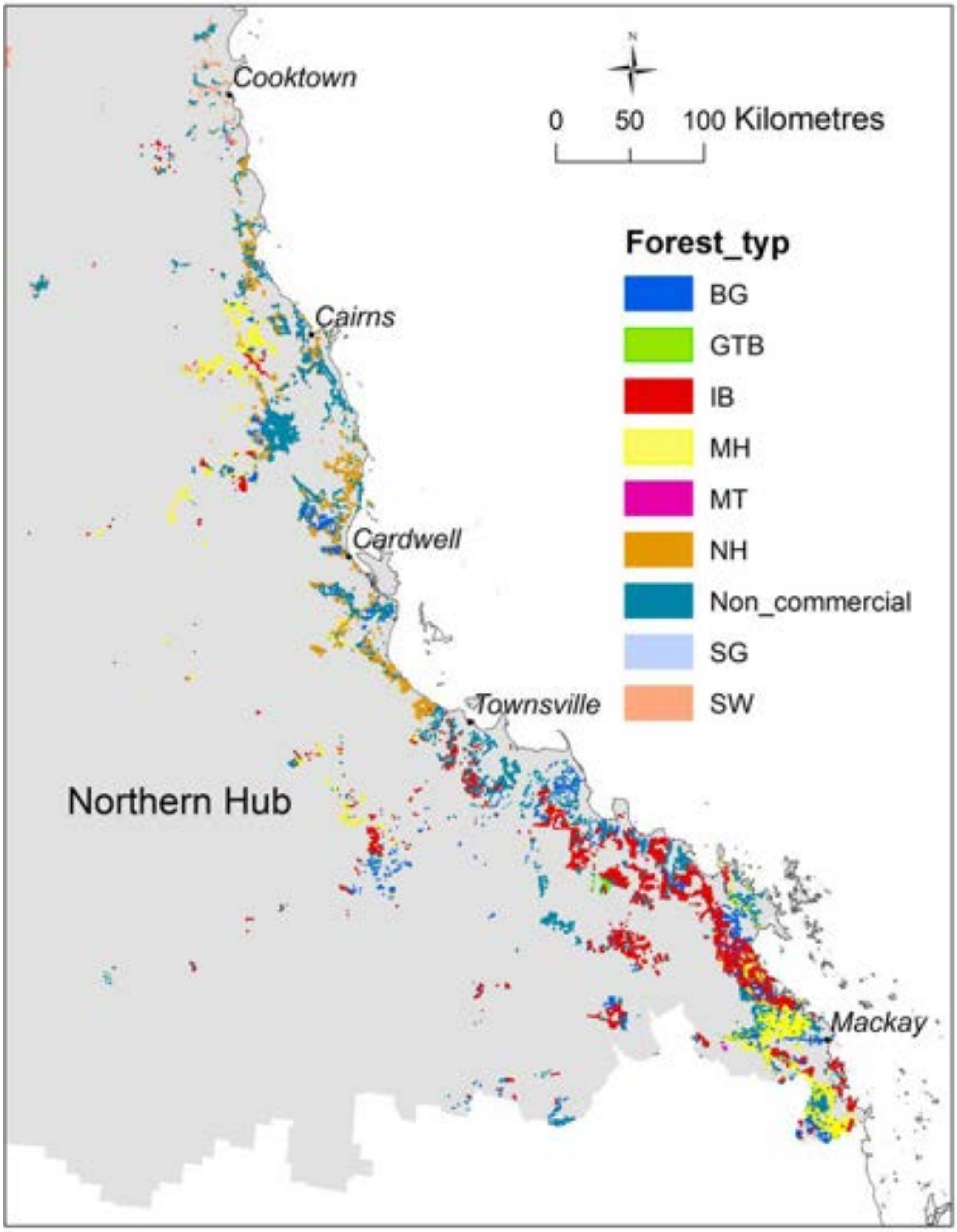

Figure 7.3b. Private native regrowth forest (Category X) by type in the area of the Northern Forestry Hub where commercial forest types were common (i.e. southern east coast of the region).

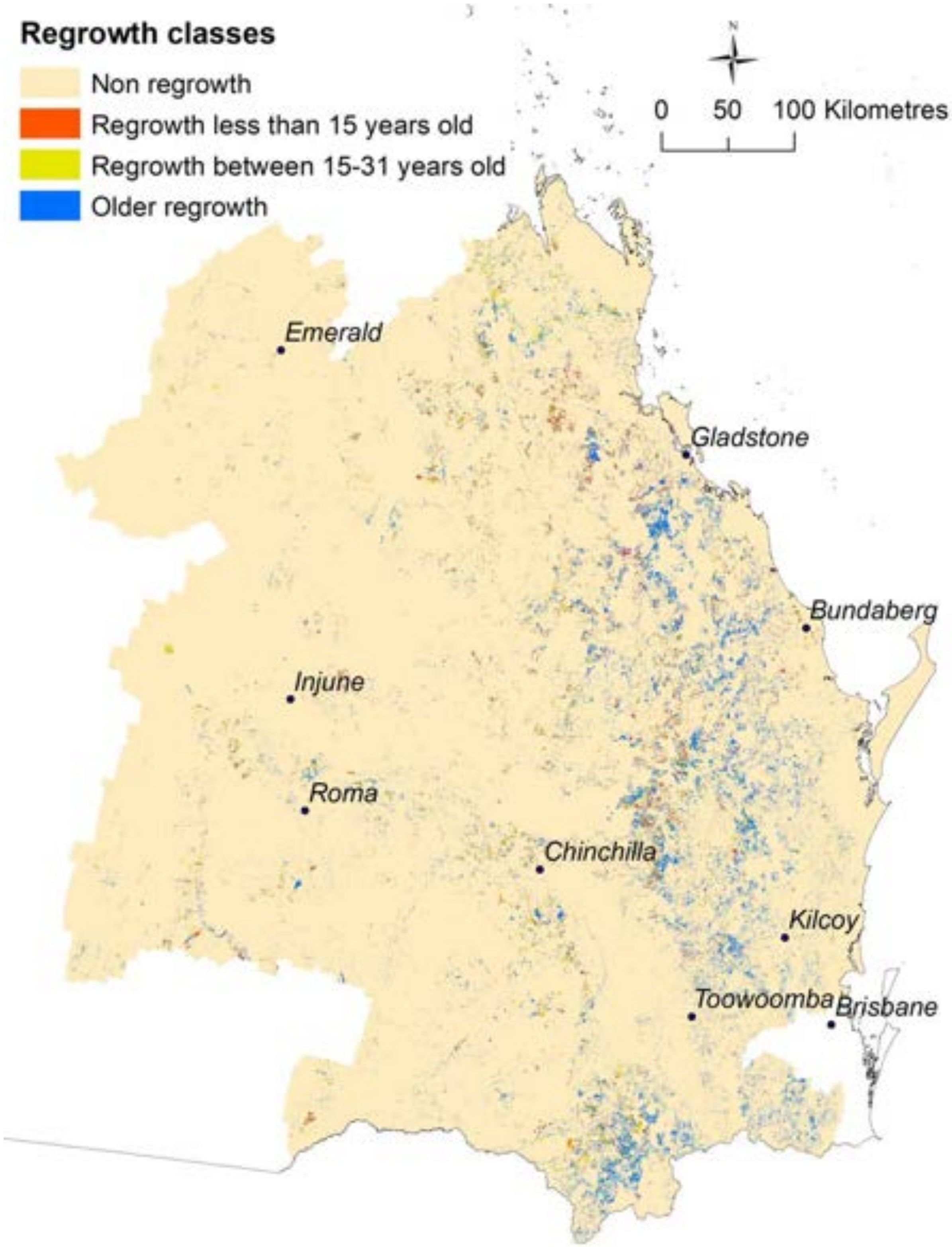

Figure 7.4. Private native regrowth in the Southern and Central Forestry Hub region by age class: age zero (non-regrowth), age 1-15 years, 15-31 years and >31 years of age. This has been determined by overlaying the SLATS 2021 age classes over the DAF Category X private native forest layer.

Table 7.2. Area (ha, with percentage of hub region total in brackets) of Category X private native forest regrowth in Queensland by forest type and forestry hub region based on DAF 2022 mapping, that was non-regrowth (age zero), aged 1-15 years, 15 to 31 years and greater than 31 years old based on the SLATS 2021 data. Note that the foliage projected cover layer used in the DAF 2022 mapping utilised a 2016-2017 dataset. Areas were rounded to the nearest 100 ha.

Forest type	Southern and Central – non-regrowth (age 0) (%)	Southern and Central 1-15 years old (%)	Southern and Central 15-31 years old (%)	Southern and Central >31 years old (%)	Northern – non-regrowth (age 0) (%)	Northern 1-15 years old (%)	Northern 15-31 years old (%)	Northern >31 years old (%)
Moist tall	1,800 (16.8)	900 (7.9)	2,100 (18.9)	6,100 (56.5)	0 (17.2)	0 (5.7)	0 (8.1)	100 (69.0)
Mixed hardwood	10,000 (19.3)	7,000 (13.6)	10,400 (20.0)	24,400 (47.1)	2,300 (22.8)	1,500 (14.4)	2,500 (24.6)	3,900 (38.2)
Spotted gum	50,900 (13.9)	41,200 (11.3)	50,000 (13.7)	223,700 (61.1)	0 (14.1)	0 (14.1)	0 (6.0)	200 (65.7)
Queensland blue gum	74,500 (22.0)	41,700 (12.3)	53,100 (15.7)	168,700 (49.9)	2,300 (25.2)	1,200 (12.9)	2,200 (24.5)	3,300 (37.4)
Gum-topped box	12,700 (19.1)	7,800 (11.7)	13,100 (19.6)	33,100 (49.6)	0 (15.2)	100 (19.2)	200 (49.8)	100 (15.8)
Ironbark	125,700 (16.4)	110,600 (14.4)	162,600 (21.1)	369,500 (48.1)	6,300 (15.5)	4,300 (10.7)	13,000 (32.0)	17,000 (41.9)
Northern hardwood	NA	NA	NA	NA	1,000 (21.6)	400 (9.4)	1,100 (24.2)	2,000 (44.8)
Savannah woodland	NA	NA	NA	NA	500 (16.8)	600 (23.7)	1,300 (45.9)	400 (13.5)
Non-commercial	125,500 (23.3)	76,000 (14.1)	114,900 (21.3)	223,300 (41.4)	4,600 (27.6)	2,500 (15.2)	3,600 (21.8)	5,900 (35.3)
Total	401,200	285,200	406,100	1,048,800	17,000	10,600	23,900	32,900

In the Northern Forestry Hub region, total area in Table 7.2 (84,400 ha) aligns with total area in Table 7.1. However, a total of 17,000 ha (20.2%) was classified as non-growth (age zero) in 2021, indicating potential land clearing since 2016-17 and a standing regrowth forest area on Category X land of 67,400 ha. Approximately 10,600 ha (12.7%) was classified as being between 1 and 15 years of age, 23,900 ha (28.3%) was classified as being between 15 and 31 years of age, and 32,900 ha (38.9%) was classified as being greater than 31 years old (Table 7.2, Figure 7.5). Of the Category X regrowth mapped by DAF, the percentages of the different forest types that were aged zero in 2021 were similar to those in the Southern and Central region (ranging from 14% for spotted gum forest to 27.6% for non-commercial forest, Table 7.2). This suggests an average re-clearing cycle of between 18 and 35 years. In this region, a large proportion of the regrowth was also classified as being >31 years old (Table 7.2).

7.5 New South Wales Private Native Forest Extent in the Hub Regions

The NE and SE Hub regions in NSW covered a total area of 14.4 M ha, of which 4.7 M ha was in the SE region and 9.7 M ha was in the NE region. The YAG mapping in the NE NSW Forestry Hub region was limited by existing LiDAR extent, particularly in the Northern Tablelands (see Figure 6.3). YAG mapping in the NE NSW Forestry Hub region is indicated in Figure 7.6. YAG mapping in the SE NSW Forestry Hub region covered the total extent of that Hub region.

As indicated in Table 7.3 and Figure 7.6, the YAG mapping suggested that there was approximately 1,626,100 ha of private native forest in the NE Forestry Hub region; however, this excludes much of the Northern Tablelands because no LiDAR data was available to derive the YAGs (see Figure 6.3). Approximately 2.4% (38,300 ha) of this area was mapped as sparse woody vegetation (Table 7.3). Commercially important forest in 2022 covered approximately 1,007,000 ha in the NE Forestry Hub region, which is illustrated in Figure 7.7.

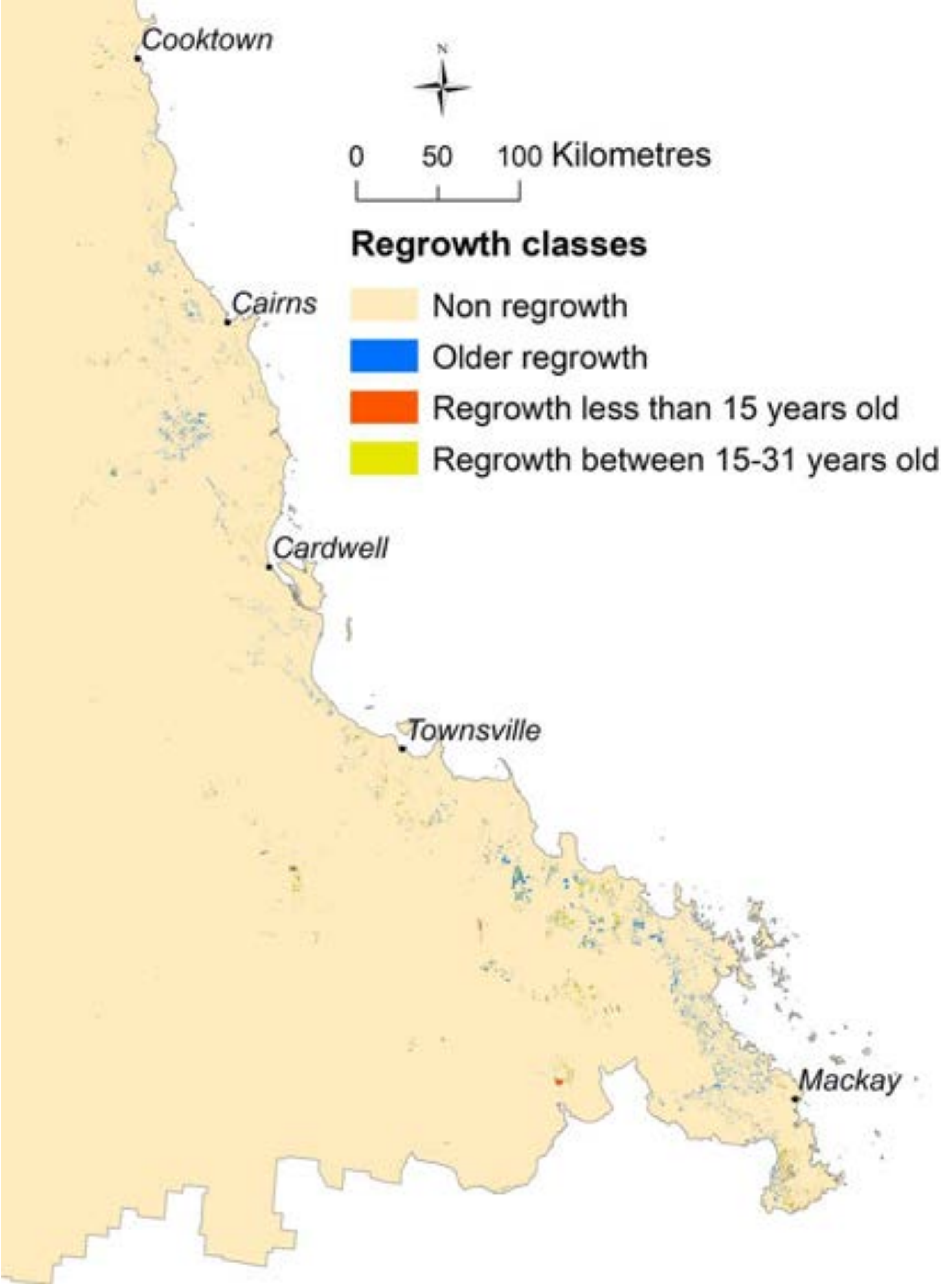

Figure 7.5. Private native regrowth in the Northern Forestry Hub region by age class: age zero (non-regrowth), age 1-15 years, 15-31 years and >31 years of age. This has been determined by overlaying the SLATS 2021 age classes over the DAF Category X private native forest layer.

Table 7.3. Areas of 'sparse woody vegetation' and total private native forest extent for each yield association group (YAG) and the areas of each that were considered commercially important in the NE Forestry Hub region in 2022. Areas are rounded to the nearest 100 ha.

Yield Association Group	Area of sparse woody vegetation (ha) private native forest	Area of private native forest (ha)	Area of commercial private native forest (ha)
Rainforest	700	50,500	40,700
Viney scrub	6,600	50,400	11,200
Blackbutt	1,100	116,600	99,500
Spotted gum	1,100	230,100	149,400
Coastal tall moist eucalypts	100	43,500	42,800
Coastal semi-moist eucalypts	1,600	322,800	288,200
Coastal dry eucalypts	13,000	457,700	141,100
Swamp sclerophyll	2,800	158,000	70,300
Tablelands tall moist eucalypts	0	7,000	7,000
Tablelands dry and semi-moist eucalypts	11,200	189,500	82,400
Total YAGs	38,300	1,626,100	1,007,000 (74,300 unclassified)

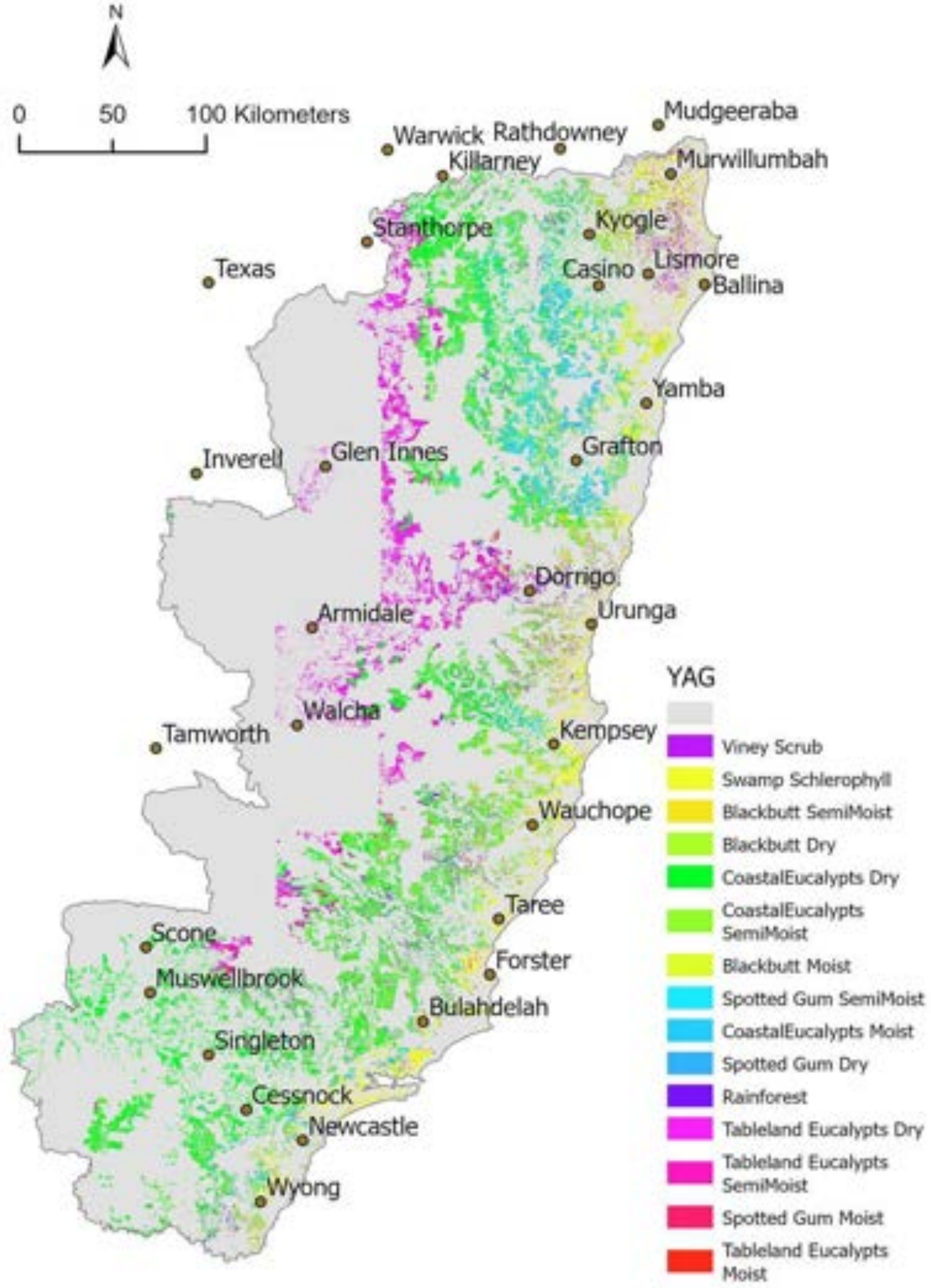

Figure 7.6. Map for NE Hub region showing private native forest yield association groups (YAGs). The extent of the YAG mapping within the NE NSW Forestry Hub region was limited by the extent of LiDAR data for this region with some areas of the Tablelands not mapped (see Figure 6.3).

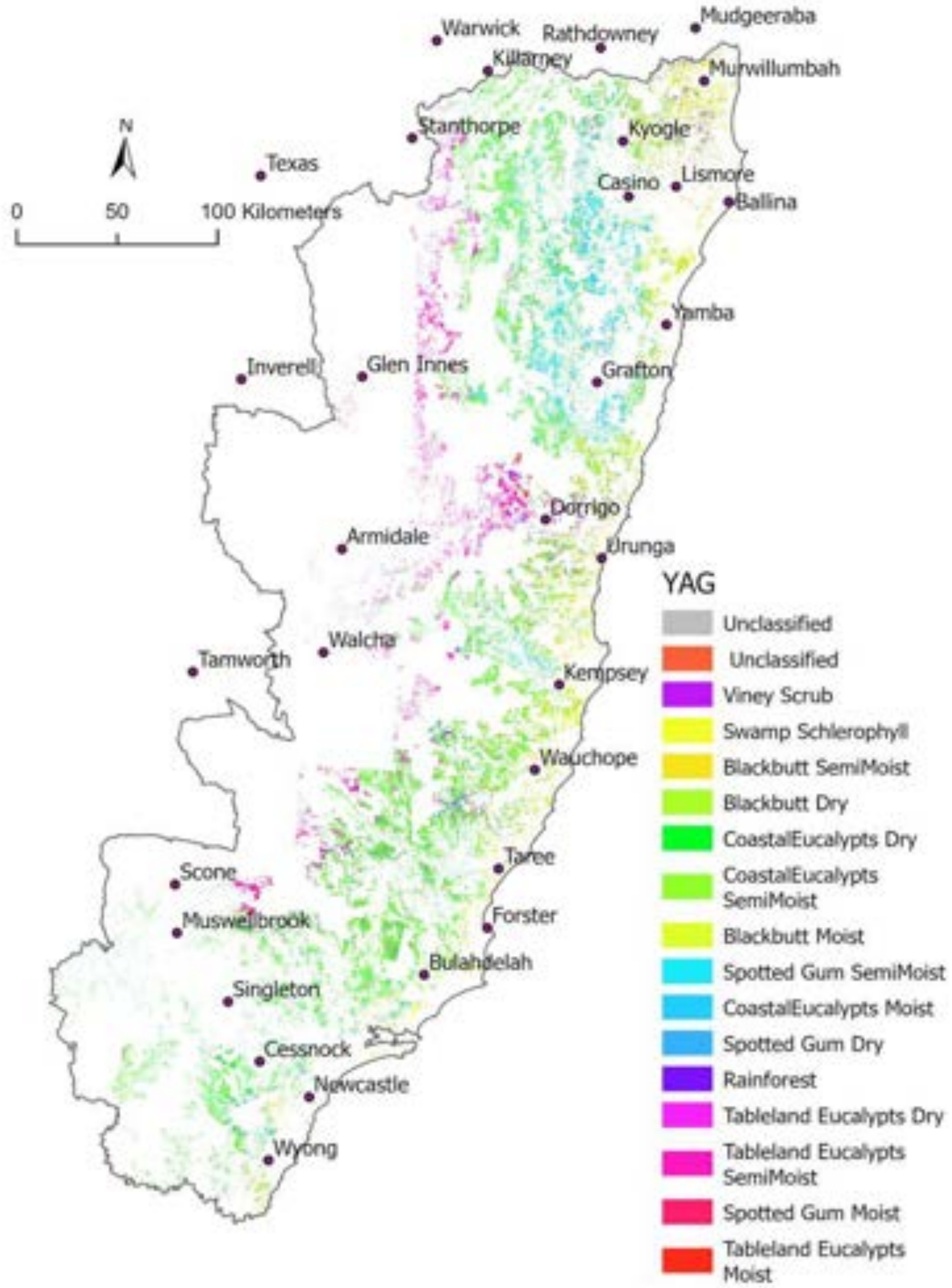

Figure 7.7. Map for NE Hub region showing private native forest yield association groups (YAGs) that were of potential commercial value (with the forest cover mask layer in 2022).

In the SE Forestry Hub region, the YAG mapping identified approximately 665,700 ha of private native forest, of which approximately 0.96% (6,400 ha) was mapped as sparse woody vegetation (Table 7.4; Figure 7.8). Commercially important forest in 2022 covered approximately 174,900 ha in the SE Forestry Hub region (Figure 7.9). Because of the way commercial forest was classified (i.e. based mostly on forest height and cover) there was virtually no sparse YAG forest in 2022 that was mapped as commercially important.

Table 7.4. Area of 'sparse woody vegetation' and total private native forest extent for each yield association group (YAG) and the area of each that were considered commercially important in the SE Forestry Hub region in 2022. Areas were rounded to the nearest 100 ha.

Yield Association Group	Area of sparse woody vegetation (ha) in private native forest	Area of private native forest (ha)	Area of commercial private native forest (ha)
Coastal dry hardwoods	1,100	93,600	38,600
Negligible forest products	4,100	385,600	11,400
Tableland gum - peppermint	100	51,100	16,100
Brown barrel - messmate	100	26,800	16,600
Silvertop ash	100	17,300	9,200
Alpine ash	0	7,100	2,800
Rainforest	100	15,000	6,800
Yellow stringybark	0	19,400	17,200
Spotted gum	7	40,200	22,600
Coastal moist hardwoods	100	9,600	9,000
Total	6,400	665,700	174,900 (24,500 unclassified)

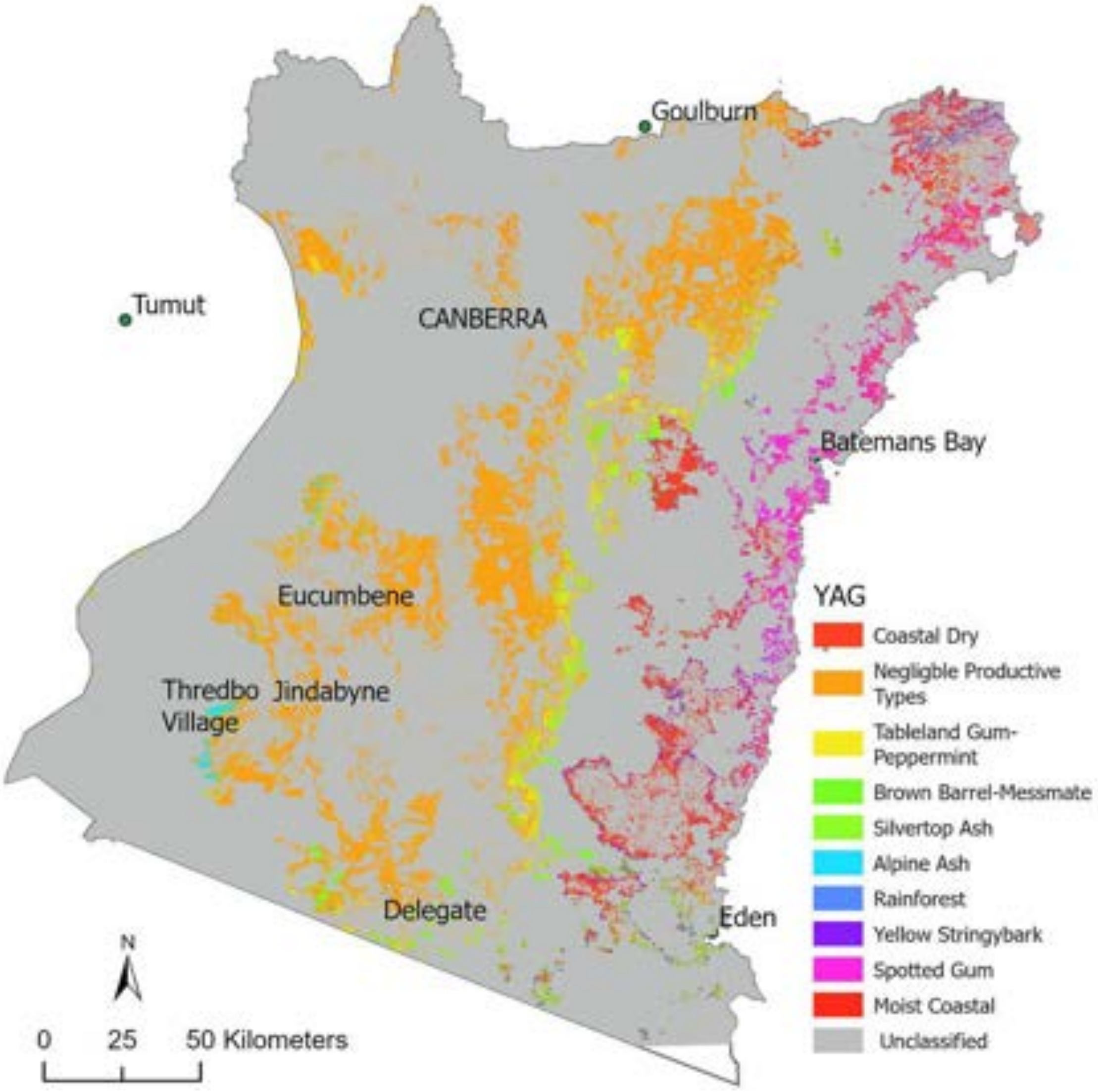

Figure 7.8. Map for SE NSW Hub region showing private native forest yield association groups (YAGs).

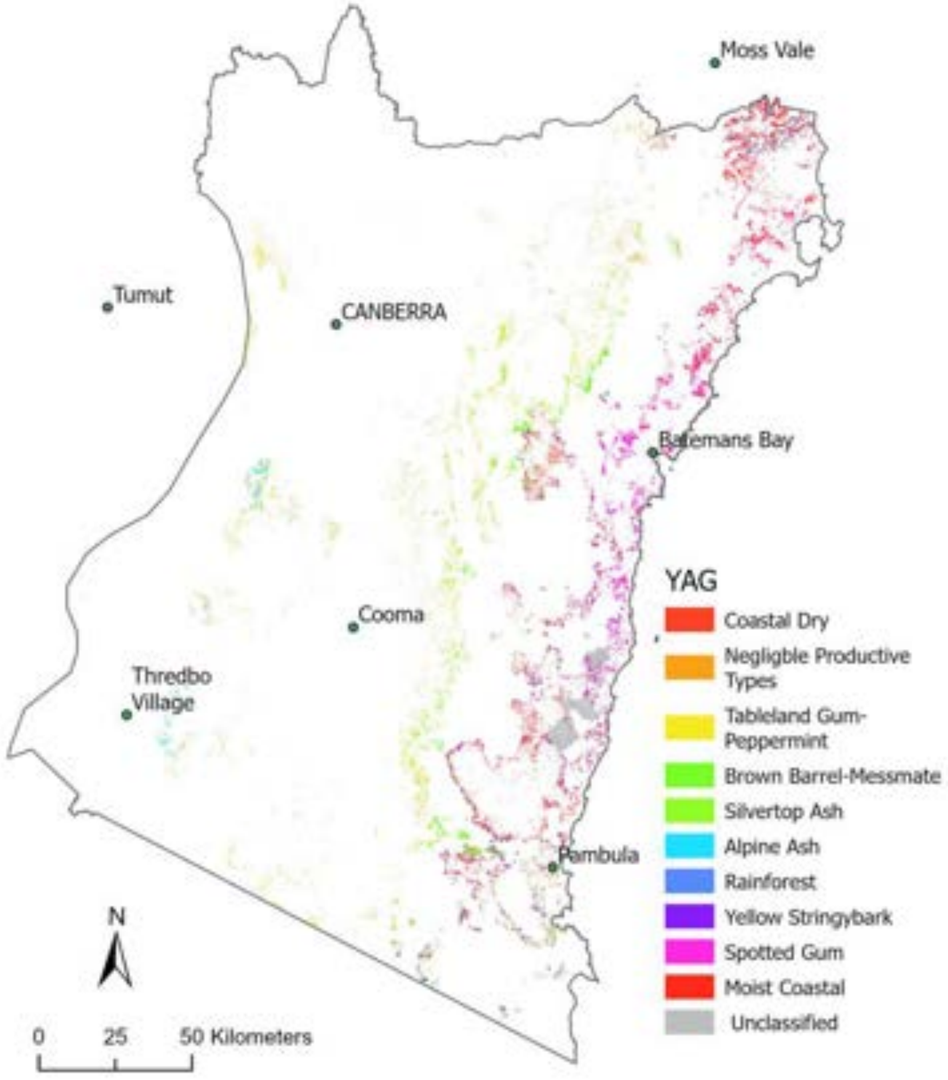

Figure 7.9. Map for SE NSW Hub region showing private native forest yield association groups (YAGs) that were of potential commercial value (with the forest cover mask layer in 2022).

7.6 Broad Trends in Clearing and Regrowth Over Time in Queensland

7.6.1 Broad Trends in Woody Vegetation Clearing Rates from the 1988 to 2018 SLATS Data (Landsat-based)

At the state level, the rates of woody vegetation clearing of non-remnant (i.e. regrowth) vegetation varied from 59,100 ha/yr in 2009-10 to 318,000 ha/yr in 2017-18. The average rate of clearing from 1997 (when remnant vegetation mapping was initiated) to 2018 was 147,000 ha/yr. The rates of clearing for the remainder of this section are for both remnant and non-remnant vegetation. From 1988 to 2018, 90% of the clearing was for pasture development, 2.5% of clearing was for cropping, 2.4% was due to forestry activities, 1.7% was due to thinning and 1.6% was due to infrastructure development. The percentage of repeat clearing since 1988 increased over time. From 1988 to 2000, the average percentage of land subjected to repeat clearing was 3.8%. From 2000 to 2010 the average percentage of land that was repeatedly cleared was 13.9%, and for the period from 2010 to 2018 the average percentage was 34.9% (Figure 7.10). That is, more than one-third of woody vegetation clearing between 2010 and 2018 was re-clearing of areas that have already been cleared at least once since 1988. Given the dominance of clearing for pasture development and the standard management practice of periodic re-clearing of regrowth to reduce competition with pasture, the average proportion of repeat clearing is likely to continue to rise over time.

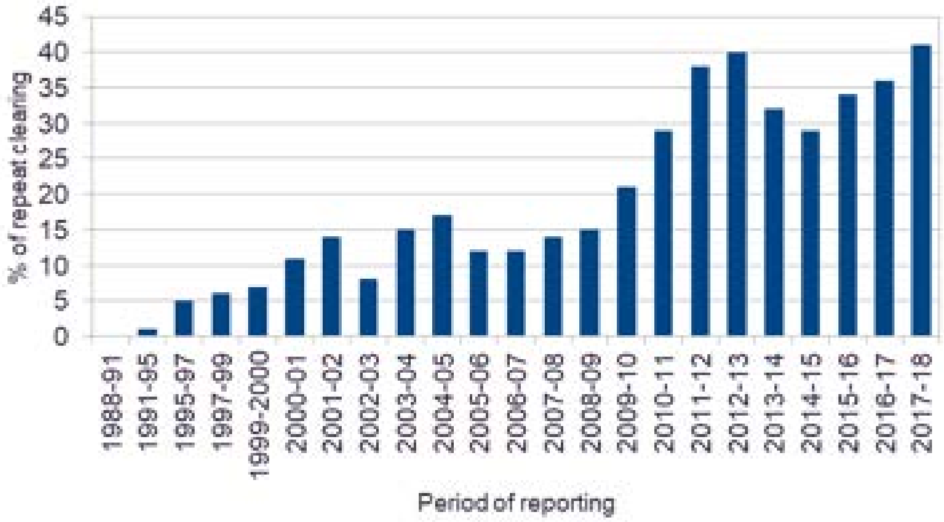

Figure 7.10. Percentage of repeat clearing based on the SLATS data from 1988 to 2018 for the State of Queensland for remnant and non-remnant vegetation. Data source: https://www.qld.gov.au/environment/land/management/mapping/statewide-monitoring/slats/slats-data/previous-slats

To allow comparisons with the Forestry Hub regions in Queensland, the SLATS data can be examined at the bioregion scale (https://www.qld.gov.au/environment/plants-animals/plants/ecosystems/descriptions/framework). There are three key bioregions in the Southern and Central Forestry Hub – Southeast Queensland, Brigalow Belt and the New

England Tableland bioregion, which are reported below (note that there are also small areas of the Mulga Lands and Central Queensland Coast bioregions within the Southern and Central Forestry Hub region). For the purposes of this report, we have focussed this summary on the four main bioregions of the Northern Forestry Hub region, namely Einasleigh Uplands, Wet Tropics, Gulf Plains and Cape York Peninsula. Several other small bioregions also contribute to the Northern Hub region but these were not considered here.

The average rates of clearing over the period from 1988 to 2018 were highest in the Brigalow Belt bioregion at 168,400 ha/yr. In the Southeast Queensland bioregion and the New England Tableland bioregion, the average rates of clearing were 16,600 ha/yr and 2,700 ha/yr, respectively. The average rates of clearing were generally lower in the northern bioregions: 4,700 ha/yr in the Gulf Plains bioregion, 3,200 ha/yr in the Einasleigh Uplands bioregion, 2,100 ha/yr in the Cape York Peninsula bioregion and 1,400 ha/yr in the Wet Tropics bioregion.

As indicated in Figures 7.11 and 7.12, the rates of clearing varied over time in both the southern and northern bioregions of interest. For example, in the Brigalow Belt and Southeast Queensland bioregions, rates of clearing peaked initially in the 1999-2000 period, declining to lower rates in the period from 2008-2010, before increasing and peaking again the period from 2015 to 2018 (Figure 7.11). A similar pattern was observed in the northern bioregions, but with a peak occurring between 2004 and 2007, a trough in the period from 2009 to 2011 followed by a second peak in 2014 to 2017, largely due to a spike in clearing rates in the Gulf Plains bioregion in 2014-15 and 2015-16 (Figure 7.12).

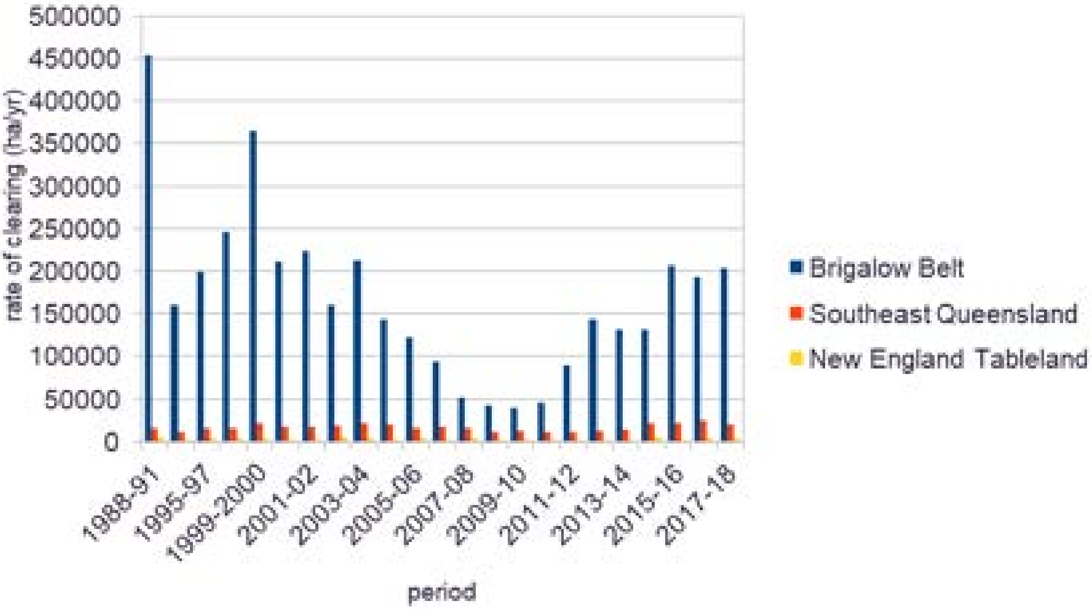

Figure 7.11. Rates of clearing from 1988 to 2018 for three key bioregions in the Southern and Central Queensland Forestry Hub region. Data source: https://www.qld.gov.au/environment/land/management/mapping/statewide-monitoring/slats/slats-data/previous-slats

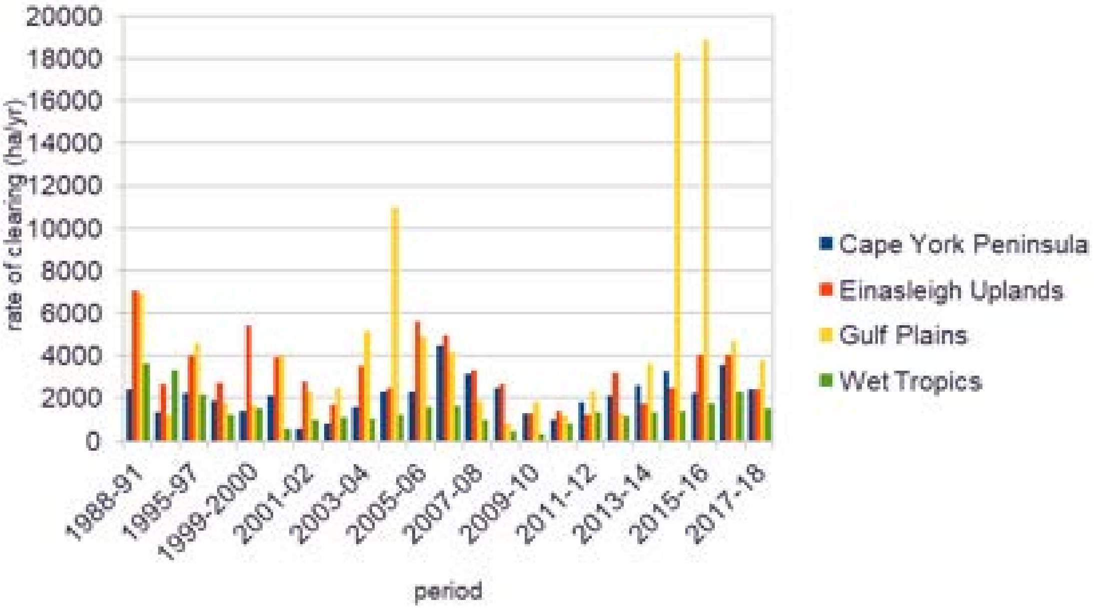

Figure 7.12. Rates of clearing from 1988 to 2018 for four key bioregions in the Northern Queensland Forestry Hub region. Data source: https://www.qld.gov.au/environment/land/management/mapping/statewide-monitoring/slats/slats-data/previous-slats

7.6.2 Broad Trends in New Regrowth and Clearing from the 2018 to 2021 SLATS Data (Sentinel-2 based)

7.6.2.1 Regrowth

There is a large area of existing regrowth vegetation in Queensland – approximately 7.6 million ha. At the state level in the 2020-21 reporting period, 59,700 ha of new regrowth was mapped. Most new regrowth occurred in the Brigalow Belt bioregion (39%, 23,500 ha) and the Southeast Queensland bioregion (20%, 12,200 ha); the two bioregions most relevant to the Southern and Central Forestry Hub region. About 67% (39,800 ha) of the new regrowth mapped occurred on pastureland, and 7% (4,000 ha) was mapped as crop, largely due to new tree-crop orchards. About 24% (14,500 ha) of the regrowth was attributed to forestry. In SLATS, forestry defined as ‘timber harvesting in state or privately owned native or exotic (e.g. pine) forests or plantations’. Forestry includes ‘partial clearing’, so this potentially could capture native forests recovering from selection harvesting. However, from the SLATS documentation it is difficult to determine exactly how regrowth and clearing (see below) attributed to forestry was classified.

Eighty percent of the new regrowth mapped was categorised as either sparse (foliage projected cover of 10-30%, which is equivalent to 20-50% crown cover) or very sparse woody vegetation (foliage projected cover of <10% which is equivalent to 0.25-20% crown cover), with 20% classified as mid-dense woody vegetation (foliage projected cover of 30-70%, which is equivalent to 50-80% crown cover).

In the Southeast Queensland bioregion the area of new regrowth increased from 7,900 ha in the 2019-2020 reporting period to 12,200 ha in the 2020-21 reporting period. In the Brigalow Belt bioregion, the area of new regrowth increased from 10,900 ha in the 2019-2020 reporting period to 23,500 ha in the 2020-21 period. The area of new regrowth was small in the New England Tableland region; only 100 ha in 2019-20 and 200 ha in 2020-2021. The area of new regrowth for the four main bioregions occurring in the Northern Forestry Hub region – Einasleigh Uplands, Wet Tropics, Gulf Plains and Cape York Peninsula was summed. The combined area of new regrowth for these bioregions increased from 2,246 ha in the 2019-2020 reporting period to 12,800 ha in the 2020-21 reporting period.

7.6.2.2 Clearing activity

The following is summarised from the Queensland Government 2020-21 SLATS Report webpage (Accessed 15 October 2024 and last updated 30 July 2023 https://www.qld.gov.au/environment/land/management/mapping/statewide-monitoring/slats/slats-reports/2020-21-slats-report/key-findings). At the state level in the 2020-21 reporting period, 82% (288,200 ha) of total tree clearing activity (349,400 ha) took place in Category X areas. Approximately 52% (182,900 ha) of the clearing activity occurred in vegetation estimated to be greater than 15-year-old. Thirty-six percent of the total clearing occurred in vegetation estimated to be less than 15-year-old and the remaining 12% occurred in vegetation that could not be reliably aged. Most clearing (89%) was attributed to pasture development, and 4% (12,900 ha) was attributed to forestry activity. As indicated above, exactly how regrowth and clearing has been attributed to forestry is unclear. It potentially includes ‘partial clearing’ in selectively harvested native forest, although forestry clearing is likely to be mostly capturing plantation forestry, which are harvested by clearfelling. Forestry clearing in 2020-21 (12,900 ha) is close to forestry regrowth in 2020-21 (14,500 ha), which is expected since, by definition, forestry is the long-term management of trees and forests, not a form of land clearing.

Most clearing activity in Queensland was considered ‘full clearing’ (96%), where less than 10% crown cover remains. In the Southeast Queensland bioregion, the area of full clearing was 23,100 ha (19,600 ha on Category X land) in the 2018-19 reporting period and remained relatively stable in the 2019-20 reporting period (19,900 ha with 17,000 ha on Category X land) and the 2020-21 reporting period (20,000 ha with 17,300 ha on Category X land). In the Brigalow Belt bioregion, full clearing declined from 266,600 ha (240,400 ha on Category X land) in the 2018-19 period to 158,500 ha (143,300 ha on Category X land) in the 2019-20 period, before increasing slightly in the 2020-21 period to 163,500 ha (149,000 on Category X land). Full clearing in the New England Tablelands bioregion was 4,400 ha (3,800 ha on Category X land) in the 2018-19 period, 1,900 ha (1,500 ha on Category X land) in the 2019-20 period and 3,300 ha (2,900 on Category X land) in the 2020-21 period.

The extent of clearing in the Northern Forestry Hub region was generally lower than that in the Southern and Central Hub region, and relatively less of this clearing was on Category X land. The combined area of full clearing for the Einasleigh Uplands, Wet Tropics, Gulf

Plains and Cape York Peninsula bioregions was 9,700 ha (3,000 ha on Category X land) in the 2018-19 period, 11,100 ha (3,900 ha on Category X land) in the 2019-20 period and 12,200 ha (5,100 ha on Category X land) in the 2020-21 period.

7.6.2.3 Net clearing

Overall, the extent of clearing exceeded the extent of new regrowth. In the period from 2019-2021 (where regrowth figures were available), the net loss in woody vegetation was 19,700 ha in the Southeast Queensland bioregion, 287,700 ha in the Brigalow Belt bioregion, 4,900 ha in the New England Tablelands bioregion and 8,300 ha in the combined Einasleigh Uplands, Wet Tropics, Gulf Plains and Cape York Peninsula bioregions. However, it is acknowledged that a likely large proportion of this clearing took place on land that has low forestry potential. The following section focuses specifically on areas where commercial forestry is possible.

7.6.3 Trends in Commercially Important Private Native Forest Regrowth Over Time in Queensland

7.6.3.1 Southern and Central Forestry Hub region

The assessed changes in regrowth extent in Queensland were limited to the area of Category X regrowth described in Section 7.4 on Queensland regrowth extent. Regrowth forest data reported in this section in Table 7.5 were based on 'The National Forest and Sparse Woody Vegetation Data, Version 5.0' (2020), which was the best available data for estimation of change in woody vegetation extent over time for all Hub regions. Table 7.5 indicates there were 1,283,200 ha of regrowth forest on Category X land in 2020 that are potentially harvestable under the current NFP ADVCC[13].

That estimate does not match the total for this region reported in Tables 7.1 and 7.2 (2,141,300 ha in 2016-17 and 1,740,100 ha still standing in 2021 based on SLATS 2021 data), as different datasets were used in calculations. The data in Tables 7.1 and 7.2 were based on a dataset from the Queensland Department of Agriculture and Fisheries (DAF) in 2022 that had been developed specifically to map the existing area of commercially important private native forest and SLATS 2021 data. An enormous discrepancy is that there was 1,048,800 ha of '>31 years old regrowth' reported in Table 7.2, compared to only 475,100 ha that 'Remained as forest vegetation' in Table 7.5. The need to rely on different datasets for the estimation of change in regrowth forest area over time versus their current extent has created similar forest area discrepancies in the other Forestry Hub regions described below.

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[13] The sum for 1991-2020 of Changed from non-woody to sparse woody vegetation, Changed from non-woody to forest vegetation, Changed from sparse woody to Forest vegetation, Remained as sparse woody vegetation, Changed from forest to sparse woody vegetation, and Remained as forest vegetation.

Table 7.5. Change detection analysis output from 2011 to 2020 and for the entire 1991-2020 period. This indicates the area (ha, and % of total area in parentheses) that changed in each category for commercially important private native forest on Category X land for the Southern and Central Queensland Hub region. Areas were rounded to the nearest 100 ha.

Area change	1991-2020	2011-2020
Changed from non-woody to sparse woody vegetation	183,700 (9.6%)	147,900 (7.7%)
Changed from non-woody to forest vegetation	182,400 (9.5%)	105,800 (5.5%)
Remained as non-woody vegetation	447,400 (23.4%)	467,900 (24.5%)
Changed from sparse woody to non-woody vegetation	103,200 (5.4%)	108,600 (5.7%)
Changed from sparse woody to forest vegetation	212,300 (11.1%)	189,800 (9.9%)
Remained as sparse woody vegetation	144,200 (7.5%)	186,600 (9.8%)
Changed from forest to non-woody vegetation	76,600 (4.0%)	51,400 (2.7%)
Changed from forest to sparse woody vegetation	85,500 (4.5%)	78,800 (4.1%)
Remained as forest vegetation	475,100 (24.9%)	572,500 (30.0%)

Rates of clearing and regrowth in the Category X regrowth extent layer estimated with ‘The National Forest and Sparse Woody Vegetation Data, Version 5.0’ (2020) were quite different to those reported at a state and Bioregional levels based on SLATS reports. For example Table 7.5 indicates for the entire period between 1991 and 2000 in the Southern and Central Queensland Hub region, 4.0% (76,600 ha) of forest (i.e. canopy cover of 20% or more) was cleared (i.e. changed from forest to non-woody vegetation) while 9.5% (182,400 ha) of area mapped as non-woody vegetation in 1991 became new forest (Table 7.5; Figure 7.13). Over this period, the rate of clearing activity (including forest clearing and sparse woody vegetation clearing, but not partial clearing of forest) was 6,200 ha per year (0.32% of Category X regrowth area per year). The rate of all new regrowth (including regrowth of sparse woody vegetation and forest, but not sparse vegetation becoming forest) was 12,600 ha per year (0.66% of Category X regrowth area per year). Over this period, 475,100 ha (24.9%) remained forest, while 447,400 ha (23.4%) remained cleared, and 144,200 ha (7.5%) remained sparse woody vegetation (Table 7.5). During this period, 183,700 ha (9.6%) changed from non-woody vegetation to sparse woody vegetation, while 103,200 ha (5.4%) changed from sparse woody vegetation to non-woody vegetation, in this period.

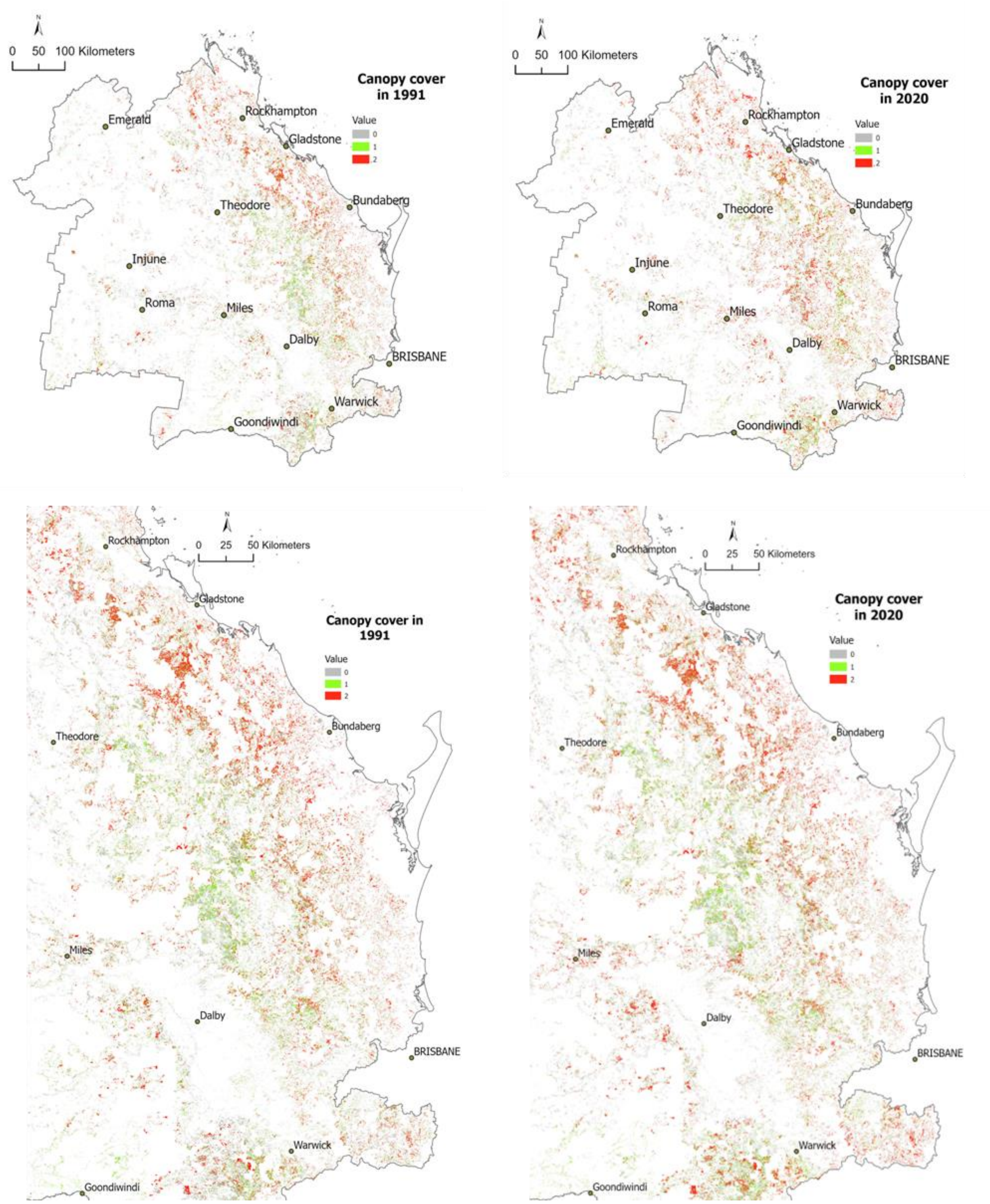

Figure 7.13. Changes in forest canopy cover (based on the National Forest and Sparse Woody Vegetation Data) between 1991 and 2020 for the Southern and Central Queensland Hub region and a south-eastern section of the region, where 0 values represent non-woody vegetation, values of 1 represent sparse forest cover and values of 2 represent forest cover.

In the period from 2011 to 2020, 2.7% (51,400 ha) of forest was cleared (i.e. changed from forest to non-woody vegetation) while 5.5% (105,800 ha) of area mapped as non-woody vegetation in 2011 became new forest (Table 7.5). Over this period, the rate of clearing activity (including forest clearing and sparse woody vegetation clearing, but not partial clearing of forest) was 17,800 ha per year (0.93% of Category X regrowth area per year). The rate of all new regrowth (including regrowth of sparse woody vegetation and forest, but not sparse vegetation becoming forest) was 28,200 ha per year (1.48% of Category X regrowth area per year). Over this period 572,500 ha (30.0%) remained forest, while 467,900 ha (24.5%) remained cleared and 186,600 ha (9.8%) remained sparse woody vegetation (Table 7.5). During this period, 147,900 ha (7.7%) changed from non-woody vegetation to sparse woody vegetation, whereas 108,600 ha (5.7%) changed from sparse woody vegetation to non-woody vegetation. The area of non-woody vegetation in this Hub region declined from approximately 813,500 ha in 1991 to 721,600 ha in 2011 and then continued to decline to 627,600 ha in 2020.

7.6.3.2 Northern Forestry Hub region

Based on ‘The National Forest and Sparse Woody Vegetation Data, Version 5.0’ (2020), Table 7.6 indicates there were 57,300 ha of regrowth forest on Category X land in 2020 that are potentially harvestable under the current NFP ADVCC[14]. That estimate does not match the total for this region reported in Tables 7.1 and 7.2 (84,400 ha in 2016-17 and 67,400 ha still standing in 2021 based on SLATS 2021 data), as different datasets were used in calculations. The data in Tables 7.1 and 7.2 were based on a dataset from the Queensland Department of Agriculture and Fisheries (DAF) in 2022 that had been developed specifically to map the existing area of commercially important private native forest and SLATS 2021 data. A large discrepancy between the two data sets is that the SLATS data in Table 7.2 indicated there were only 5900 ha ‘>31 years old’, while Table 7.6 indicated 31,600 ha ‘Remained as forest vegetation’ from 1991 to 2020. The larger area of ‘Remained as forest vegetation’ could be partly explained by forest that was cleared during the period and had returned to forest cover by 2020.

For the entire period between 1991 and 2020 in the Northern Queensland Hub region, 6.6% (5,200 ha) of Category X forest (canopy cover of 20% or more) was cleared while 8.9% (7,000 ha) of area mapped as non-woody vegetation in 1991 became new forest (Table 7.6). Over this period, the rate of clearing activity (including forest clearing and sparse woody vegetation clearing, but not partial clearing of forest) was 300 ha per year (0.38% of Category X regrowth area per year). The rate of all new regrowth (including regrowth of sparse woody vegetation and forest, but not sparse vegetation becoming forest) was 400 ha per year (0.54% of the Category X regrowth area per year). Over this period, 31,600 ha (40.2%) remained forest, while 12,600 ha (16.0%) remained cleared and 3,100 ha (4.0%) remained sparse woody vegetation (Table 7.6). During this period, 5,300 ha (6.8%) changed from non-woody vegetation to sparse woody vegetation, whereas 3,500 ha (4.4%) changed from sparse woody vegetation to non-woody vegetation.

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[14] The sum for 1991-2020 of Changed from non-woody to sparse woody vegetation, Changed from non-woody to forest vegetation, Changed from sparse woody to Forest vegetation, Remained as sparse woody vegetation, Changed from forest to sparse woody vegetation, and Remained as forest vegetation.

Table 7.6. Change detection analysis output from 2011 to 2020 and for the entire 1991-2020 period. This indicates the area (ha, and % of total area in parentheses) that changed in each category for commercially important private native forest on Category X land in the Northern Queensland Hub region. Areas were rounded to the nearest 100 ha.

Area change	1991-2020	2011-2020
Changed from non-woody to sparse woody vegetation	5,300 (6.8%)	1,500 (1.9%)
Changed from non-woody to forest vegetation	7,000 (8.9%)	2,800 (3.5%)
Remained as non-woody vegetation	12,600 (16.0%)	11,400 (14.5%)
Changed from sparse woody to non-woody vegetation	3,500 (4.4%)	6,700 (8.5%)
Changed from sparse woody to forest vegetation	6,400 (8.1%)	10,900 (13.8%)
Remained as sparse woody vegetation	3,100 (4.0%)	8,000 (10.1%)
Changed from forest to non-woody vegetation	5,200 (6.6%)	3,100 (4.0%)
Changed from forest to sparse woody vegetation	3,900 (5.0%)	2,900 (3.7%)
Remained as forest vegetation	31,600 (40.2%)	31,400 (39.9%)

In the period from 2011 to 2020, 4.0% (3,100 ha) of forest was cleared (i.e. changed from forest to non-woody vegetation) whereas 3.5% (2,800 ha) of the area mapped as non-woody vegetation in 2011 became new forest (Table 7.6). Over this period, the rate of clearing activity (including forest clearing and sparse woody vegetation clearing, but not partial clearing of forest) was 1,100 ha per year (1.39% of Category X regrowth area per year), which exceeded the rate of all new regrowth (including regrowth of sparse woody vegetation and forest, but not sparse vegetation becoming forest) at 500 ha per year (0.60% of the Category X regrowth area per year). Over this period, 31,400 ha (39.9%) remained forest, whereas 11,400 ha (14.5%) remained cleared and 8,000 ha (10.1%) remained sparse woody vegetation (Table 7.6). In this period, 1,500 ha (1.9%) changed from non-woody vegetation to sparse woody vegetation, while 6,700 ha (8.5%) changed from sparse woody vegetation to non-woody vegetation. The area of non-woody vegetation in this Hub region declined from approximately 24,900 ha in 1991 to 15,700 ha in 2011, before increasing in 2022 to 21,200 ha. This suggests there was re-clearing over around 5,500 ha between 2011 and 2022.

7.7 Broad Trends in Clearing and Regrowth Over Time in NSW

7.7.1 Broad Trends in Clearing from 1988 to 2020 Based on SLATS Data and Reports

SLATS data in NSW was divided into two periods: (1) 1988-2010, based on Landsat; and (2) 2010-2020, based on SPOT and Sentinel 2 satellites. Woody vegetation loss was categorised as being due to agriculture, forestry (forest harvesting activities) and infrastructure. Over the period from 1988 to 2010 the average rate of woody vegetation loss due to agriculture was 19,800 ha/yr, and that due to infrastructure was 3,500 ha/yr. The average rate of loss due to forestry was 15,600 ha/yr, although it is unclear to what extent tree cover had to be disturbed in selection harvesting operations in native forests for the activity to be considered clearing. The rates of woody vegetation loss remained relatively stable over time, but with increasing loss due to forestry activities (particularly 2007-2010; Figure 7.14a). In the period from 2010-2020, average rates of woody vegetation loss were 15,300 ha/yr, 22,900 ha/yr and 5,800 ha/yr for agriculture, forestry and infrastructure, respectively. There appeared to be a slight increase in clearing due to agriculture development from 2016 to 2019 (Figure 7.14b). Clearing due to forestry activities tended to be in the forestry hub regions, while clearing for agriculture was widespread across the eastern half of the state (State of New South Wales and Department of Planning and Environment 2022).

Over 90% of the clearing in NSW due to forestry was due to harvesting of plantations in State Forest and on private or leasehold land, and harvesting of native State Forest. As suggested by Figure 7.15, the average rate of woody vegetation loss between 2010 and 2020, due to native forest harvesting on freehold or leasehold land was 2,000 ha/yr. It is not clear from documentation accompanying the dataset whether some selection harvesting in native forests has been captured, but it is likely some of the ‘clearing’ is selection harvesting. Rates of loss due to this harvesting appeared to be higher in the years from 2016 to 2020, than in the preceding six years (Figure 7.15).

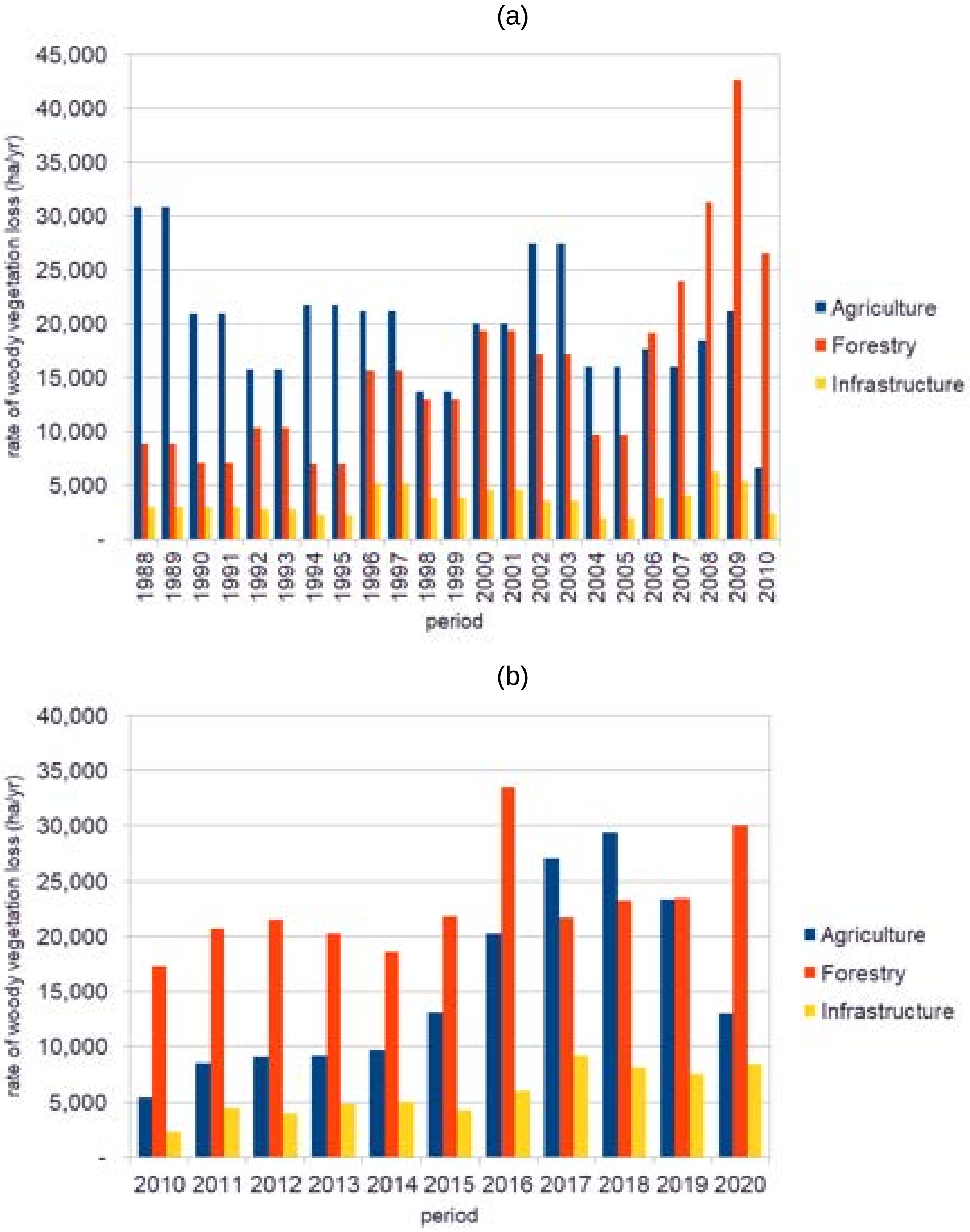


Figure 7.14. Rates of woody vegetation loss for the State of NSW over time, based on two separate periods: (a) 1988 to 2010; and (b) 2010 to 2020; for the three different categories of vegetation loss (agriculture, forestry and infrastructure). Data source: State of New South Wales and Department of Planning and Environment 2022.

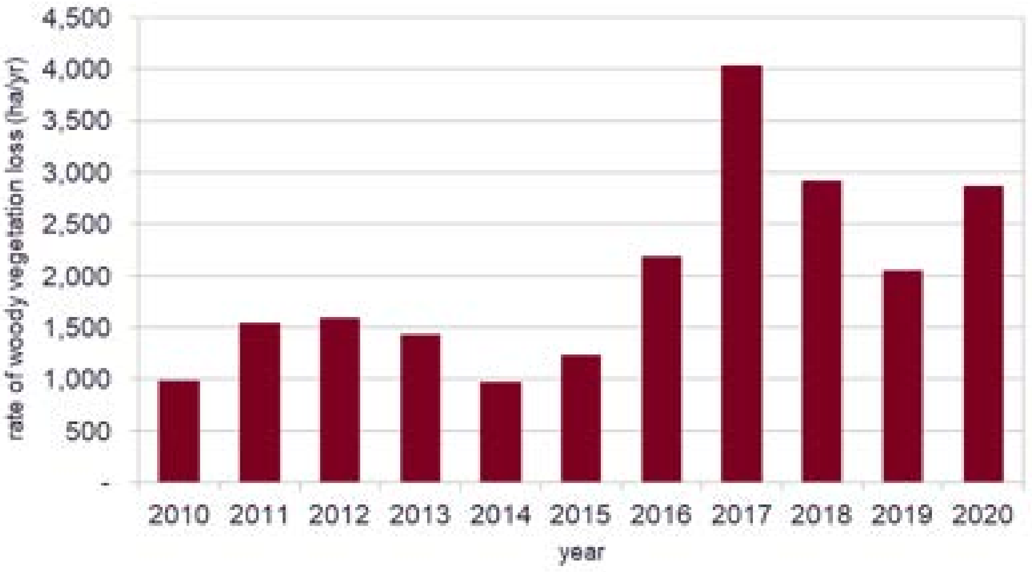


Figure 7.15. Rates of woody vegetation loss for the State of NSW from 2010 to 2020, based on native forestry activities on freehold or leasehold land. Data source: State of New South Wales and Department of Planning and Environment 2022.

7.7.2 Trends in Private Native Forest Regrowth Over Time in NSW

7.7.2.1 North East NSW Forestry Hub region

The changes in regrowth extent in NSW were limited to the area of private forest YAG mapping described in Section 7.5 on New South Wales regrowth extent. The total area considered was approximately 2,575,000 ha in the NE NSW Hub region (Table 7.7), defined by the combination of the National Forest and Sparse Woody Vegetation Data layer and the National Forest Tenure layer. The difference in area estimate relative to the YAG mapping in Table 7.3 is likely due to inclusion of the Northern Tablelands, inclusion of native and conifer timber plantations, some private native forest not in the YAG data, and some horticultural crops.

As indicated in Table 7.7, for the entire period between 1991 and 2022 in the NE Hub region, 2.5% (63,500 ha) of forest (canopy cover of 20% or more) was cleared, while 4.4% (114,300 ha) of area mapped as non-woody vegetation in 1991 became new forest. Over this period, the rate of all clearing activity (including forest clearing and sparse woody vegetation clearing, but not partial clearing of forest) was 2,700 ha per year (0.11% of the private native forest area per year). The rate of all new regrowth (including the regrowth of sparse woody vegetation and forest, but not sparse vegetation becoming forest) was 4,800 ha per year (0.19% of the private native forest area per year). Over this period, 2,058,200 ha (79.9%) remained forest, while 72,500 ha (2.8%) remained cleared and 29,000 ha (1.1%) remained sparse woody vegetation (Table 7.7). During this period 34,300 ha

(1.3%) changed from non-woody vegetation to sparse woody vegetation, while 21,000 ha (0.8%) changed from sparse woody vegetation to non-woody vegetation.

Table 7.7. Change detection analysis output from 2011 to 2022 and for the entire 1991-2022 period. This indicates the area (ha, and % in parentheses) of private native forest that changed in each category for the NE NSW Hub region. Areas were rounded to the nearest 100 ha.

Area change	1991-2022	2011-2022
Changed from non-woody to sparse woody vegetation	34,300 (1.3%)	27,800 (1.1%)
Changed from non-woody to forest vegetation	114,300 (4.4%)	37,900 (1.5%)
Remained as non-woody vegetation	72,500 (2.8%)	71,000 (2.8)
Changed from sparse woody to non-woody vegetation	21,000 (0.8%)	28,900 (1.1%)
Changed from sparse woody to forest vegetation	138,900 (5.4%)	96,200 (3.7%)
Remained as sparse woody vegetation	29,000 (1.1%)	43,000 (1.7%)
Changed from forest to non-woody vegetation	63,500 (2.5%)	57,100 (2.2%)
Changed from forest to sparse woody vegetation	43,500 (1.7%)	36,100 (1.4%)
Remained as forest vegetation	2,058,200 (79.9%)	2,177,600 (84.5%)

From 2011 to 2022, 2.2% (57,100 ha) of forest was cleared (i.e. changed from forest to non-woody vegetation) while 1.5% (37,900 ha) of area mapped as non-woody vegetation in 2011 became new forest (Table 7.7). Over this period, the rate of all clearing activity (including forest clearing and sparse woody vegetation clearing, but not partial clearing of forest) was 7,800 ha per year (0.30% of the private native forest area per year). The rate of all regrowth (including regrowth of sparse woody vegetation and forest, but not sparse vegetation becoming forest) was 6,000 ha per year (0.23% of the private native forest area per year). Over this period, 2,177,600 ha (84.5%) remained forest, while 71,000 ha (2.8%) remained cleared, and 43,000 ha (1.7%) remained sparse woody vegetation (Table 7.7). During this period, 27,800 ha (1.1%) changed from non-woody vegetation to sparse woody vegetation while 28,900 ha (1.1%) changed from sparse woody vegetation to non-woody vegetation. The area of non-woody vegetation in this Hub region declined from approximately 211,100 ha in 1991 to 136,700 ha in 2011, before increasing in 2022 to 157,000 ha. This suggests there was average annual re-clearing of around 1845 ha/y ha between 2011 and 2022 (20,300 ha / 11 years).

Figure 7.16 and Table 7.8 illustrate that between 1991 and 2022 there was also a net increase in the area of potential commercially important private native forest of around 74,000 ha. Only one yield association group (swamp sclerophyll) showed a net decline in forest area over this period (Table 7.8). Note this increase in YAG forest area is net of the changes in forest cover summarised in Table 7.7 and does not include the Northern Tablelands. Therefore, it underestimates regrowth private native forest regrowth in the NE NSW Forestry Hub region.

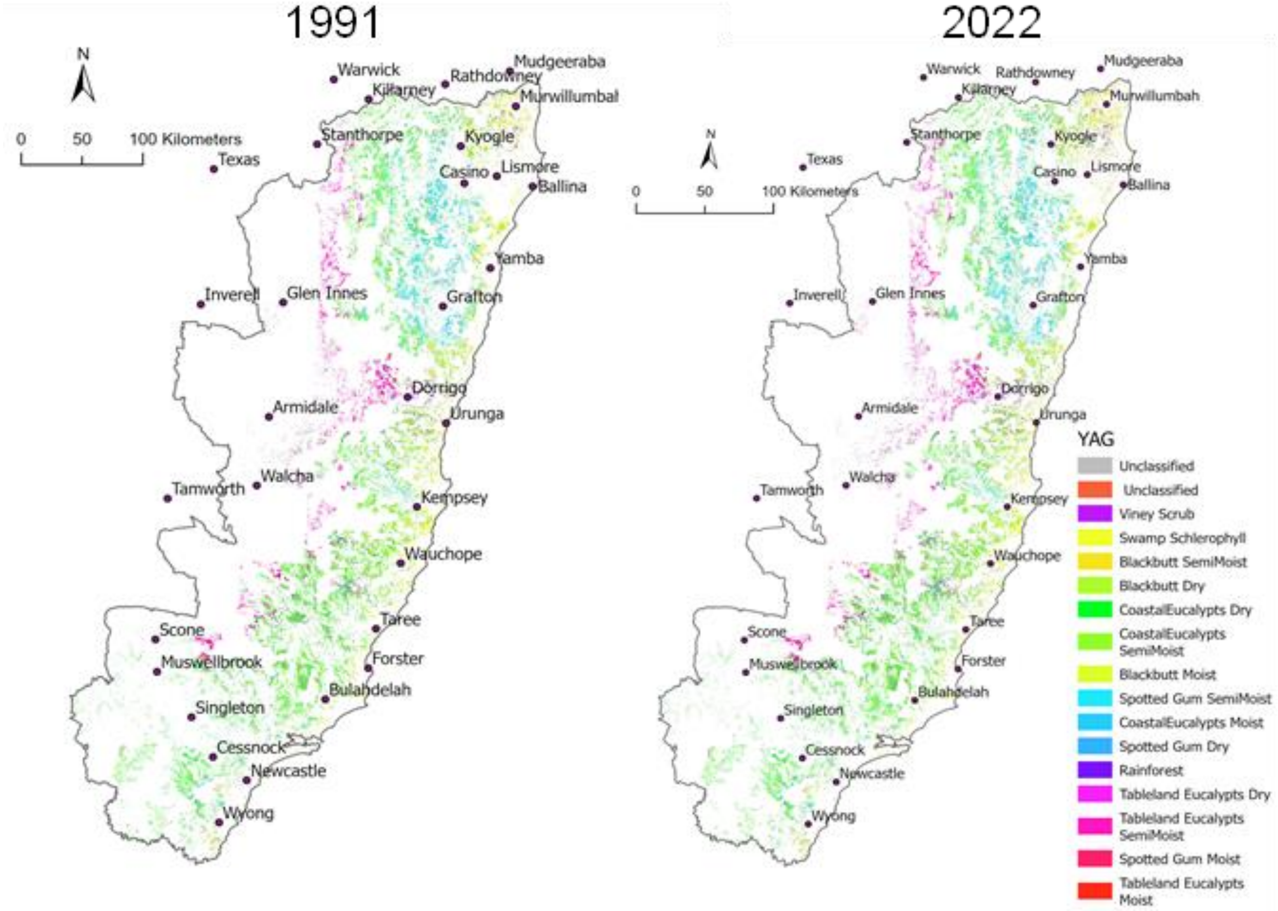


Figure 7.16. Potentially commercial forest within different yield association groups in 1991 (left) and 2022 (right) for NE NSW Hub region. At this map scale it is difficult to see changes in forest area; these are reported in Table 7.8.

7.7.2.2 South East NSW Forestry Hub region

The total area considered was approximately 887,000 ha in the SE NSW Hub region. For the entire period between 1991 and 2022 in the SE NSW Hub region, 3.2% (28,200 ha) of forest (canopy cover of 20% or more) was cleared, while 4.9% (42,400 ha) of the area mapped as non-woody vegetation in 1991 became new forest (Table 7.9). Over this period, the rate of all clearing activity (including forest clearing and sparse woody vegetation clearing, but not partial clearing of forest) was 1,000 ha per year (0.11% of the private native forest area per year). The rate of all regrowth (including regrowth of sparse woody vegetation and forest, but not sparse vegetation becoming forest) was 1,600 ha per year (0.18% of the private native forest area per year). Over this period, 729,900 ha (83.8%) remained forest, while 20,600 ha (2.4%) remained cleared and 3,400 ha (0.4%) remained sparse woody vegetation (Table 7.9). In this period, 7,400 ha (0.8%) changed from non-woody vegetation to sparse woody vegetation, whereas 1,500 ha (0.2%) changed from sparse woody vegetation to non-woody vegetation.

Table 7.8. Change in commercial forest cover from 1991 to 2022 for yield association groups in the NE NSW Hub region. Positive and negative areas indicate increases and decreases in forest area, respectively. Areas have been rounded to the nearest 100 ha.

Yield association group	Area (ha)
Rainforest	13,100
Viney scrub	5,500
Blackbutt	10,200
Spotted gum	12,100
Coastal tall moist eucalypts	1,200
Coastal semi-moist eucalypts	11,100
Coastal dry eucalypts	13,900
Swamp sclerophyll	-16,400
Tablelands tall moist eucalypts	200
Tablelands dry and semi-moist eucalypts	5,300
Unclassified	17,500
Total	**73,800**

In the period from 2011 to 2022, 2.9% (25,100 ha) of forest was cleared (i.e. changed from forest to non-woody vegetation) while 2.5% (21,700 ha) of the area mapped as non-woody vegetation in 2011 became new forest (Table 7.9). Over this period, the rate of all clearing activity (including forest clearing and sparse woody vegetation clearing, but not partial clearing of forest) was 2,800 ha per year (0.32% of the private native forest area per year). The rate of all regrowth (including regrowth of sparse woody vegetation and forest, but not sparse vegetation becoming forest) was 2,600 ha per year (0.30% of the private native forest area per year). During this period, 749,400 ha (85.8%) remained forest, while 21,900 ha (2.5%) remained cleared and 6,000 ha (0.7%) remained sparse woody vegetation (Table 7.9). Over this period, 7,000 ha (0.8%) changed from non-woody vegetation to sparse woody vegetation, while 5,700 ha (0.7%) changed from sparse woody vegetation to non-woody vegetation. The area of non-woody vegetation in this Hub region declined from approximately 70,400 ha in 1991 to 50,600 ha in 2011, before increasing in 2022 to 51,500 ha. This suggests there was re-clearing of around 900 ha between 2011 and 2022.

Between 1991 and 2022 there was also a net positive change of around 11,500 ha of potential commercially important private native forest (Figure 7.17, Table 7.10). All yield association groups showed an increase in forest cover over this period except the alpine ash group, which showed no change in area (Table 7.10). Note this increase in YAG forest area is net of the changes in forest cover summarised in Table 7.9. Therefore, it underestimates private native forest regrowth in the SE NSW Forestry Hub region in 2022, since this estimate is net of area cleared since 1991.

Table 7.9. Change detection analysis output from 2011 to 2022 and for the entire 1991-2022 period. This indicates the area (ha, and % of total area in parentheses) of private native forest that changed in each category for the SE NSW Hub region. Areas were rounded to the nearest 100 ha.

Area change	1991-2022	2011-2022
Changed from non-woody to sparse woody vegetation	7,400 (0.8%)	7,000 (0.8%)
Changed from non-woody to forest vegetation	42,400 (4.9%)	21,700 (2.5%)
Remained as non-woody vegetation	20,600 (2.4%)	21,900 (2.5%)
Changed from sparse woody to non-woody vegetation	1,500 (0.2%)	5,700 (0.7%)
Changed from sparse woody to forest vegetation	30,100 (3.5%)	31,200 (3.6%)
Remained as sparse woody vegetation	3,400 (0.4%)	6,000 (0.7%)
Changed from forest to non-woody vegetation	28,200 (3.2%)	25,100 (2.9%)
Changed from forest to sparse woody vegetation	7,300 (0.8%)	5,000 (0.6%)
Remained as forest vegetation	729,900 (83.8%)	749,400 (85.8%)

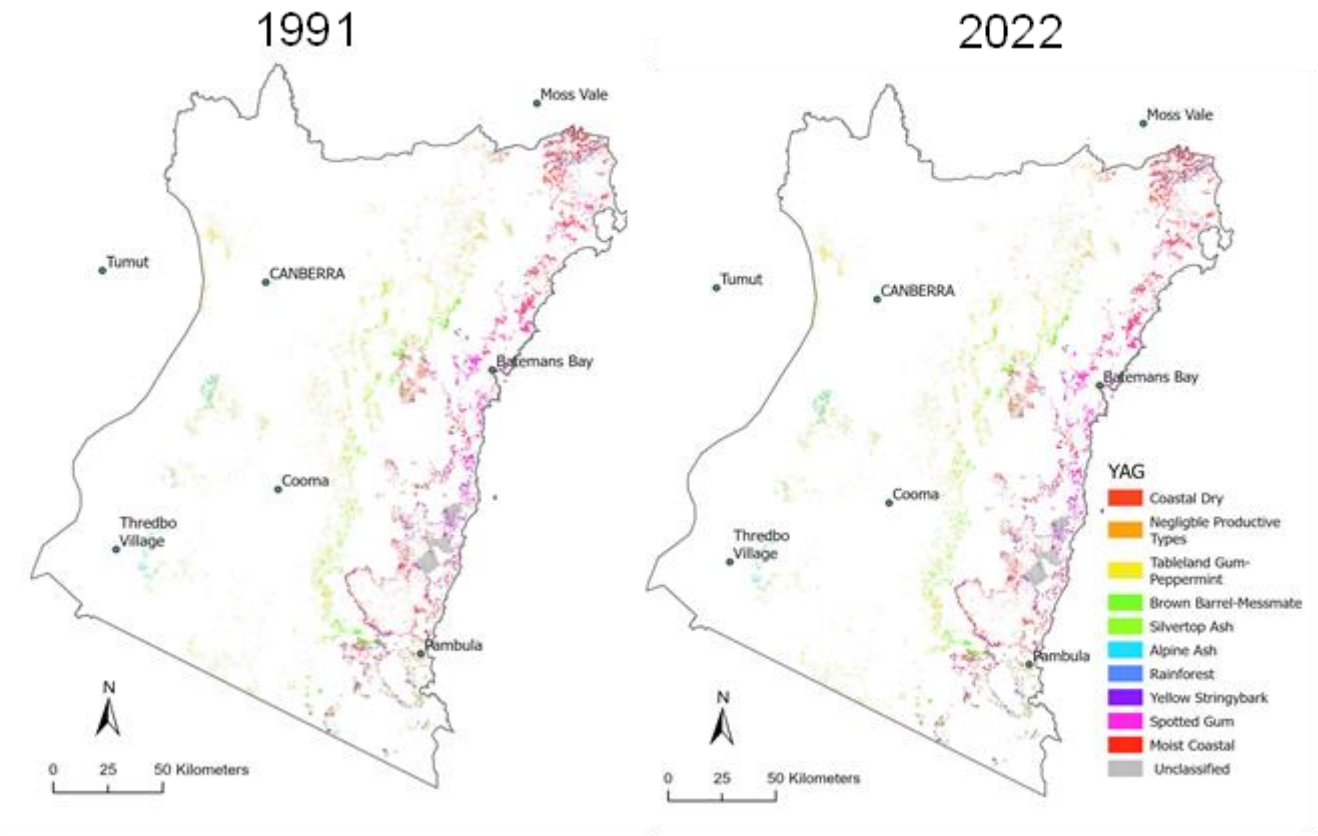


Figure 7.17. Potential commercial forest within different yield association groups in 1991 (left) and 2022 (right) for SE NSW Hub region. At this map scale it is difficult to see changes in forest area; these are reported in Table 7.9.

Table 7.10. Change in commercial forest cover (area, ha) from 1991 to 2022, for yield association groups in the SE NSW Hub region. Areas were rounded to the nearest 100 ha.

Yield Association Group	Area (ha)
Coastal dry hardwoods	2,900
Negligible forest products	1,000
Tableland gum - peppermint	900
Brown barrel - messmate	1,000
Silvertop ash	400
Alpine ash	0
Rainforest	500
Yellow stringybark	700
Spotted gum	1,700
Coastal moist hardwoods	400
Unclassified	2,000
Total	**11,600**

7.8 Best estimates of trends over time and standing commercially important regrowth native forest in Queensland and New South Wales

Estimating the area of native forest regrowth was an important aim of this research. Tables 7.5, 7.6, 7.7 and 7.9 provide the best estimates of the area of potentially commercially important private native forest regrowth in Queensland and New South Wales. This assessment has relied on the YAG mapping for private native forest in NSW, forest type mapping on Category X land in Queensland, and the National Forest and Sparse Woody Vegetation Data, Version 7.0 (2022 release) layer (see Section 7.2.2 and https://data.gov.au/dataset/ds-dga-69d09a6c-df77-439f-8bc7-87822cd520fd/details, Australian Government Department of Climate Change, Energy, the Environment and Water). There was no existing commercially important native forest regrowth mapping in NSW against which the estimates reported here can be compared. Queensland does have private native forest regrowth mapping described in earlier sections of this Chapter and against which the numbers reported here are compared below.

7.8.1 Trends in area of commercially important private sparse woody and forest vegetation from 1991 to 2020 for Queensland and from 1991 to 2022 for New South Wales

Sparse woody vegetation with commercially important species has the potential to become commercially important private native forest. The assessment of trends in area of commercially important sparse woody and forest vegetation over time can highlight the extent to which sustainable timber production with carbon sequestration, possibly in combination with livestock production as a silvopastoral system, has been foregone to maximise income from other pursuits. Table 7.11 reports the increases and decreases in commercially important sparse woody and forest vegetation over 30 to 32 years and 10 to 12 years for the Queensland and New South Wales Hub regions. Overall, there was a net increase in sparse woody and forest cover between 1991 and 2020-22, despite clearing exceeding recruitment of regrowth over the period 2011 to 2020-22. It is not particularly meaningful to compare regrowth and deforestation levels over 30+ years against the most recent 10 to 12 years for which data is available. This is because 30 years provides ample time for regeneration to occur so that forest cleared in, for example, year 4, is forest again by year 27 and recorded as ‘forest remaining forest’, even though it was cleared during the evaluation period. Discussion of Table 7.11 has focussed on the period 2011 to 2020-22.

During 2011 to 2020-22, 409,400 ha (38,308 ha/y) of commercially important sparse woody and forest vegetation of uncertain age were cleared throughout the four Forestry Hub regions, resulting in carbon emissions and the delay of potential development of sustainable timber production forests or silvopastoral systems. Over the same period 352,400 ha (33,667 ha/y) regrew into sparse woody or forest vegetation up to 10 to 12 years old from non woody vegetation. Therefore, there was a net loss of commercially important sparse woody and forest vegetation throughout the Forestry Hub regions of 57,000 ha (4642 ha/y).

Table 7.11. Trends in area of commercially important sparse woody and forest vegetation over time in Queensland and New South Wales

Vegetation statistic	Area by Forestry Hub region and time period (ha)									
	S&C QLD		N QLD		NE NSW		SE NSW		Total	
	1991 to 2020	2011 to 2020	1991 to 2020	2011 to 2020	1991 to 2022	2011 to 2022	1991 to 2022	2011 to 2022	1991 to 2020-22	2011 to 2020-22
Non woody to sparse woody or forest vegetation [a]	366,100	253,700	12,300	4,300	148,600	65,700	49,800	28,700	576,800	352,400
Forest or sparse woody to non woody vegetation and forest to sparse woody vegetation [a]	265,300	238,800	12,600	12,700	128,000	122,100	37,000	35,800	442,900	409,400
Net increase in sparse woody and forest vegetation [b]	100,800	14,900	-300	-8,400	20,600	-56,400	12,800	-7,100	133,900	-57,000
Average annual increase in sparse woody and forest vegetation [c]	12,200	25,400	400	400	4,644	5,500	1,600	2,400	18,800	33,700
Average annual loss of sparse woody and forest vegetation [c]	8,843	23,900	400	1,300	4,000	10,200	1,200	3,000	14,400	38,300
Average net annual increase in sparse woody and forest veg. [c]	3,400	1,500	-10	-800	644	-4,700	400	-600	4,400	-4,600

Notes: a. These areas are from Tables 7.5, 7.6, 7.7 and 7.9.

b. Non woody to sparse woody or forest vegetation area minus forest or sparse woody to non woody vegetation and forest to sparse woody vegetation.

c. Each of these three rows have been calculated as the area estimate from the first three rows, respectively, divided by 30 (1991 to 2020) or 10 (2011 to 2020) years for Queensland, and 32 (1991 to 2022) or 12 (2011 to 2022) years for New South Wales.

The level of clearing was greatest in the South and Central Queensland Forestry Hub region at 238,800 ha (23,880 ha/y). However, this was offset by regrowth of 253,700 ha, such that this Hub region experienced an increase in sparse woody and forest cover (14,900 ha in total and 1490 ha/y). Nevertheless, the clearing of 238,800 ha of potential commercially important forests represents a large opportunity cost in terms of foregone hardwood timber production and carbon sequestration, since the average age and level of biomass of sparse woody and forest vegetation cleared would likely have been greater than the average in the up to 10- to 12-year-old regrowth that established during the same time period.

The region with the second largest area of clearing was the North East New South Wales Forestry Hub, where 122,100 ha were cleared (10,175 ha/y), and 65,700 ha regrew, resulting in a net loss of 56,400 ha. Smaller net total losses of sparse woody and forest vegetation occurred in the North Queensland (8400 ha) and South East New South Wales (7100 ha) Hub regions.

Existing ACCU methods have not incentivised retention of commercially important private regrowth native forests. A native forest ACCU method compatible with timber harvesting may overcome some of the opportunity cost of foregone livestock or other agricultural income while the timber production forest is developing. In this way forest cover on the landscape could be increased over time.

7.8.2 Standing area of commercially important private native forest regrowth in Queensland (2020) and New South Wales (2022)

For the purposes of assessment of standing native forest regrowth, the regrowth has been divided into two categories.

1. Strictly post-1990 regrowth: land that had non-woody vegetation in 1991, but was sparse woody or forest in 2020 to 2022, and land that was forest in 1991, but was sparse woody vegetation in 2020 to 2022; and
2. Not strictly post-1990 regrowth: land that had woody vegetation in 1991, but is likely to have post-1990 regrowth forest structure in 2020 to 2022 because of observed changes in woody vegetation cover.

The strictly post-1990 regrowth category includes ‘Changed from non-woody to sparse woody vegetation’, ‘Changed from non-woody to forest vegetation’, and ‘Changed from forest to sparse woody vegetation’. The not strictly post-1990 regrowth category includes ‘Changed from sparse woody to forest vegetation’ and ‘Remained as sparse woody vegetation’. It is important to highlight that land that ‘Changed from forest to sparse woody vegetation’ and ‘Remained as sparse woody vegetation’ could be periodically re-cleared regrowth or isolated paddock trees with at least 5% canopy cover (which is not regrowth). It is impossible to determine the area that is not regrowth without a far more detailed spatial analysis over shorter time steps.

In all Hub regions, there are large areas of forest that ‘Remained as forest vegetation’ from 1991 to 2020 or 2022. It is possible that some of these areas are regrowth forest if, for example, they were cleared or severely disturbed in the first half of the period and had attained a level of tree cover that allows them to be classified as forest by 2020 to 22. A more detailed spatial analysis that assesses tree cover change over shorter time intervals than was possible in this study is necessary to determine the possible extent of regrowth forest within the category ‘Remained as forest vegetation’.

Table 7.12 reports the strictly and non-strictly post-1990 regrowth throughout the four Forestry Hub regions. The total regrowth area within forest types that can be potentially managed for timber production is 1.3 M ha, of which 0.88 M ha are commercially important.

Queensland has existing private native forest regrowth mapping that indicated a total of 1,740,100 ha of forest potentially harvestable under the NFP ADVCC in the Southern and Central Queensland Hub region, of which 1,325,900 ha are in forest types considered commercially important by the timber industry (Table 7.2). However, Table 7.2 reveals that 825,500 ha out of the 1,325,900 ha was ‘>31 years old’ based on the SLATS 2021 data, suggesting it is pre-1990 regrowth. Hence, the SLATS data indicated there was only about 500,400 ha of commercially important regrowth in the Southern and Central Queensland Hub region up to 31 years old in 2021, which is in the ‘ball park’ of the 614,200 ha based on the National Forest and Sparse Woody Vegetation Data, Version 7.0 (2022 release), and reported in Table 7.12. For the Northern Queensland Forestry Hub region, the SLATS data indicated there was about 25,000 ha of commercially important regrowth forest up to 31 years old in 2021 (Table 7.2), which was similar to the analysis based on the National Forest and Sparse Woody Vegetation Data (21,100; Table 7.12).

7.8.3 Cleared and total potential area of commercially important private native forest regrowth in Queensland (2020) and New South Wales (2022)

A more complete picture of the potential total area that could support commercially important private native forest regrowth can be provided by including the area that was cleared or remained cleared in Queensland (1991 to 2020) and New South Wales (1991 to 2022). These estimates are reported in Table 7.13, which indicates 604,600 ha of cleared commercially important forests that could become regrowth throughout the studied Forestry Hub regions. About 79% and 16% of this potential is in the South and Central Queensland Forestry Hub and North East New South Wales Hub regions, respectively. When these cleared areas are added to the standing area of commercially important regrowth, the total potential area of commercially important regrowth throughout the studied Hub regions is almost 1.5 M ha.

Table 7.12. Standing commercially important post-1990 private native forest regrowth in Queensland (2020) and New South Wales (2022)

Regrowth forest category	Forest area by region (ha)						
	S&C QLD Hub	N QLD Hub	Total QLD	NE NSW Hub	SE NSW Hub	Total NSW	Total QLD and NSW
Changed from non-woody to sparse woody [a]	183,700	5300	189,000	34,300	7,400	41,700	230,700
Changed from non-woody to forest [a]	182,400	7000	189,400	114,300	42,400	156,700	346,100
Changed from forest to sparse woody [a]	85,500	3900	89,400	43,500	7300	50,800	140,200
1. Strictly post-1990 regrowth total	**451,600**	**16,200**	**467,800**	**192,100**	**57,100**	**249,200**	**717,000**
Remained sparse woody	144,200	3100	147,300	29,000	3400	32,400	179,700
Changed from sparse woody to forest [a]	212,300	6400	218,700	138,900	30,100	169,000	387,700
2. Not strictly post-1990 regrowth total	**356,500**	**9500**	**366,000**	**167,900**	**33,500**	**201,400**	**567,400**
Total regrowth [b]	808,100	25,700	833,800	360,000	90,600	450,600	1,284,400
Percent commercially important (%) [c]	76	82	76	62	26	55	69
Commercially important regrowth [d]	**614,200**	**21,100**	**635,300**	**223,200**	**23,600**	**246,800**	**882,100**

Notes: a. From Tables 7.5, 7.6, 7.7 and 7.9.
b. Sum of Strictly post-1990 regrowth and Not strictly post-1990 regrowth.
c. In Queensland is 1 minus the percent of non-commercial forest in Table 7.2. In New South Wales is the total commercial forest YAG area divided by the total YAG area in Tables 7.3 and 7.4.
d. Total regrowth multiplied by the percent commercially important.

Table 7.13. Cleared and total potential area of commercially important regrowth private native forest in Queensland (2020) and New South Wales (2022)

Regrowth forest category	**Forest area by region (ha)**						
	S&C QLD Hub	**N QLD Hub**	**Total QLD**	**NE NSW Hub**	**SE NSW Hub**	**Total NSW**	**Total QLD and NSW**
Remained as non-woody vegetation [a]	447,400	12,600	460,000	72,500	20,600	93,100	553,100
Changed from sparse woody to non-woody [a]	103,200	3,500	106,700	21,000	1,500	22,500	129,200
Changed from forest to non-woody [a]	76,600	5,200	81,800	63,500	28,200	91,700	173,500
Total cleared area [b]	**627,200**	**21,300**	**648,500**	**157,000**	**50,300**	**207,300**	**855,800**
Percent commercially important (%) [c]	76	82	76	62	26	55	69
Commercially important cleared area [d]	**476,700**	**17,500**	**494,200**	**97,300**	**13,100**	**110,400**	**604,600**
Commercially important regrowth [e]	614,200	21,100	635,300	223,200	23,600	246,800	882,100
Total potential area of commercially important regrowth [f]	**1,090,900**	**38,600**	**1,129,500**	**320,500**	**36,700**	**357,200**	**1,486,700**

Notes: a. From Tables 7.5, 7.6, 7.7 and 7.9. Changes from 1991 to 2020 (QLD) or 2022 (NSW)
b. Sum of the three rows above.
c. In Queensland is 1 minus the percent of non-commercial forest in Table 7.2. In New South Wales is the total commercial forest YAG area divided by the total YAG area in Tables 7.3 and 7.4.
d. Total cleared area multiplied by the percent commercially important.
e. From Table 7.12.
f. Sum of commercially important cleared area and commercially important regrowth.

7.9 Timber volume and carbon sequestration potential in Queensland's private native regrowth forests on Category X land

FullCAM simulation estimates of timber volume and carbon sequestration in selected forest types are reported in Chapter 8. Here, an estimate of the potential future timber volume growth and carbon sequestration Queensland's Hub regions is made using expected timber growth rates, carbon sequestration rates and the areas of various forest types. The total area of commercially important regrowth forest on Category X land (pre-1990 and post-1990 regrowth) reported in Table 7.1 has been simulated to estimate timber production and carbon sequestration. No reliable growth rates (MAI) were available for the YAGs of NSW on private land. Consequently, no attempt was made to estimate volume and carbon sequestration potential of the NSW Hub regions.

The following timber volume and carbon estimates for the Queensland Hubs should be considered with a low-level of confidence given likely errors in: (1) the potential areas of the commercial forest types, which have not been adequately checked with on-ground surveys, and include large areas of forest that are pre-1990 regrowth; and (2) estimates of forest growth rates, which are based on a relatively small subset of private native forest plots in the Southern and Central Forestry Hub region (Lewis et al. 2020). Also, the carbon sequestration estimates include carbon sequestered due to tree growth only (above and below-ground biomass) and do not consider carbon stored in harvested wood products or avoided consumption of high embedded carbon substitutes, such as steel, concrete and carpet. As reported in Table 7.2, most commercially important private native forest in the Southern and Central Queensland Forestry Hub region is at least 31 years old and therefore has lower future growth potential than younger regrowth stands.

Future timber volume estimates in Queensland were based on expected MAIs for different regrowth forest types (with and without silvicultural management) derived from empirical data and expert opinion (Lewis et al. 2020). Timber growth rates are particularly uncertain for the Northern Hub region in Queensland, where private native forest growth rates have not been empirically estimated. Future carbon stocks were estimated based on the above-ground biomass increments (with and without silvicultural management) reported in Lewis et al. (2020), along with a root to shoot factor of 25%.

7.9.1 South and Central Queensland Forestry Hub region

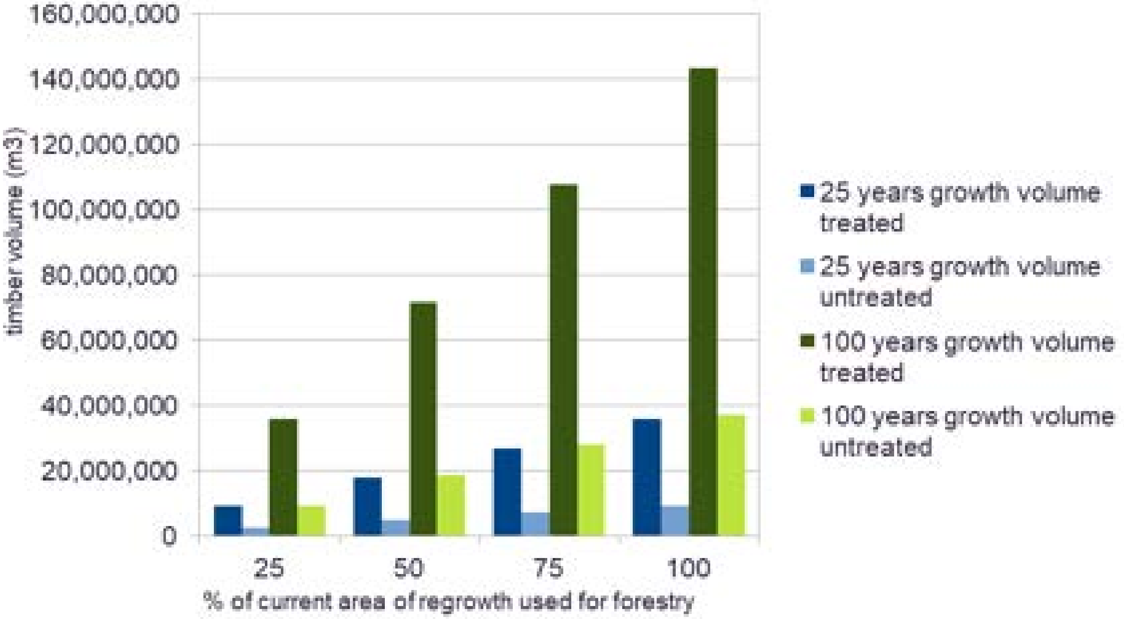
Based on the predicted volume mean annual increment (MAI) adopted in the study area by Francis et al. (2023) for managed and unmanaged forest (Table 6.6) and the area of each forest type reported in Table 7.1, volume and carbon sequestration were predicted over the next 25 and 100 years. Only the 25-year simulations are described.

Assuming all Category X regrowth is allowed to grow for 25 years (i.e. that the area remains the same over time), without silvicultural management, then this would equate to approximately 9.26 million m^3 of timber grown on this land (Figure 7.18a, 370,500 m^3/year). This is equivalent to an average MAI of 0.23 m^3/ha/y across 1.6 M ha of commercially important regrowth forest of Category X land in Table 7.1. This growth will sequester approximately 104.7 million tonnes of carbon or 384.3 million tonnes of CO_2-equivalents (Figure 7.18b).

To put these figures in perspective, in 2019, Australia's total greenhouse gas emissions were 508 million tonnes of CO_2-equivalents. Continued growth of Category X forests in the Southern and Central Queensland Forestry Hub region could sequester about 15.4 M t CO_2-e/y (384.3 M t CO_2e over 25 years), which is an average of 9.6 t CO_2-e/ha/y without considering the carbon benefits of harvested wood products and avoided substitutes. This is equivalent to 3% of national annual carbon emissions. Hence, regrowth forests can potentially play an important role in offsetting annual greenhouse gas emissions and could help the red meat industry (with annual emissions of around 54.6 million tonnes of CO_2-equivalents) meet their carbon-neutral targets (MLA, 2022).

If all Category X regrowth was managed with good silvicultural practices for 25 years, the volume of timber grown over this time could be approximately 35.8 million m^3 (1.43 million m^3/year, with 88.3 million tonnes of carbon sequestered or 324.2 million tonnes of CO_2-equivalents (Figure 7.18a and b). This is less than carbon sequestration in the unmanaged forest because harvested wood products and avoided substitutes have not been considered. The wood product growth rate is equivalent to an average MAI of 0.89 m^3/ha/y.

(a)



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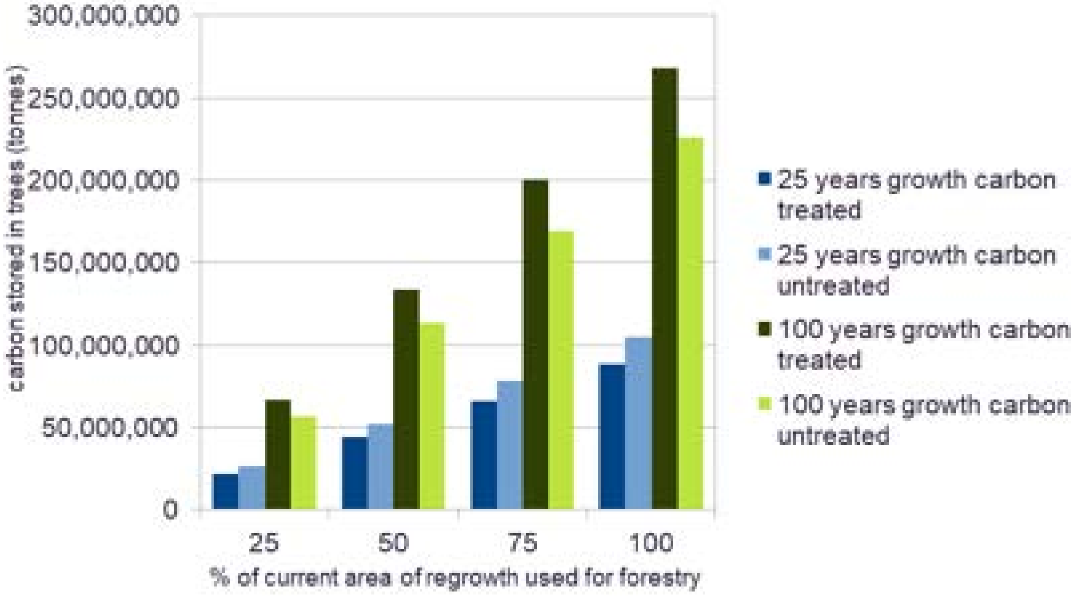


Figure 7.18. Volume of timber (m^3) (a) and tonnes of carbon stored in trees (b) over 25 and 100 year periods with and without silvicultural management, based on differing proportions of Category X regrowth forest area retained as forest in the Southern and Central Queensland Forestry Hub region. Timber volumes are based on areas reported in Table 7.1 and MAIs reported in Table 6.6. Rates of carbon accumulation were based on Lewis et al. (2020) for private native forest, where biomass accumulation rate was based on ‘regrowth’ for the first 25 years (1.65 and 1.96 tonnes of tree carbon per hectare per year in managed and unmanaged forest, respectively) and ‘remnant’ for the 100-year period (1.25 and 1.06 tonnes of tree carbon per hectare per year in managed and unmanaged forest, respectively).

Based on the change detection analysis for the period between 1991 and 2020, we estimated that there was around 182,000 ha of Category X regrowth that was cleared in 1991 and forest with a canopy cover of at least 20% in 2020 (Table 7.5). Over this period, there was a net increase in forest vegetation within this geographical extent (a net increase of 6,400 ha/year). While we did not calculate the area of individual commercial forest types in this new forest, we can assume that the proportions of forest types are similar to those in Table 7.1. Using this breakdown of forest types, and if we assume (conservatively) that this area of Category X forest is allowed to grow without silvicultural management over the next 25 years, this would result in approximately 789,000 m^3 of timber grown on this land (31,600 m^3/year) (Figure 7.19). This is equivalent to approximately 8.9 million tonnes of carbon sequestered or 32.7 million tonnes of CO2-equivalents. If this forest was managed with good silviclutural practices the volume of timber grown over this time could be approximately 3.05 million m^3 (122,100 m^3/year), with 27.6 million tonnes of CO2-equivalents sequestered (Figure 7.19). There is also a large area of Category X forest that remained forest over the 29 year period (i.e. 475,100 ha) in this region that would add further timber volume and carbon accumulation to that estimated above if it continued to be retained into the future.

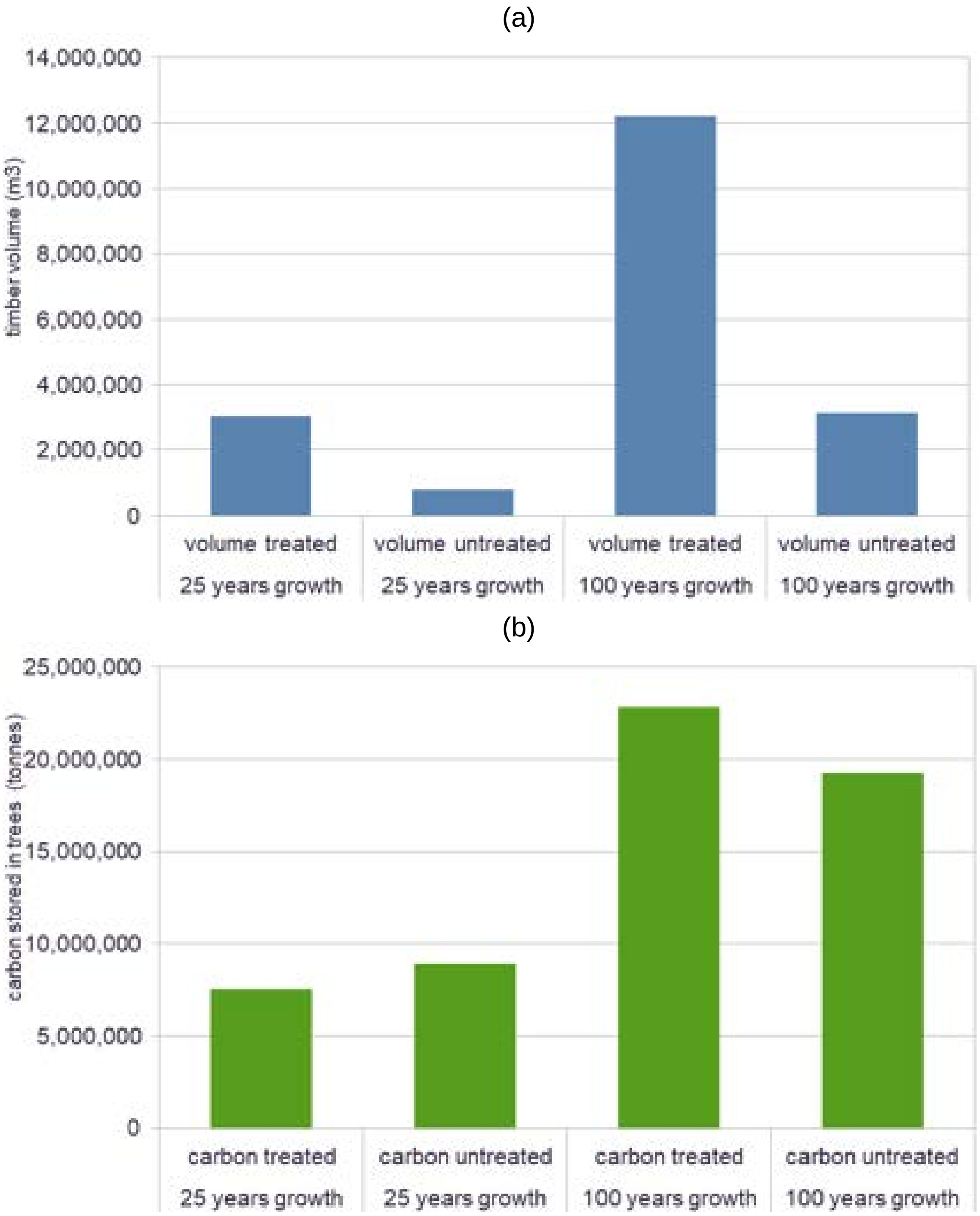


Figure 7.19. Volume of timber (m^3) (a) and tonnes of carbon stored in trees (b) over 25 and 100 year periods with and without silvicultural management, based on the area of Category X regrowth forest that was non-forest in 1991, but forest (with at least 20% canopy cover) in the year 2020 (182,400 ha) in the South and Central Hub Queensland region. Refer to Figure 7.18 caption for assumptions on tree volume and carbon growth.

7.9.2 North Queensland Forestry Hub region

For the purpose of this analysis, it was assumed that forest growth rates for the commercial forest types in southern Queensland were also applied to the same forest types in northern Queensland. Volume growth rates for the northern hardwoods and savannah woodlands forest types were not available, so we assumed that the northern hardwoods had the same rate of growth as the mixed hardwoods forest type, and that savannah woodlands had the same rate of growth as the ironbark forest type.

Assuming that all Category X regrowth is allowed to grow (i.e. the area remains the same over time) for the next 25 years, then this would equate to 349,000 m^3 of timber grown on this land (Figure 7.20a, 14,000 m^3/year). This is equivalent to approximately 4.1 million tonnes of carbon sequestered or 15.1 million tonnes of CO2-equivalents (Figure 7.20b). If this forest was managed with good silviclutural practices the volume of timber grown over this time could be approximately 1.38 million m^3 (55,200 m^3/year), with 12.8 million tonnes of CO2-equivalents sequestered. If 50% of the currently mapped Category X regrowth was allowed to grow without silvicultural management over the next 25 years, this would result in 174,600 m^3 of timber grown on this land (Figure 7.20a). This is equivalent to approximately 2.06 million tonnes of carbon sequestered or 7.6 million tonnes of CO2-equivalents. If this forest was managed with good silviclutural practices, the volume of timber grown over this time could be approximately 690,000 m^3, with 6.4 million tonnes of CO2-equivalents sequestered (Figure 7.20).

Based on the change detection analysis for the period between 1991 and 2020, we estimated that there was around 7,000 ha of Category X regrowth that was cleared in 1991 and forest with a canopy cover of at least 20% in 2020. However, if we assume (conservatively) that the 7000 ha of Category X forest is allowed to grow without silvicultural management over the next 25 years, this would result in approximately 29,100 m^3 of timber grown on this land (1,200 m^3/year) (Figure 7.21). This is equivalent to approximately 343,800 tonnes of carbon sequestered or 1.26 million tonnes of CO_2-equivalents. If this forest was managed with good silviclutural practices, the volume of timber grown over 25 years could be approximately 115,000 m^3 (4,600 m^3/year), with around 290,000 tonnes of carbon sequestered or 1.06 million tonnes of CO_2-equivalents sequestered (Figure 7.21). There is also a large area of Category X forest that remained forest over the 29 year period (i.e. 31,600 ha) in this region that would add further timber volume and carbon accumulation to that estimated above.

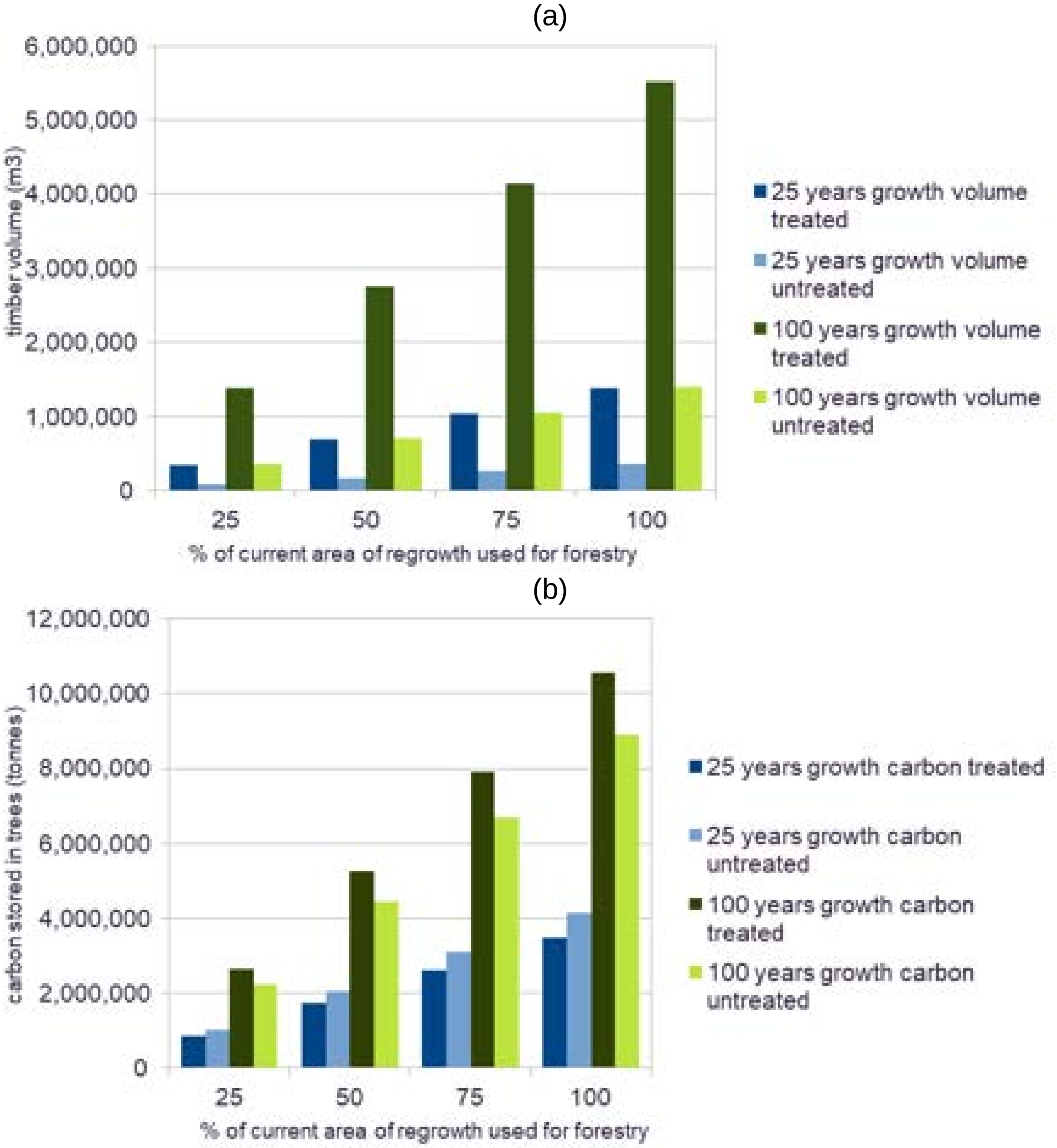
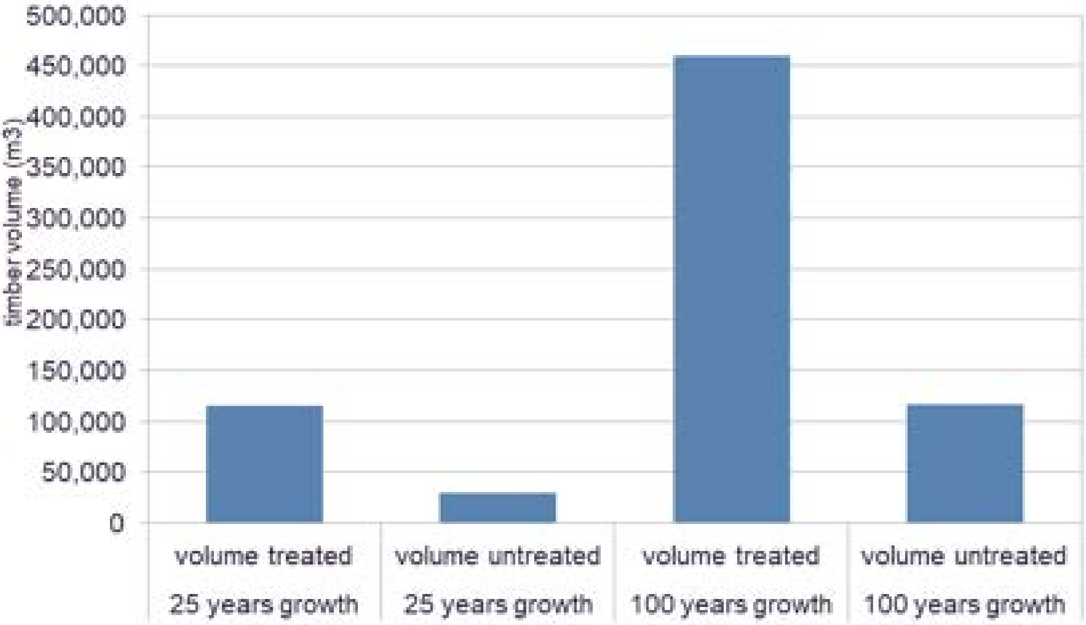


Figure 7.20. Volume of timber (m^3) (a) and tonnes of carbon stored in trees (b) over 25- and 100-year periods with and without silvicultural management, based on differing proportions of Category X regrowth forest area that was retained as forest in the North Queensland Forestry Hub region. Timber volumes are based on the areas reported in Table 7.1 and MAIs reported in Table 6.6, with the assumption that savannah woodlands grow at the same rate as ironbark forests and that northern hardwoods grow at the same rate as mixed hardwood forests. Rates of carbon accumulation were based on Lewis et al. (2020) for private native forest, where biomass accumulation rate was based on 'regrowth' for the first 25 years (1.65 and 1.96 tonnes of tree carbon per hectare per year in managed and unmanaged forest, respectively) and 'remnant' for the 100-year period (1.25 and 1.06 tonnes of tree carbon/ha/y in managed and unmanaged forest, respectively).

(a)



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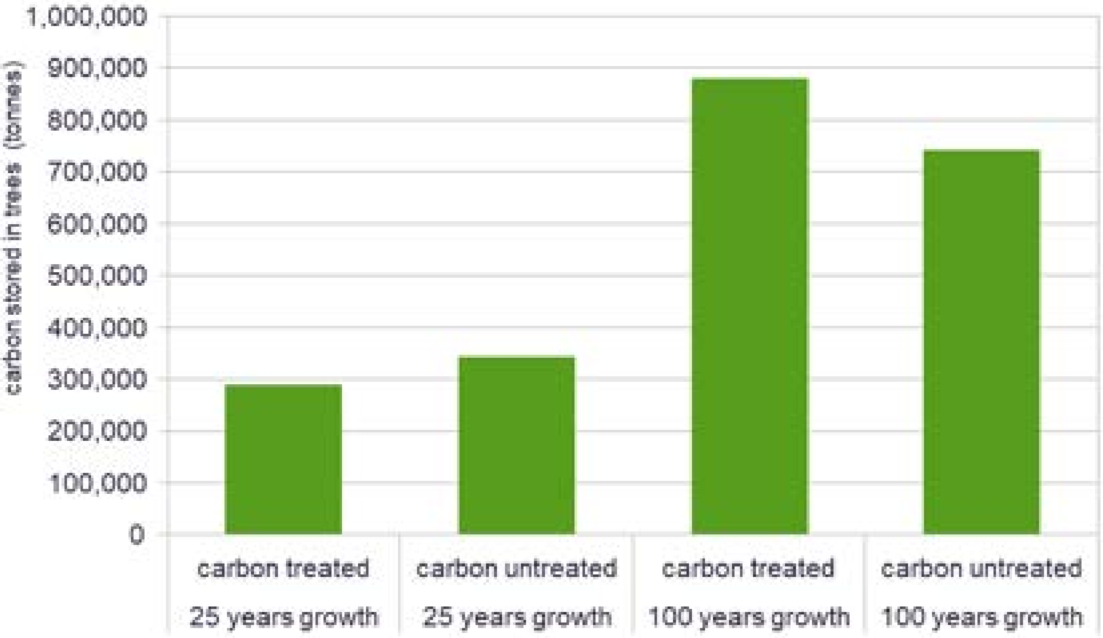

Figure 7.21. Volume of timber (m^3) (a) and tonnes of carbon stored in trees (b) over 25 and 100 year periods with and without silvicultural management, based on the area of Category X regrowth forest that was non-forest in 1991, but forest (with at least 20% canopy cover) in the year 2020 (7,000 ha) in the North Queensland Hub region. Refer to Figure 7.20 caption for assumptions on tree volume and carbon growth over time.

7.10 Conclusions and policy implications

The private native forest regrowth estimates derived in this study were based on the National Forest and Sparse Woody Vegetation Data, Version 7.0 (2022 release) and revealed there is at least about 1.3 M ha of post-1990 regrowth throughout the Southern and Central Queensland, Northern Queensland, North East New South Wales and South East New South Wales Hub regions, of which 0.88 M ha is commercially important for industry. The Southern and Central Queensland Hub region alone has 0.61 M ha (69%) of the commercially important post-1990 regrowth. There are 0.25 M ha of commercially important private native post-1990 regrowth forests in New South Wales (28% of the total).

These reported areas are substantial when compared to land areas that might become available for new plantation establishment in these regions, particularly considering the high upfront costs of establishing plantation forests. Indeed, Whittle et al. (2019) suggested few or no new long-rotation hardwood plantations will be established under policy settings and economic conditions at that time. In fact, the area of hardwood plantations in NSW and Queensland have declined substantially over the last decade (https://www.agriculture.gov.au/abares/research-topics/forests/forest-economics/plantations-update#download-the-overview-report-and-datasets).

There are no existing published estimates of commercially important regrowth in New South Wales against which our estimates can be compared. Existing private native forest regrowth mapping in the Southern and Central Queensland Forestry Hub region indicated a total of 1.74 M ha of forest potentially harvestable regrowth under the NFP ADVCC, of which 1.33 M ha were in forest types considered commercially important by the timber industry. However, 0.83 M ha of the commercially important regrowth in the Southern and Central Queensland Forestry Hub region was '>31 years old' based on the SLATS 2021 data, suggesting it was pre-1990 regrowth. Pre-1990 native forest regrowth is important for timber production and carbon sequestration, but not a focus of this report.

This research has highlighted the scale of opportunity for improved management of post-1990 regrowth private native forests. Based on previously published rates of forest growth for commercial forest types in Queensland, the timber production and carbon sequestration potential of this regrowth is substantial. However, this research has also highlighted the challenge. For the geographic areas investigated in this study, the rates of regrowth exceeded the rates of clearing in all Hub regions over the period from 1991 to 2020 or 2022. Nevertheless, in the last 9 to 11 years (2011 to 2020 or 2022), rates of clearing did exceed rates of regrowth in the North Queensland Hub region and the NE and SE NSW Hub regions. This suggests that forestry management alone was not a strong enough incentive for landholders to maintain their commercially important regrowth forests. Incentives or changes in policy are needed to encourage landholders to maintain native forest regrowth. Development of an ACCU scheme for native regrowth forests managed for timber production could provide such an incentive.

8. FullCAM Carbon Accounting of Alternative Native Forest Regrowth Management Scenarios

Tom Lewis, Martin Timperley and Tyron Venn

8.1 Aim

The aim of this chapter was to perform FullCAM simulations for a range of regrowth forest sites and to compare the effect of alternative management scenarios on carbon sequestration. Management scenarios investigated were: (1) business as usual, with re-clearing on a 20-year cycle; (2) forestry management, with silvicultural harvesting; (3) permanent clearing of regrowth for grazing production; and (4) management for conservation. An event schedule was derived for each scenario for FullCAM, and simulations were run over a 200-year period from the year 2020. We ran simulations at four locations in each Hub region in Queensland and NSW, for key regrowth forest types, to allow averages for the management scenarios by forest type to be calculated and compared.

8.2 Methods

FullCAM (2023 Public Release Beta Version) was used to model long-term carbon stocks on grazing land under the following four management scenarios:

- Scenario 1: Business-as-usual – a 20-year cyclical regrowth and re-clearing regime;
- Scenario 2: Native regrowth vegetation managed for selection timber harvesting (carbon stored both in biomass onsite and in harvested wood products, HWPs);
- Scenario 3: Native regrowth vegetation is permanently suppressed and the site is managed for livestock grazing; and
- Scenario 4: Native regrowth vegetation is preserved, and the site is managed for conservation.

The scope of this analysis aligns with the carbon accounting framework employed by NCAS and the ACCU scheme, with the carbon abatement potential of each scenario based on the total carbon stocks of on-site biomass and HWPs.

8.2.1 Queensland and New South Wales Study Sites

In the Southern and Central Queensland Hub region, four sites known to be spotted gum regrowth forest were selected. The focus on spotted gum dominant stands in this region was due to the large extent of these forests (see Section 6.2), as well as their commercial importance to the timber industry as the state's highest volume source of native hardwood (Business Queensland, 2021). In the Northern Queensland Hub region, four sites that were mapped as ironbark regrowth were selected. Ironbark was the most common regrowth forest type mapped in the Northern Queensland Hub region, making up nearly 50% of commercial regrowth forest types in the region. While the commercial importance of ironbark forest varies depending on site productivity, ironbarks represent a significant proportion of the sawn timber in Queensland hardwood mills. The selection of four sites in each Hub region, as indicated in Table 8.1 facilitated some accommodation of the natural variation in climate, elevation, soils and other characteristics that can influence forest growth.

Table 8.1. Locations of points where FullCAM modelling was undertaken in Queensland and maximum above-ground (Max AG) tree biomass associated with each site.

Site name / forest type	Forestry Hub region	Latitude	Longitude	Max AG tree biomass (tdm/ha)
Rathdowney / spotted gum	S&C	-28.22	152.88	280.3
Gundiah / spotted gum	S&C	-25.79	152.45	51.64
Gayndah / spotted gum	S&C	-25.81	151.69	80.22
Gin Gin / spotted gum	S&C	-25.16	151.83	86.32
East 1 / ironbark	Northern	-19.96	147.86	41.83
East 2 / ironbark	Northern	-20.29	148.37	66.14
West 1 / ironbark	Northern	-19.92	146.18	26.4
West 2 / ironbark	Northern	-17.86	145.35	71.6

In the NE and SE NSW Forestry Hub regions, dry coastal eucalypt forests were the dominant forest type (or yield association grouping) with commercial timber value on privately owned land. In the absence of reliable regrowth mapping in NSW, this forest type was selected for carbon accounting case studies based on their dominance on private land (regrowth or not). In each of the NSW Hub regions, four sites were randomly selected that contained this forest type according to the forest type mapping to cover a range in the factors that might influence growth and had varying maximum above-ground biomass levels (Table 8.2).

Table 8.2. Locations of points where FullCAM modelling was undertaken in NSW and maximum above-ground (Max AG) tree biomass associated with each site.

Site name / forest type	Forestry Hub region	Latitude	Longitude	Max AG tree biomass (tdm/ha)
Coastal Euc Dry 1	NE NSW	-28.51	152.2	111.4
Coastal Euc Dry 2	NE NSW	-29.26	152.6	97.6
Coastal Euc Dry 3	NE NSW	-30.93	151.97	180.9
Coastal Euc Dry 4	NE NSW	-29.07	152.38	196.7
Coastal Euc Dry 5	SE NSW	-35.69	149.8	312.1
Coastal Euc Dry 6	SE NSW	-36.5	149.76	245.2
Coastal Euc Dry 7	SE NSW	-36.92	149.58	279.6
Coastal Euc Dry 8	SE NSW	-34.92	150.39	109.2

8.2.2 FullCAM Regrowth Management Scenarios: Timing, Initial Conditions and Simulated Management Events

For this assessment, carbon stocks of each site were modelled between the period of 1820 and 2220 and covered three distinct land management phases.

- Phase 1 of the assessment takes place between 1820 and 1960. Over this time, it was assumed that each site was covered by mature forest which was permitted to grow undisturbed to a point of old growth equilibrium, where carbon stocks stabilised.
- Phase 2 is the active management of these sites commencing in 1960. The study area was cleared of all trees, and debris was removed through a subsequent prescribed fire. From this point until the commencement of Phase 3, these areas were then maintained for low intensity grazing, with native regrowth being re-cleared every 20 years to prevent forest from reestablishing itself on-site. The final modelled clearing was in 2020.
- Phase 3 is the implementation of each of the four alternative land management scenarios described above, commencing in 2020. These regimes were continued until the end of the modelling period in 2220.

The timeline of the modelling period is outlined in Figure 8.1. Further details about forest management events are provided in the scenario descriptions below.

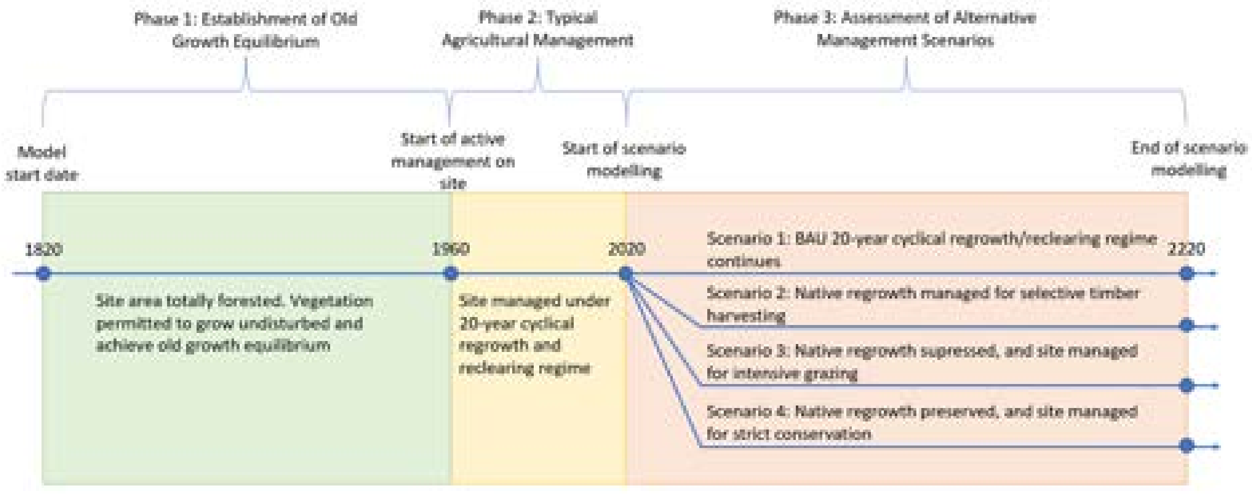

Figure 8.1. Timeline of FullCAM carbon stock modelling period. Results reported focus on Phase 3 – the last 200 years of the simulation.

Scenario 1 – Business as usual (BAU) - cyclical regrowth and re-clearing of native vegetation.

Under this scenario, the 20-year cyclical regrowth and re-clearing regime that commenced in 1960 continues unabated throughout the study period. Key events modelled within FullCAM that occur throughout a single 20-year regrowth and re-clearing cycle are summarised in Table 8.3.

Table 8.3. Key events occurring during the BAU regrowth and re-clearing regime of Scenario 1.

Years since forest clearing	Management action	Details
0	Forest clearing	100% of trees on-site cleared with all stems and branches transferred to the deadwood carbon pool. No timber is recovered.
0.5	Prescribed debris fire	Prescribed fire applied to 100% of the site to remove debris and deadwood from the clearing event. Typically done to encourage pasture growth.
1-20	Regrowth of forest / woodland	Native regrowth forest permitted to regenerate on the site for 20 years until the next clearing event.

Scenario 2 – Native regrowth managed for selection timber harvesting.

For this scenario native regrowth is managed under a selection harvesting regime. This approach permits the forest to regenerate for 40 years (2020 to 2060) after the final clearing event in 2020 prior to the first harvest in 2060, which selectively removes 30% of stems across the site. Following the harvest (referred to as ‘thinning’ in FullCAM because it is a partial harvest, not clearfall), each site was also subjected to a prescribed forest debris fire (known as a top disposal burn) to remove deadwood and debris and promote regeneration. To maintain a long-term sustainable yield for each site and allow for the forest to regenerate biomass removed from the harvest, a return interval of 20 years was permitted between each selection harvest for the remainder of the study period. A summary of events modelled within FullCAM over a single harvest rotation commencing in 2060 are summarised within Table 8.4.

This harvesting regime has been designed to broadly align to Queensland’s private native forestry regulations (even though some regrowth in Queensland does not need to adhere to these regulations) outlined in the Managing a Native Forest Practice: A Self-Assessable Vegetation Clearing Guide 2014 (the Code) (Department of Natural Resources and Mines, 2014). This Code seeks to ensure that forests can be sustainably managed for timber harvesting while conserving its natural values. To do so, the Code stipulates the type of harvest and silvicultural regimes that are allowable across different forest types (Department of Natural Resources and Mines, 2014). In NSW, similar Codes of Practice exist. For example, in Northern NSW the Code allows harvesting with single tree selection, but requires maintenance of a basal area of 14 m^2/ha, while the Southern NSW Code requires maintenance of a basal area of 12 m^2/ha over the net harvestable area of a Forest Management Plan. The use of a 20-year return interval for harvesting was based on guidance provided by the Private Forestry Service Queensland in their Native Forest Stand Management Guide (Ryan, 2017).

Table 8.4. Key events occurring over a single harvest rotation during Scenario 2.

Years since forest thinning	Management action	Details
0	Forest thinning	30% of tree stems harvested over 100% of the site
0.5	Top-disposal burn	Prescribed fire applied to 100% of the site to remove debris and deadwood from the clearing event and promote regeneration.
0.5-20	Regrowth of forest / woodland	Forest permitted to regenerate on the site for 20 years until the next thinning event.

Scenario 3 – Maintaining pastures for intensive grazing.

For this scenario, the land is maintained as pasture with all forest regrowth being suppressed after the final clearing event in 2020 (zero years since the start of the regime). As such, no tree growth will occur over the study period with biomass limited to the monsoonal perennial or NSW perennial ground-cover and debris.

Scenario 4 – Native regrowth preserved for conservation.

This scenario sees the site being managed for conservation over the study period commencing in 2020 (zero years since the start of the regime). All native regrowth is permitted to regrow and mature without any further anthropogenic disturbances or growth suppression over the study period.

8.2.3 FullCAM Model Settings for Estimation of Biomass Growth and Carbon Sequestration in Biomass and Harvested Wood Products

Changes in carbon stocks among management scenarios were assessed and compared within the forest components and HWP pools indicated in Table 8.5. While assisted natural regeneration (ANR) and Plantation Forestry ACCU Scheme methods include only the trees, debris and forest products pools (Clean Energy Regulator, 2023e, 2023f), this analysis has also included the crops pool to better account for the abatement associated with maintaining the site as a pasture under Scenarios 1 and 3. The soil carbon pool has been excluded from this assessment due to its omission from these vegetation-based ACCU Scheme methods.

Table 8.5. Carbon pools reported on in the current study.

Carbon pool	Component
Total site	Sum of below components
Trees	Including above and below-ground biomass
Crops (pasture)	Including above and below-ground biomass
Debris	Including forest litter and deadwood
Harvested wood products	Including products in use and products in landfill

8.2.3.1 Forest structure, growth and carbon partitioning attributes

In the Southern and Central Qld Forestry Hub region, forest cover was modelled as a 'Eucalyptus Open Forest' in FullCAM, which is representative of spotted gum forest and is consistent with the vegetation cover expected to have occurred on each site prior to 1750 (pre-European, pre-clearing), as indicated by the National Vegetation Information System (NVIS) and Queensland Regional Ecosystem mapping. Eighty percent of the site area was assumed to be covered in forest. In the Northern Qld Forestry Hub region, forest cover was modelled as a 'Eucalyptus Woodland' in FullCAM, which is representative of ironbark dominated woodlands, and is consistent with the pre-clearing vegetation mapping for these locations (Queensland Globe, Regional Ecosystems). For these sites 50% of the site was assumed to be covered with forest. In the NE and SE NSW Forestry Hub regions forest cover was modelled as a 'Eucalyptus Open Forest', which is representative of the Coastal Dry Eucalyptus yield association group, with 80% forest cover assumed.

The default FullCAM tree yield formula for each location was adopted to estimate forest growth over time. To ensure that biomass accumulation rates were increased following partial (i.e. selection) harvesting events, the 'maximum years to regrow post-thin' was set to 60 years for all tree biomass components in the 'Enable biomass based age adjustment' settings. This adjustment was based on CSIRO FullCAM expert advice.

Wood density of 800 kg dm/m^3 was assumed for the open eucalypt forest sites (Southern and Central Hub and NE and SE NSW Hub, Ilic et al., 2000), 890 kg dm/m^3 was assumed for the eucalypt woodland (Northern Qld Hub, FullCAM default). Using the FullCAM default values, we assumed that the forest would grow at its maximum rate at the age of 10 years. The percentage biomass partitioned to each tree component was based on measured proportions determined by Ximenes et al. (2005), except for the Northern QLD Hub where FullCAM default values were used. Corresponding carbon fractions associated with each component were based on the FullCAM defaults (Australian Government, 2023a) in all Hub regions, as reported in Table 8.6. The partitioning of biomass between below and above ground tree components (known as the root to shoot ratio - RS) was estimated to be 0.25 in the Southern and Central QLD Hub, and the NE and SE NSW Hubs. This RS was selected as it is in line with findings from various Australian studies, namely Easdale et al. (2019) and Keith et al. (1997) who reported a RS of around 0.24 and 0.25 for temperate native eucalypt forests. The FullCAM default RS was adopted for the Northern Queensland Hub. Adopted values for partitioning of biomass are reported in Table 8.6.

Table 8.6. Partitioning of biomass between the tree components and carbon fraction of biomass for each tree component.

Tree component	Fraction of biomass by Hub region (% dm)		Carbon fraction in biomass (% of dm)
	SC Qld, NE NSW, SE NSW	N Qld	
Stem	50.2	31.3	50
Branches	17.83	19.7	47
Bark	5.76	7.7	49
Leaves	6.23	11.1	52
Coarse roots	16.79	23.3	50
Fine roots	3.19	6.8	48

8.2.3.2 Ground cover attributes

Prior to the first clearing event in 1960, all sites were assumed to be populated with perennial pasture in the forest understorey. Black speargrass was expected to occur onsite for the Queensland sites, which is representative of the native perennial pasture, pre-disturbance ground-cover. However, after the initial clearing and commencement of active management at each Queensland site, black speargrass was replaced by an improved perennial grass to make the pasture more suited to intensive grazing. In NSW perennial pastures were assumed throughout the simulation period. Key attributes for pasture components (referred to as ‘crop’ in FullCAM) are summarised in Table 8.7.

An attempt was made to incorporate the impacts of grazing on ground-cover biomass in the model during times when livestock were permitted on each site. However, FullCAM modelled a steep decline and eventual total loss ground-cover biomass. This is not reflective of sustainably managed grazing pastures and is more indicative of significant overgrazing. With very little literature published on the use of FullCAM in grazing systems, and grazing not enabled for the modelling of any vegetation-based ACCU Scheme method, it was decided that grazing would be excluded from this assessment. Nevertheless, pasture biomass (crop) was still modelled in all scenarios, where it essentially became a constant value over time.

Table 8.7. Key attributes of ground cover species found on-site during the modelling period (Australian Government, 2023a).

Attribute	Leaves or Roots	Black speargrass (Qld)	Monsoonal perennial (Qld)	NSW perennial
Fraction of biomass allocated to each component (% dm)	Leaves	53	53	53
	Roots	47	47	47
Carbon fraction of each biomass component (% of dm)	Leaves	43.5	43.5	40.9
	Roots	39.5	39.5	40.9

8.2.3.3 Carbon stored in harvested wood products and landfill

Much of the carbon stored in biomass that is removed from site during a harvest event is stored for significant periods of time within harvested wood products (HWPs). The majority of carbon within these products is retained indefinitely, with only minimal conversion of carbon to gaseous end products through decay both while in use and when deposited within landfills. The mix of products created from timber harvested from each site has been based on industry data collected by Francis et al. (2020) who assessed the total product throughput of sawmills located in Southern Queensland and Northern New South Wales. The proportion of the total harvested timber volume allocated to each product along with the percentage of total biomass lost to mill residue is outlined in Table 8.8. While pulpwood may be harvested in NSW private native forests, it is unlikely that the dry coastal forests of NSW generate pulpwood (Ximenes pers. comm.). The ‘packing wood’ category in FullCAM was used to capture timber going to green landscaping and fencing markets.

Only timber from the tree’s stem is harvested for production. All other tree components (accounting for 49.8–68.7% of total tree biomass) are left behind as harvest residue, with their carbon stocks transferred to the debris carbon pool as litter and deadwood.

Table 8.8. The proportion of the total harvested timber volume allocated to each product along with the percentage of total biomass lost to mill residue (Francis et al., 2020).

Product	Proportion of harvested stem biomass (%)
Packing wood (green landscaping and fencing)	10.36
Utility poles	8.08
Construction wood (including decking, flooring and structural sawn timber)	27.72
Mill residue	53.85
Pulp	0

In a full life-cycle analysis of carbon, the product’s lifespan should be considered along with it’s expected decomposition rate while in use and when deposited in landfill. For this analysis, decay rates of HWPs have been based on research at the University of Queensland undertaken by Jurss (2021) who compiled decay rates on various HWPs produced within southeast Queensland and across Australia. One hundred percent of all mill residue was assumed to decompose in the year that it was produced. We assumed that no packing wood is moved to landfill, rather a small proportion (2.7%; 25-year half-life) decomposes while in use each year. We assumed that 1.37% (50-year half-life) of utility poles and 1.96% (35-year half-life) of construction wood ends its service life and is transferred to landfill each year. Presently, the National Carbon Accounting System applies a conservative estimate of carbon emissions from HWPs in landfill, assuming a total of 10% of the carbon in wood products transferred to landfill will be emitted to the atmosphere. Ximenes et al. (2019) found that only up to 1.4% of carbon in HWPs is emitted, with the remainder sequestered in the anaerobic conditions of the landfill. The Ximenes et al. (2019) factor has been adopted in this study and 1.4% of carbon in HWPs arriving at the landfill is assumed to be emitted in the year of arrival.

8.2.4 Carbon Displacement Factors for Harvested Wood Products

Changes in the extent of harvesting that takes place in Australia's native forests affects the quantity of native timber derived products that are available for use within the domestic market. Therefore, as the supply of these products declines, it is reasonable to expect that other materials will be utilised as substitutes. To effectively account for carbon outcomes associated with the management of domestic forests, the emissions trade-offs between these substitute materials and locally produced native hardwood products must be understood. To do so, a preliminary lifecycle analysis has been undertaken to assess the carbon impacts that result from displacing the harvested wood products (HWPs) manufactured from the study site when managed for selection timber harvesting with substitute materials that would likely be used had the site been managed for strict conservation instead.

To enable a comparison of carbon 'costs' of substitute products, the net difference in the emission footprint between the HWPs and the replacement material must be determined. This substitution impact is expressed using a displacement factor (DF), which represents the quantity of emissions avoided by using timber harvested rather than the material that is likely to be used in its place. As such, the avoided use of materials with higher emissions footprints will result in greater carbon 'savings' from utilising native forest timber products.

The DF captures the carbon impacts associated with both the geologic carbon emissions (from burning fossil fuels) and permanently lost biogenic carbon (i.e. carbon originating from biological sources, in this case from the use of alternative HWPs sourced elsewhere) that are avoided through the use of a quantity of HWP derived from native regrowth forests. To allow for DFs to be applied across a range of forest product types, they are expressed as the tonnes of carbon emissions permanently avoided through the use of a quantity of HWP that stores 1 tonne of carbon (tC avoided from producing the substitute per tC stored in the HWP; $tC.\ tC^{-1}$) (Ximenes et al., 2016). For this assessment, DFs have been derived from work currently underway by Venn (unpublished) to assess the carbon sequestration potential of subtropical eucalypt forests in southeast Queensland. In this study, the DF of products derived from harvested native regrowth forests have been quantified by:

- Determining the emissions associated with the production of HWPs from native regrowth forests. These emissions have been based on analysis conducted by Ximenes et al. (2016) for northern New South Wales native forest products and consider the harvesting, transport and processing associated with these products. Forest types and harvesting activities in northern New South Wales native forests are similar to forests in the Southern and Central Queensland Forestry Hub region.
- Identifying the most likely substitute product mixes. This has been determined by Venn (unpublished) based on market data, as well as the expert opinion of

members of the southern Queensland hardwood industry, including industry experts in government agencies and sawmill managers. Where more than one substitute product has been identified, the likely proportion of the market captured by each has also been determined.

- Quantifying the emissions associated with substitute products. These factors were based on those developed by Ximenes et al. (2016) which were derived using a comprehensive lifecycle assessment 'cradle-to-gate' methodology.

The DFs developed by this analysis are outlined in Table 8.9. Temporal variation in DFs was factored into the analysis by assuming that geologic component declines linearly to zero by 2050, with the de-carbonising of society. The biogenic component was assumed to remain constant over time.

Table 8.9. Displacement factors (tonnes carbon avoided per tonnes carbon in HWP) for different HWPs of the study (based on Venn, unpublished). Geologic carbon decreased linearly to 0 between 2020 and 2050.

Product	Geologic C and permanently lost biogenic C	Biogenic C from plantation forest substitutes	Total Displacement Factor
Packing wood	1.22	1.35	2.57
Utility poles	0.43	0.57	1
Construction wood	1.22	1.35	2.57

To capture the benefits that result from the use of products created from timber produced on site relative to using alternative materials, these DFs were then applied to the selection forestry scenario using the following equation:

$$Avoided\ emissions\ from\ substitute\ (tC.\ ha{-1}) = HWP\ carbon\ stock\ (tC.\ ha{-1}) \times displacement\ factor\ (tC.\ tC{-1})$$

Carbon benefits can also be derived from the use of wood biomass in the generation of bioenergy to displace the use of fossil fuels (Ximenes et al., 2016). However, bioenergy DFs have been excluded from this analysis. This is recognised as an area that requires further work.

8.3 Results

The year-on-year accumulation and transfer of carbon within each scenario was modelled within FullCAM and then averaged across all locations for a given Hub region. Outcomes are graphically represented from the year 1900 onward and illustrate three distinct phases of land management:

- Phase 1 (1920–1960): The forest covering the site prior the commencement of active management, which had fully matured and reached a steady state of biomass.
- Phase 2 (1960–2020): The mature forest was cleared and the site actively managed under a 20-year cyclical regrowth and re-clearing regime.
- Phase 3 (2020–2220): The site is managed under each land management scenario.

The long-term average carbon stock over the study period has also been determined for all scenarios to account for carbon stocks fluctuating over time due to ongoing harvesting or clearing cycles in Scenarios 1 and 2, as well as the average accumulation of carbon stock in Scenarios 3 and 4. These have been calculated over both 100-year (consistent with the Plantation Forestry ACCU Scheme Method), and 200-year (covering the total study period) intervals.

The year-on-year carbon stocks of each scenario, averaged across all sites for a given Hub region are summarised in Appendix C. Each figure in Appendix C depicts both the total carbon stock under each management scenario, as well as the relative contribution of each relevant carbon pool, including trees, crops, debris and harvested wood products. The total long-term average carbon stocks of Scenarios 1 and 2 are also represented (short green dashes for the 100-year average and long green dashes for the 200-year average).

For each Hub region, the carbon stocks across all land management scenarios are consistent during the modelling of Phase 1 and Phase 2, before diverging as each land management scenario is implemented (Phase 3). During Phase 1, carbon stocks had reached a relative steady state, with vegetation approaching the maximum biomass that could be supported on each site. The site's carbon stocks drop dramatically following clearing and active management for low intensity grazing during Phase 2. Over this period the total carbon stocks fluctuated either side of each clearing event, and never approached the carbon levels achieved by the undisturbed forest initially covering each site. During this period, the crop and debris pools remain relatively stable with the removal and regeneration of trees being the primary driver in carbon stock fluctuations.

In Sections 8.3.1 to 8.3.4, the results from FullCAM modelling of carbon under each land management scenario in each Hub region are reported. Section 8.3.5 summarises the variation in FullCAM modelled carbon stocks between the Hub regions and land management scenarios. In Section 8.3.6, the carbon benefits of avoiding the use of substitute products through the utilisation of timber from regrowth native forest are added to the FullCAM carbon estimates reported in Sections 8.3.1 to 8.3.4.

8.3.1 FullCAM Modelling of Spotted Gum Regrowth Forest Carbon Stocks – Southern and Central Qld Forestry Hub Region

Averaged model outputs for each scenario are presented in Appendix C. Figure 8.2 provides a comparative illustration of the year-on-year total carbon stock of each scenario averaged across all four sites, along with the 100-year and 200-year long term average carbon stock of scenarios 1 and 2. Figure 8.2 indicates that in Phase 3 of the modelling, the greatest carbon stock was achieved over time in the strict conservation scenario (4), with the lowest carbon stock achieved in the grazing scenario (3). Both the selective timber harvesting (2) and BAU (1) scenarios resulted in cyclical increases in carbon, followed by sharp declines in carbon after each clearing or harvest event. However, the selective timber harvesting resulted in consistently higher carbon stocks than the BAU.

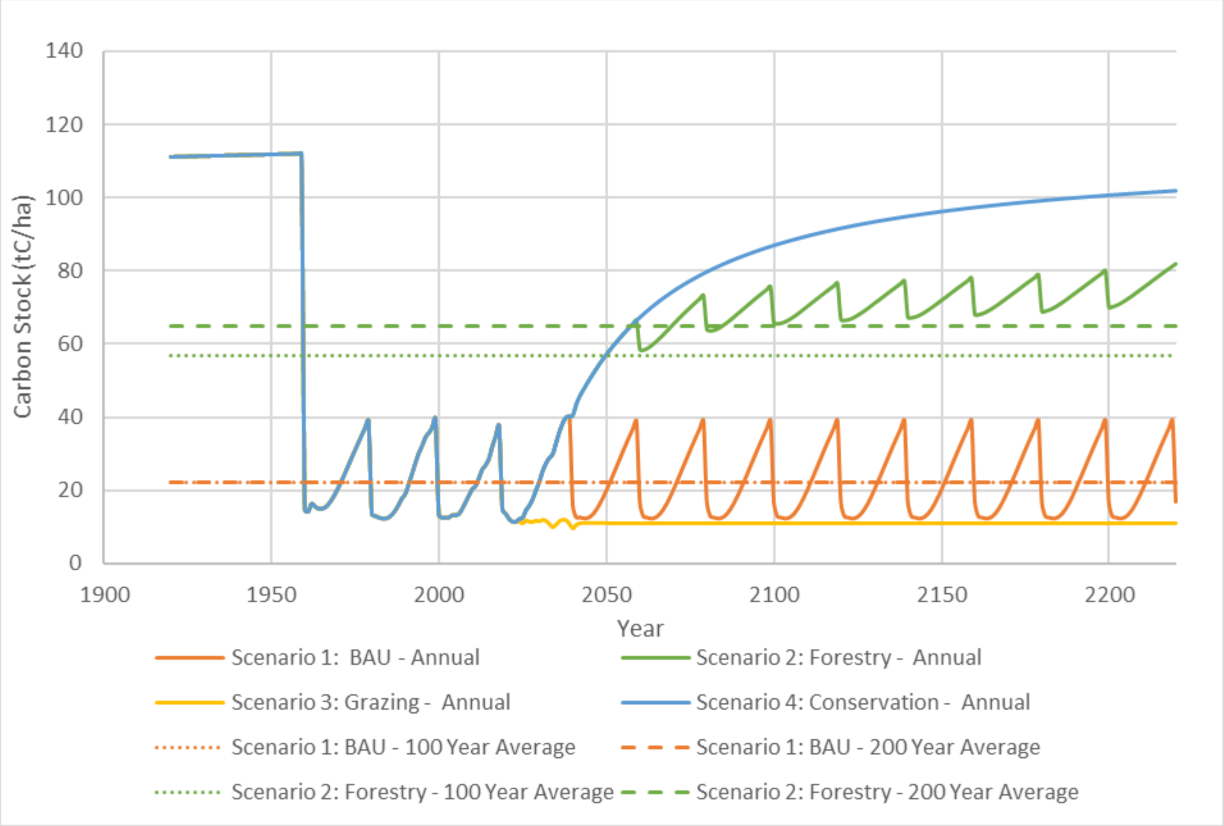

Figure 8.2. Comparison of the year-on-year carbon stock of each scenario, averaged across all spotted gum regrowth forest sites. The 100-year and 200-year long term average carbon stock of scenarios 1 and 2 are also depicted.

The selective harvesting scenario includes a HWP pool, which increased incrementally with each harvest cycle, as forest biomass was transferred to and stored within these products. HWP carbon stocks then gradually declined at the rate which each product type exists its useful life and decomposes in landfill. This decay does not exceed the rate which forest biomass enters the pool from each harvest, causing it to trend upwards over time, with the pool growing from 3 tC/ha after the first harvest to 16 tC/ha after the final harvest. Figure 8.3 illustrates the carbon stocks stored within HWPs both in use and deposited in landfill over the study period and depicts the contributions of the landfill pool increasing over time.

As indicated in Figure C1 in Appendix C, carbon stocks on-site in the forestry scenario (2) remain relatively stable from the second harvest. Increasing carbon stocks within the HWP pool illustrated in Figure 8.3 cause the scenario's total carbon stocks (the solid green line in Figure 8.2) to grow steadily throughout the study period. The growing HWP and landfill carbon pool, plus the relative importance of the initially low on-site carbon stock as the regrowth forest matures prior to the first harvest, result in a difference of 8 tC/ha between the 100- and 200-year long-term average carbon stocks for spotted gum regrowth land management scenario 2 (57 tC/ha and 65 tC/ha, respectively; the dashed green lines in Figure 8.2).

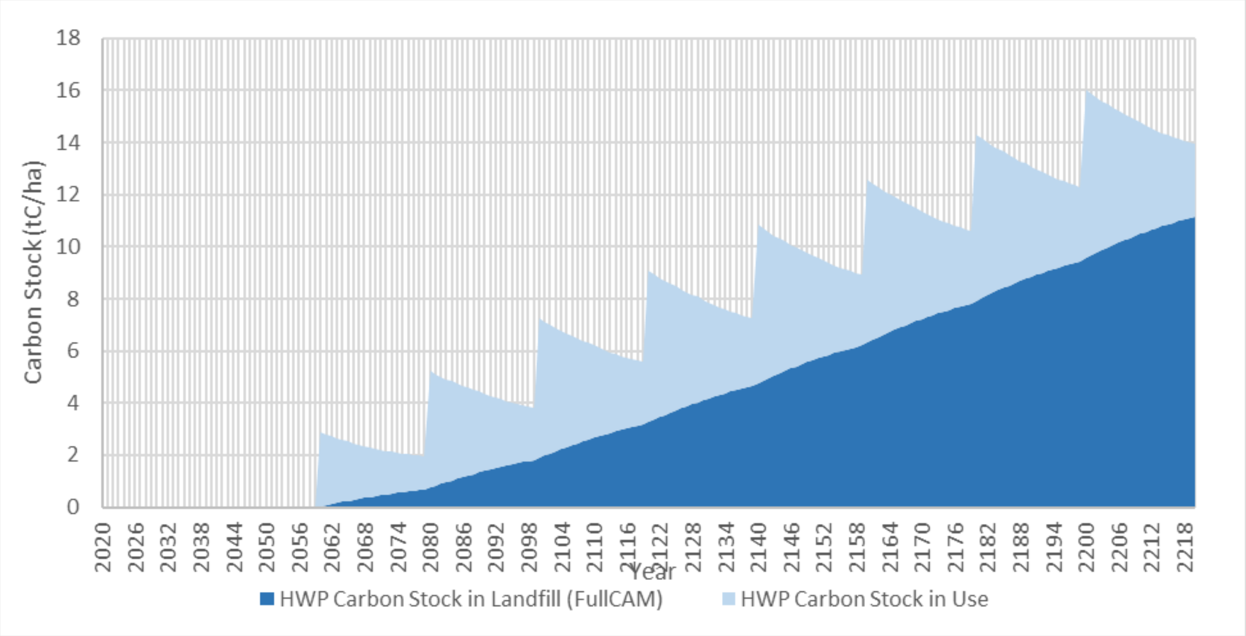

Figure 8.3. Spotted gum regrowth forest harvested wood product carbon stock in use (light blue area) and deposited in landfill (dark blue area) in land management Scenario 2.

8.3.2 FullCAM Modelling of Ironbark Woodland Regrowth Forest Carbon Stocks – Northern Qld Forestry Hub Region

Averaged model outputs for each scenario are presented in Appendix C. Figure 8.4 provides a comparative illustration of the year-on-year total carbon stock of each scenario averaged across all four ironbark woodland sites, along with the 100-year and 200-year long term average carbon stock of scenarios 1 and 2. Trends in carbon stocks across land management scenarios were similar to the spotted gum forest of the Southern and Central Qld region (Figure 8.2), but carbon stocks were lower for the ironbark woodland sites.

As illustrated in Figure 8.5, the HWP carbon pool grew from 0.8 tC/ha after the first harvest to 4.2 tC/ha after the final harvest in these relatively low productivity ironbark woodlands. There was a difference of 2.5 tC/ha between the 100- and 200-year long-term average carbon stocks for the selective timber harvesting scenario (40.5 tC/ha and 43.0 tC/ha, respectively; green dashed lines in Figure 8.4).

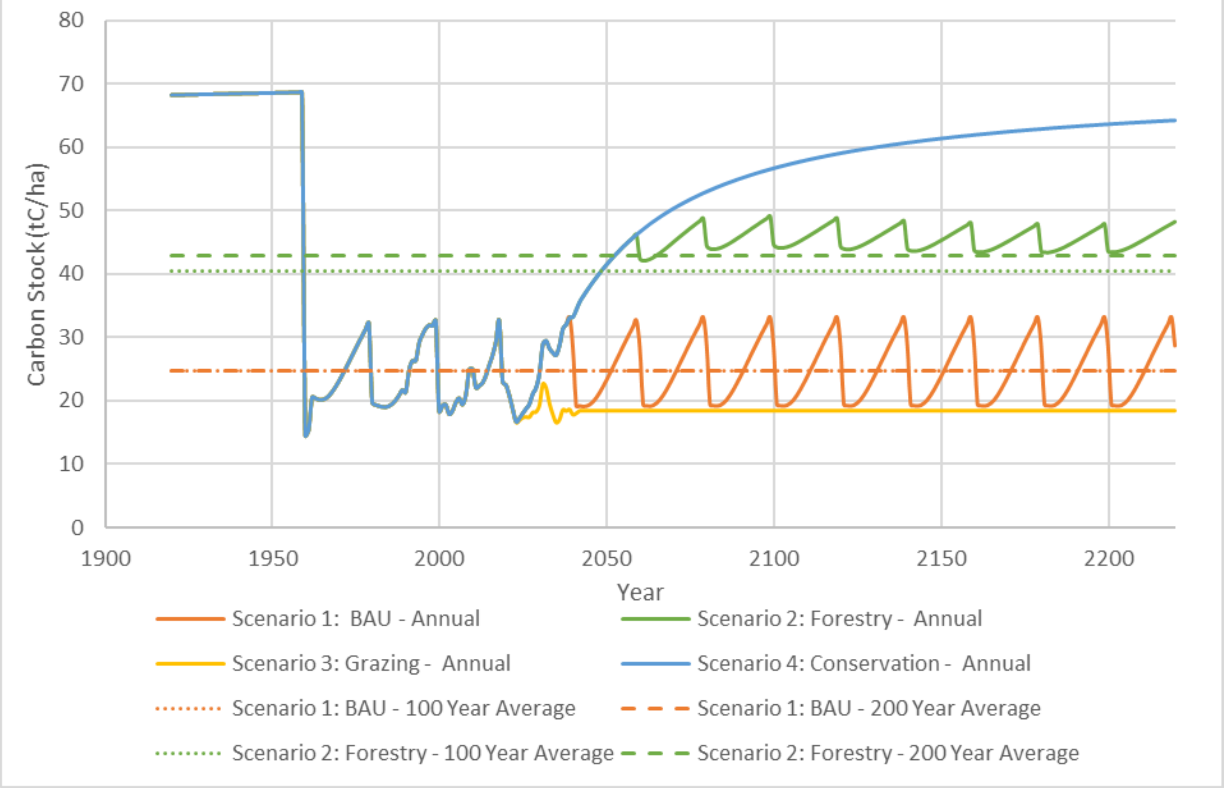

Figure 8.4. Comparison of the year-on-year carbon stock of each scenario, averaged across ironbark woodland regrowth forest sites in the Northern Queensland Hub region. The 100-year and 200-year long term average carbon stock of scenarios 1 and 2 are also depicted.

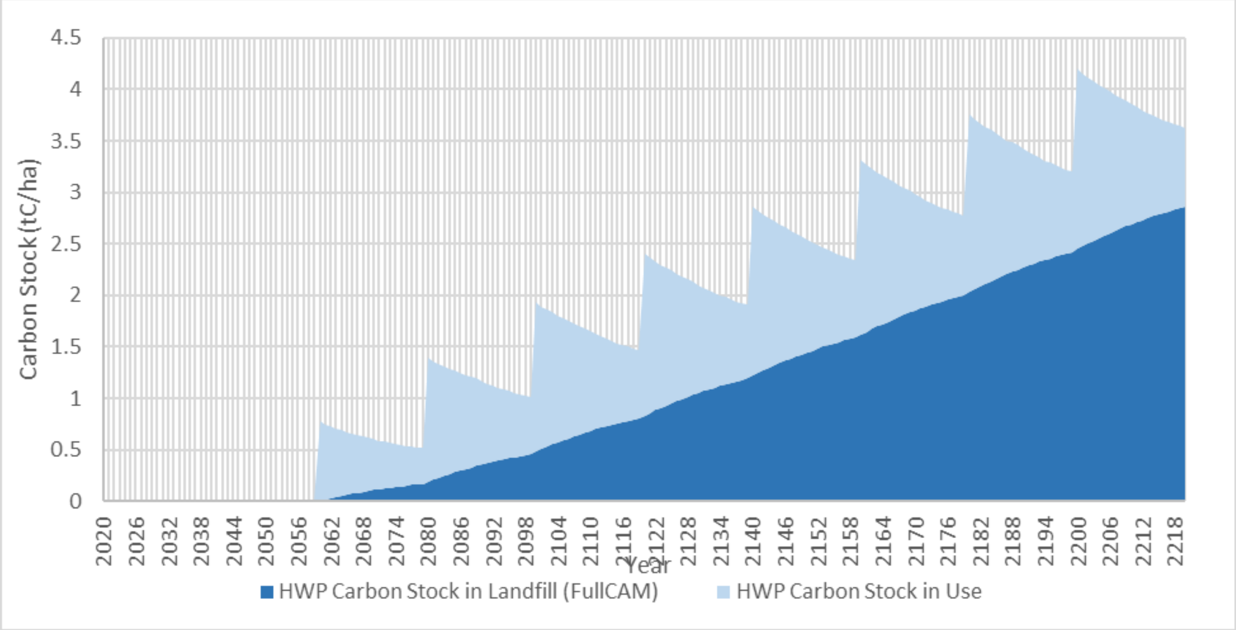

Figure 8.5. Harvested wood product carbon stock in use (light blue area) and deposited in landfill (dark blue area) over the Scenario 2 study period for the Northern Hub region ironbark woodlands.

8.3.3 FullCAM Modelling of Coastal Dry Eucalypt Forest Regrowth Forest Carbon Stocks – NE NSW Forestry Hub region

Averaged model outputs for each scenario are presented in Appendix C. Figure 8.6 provides a comparative illustration of the year-on-year total carbon stock of each scenario averaged across the four coastal dry eucalypt forest regrowth sites in northeast NSW, along with the 100-year and 200-year long term average carbon stock of scenarios 1 and 2. Carbon stock trends were similar to those estimated for Queensland, but carbon stocks were generally higher in this NSW region (Figure 8.6) than in the Southern and Central Qld region (Figure 8.2).

As with the other Hub regions, Figure 8.7 illustrates that the size of the HWP pool in the North East NSW Hub region increased incrementally with each harvest cycle, as forest biomass is transferred to and stored within these products and the landfill pool. This pool grew from 3.4 tC/ha after the first harvest to 18.9 tC/ha after the final harvest. Overall, there was a difference of 9.4 tC/ha between the 100- and 200-year long-term average carbon stocks for the selective timber harvesting scenario in the North East NSW Hub region (77.8 tC/ha and 87.4 tC/ha, respectively; green dashed lines in Figure 8.6).

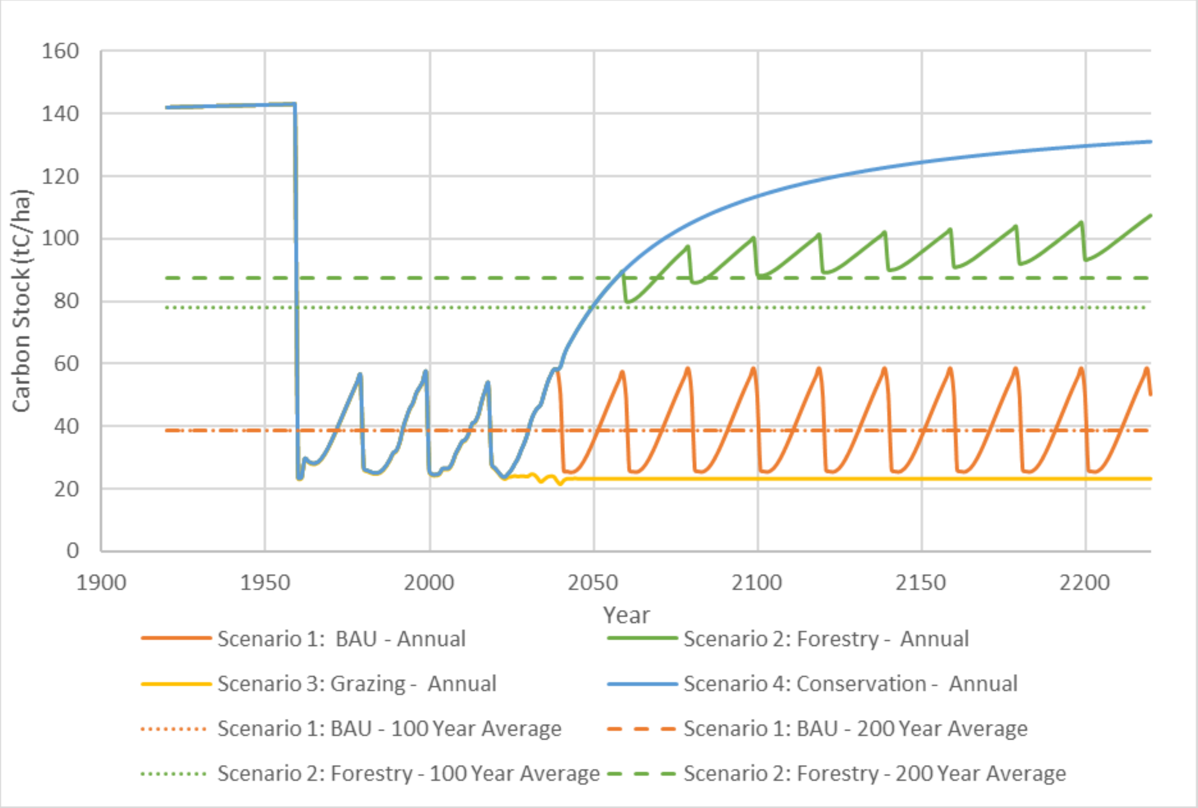

Figure 8.6. Comparison of the year-on-year carbon stock of each scenario, averaged across all sites for coastal dry eucalypt forest in the Northeast NSW Hub region. The 100-year and 200-year long term average carbon stock of scenarios 1 and 2 are also depicted.

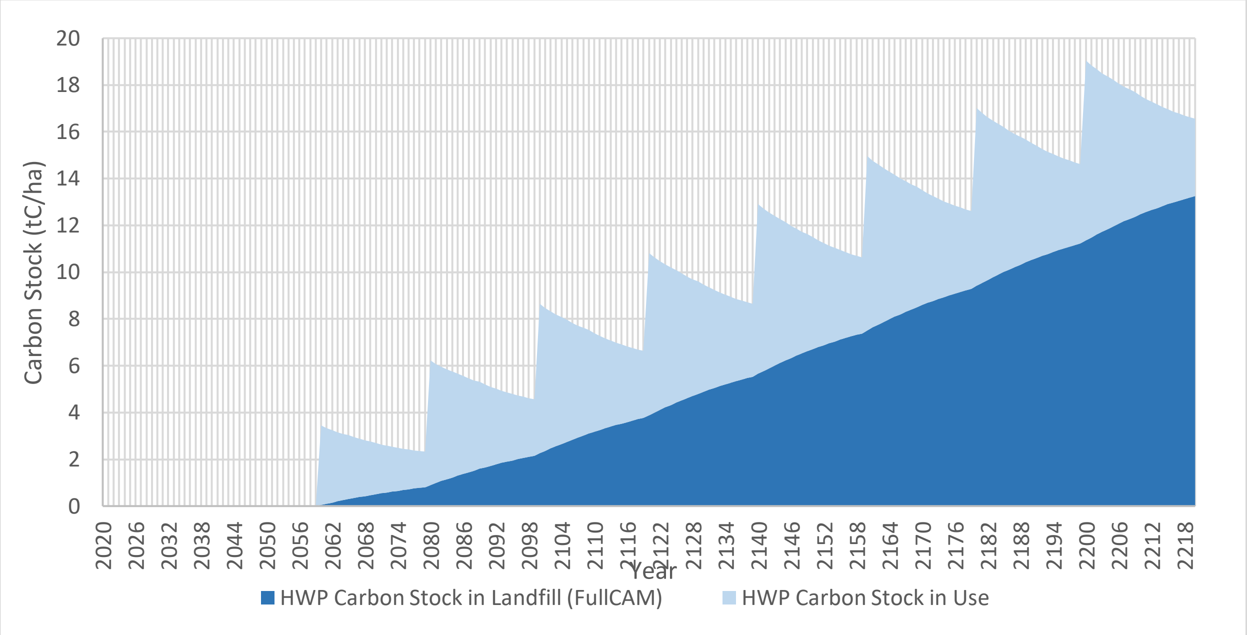

Figure 8.7. Harvested wood product carbon stock in use (light blue area) and deposited in landfill (dark blue area) over the Scenario 2 study period for for coastal dry eucalypt forest in the North East NSW Hub region.

8.3.4 FullCAM Modelling of Coastal Dry Eucalypt Forest Regrowth Forest Carbon Stocks – SE NSW Forestry Hub Region

Averaged model outputs for each scenario are presented in Appendix C. Figure 8.8 provides a comparative illustration of the year-on-year total carbon stock of each scenario averaged across four sites of coastal dry eucalypt forest in the South East NSW Hub region, along with the 100-year and 200-year long term average carbon stock levels for scenarios 1 and 2. Carbon stock trends were similar to the other Hub regions, but average carbon stocks were highest in this NSW Hub region.

As illustrated in Figure 8.9, the size of the HWP and landfill pools associated with the selective timber harvesting scenario increased from 5.6 tC/ha after the first harvest to 30.6 tC/ha after the final harvest in the South East NSW Hub region. While total carbon stocks on-site remained relatively stable from the second harvest onward (see Appendix C), increasing carbon stocks within the HWP and landfill pools grew the scenario’s total carbon stocks steadily throughout the study period (solid green line in Figure 8.8). There is a difference of 15.6 tC/ha between the 100- and 200-year long-term average carbon stocks in the selective timber harvesting scenario for the South East NSW Hub region (107.9 tC/ha and 123.5 tC/ha, respectively; green dashed lines in Figure 8.8).

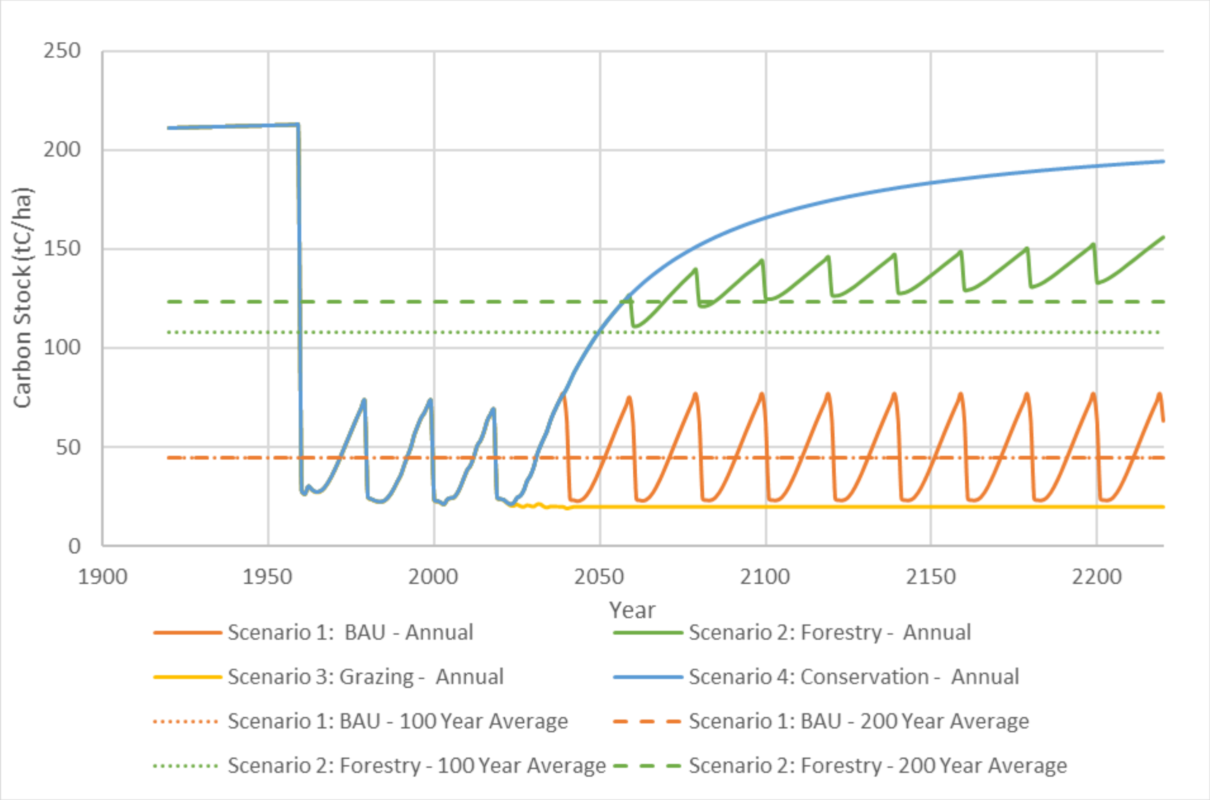

Figure 8.8. Comparison of the year-on-year carbon stock of each scenario, averaged across all sites in the coastal dry eucalypt forests of the South East NSW Hub region. The 100-year and 200-year long term average carbon stock of scenarios 1 and 2 are also depicted.

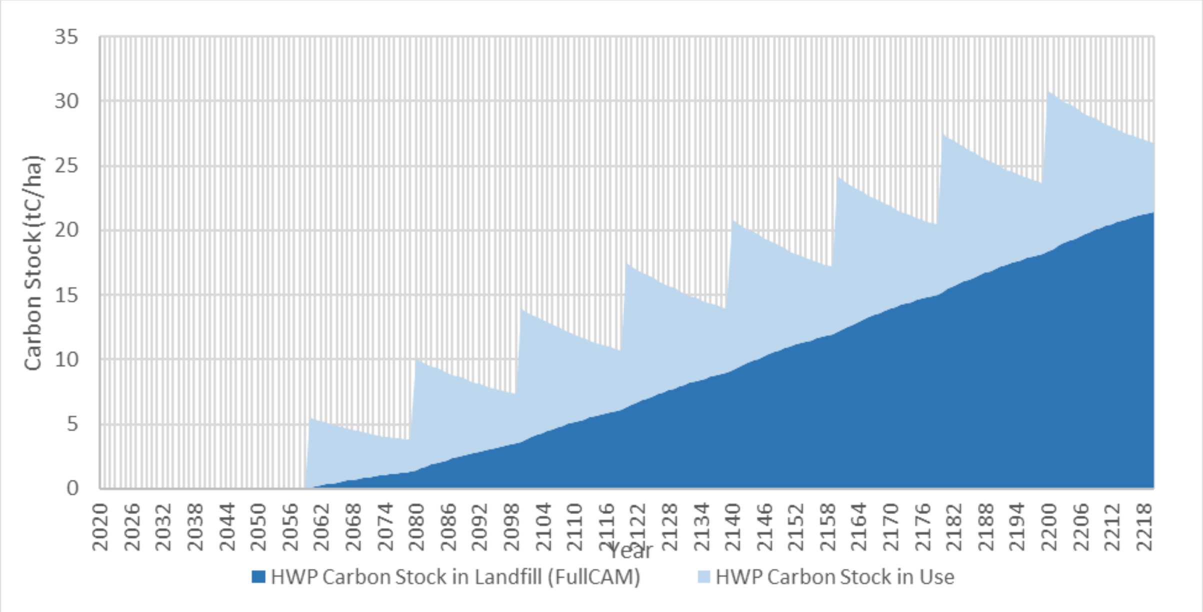

Figure 8.9. Harvested wood product carbon stock in use (light blue area) and deposited in landfill (dark blue area) for Scenario 2 in the coastal dry eucalypt forests of the South East NSW Hub region.

8.3.5 Summary of Variation in FullCAM Modelled Carbon Stocks Between the Hub Regions and Land Management Scenarios

There was significant variation among sites, both within a Hub region and among the different Hub regions (see Table C1 in Appendix C for within Hub variation). Site carbon stocks were generally lowest in the woodland ecosystems of the Northern Queensland Forestry Hub region and were highest in the SE NSW Hub region. For example, mean carbon stocks for the selective timber harvesting scenario were more than three times greater in the SE NSW Hub region than in the Northern Queensland region. Carbon stocks in the SE NSW Hub region were also almost double the carbon stocks in the Southern and Central Queensland Hub region.

Table 8.10 reports the long-term average carbon stocks of each land management scenario over the 100-year (2020–2120) and 200-year (2020–2220) intervals for all four Hub regions. Changes in the carbon stocks compared to the initial undisturbed forest carbon stock (Phase 1) are also provided.

Managing the site for intensive grazing (scenario 3) resulted in the lowest carbon stocks over the entire study period in all cases (Table 8.10). By entirely suppressing tree growth, carbon pools were limited to the relatively small pasture and debris pools which reach their maximum stocks within year 1 as the perennial grasses mature. This resulted in Scenario 3 long-term average carbon stocks being 73% to 91% less than the undisturbed forest over 200 years.

The reduction in carbon stocks relative to the undisturbed forest was less under the selection harvesting regime (scenario 2); which resulted in an average of 41% to 49% less carbon over 100 years, and 37% to 42% less over 200 years (Table 8.10). The key contributor to this discrepancy was changes in tree carbon stocks (see Appendix C for detailed breakdown of carbon pools under each land management scenario). A notable proportion the selection harvesting scenario’s carbon stocks were stored within the HWP and landfill pools, which accounted for an average of 2% to 4% of sequestered carbon over the 100-year period, increasing to 4% to 7% over the 200-year timeframe. Note that these long-term averages mask the growing importance of the HWP and landfill pools. For example, in year 200 of the simulation for the South and Central Queensland Hub region, the HWP and landfill pools accounted for 20% (16 tC/ha) of total carbon stored (80 tC/ha).

The continued maturation of native forest that occurs within the strict conservation scenario produces the highest on-site carbon stocks over both 100- and 200-year intervals in all Hub regions. After 200 years the native regrowth forest had reached maturity and stored between 53.9 tC/ha and 155.5 tC/ha (Table 8.10). When the long-term average carbon stocks of the forest are compared to the undisturbed forest at the end of Phase 1, Scenario 4 stored 33% to 42% less carbon over a 100-year period and 21% to 27% less over 200 years. Relative to the carbon levels in the undisturbed forest at the end of Phase 1, the average carbon stocks the strict conservation scenario exceeded the native forestry scenario by 7 to 8 percentage points over 100 years and 14 to 16 percentage points over 200 years. However, the comparison of carbon stocks in the conservation and selection harvesting scenarios modelled in FullCAM ignores carbon emissions associated with supplying society with substitute products if the regrowth forests are not managed under a selection harvesting regime. This is considered in the following section.

Table 8.10. Comparison of the 100-year and 200-year long term carbon stock of each land management scenario during Phase 3, averaged across all four sites in each Hub region. The percentage change in carbon stock compared to the maximum carbon stock of the undisturbed forest in Phase 1 is also presented.

Carbon stock attribute by Hub region	Land management scenario			
	1. Business as usual	2. Timber harvesting	3. Livestock grazing	4. Conservation
Southern and Central Qld				
Long Term Average Carbon Stock (tC/ha) – 100 Year	22.2	56.7	11.1	65.3
Change from undisturbed forest – 100 Year	-80%	-49%	-90%	-42%
Long Term Average Carbon Stock (tC/ha) – 200 Year	22.1	64.9	11.1	81.5
Change from undisturbed forest – 200 Year	-80%	-42%	-90%	-27%
Northern Qld				
Long Term Average Carbon Stock (tC/ha) – 100 Year	24.8	40.5	18.6	45.7
Change from undisturbed forest – 100 Year	-64%	-41%	-73%	-33%
Long Term Average Carbon Stock (tC/ha) – 200 Year	24.8	43.0	18.6	53.9
Change from undisturbed forest – 200 Year	-64%	-37%	-73%	-21%
NE NSW				
Long Term Average Carbon Stock (tC/ha) – 100 Year	38.7	77.8	23.6	88.1
Change from undisturbed forest – 100 Year	-73%	-46%	-84%	-38%
Long Term Average Carbon Stock (tC/ha) – 200 Year	38.8	87.4	23.5	107.2
Change from undisturbed forest – 200 Year	-73%	-39%	-84%	-25%
SE NSW				
Long Term Average Carbon Stock (tC/ha) – 100 Year	44.6	107.9	20.2	124.5
Change from undisturbed forest – 100 Year	-79%	-49%	-91%	-42%
Long Term Average Carbon Stock (tC/ha) – 200 Year	44.8	123.5	20.1	155.5
Change from undisturbed forest – 200 Year	-79%	-42%	-91%	-27%

8.3.6 Adding the Avoided Carbon Emissions from Substitute Products to the FullCAM Carbon Estimates

Figure 8.10 illustrates the outcomes of carbon stock analysis when displacement factors are adopted that account for the benefits of avoided substitute products associated with managing native forest under the selection harvesting regimes modelled in Scenario 2. Results are illustrated for Phase 3 of the modelling period (2020–2220). Green shaded areas represent the different carbon pools associated with the sites managed for native forestry. The total on-site carbon pool (dark green area) and HWP and landfill carbon pools (medium green area) are equal to those reported for Scenario 2 in each Hub region above. The carbon emissions ‘savings’ from using HWPs instead of substitutes are represented by the light green shaded area. These outcomes are compared to the total carbon stocks associated with the strict conservation management regime (Scenario 4 from the analysis in each Hub region presented above), which is represented by the black line.

Unlike other carbon pools, where stored carbon can return to the atmosphere due to decay or changes in land management practices, the carbon savings from avoided use of substitutes are an immediate and permanent reduction in carbon emissions. These savings result from the avoidance of emissions from the permanent loss of biogenic carbon (e.g. avoided imported tropical hardwoods from poorly managed forests in Asia and the pacific, such as merbau) and the consumption of fossil fuels needed to produce the alternative products (e.g. steel and plastic) (Sathre & O’Connor, 2010). As a result, the avoided carbon emissions represented in this pool increase as more timber is harvested from the regrowth native forests and converted to HWPs.

When emissions from substitute products are ignored, Figures 8.2, 8.4, 8.6 and 8.8 revealed that the conservation scenario has the same carbon stock as the forestry scenario until the first harvest, and always had higher carbon stocks after the first harvest in 2060. However, when substitute product carbon emissions are included, the carbon abatement associated with managing regrowth for native forestry exceeded that of strict conservation by the year 2073 in the Southern and Central Queensland and both NSW Hub regions. That is, the carbon stocks of the conservation scenario exceeded selection forestry scenario for a maximum of 13 years after the first selection harvest (Figure 8.10a,c,d). This indicates a negligible medium-term carbon cost of selection forestry, followed by increasing long-run carbon benefit.

Nevertheless, for the comparatively low productivity ironbark woodlands in the Northern Queensland Hub region, the carbon abatement associated with managing sites for native forestry did not exceed that of strict conservation until 168 years into the simulation (year 2188) (Figure 8.10b). This suggests the carbon benefit of selection forestry is sensitive to site productivity, with more productive timber producing sites having the greater carbon storage potential relative to the alternative of strict conservation.

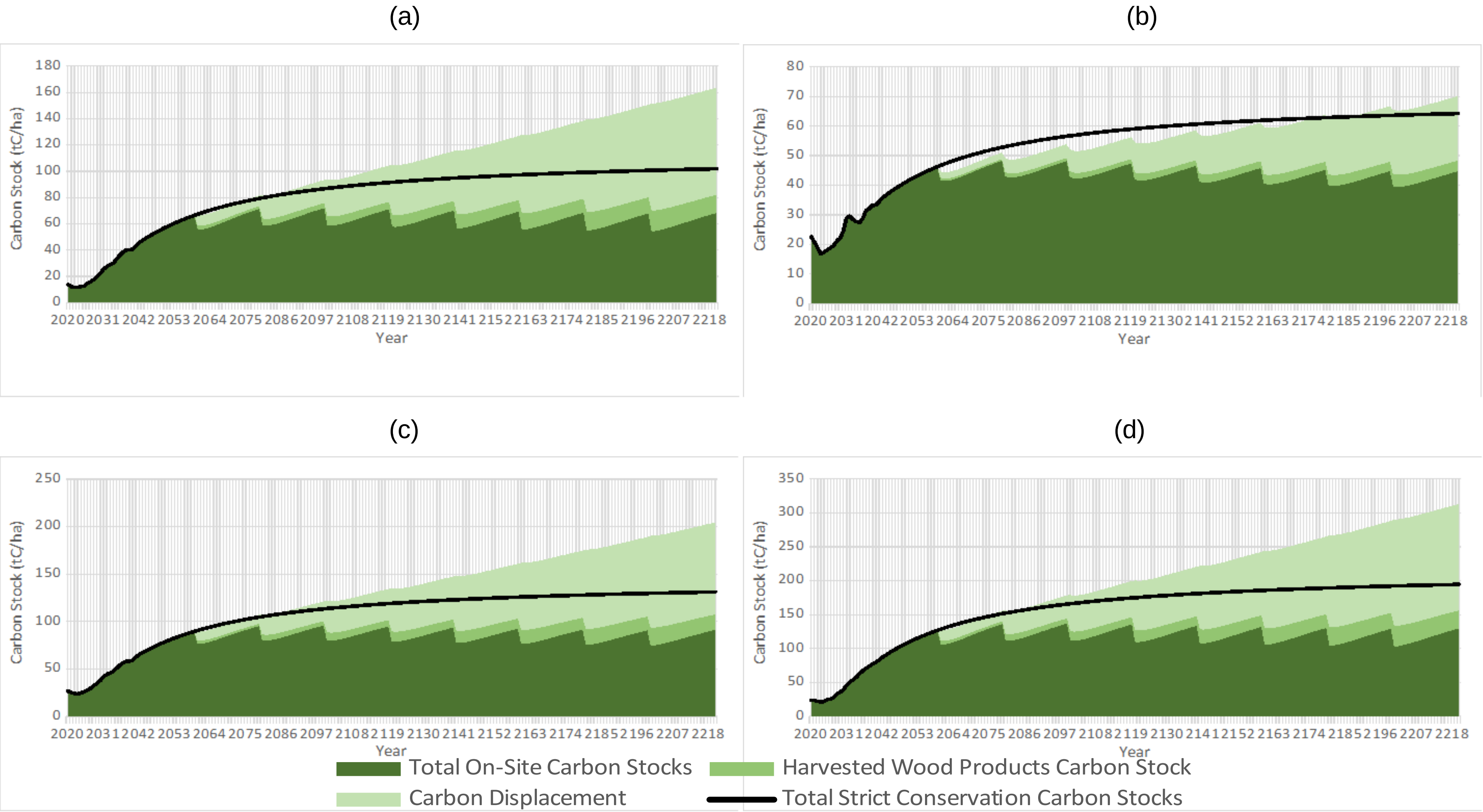

Figure 8.10. Comparison of the year-on-year carbon stock of the conservation scenario (black line) to the selection timber harvesting scenario (total green area) when the carbon benefits of displacing substitute materials are also considered (light green area only) for (a) Southern and Central Queensland; (b) Northern Queensland; (c) North East New South Wales; and (d) South East New South Wales. Note the different y-axis scales between regions.

Table 8.11 provides a comparison of the 100-year and 200-year long term average total carbon stocks of the selection harvesting and strict conservation regimes for:

(i) carbon stock on site only (Scenario 2 = dark green area in Figure 8.10; Scenario 4 = black line in Figure 8.10); and

(ii) Carbon stock on-site, plus HWPs and avoided carbon emissions from substitute products (Scenario 2 = sum of all shaded areas in Figure 8.10; Scenario 4 = black line in Figure 8.10).

The comparison metric for (i) and (ii) is the percentage difference in carbon stock of Scenario 2 relative to Scenario 4, which has been calculated as follows.

(Average carbon stock in Scenario 2 – Average carbon stock in Scenario 4) / Average carbon stock in Scenario 4

A negative percentage indicates the Scenario 2 stores less carbon than Scenario 4. Table 8.11 indicates the long-term average carbon stocks of the selection harvesting regime in the NSW and Southern and Central Queensland Hub regions were 3% to 4% higher over 100 years (column 3) than the strict conservation scenario, despite storing 15-17% less carbon on-site (column 2). Over 200-years in these Hub regions, strict conservation stored 26% to 29% more carbon on-site (column 2); however, the carbon stored in HWPs plus permanent displacement of emissions from the use of HWPs resulted in the selection harvesting regime having 21% to 23% greater average carbon abatement impact overall.

Table 8.11. Percentage difference in total carbon stocks and carbon stocks including displacement factors associated with HWPs produced on-site between the selection harvesting and strict conservation regimes for the 100-year and 200-year averages. Negative values indicate lower carbon stocks relative to the conservation regime.

Time period and Hub region	Carbon stock in scenario 2 relative to carbon stock in scenario 4 (%)	
	Carbon stock on-site only	Carbon stock on-site, plus HWPs and avoided carbon emissions from substitute products
100-year average carbon stock		
Southern and Central Qld	-17%	4%
Northern Qld	-13%	-5%
NE NSW	-15%	3%
SE NSW	-17%	4%
200-year average carbon stock		
Southern and Central Qld	-29%	23%
Northern Qld	-24%	-3%
NE NSW	-26%	21%
SE NSW	-29%	23%

Due to low forest productivity, the Northern Queensland Hub region stored an average of between 5% and 3% less carbon over 100 and 200 years, respectively, when carbon stored in HWPs and avoided emissions from substitute products were included (column 3 in Table 8.11).

8.4 Discussion

At all sites, across all four Hub regions, carbon gains associated with retention of forest for selection timber harvesting or conservation were greater than those associated with repeated re-clearing of regrowth and permanent exclusion of regrowth for grazing. The outcomes of this analysis indicate that regenerating and managing native regrowth forests for selection timber harvesting can sequester significant quantities of carbon on-site, within the products derived from each harvest and in the avoided consumption of substitute products.

Using the FullCAM carbon accounting framework adopted by NCAS and the ACCU Scheme (which ignores avoided substitutes), the 100-year long term average carbon stocks of sites managed for selection harvesting (Scenario 2) were 64% to 155% greater than for sites maintained for low intensity grazing under a 20-year clearing regime (Scenario 1). And between 118% and 434% greater when compared to Scenario 3, where native forest regrowth was suppressed entirely[15]. However, the 100-year long term average carbon stocks of sites managed for selection harvesting were between 11% and 13% lower than for the strict conservation land management scenario (Scenario 4)[2].

In Section 8.3.6 it was revealed that when avoided consumption of substitute products is accounted for, the 100-year long term average carbon stocks under the selection harvesting regime are greater than under the strict conservation regime in both New South Wales Hub regions and the South and Central Queensland Hub region. This modelling suggests that there is merit in developing a vegetation-based ACCU Scheme method that incentivises the regeneration and management of native regrowth forests for sustainable selection timber harvesting.

From the limited number of FullCAM simulations carried out in this study, it appears carbon gains from encouraging retention of regrowth for timber production or conservation will be greater on a given site in the NSW Hub regions than in the Queensland Hub regions, and especially greater than the North Queensland Hub region (Figure 8.10). However, the analyses are location specific (dependent on site productivity) and the regional carbon gains that could be achieved are also dependent on the areas of regrowth forest available in the landscape.

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[15] Percentages calculated as: (Carbon stock for Scenario 2 from Table 10 – Carbon stock for the selected alternative scenario from Table 10) / Carbon stock for the selected alternative scenario from Table 10.

8.4.1 Carbon Sequestration Potential of Private Native Forestry at the Landscape Scale

The 1.5 M ha of standing post-1990 and cleared areas with commercially important private regrowth potential in 2020 to 2022 (Table 7.13) indicates the existence of a substantial carbon abatement opportunity. Assuming 50% of this total potential area is managed for forestry and silvopastoral systems (Scenario 2) rather than business as usual (Scenario 1), and multiplying these areas by the additional carbon that can be sequestered per hectare in Scenario 2 relative to Scenario 1 (Table 8.10), reveals that 750,000 ha of managed private native forest regrowth can sequester an additional 26.5 M tC (97.2 M tCO_2-e) over 100 years. This carbon sequestration potential is dominated by South and Central QLD (71%) and North East NSW (24%).

The 100-year sequestration potential of 750,000 ha of Scenario 2 regrowth is equivalent to less than three years of NCAS-reported increased sequestration due to reduced native forest harvesting in recent years. This provides another perspective of the magnitude of the carbon benefit Australia has been reporting for reduced native forest harvesting. The 97.2 M tCO_2-e potentially sequestered in regrowth managed under Scenario 2 is also equivalent to 24% of the annual emissions produced by Australia's energy sector in 2021 (404.03 M tCO_2-e).

If 750,000 ha of commercially important regrowth in the Hub regions was managed as silvopastoral systems, this could increase long-term sawlog and electricity distribution pole production by about 975,000 m^3/y. To put this timber production potential in perspective, it is equivalent to 15% of Australia's annual imports of solid wood RWE volume in 2018.

If the 750,000 ha of regrowth was instead managed for strict conservation (Scenario 4), the FullCAM simulations suggested 25% more carbon could be sequestered on site (33.3 M tC or 121.9 M tCO_2-e). However, FullCAM modelling of Scenario 4 does not account for emissions from Australians consuming substitute products instead of the 975,000 m^3/y timber that could be produced. Furthermore, this management regime would generate no timber income, and livestock income will decline to zero. Therefore, this management regime is unlikely to generate interest among landholders who aim to maintain or increase the profitability of their business over time.

If a native forestry ACCU method was developed, the undiscounted value of 97.2 M tCO_2-e sequestered in 750,000 ha of native forestry (Scenario 2) regrowth, estimated at the June 2024 ACCU spot market price of $33.47/t CO_2-e, would be $3.25 billion. Assuming the long-term average additional level of carbon per hectare in the managed regrowth is reached over 20 years, this is equivalent to an average gross carbon revenue (excluding all costs of participation in the carbon market) of $217/ha/y until payments end in year 20[16]. If Australia chooses to adopt a LCA approach in its national carbon accounts, avoided emissions from substitute products could also be accommodated in a future forestry ACCU method, and the creditable potential for carbon abatement in managed forests will be much higher. These carbon payments could reduce the opportunity cost of foregone livestock production while the timber producing silvopastoral system is developing. While carbon could become an important income stream for some

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[16] Average annual gross carbon revenue over 20 years = 97.2 M tCO2-e / 750,000 ha / 20 years x $33.47

landholders, it is important to recognise that any carbon credits sold can no longer be counted towards reducing the net carbon emissions of their own business.

8.4.2 Limitations of the Modelling Approach

This analysis was constrained by several limitations, which present opportunities for further research. A major limitation of the current analysis is the limited geographical extent; the number of sample points at which the FullCAM scenarios were run. We cannot be certain that the data points selected are representative of native regrowth forest in the Hub regions investigated. The maximum biomass that can occur on a given site varied greatly depending on the location of the points selected, and this has a strong influence on the modelled carbon pools at that site. FullCAM is a national model that does not always provide accurate predictions of carbon stocks at an individual location. A landscape scale analysis (e.g. with a model such as FlintPro) is recommended to better estimate carbon storage of regrowth forest across the landscape. Nevertheless, for the purposes of the current study where comparison among different land-use scenarios was the aim, the results presented still provide valid comparative case studies, and highlight the potential of native regrowth to sequester carbon.

There were a number of limitations associated with the use of FullCAM in our analysis, including:

Bio-energy displacement factors: The carbon benefits derived from the use of woody biomass in the generation of bioenergy to displace the use of fossil fuels was excluded from this analysis. It is recommended that future studies conduct a literature review to identify location specific bioenergy displacement factors to incorporate into the model to fully capture all substitution benefits from the use of HWPs.

Wildfires: The impact of wildfires on carbon storage were not accounted for in this study due to the unavailability of appropriate factors and parameters, and the unpredictability in the frequency of wildfire occurrence across the large landscapes examined in Queensland and New South Wales. This has the potential to significantly influence the analysis. A notable example is that top disposal burns were conducted after each harvest in Scenario 2, thereby reducing the debris pool. However, no fire occurs onsite during Phase 3 for the conservation scenario (Scenario 4), allowing the debris pool to accumulate unabated. While it is expected that wildfire will reduce the carbon stocks of all scenarios, their impact will likely vary based on the nature of the management regime. It is likely that carbon stocks of the conservation forest will be more severely impacted by wildfire than in the selectively harvested forest (Venn 2023).

Grazing: An attempt was made to incorporate the impacts of grazing on ground-cover biomass in the model during times when livestock were permitted on each site. However, FullCAM modelled a steep decline and eventual total loss ground-cover biomass. This is not reflective of sustainably managed grazing pastures and is more indicative of significant overgrazing. With very little literature published on the use of FullCAM in grazing systems, and grazing not enabled for the modelling of any vegetation-based ACCU Scheme method, it was decided that grazing would be excluded from this assessment. This exclusion will have influenced carbon stocks related to the crop and debris pool, especially in Scenario's 1 and 3 where grazing is expected to occur throughout Phases 2 and 3 of the analysis. Consequently, the FullCAM analysis resulted in pasture biomass levels remaining relatively high and stable over time. This is not a critical limitation of the scenario analysis, as it is the relative difference in carbon levels between the scenarios that is important, not the absolute levels of carbon predicted by FullCAM.

A further limitation in relation to grazing was the absence of accounting for carbon leakage associated with de-stocking the management areas (i.e. a grazing displacement factor was not considered here). Livestock grazing often continues in the understorey of open forests and woodlands, although the availability of pasture declines with increasing tree cover, which decreases animal stocking rates (Lewis et al., 2020). This is why the BAU scenario (1) involves the periodic re-clearing of forest. The scenario with management for selection timber harvesting (2) involves periodic thinning that maintains pasture production, albeit at average levels less than the BAU scenario. The fourth scenario in which native regrowth is preserved for conservation has very low average levels of pasture production. Given that Australia exports 67% of its beef and veal production (https://www.mla.com.au/about-mla/the-red-meat-industry/), declining output will likely stimulate land use change in other parts of the world (e.g. Brazilian Amazon) to increase supply to meet global demand. Thus, reduced production in Australia will likely increase carbon emissions from land clearing and livestock elsewhere. This carbon leakage, which will be greatest for the native regrowth conservation scenario (4), has not been accommodated in the analysis.

Carbon storage in trees and debris pool decay: FullCAM default parameters may not accurately represent carbon storage in mature trees, as mature trees often show evidence of decay over time (Ximenes et al. 2018). This issue is explained in detail in Chapter 4. Further research is needed to inform the FullCAM model on mature tree decay rates, and decay rates of dead wood more generally. For example, FullCAM overestimates the decay rate of stumps and coarse roots from harvested trees and therefore overestimates the rate of carbon emissions associated with dead organic matter produced from forest harvesting (Ximenes & Gardner, 2006).

Chapter 4 also outlined problems in the default FullCAM above-ground biomass fraction allocations, which results in an under-estimation of the proportion of biomass allocated to stems of trees in commercially important forest types. We overcame this issue by applying biomass fractions reported by Ximenes et al. (2005) for the open eucalypt forest sites (i.e. three of the four hub regions), but used the FullCAM default values for the ironbark woodlands in the Northern Queensland Hub region).

Forest thinning response: In currently available Public Release version of FullCAM (2020), current annual increment declines with forest age and forest age is not 're-set' by a selection harvest (age is reset with a clearfall harvest), nor is a forest thinning growth response simulated following a selection harvest. In selectively harvested forests this can result in a decline in carbon stocks over time as trees are harvested and current annual increment approaches zero with increasing forest age. In this study we accessed the 2023 Public Release Beta Version of FullCAM, which permitted a forest growth response following selection harvest (i.e. thinning) events. This FullCAM version is available on request from the Department of Climate Change, Energy, the Environment and Water; however, this version of the software is not currently in use for ACCU modelling.

8.5 Recommendations and Conclusions

Results presented here suggest that further work should be undertaken to develop a native forestry ACCU Scheme methodology. It is evident that native forests managed for timber production can play a significant role in climate change mitigation, both through storage of carbon on-site and within HWPs, as well as by avoiding the use of materials that have a high embodied carbon. A native forestry ACCU method can provide incentive for large-scale reforestation across private lands in the Queensland and NSW Forestry Hub regions. This would result in substantial carbon sequestration opportunities and help secure a sustainable supply of domestic hardwood timber.

9. Modelling of Fire in Native Regrowth Forests

Covey Associates Pty Ltd and Sean Ryan

Executive Summary (full report in Appendix D)

The full chapter on modelling of fire in native regrowth forests has been included at the end of the document as an appendix because of formatting inconsistencies with the remainder of the report. The reader is strongly encouraged to read the chapter in its entirety.

The University of Queensland commissioned Covey Associates to contribute to a Regional Forestry Hub project to investigate potential fire behaviour within privately managed regrowth forests under two management regimes. These two management regimes are unmanaged and managed regrowth in spotted gum and blackbutt native forest regrowth. Unmanaged regrowth forests are where the forest is left to grow and mature without anthropogenic intervention, and managed regrowth is where the regrowth is managed for selection timber harvesting, including silvicultural treatments and prescribed fire.

We completed fire behaviour modelling using the Vesta Mark 2 fire spread model for each Blackbutt and Spotted Gum open forest system under a typical seasonal bad fire weather day and a more extreme fire weather day based on an analysis of the Forest Fire Danger Index at nearby Automatic Weather Stations. Modelled outputs included estimates of the rate of spread and fire intensity. Fuel parameters were based on photographic evidence for spotted gum and blackbutt forests (Refer to Appendix D Figures 2 and 3) from managed and unmanaged forests. Twenty-one years of weather records from Gayndah Airport AWS and Toowoomba Airport AWS, representing climatic conditions for regrowth spotted gum and blackbutt forests in Queensland, respectively, were used to develop credible worst-case fire weather scenarios.

In the managed forest scenarios, Vesta Mark 2 modelling found reducing fuels, particularly elevated fuels, reduced overall fire intensity, flame height and propensity for crown fire development. However, the removal of fuel increased simulated wind speed such that there was only a minor reduction in modelled rate of spread in managed versus unmanaged forest, with no notable difference at the peak fire weather of the day. The estimated reduced fire intensity in managed forests can reduce potential carbon losses. The use of prescribed fire in managed forest systems has been shown to have short-term losses in forest carbon stores but no long-term impact through the deposition of pyrogenic carbon and biomass recovery.

10. Conclusion and Recommendations

Tyron Venn

To provide a basis for tracking progress towards and assessing compliance with its Nationally Determined Contribution (NDC) to global efforts to reduce greenhouse gas (GHG) emissions and to fulfill GHG reporting commitments to the UNFCCC, Australia has developed and maintained a National Carbon Accounting System (NCAS). As part of this system, Australia has produced its own UNFCCC approved country-specific methodology to account for emissions and removals from its land use, land use change and forestry (LULUCF) sector – the Full Carbon Accounting Model (FullCAM). FullCAM simulations are employed to estimate changes in carbon stocks due to growth and disturbances of native forests in Australia, including native forestry.

Australia's successful lobbying of the UNFCCC to include net emissions from the LULUCF sector in calculations of 1990 baseline GHG emissions was highly favourable, as it has allowed Australia to meet all its international GHG obligations to date while increasing emissions in other sectors or the economy, particularly the energy sector. When the LULUCF sector is excluded from Australia's national carbon accounts, GHG emissions have increased by 90.6 M tCO_2-e/y since 1990.

The LULUCF sector emitted 198.2 M tCO_2-e/y in 1990 but represented a net sink of 63.9 Mt CO_2-e/y in 2021. Historically, the emissions reduction achieved in the LULUCF sector was largely due to reducing emissions from land clearing, coupled with sequestration in regrowth on previously cleared lands. However, particularly since 2010, the importance of reduced land clearing for carbon emissions reduction has waned. Fortunately for Australia, the national carbon accounts show that the contribution of reduced native forest harvesting to reducing the nation's GHG emissions has dramatically increased since 2010. By 2021, the decline of Australia's native forestry industry was responsible for 55% of net carbon sequestration in the LULUCF sector, removing a quantity of GHGs from the atmosphere equivalent to 9% of Australia's total annual emissions from the energy sector per annum. The description in Australia's National Inventory Report on how the carbon removals due to reduced native forest harvesting were calculated is unclear. It is recommended that these methods be clearly articulated in future national GHG inventory reports, including spatially explicit reporting by forest type and time since avoided harvest disturbance.

Closer examination of NCAS and FullCAM revealed several technical limitations that likely result in a substantial underestimation of the carbon abatement potential of native forests managed for selection timber harvesting relative to strict conservation.

1. Overestimation of the carbon storage potential of mature trees by failing to account for increasing rates of decay as trees age;
2. Underestimation of the proportion of biomass allocated to the woody components (stems) of trees in commercially important forest types, which overestimates the level of forest residue carbon that will rapidly decay following a selection harvest;

3. Overestimation of the rate of decay of coarse dead roots, thereby discounting their carbon storage potential within production forests;
4. Overestimation of the rate of decay of wood products deposited within landfill, thereby discounting the climate mitigation potential of HWPs produced from sustainably managed production forests;
5. Failure to adopt a lifecycle analysis (LCA) of carbon approach to account for the carbon benefit of native forestry of avoided consumption of fossil fuel intensive substitutes (e.g. steel, concrete, brick, plastic and carpet), or imported wood from nations where forests are not as well managed as Australia's; and
6. Likely overestimation of the long-term average on-site carbon storage potential of strict conservation forests relative to forests managed for selection timber harvesting due to a questionable NCAS definition of 'natural' wildfire, the exclusion of their emissions from the national GHG accounts, and an assumption that forest management makes little difference to wildfire-related carbon fluxes.

Therefore, NCAS and FullCAM cannot be used to inform forest and carbon policy, nor evaluate carbon outcomes associated with the management of domestic forests for wood products. It is recommended that these limitations be addressed, including the development of a forest carbon accounting model within a LCA framework.

The native forest focus of this report was on post-1990 commercially important private regrowth in the South East New South Wales (NSW), North East NSW, South and Central Queensland (QLD) and North QLD Forestry Hub regions. The dominant land use in areas with commercially important native forest regrowth is production of livestock. Spatial analyses revealed there were about 882,000 ha of standing commercially important private native forest regrowth in 2020-22. A more complete picture of the potential total area that could support commercially important private native forest regrowth can be provided by also including the 605,000 ha that was cleared or remained cleared between 1991 and 2020-22. This suggests a total potential area of commercially important private native forest regrowth of 1,487,000 ha.

Spatial analyses revealed tens of thousands of hectares of this regrowth continues to be re-cleared annually throughout the Forestry Hub regions. Existing native vegetation ACCU projects have been established predominantly in low-productivity arid and semi-arid agricultural landscapes. Historic and existing Australian Carbon Credit Unit (ACCU) methods have not sufficiently incentivised the retention of commercially important native forest types in relatively productive agricultural landscapes. These methods have high opportunity cost of foregone agricultural and timber income streams because they prohibit thinning and timber harvesting, and will reduce livestock income to zero as regrowth ages. Potential carbon income streams from native forest regrowth continue only until the 100-year average additional (compared to business as usual) carbon stock level is reached, which is typically within 15 to 25 years. Thus, existing native forest ACCU methods decrease the medium and long-term income earning potential of farms. Lower farm incomes will likely be capitalised into lower property values, particularly in areas where there is not strong demand for 'rural lifestyle' blocks.

In October 2024, the Federal Government announced it agreed to prioritise four new proponent-led ACCU methods, including two relevant to native forests in the Hub regions considered in this report: Improved Native Forest Management (INFM) in Multiple-use Public Forests; and Improved Avoided Clearing of Native Regrowth (IACNR). INFM has not been designed for application to private native forest. From publicly available information, it is unclear how IACNR will overcome the high opportunity costs of participation in relatively productive agricultural landscapes with commercially important regrowth forest types. IACNR was proposed by the Queensland Government Department of Environment, Science and Innovation and it is unlikely to permit thinning and selection timber harvesting at a level that would encourage landholders to retain regrowth to establish silvopastoral systems such that medium and long-term farm productivity can be maintained or increased.

FullCAM simulations in commercially important private native forest regrowth indicated substantial opportunities for increased carbon sequestration in regrowth forests managed for selection timber harvesting relative to periodic reclearing (i.e. business as usual). A preliminary LCA of carbon in selectively harvested native forests revealed the true carbon benefit (as ‘seen’ by the atmosphere) of sustainable timber production is likely to be much greater than indicated by FullCAM, and in the long-run will exceed the level of carbon sequestered in strict conservation forests for many commercially important forest types.

Vesta 2 wildfire simulation modelling in commercially important private native forest regrowth highlighted strong potential for reduced GHG emissions from wildfire in managed forests versus strict conservation forests. In addition, the management-induced changes in wildfire behaviour will also reduce risk to human lives, livestock, infrastructure and other assets.

Unsurprisingly, ACCU methods that effectively extinguish the medium and long-term income generating capacity of land are not attractive to landholders in relatively productive agricultural landscapes. This study highlighted that Australia’s GHG accounting framework underestimates the carbon abatement potential of native forestry relative to strict conservation. Although commercially important private native forest regrowth managed for timber production has high carbon sequestration potential, there are no ACCU methods that incentivise retention of native forest regrowth by permitting thinning and native forestry.

It is recommended that a native forestry ACCU method be developed to incentivise large-scale retention of commercially important private native forest regrowth. The Forestry Australia proposed Enhancing Native Forest Resilience (ENFR) ACCU method, which was not prioritised for development by the Federal Government in 2024, could be developed to accommodate management of private native forest regrowth. Improvement of forest policy to remove sovereign risk associated with sustainable private native forestry will also be essential to motivate adoption.

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Appendix A. Non-Spatially Explicit Greenhouse Gas Accounting Methodology for Forest Land Remaining Forest Land

The non-spatially explicit estate method of FullCAM (a UNFCCC Tier 3, Approach 2 compliant method) is used for both public and private native forests in QLD and WA, and for private native forests only in VIC, NSW and TAS. For private native forests in NSW, an estate model has been developed drawing on the parameters and settings used in spatial modelling of public native forests in that state. Specifics about this approach for NSW are not provided in Australia's 2021 National Inventory Report. For all other states, the estate method and parameters described below apply, which has been summarised from the Australia's 2021 National Inventory Volumes 1 and 2 (Australian Government, 2023a, 2023b). Developing a spatial model for Queensland is reported as being a priority of the Department of Climate Change, Energy, the Environment and Water, but is not yet available.

- In the estate method, changes in living biomass are the net result of:
- sequestration of carbon in above ground and below ground biomass determined from growth models;
- losses from the harvest of wood products (transferred to the harvested wood products pool); and
- movement of residue material (including below ground biomass) to dead organic matter (DOM) and soils.

A.1 Sequestration of carbon in above ground and below ground biomass

Sequestration is based on forest types consistent with reporting under the Montreal Process National Forest Inventory and the NVIS Major Vegetation Groups (MVG). The NVIS MVGs are illustrated in Figure . An age class structure in 1989-90 is assumed (Table 6.4.9 in Volume 1 (Australian Government, 2023a)). Assumed current annual increment (CAI) in forest growth for the different forest types over time are presented in Figure , and cumulative above-ground carbon estimates based on Figure A.2 are illustrated in Figure. The estate method assumes below-ground biomass is 25% of above-ground biomass for tall dense eucalypt forest and medium dense eucalypt forest, and 20% for all other forest types.

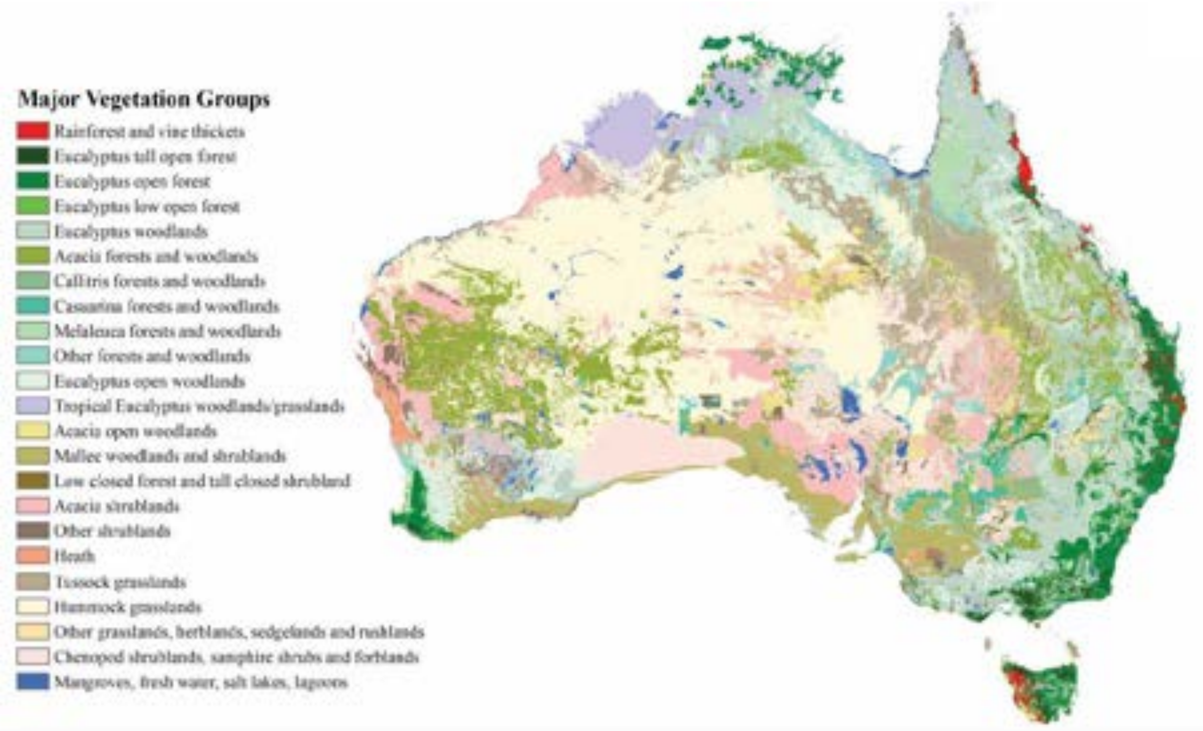

Figure A.1. National Vegetation Information System, Major Vegetation Groups. (National Inventory 2021 Vol 2)

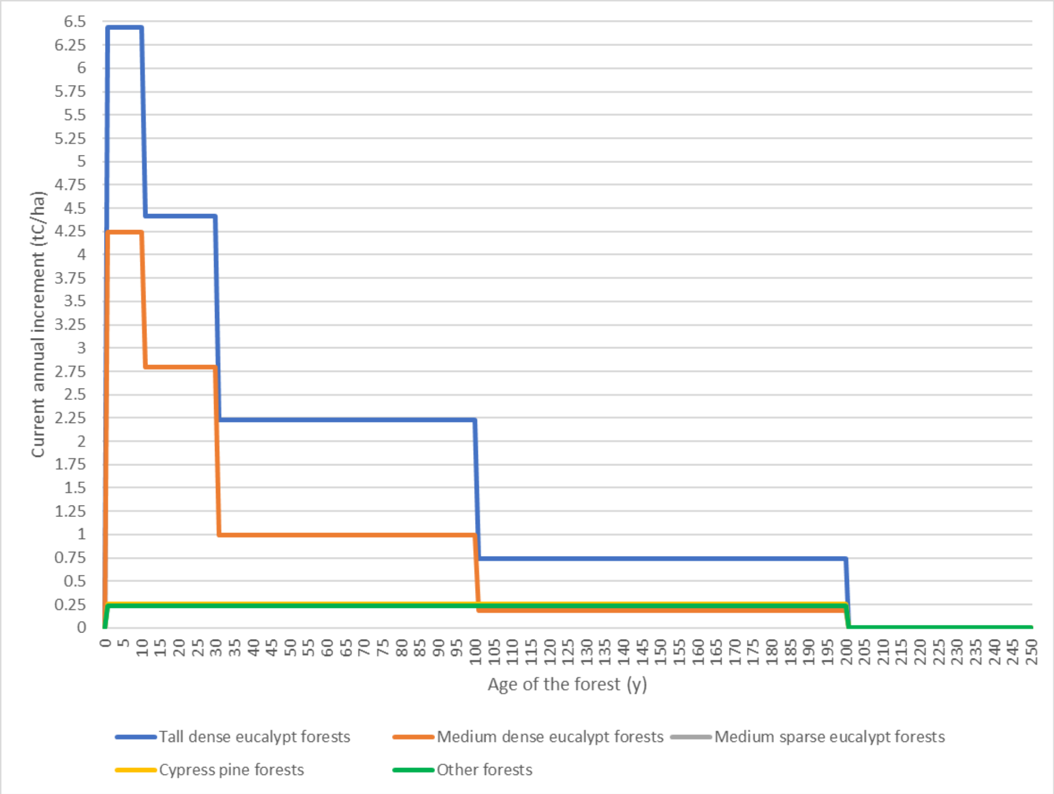

Figure A.2. Estate method current annual increment of above-ground biomass by forest type and age

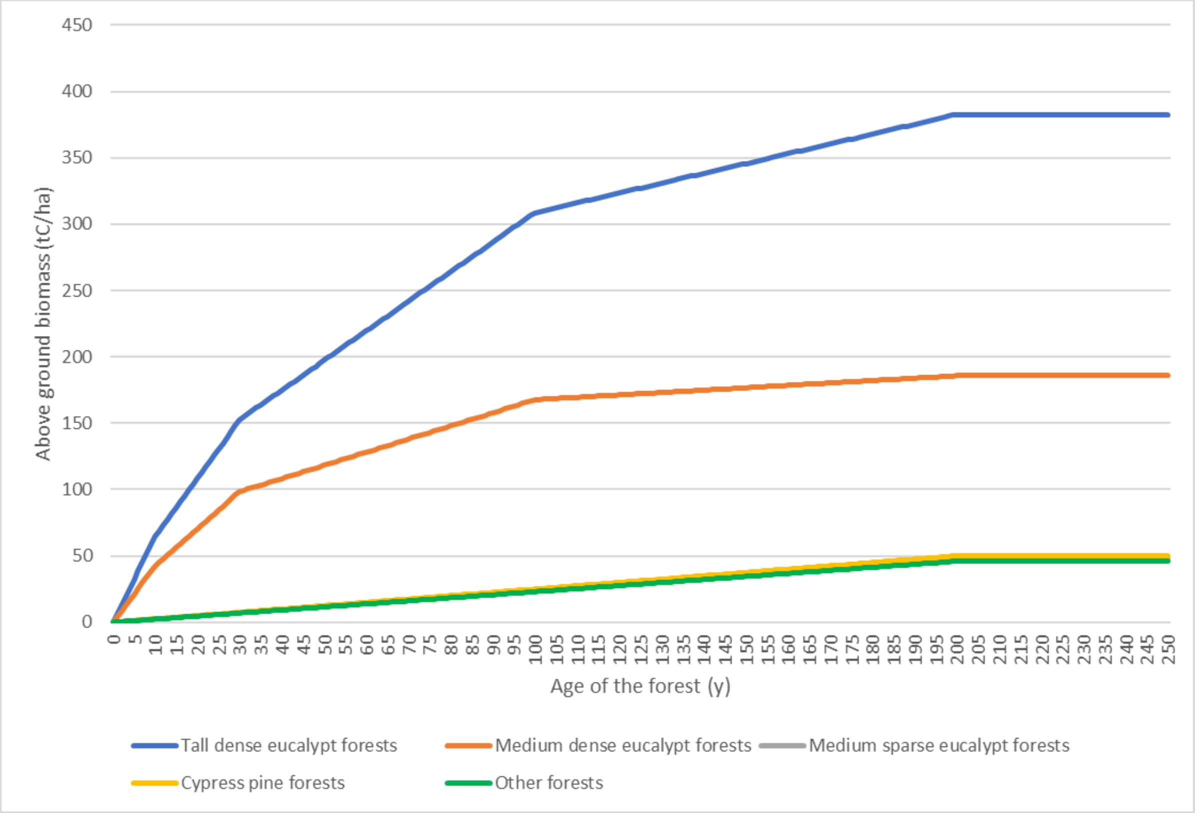

Figure A.3. Estate method cumulative above-ground biomass by forest type and age

As indicated in Figure and Figure, the estate method assumes an above-ground carbon equilibrium in what the inventory describes as senescent forests greater than 200 years old. In reality, it is unlikely a carbon equilibrium would be reached before a decrease from a maximum level of carbon accumulation. This is because much of the carbon in a forest is in the tree boles, and trees over 200 years old will have a high level of hollows and other defects compared to a younger forest, while continuing to suppress the growth of younger trees. It is probable that in many forest types the decay of old trees will exceed the sum of carbon sequestration in the old trees and suppressed younger trees for a time before the old trees lose their competitive edge. Thus, it is probable that biomass carbon per hectare in some forest types will be greater at ages under 200 than at ages over 200.

A.2 Losses from harvested wood products

The estate method assumes no commercial harvesting is possible from native forests less than 30 years. Areas subject to clearfall harvesting are assumed to regrow from age zero. Areas subject to selection harvesting, which is the silviculture employed in northern NSW and QLD, are assumed to regrow at the same rate they were growing prior to harvest. That is, there is no modelled thinning growth response effect for the forest in the estate method. The estate method is silent about whether selection harvesting results in any ‘age re-setting’ of the forest in lieu of a thinning growth response, which would affect modelled

CAI. The implication of not modelling a thinning growth response is examined below. Carbon in harvested wood products is not reported in the Forest Land Remaining Forest Land category, which only accounts for carbon on the forest land. Carbon stocks in wood products are transferred to harvested wood products pool described in Section 0.

If the estate method for accounting for harvesting does not reset age, it will model carbon stocks in a sustainably managed selectively harvested forest as permanently decreasing over time. This is illustrated in Figure for the most common commercial forest type in QLD and NSW, the Eucalyptus open forest (Figure A.1), with an inventory forest class of medium dense eucalypt forest. In QLD, where there is no native forest pulpwood market, selectively harvested medium dense eucalypt forest is assumed by the estate method to remove 40% of the above ground biomass. Three selection harvesting scenarios are considered in Figure :

A. Harvest at age 50 and then every 40 years thereafter and the age is not reset;

B. Harvest at age 100 and then every 40 years thereafter and the age is not reset; and

C. Harvest at age 50 and then every 40 years thereafter and the age is reset.

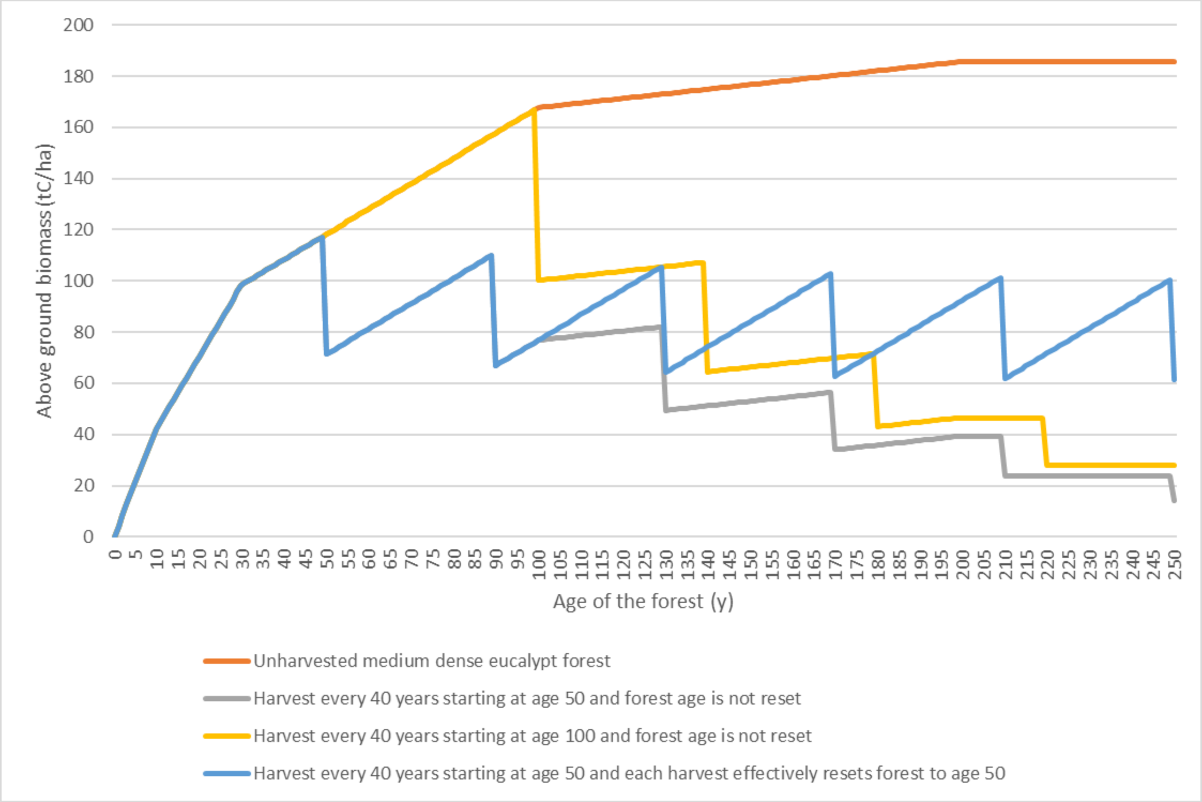

Figure A.4. Estate method accounting for above ground biomass in selectively harvested medium dense eucalypt forest in Queensland

In scenarios A and B, the carbon stocks decline over time (grey and yellow lines, respectively). This is because after year 100, carbon CAI is only 0.18 tC/ha/y, and then it drops to zero when age exceeds 200 years. These carbon sequestration rates cannot recover the 40% of biomass harvested before the next harvest in 40 years. In contrast, with scenario C the selection harvest is modelled to reset forest age to 50 years. The relatively high CAI (0.99 tC/ha/y; Figure 6) can recover the biomass removed by the selection harvest before the next harvest.

Note that while existing versions of FullCAM fail to account for this forest thinning growth response, it is intended to be incorporated into future updates, and is included within the 2023 Public Release Beta Version.

A.3 Estimating changes in debris and soil carbon

The annual change in DOM in harvested native forests is the net result of additions from harvest residue and turnover, and losses due to decay and turnover into soils. Losses are caused by decomposition of both natural accumulation and harvest residue, and burning of residues as part of some silvicultural systems. Soil carbon is estimated using FullCAM operating in estate mode with a national soil carbon map (Annex 5.6.5) as the base input data. FullCAM simulates changes in soil carbon using the Roth-C soil carbon model. The Roth-C model computes turnover of organic carbon in soils, taking into account clay content, temperature, moisture content, plant material inputs and plant cover.

Appendix B. Australia's Approach to the Disaggregation of Interannual Variability due to Natural Disturbance Fires

B.1 Overview

Fire is the major cause of natural disturbance of Australia's terrestrial carbon stocks (Australian Government, 2023a). Most native landscapes are highly adapted to fire and while the frequency and intensity of fire regimes vary greatly across the country, modelling for the National GHG Inventory groups them into two major zones:

1. **The savanna fire zone**: This area is comprised of the Northern Territory and the northern regions of Queensland and Western Australia. Fire within this zone is a frequent occurrence within wet/dry tropical, subtropical and semi-arid forests and grasslands. Notably, the seasonality of burning has a large impact on the fire characteristics, with late dry season fires being larger and more intense than those occurring in the early dry season.
2. **The temperate fire zone**: This area covers much of New South Wales, Victoria, the Australian Capital Territory, South Australia, Tasmania and the southern regions of Queensland and Western Australia. Fire in temperate forests is less frequent but more intense than savannah fires. Despite extreme fire events occurring in these areas in some years, they generally do not result in stand replacement, with eucalypts recovering lost biomass quickly, especially after lower intensity fires.

The major fire zones and reoccurrence frequency of fire events across the country since 1988 is depicted in Figure .

B.2 Disaggregation of Emissions and Removals from Natural Disturbances as a Result of Wildfire in Temperate Forests

Australia has developed its own methodology to identify and quantify the changes in carbon stocks associated with natural disturbances from wildfire on managed lands. In Australia, all lands are considered managed lands. The five key steps associated with this approach are outlined below.

B.2.1 Define what constitutes a natural disturbance and clarify what natural disturbances are identified within the inventory.

In line with the rationale of the MLP, all terrestrial GHG emissions and removals are reported within the National Inventory. To disaggregate changes in carbon stocks that occur from human activities, Australia has defined emissions and removals from 'natural disturbances' as originating from fires which have the following characteristics:

> *"Natural disturbance fires are considered to be caused by non-anthropogenic events and circumstances beyond the control of, and not materially influenced by, Australian authorities and occur despite costly and on-going efforts across regional and national government agencies and emergency services organisations to prevent, manage and*

> *control natural disturbances to the extent practicable. These fires are considered to be part of the 'natural background' of non-anthropogenic emissions and removals, which under the Managed Land Proxy are understood to average out over time and space."(Australian Government, 2023a, p. 297)*.

According to this definition, the distinguishing characteristic of a natural disturbance fire is that their occurrence is beyond the ability of Australian authorities to prevent, manage and control. This has been used to describe extreme wildfire events that occur exclusively within the temperate fire zone in forests classified within the 'Land Remaining Forest Land' category. Therefore, all savanna fires, prescribed burns and fires occurring on areas classed as 'Land Converted to Forest Land' are considered to be anthropogenic and cannot be designated as a natural disturbance (Australian Government, 2023a).

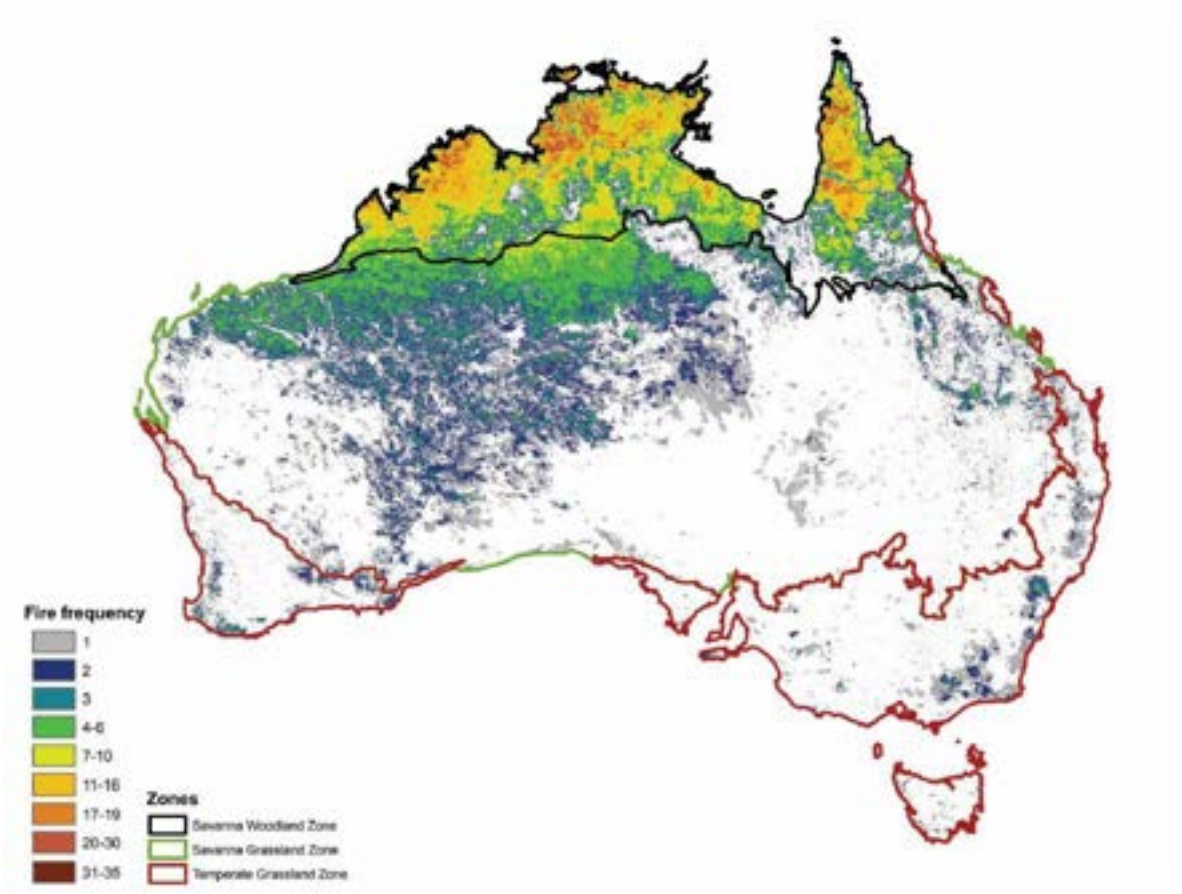

Figure B.1. Forest and grassland wildfire frequency, 1988–2021 (Australian Government, 2023a)

B.2.2 Quantify the inter-annual variability of all wildfires.

The total emissions and removals across all managed lands for a given year are first estimated. This is the first order approximation of carbon flux associated with human influences consistent with the MLP (see the red box of Figure) and includes changes in carbon stocks associated with fires from both anthropogenic activities and natural disturbances.

Carbon stock changes associated with fires are identified and quantified using the spatially explicit capabilities of the FullCAM modelling system (Tier 3, Approach 3). The time and location of fires occurring across the country are first identified using a monthly series of satellite-based remote sensing data sourced from the Advanced Very High-Resolution Radiometer (AVHRR). This data is simulated at a 25 m x 25 m resolution and used to identify burnt areas through using both analytical tools[17] and visual interpretation by experienced operators (Australian Government, 2023a). Due to challenges associated with identifying burnt areas where the forest canopy remains intact, maps of the location of prescribed burns are provided directly by state and territory authorities (Australian Government, 2023a).

FullCAM will proceed to model both the initial GHG emissions and subsequent recoveries of carbon stocks associated with the fires. All fires are assumed to be ‘typical’ non-stand replacing events, with the root systems of live biomass being retained. The post-fire regrowth is determined using the biomass recovery function with live vegetation continuing to grow at equilibrium conditions of growth until pre-disturbance levels are reached to ensure completeness and balance in reporting (Australian Government, 2023a). While the level of disturbance associated with a fire is site specific, typically around 10% of initial live biomass is modelled to be lost with recovery taking between 10 to 15 years in temperate forests (Australian Government, 2023a).

Additionally, fires will irregularly burn the landscape and leave patches of vegetation intact at a finer scale than the satellite image resolution. To account for this, FullCAM will only model fire events on a proportion of pixels within the identified fire scar in accordance with a site-specific patchiness value that varies across the landscape (Australian Government, 2023a).

B.2.3 Identify and quantify emissions and removals associated with natural disturbance fires.

The carbon stock changes associated specifically with natural disturbance fires are then identified based on the characteristics defined in Step 1. This is undertaken in the two-step process outlined below and summarised in Table .

- First, on a national level, natural disturbance fires are defined as occurring in ‘outlier’ extreme fire years where outcomes at the national level were beyond the control of authorities to manage. To identify such years, the annual carbon stock change associated with fires is compared to a threshold level that is two standard

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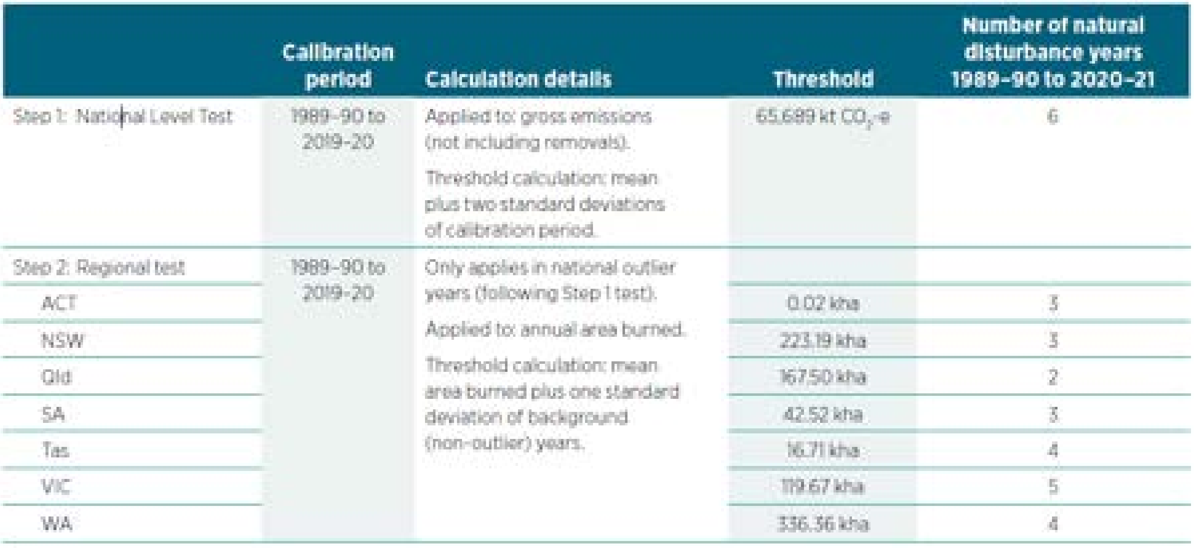
[17] The Burnt Area product produced by the Western Australian Land Authority (Landgate)

deviations above the mean of gross annual emissions from all fires after iteratively excluding outliers[18] (Australian Government, 2023a).

- Then, once an ‘extreme fire year’ has been determined at a national level, natural disturbance fires are identified and tracked spatially at a state and territory level. For fires to be classified as natural disturbances the area burned during the local fire season must exceed the state or territories own natural disturbance threshold, which is defined as the average area burned during the calibration period plus one standard deviation of the non-natural disturbance years (Australian Government, 2023a).

This natural disturbance test therefore identifies natural disturbance fires “within each state or territory for a year in which both the area burned exceeds the State or Territory natural disturbance threshold and the national emissions from total area burned exceeds the national natural disturbance threshold” (Australian Government, 2023a, p. 299)

Table B.1. Calculations for the natural disturbance test in States and Territories, 1989–90 to 2020–21 (Australian Government, 2023a)



	Calibration period	Calculation details	Threshold	Number of natural disturbance years 1989–90 to 2020–21
Step 1: National Level Test	1989–90 to 2019–20	Applied to: gross emissions (not including removals). Threshold calculation: mean plus two standard deviations of calibration period.	65,689 kt CO_2-e	6
Step 2: Regional test	1989–90 to 2019–20	Only applies in national outlier years (following Step 1 test). Applied to: annual area burned. Threshold calculation: mean area burned plus one standard deviation of background (non-outlier) years.		
ACT			0.02 kha	3
NSW			223.19 kha	3
Qld			167.50 kha	2
SA			42.52 kha	3
Tas			16.71 kha	4
VIC			119.67 kha	5
WA			336.36 kha	4

Modelling is also undertaken on areas affected by natural disturbance fires to ensure that the initial GHG emissions and ongoing removals from regrowth will average out over time, in line with the IPCC’s MLP methodology.

B.2.4 Disaggregate emissions and removals due to natural disturbances and identify the trend in emissions and removals associated with human activity.

Once the annual emissions associated with natural disturbance fires have been identified, they are then subtracted from the total estimate of the MLP emissions and removals. This thereby generates an estimate of the total carbon stock change associated with human

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[18] This ‘national natural disturbance threshold’ is based on a calibration period of 1989–90 to 2019–20 Australian Government. (2023a). *National Inventory Report 2021*.

activity within the LULUCF sector. The subsequent GHG removals from regeneration in the years following the natural disturbance will also be disaggregated within the MLP until balance is achieved.

Annual values for both anthropogenic activity and natural disturbances are then reported within Australia's National Inventory. However, while this process will disaggregate the majority of emissions and removals associated with natural disturbances, the IPCC recognises that the remaining carbon stock exchange attributed to human activities "might still include some effects of IAV of natural disturbances and other natural effects" (IPCC, 2019c). To account for any remaining IAV from natural disturbances, the carbon flux associated with human activities is reported after averaging out initial carbon stock losses and subsequent recoveries. In doing so the long-run trend in carbon stocks changes associated with human activity can be discerned (Australian Government, 2023a).

Figure B.2 illustrates the total interannual variability in emissions and subsequent regrowth following wildfires from 1989-90 to 2019-20 with the dark green bars. Future carbon sequestration due to regrowth following the 2019-20 wildfires are illustrated as light green bars. The red line is long-run average carbon emissions and removals associated with anthropogenic fires after applying the natural disturbance provision. In the context of Figure 3.7, this red line represents the emissions and removals in the red box, minus the emissions and removals from the green box.

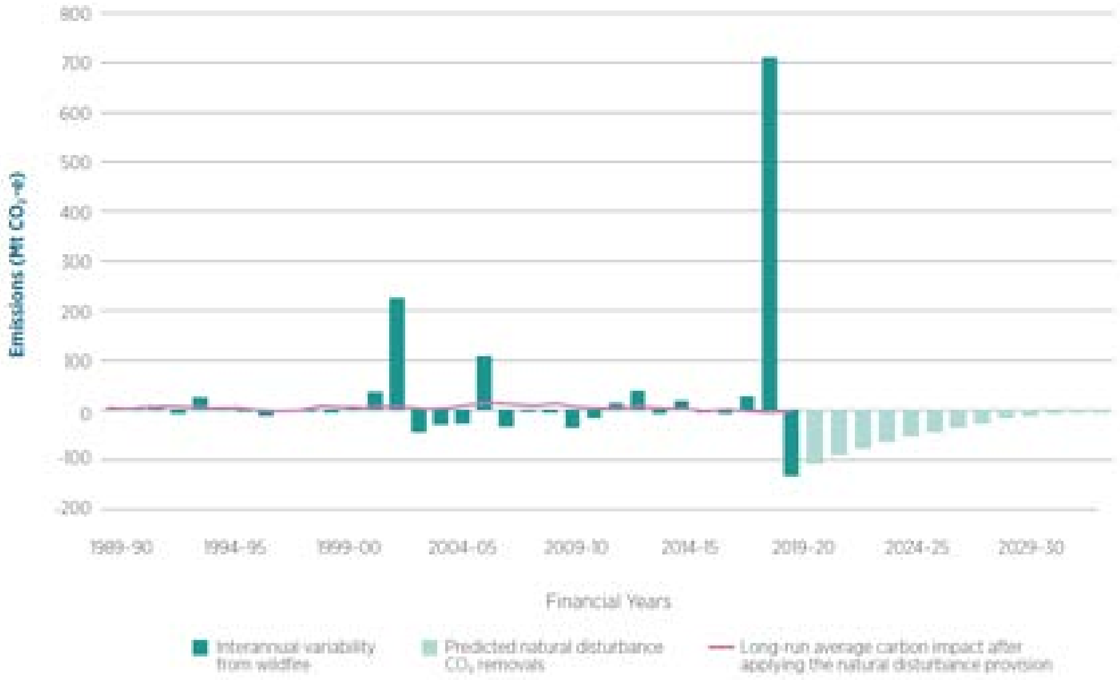

Figure B.2. Interannual variability from wildfire, including 'background' emissions and removals (Australian Government, 2023a)

B.2.5 Monitor forest recovery and land-use change.

FullCAM will then spatially track areas affected by natural disturbance fires to monitor and assess ongoing forest recovery. In areas where permanent land use change has been identified following the fire, emissions and the subsequent removals are considered to be anthropogenic. Additionally, if salvage harvesting is identified as occurring in areas following a natural disturbance, then its associated emissions are also considered anthropogenic.

Appendix C. Complete FullCAM Simulation Results for Each Hub Region.

C.1 Spotted gum forest – Southern and Central Qld Forestry Hub region

During Phase 1, carbon stocks had reached a relative steady state, with vegetation approaching the maximum biomass that could be supported on each site. At this point, the total site carbon stocks averaged across all sites is 112 tC/ha, 72% of which is stored in trees, while debris and grasses store the remaining 23% and 5% respectively (Figure C1). The site's carbon stocks drop dramatically following clearing and active management for low intensity grazing during Phase 2. Over this period the total carbon stocks fluctuated between around 39 tC/ha and 14 tC/ha on either side of each clearing event, thereby never exceeding more than 35% of that achieved by the undisturbed forest initially covering each site (Figure C1). During this period, the crop and debris pools remain relatively stable with the removal and regeneration of trees being the primary driver in carbon stock fluctuations.

Scenario 1 – Business as usual cyclical regrowth and re-clearing of native vegetation:

With Scenario 1 being a continuation of the Phase 2 management regime, carbon stocks followed the same trends over the entire study period (Figure C1). As there is no variation in management activities over this time, the long-term average carbon stocks over both 100- and 200-year periods were essentially the same at 22.2 and 22.1 tC/ha respectively, approximately 20% of the site's initial forest carbon stocks.

Scenario 2 – Native regrowth managed for selection timber harvesting regime:

When the sites shift to a selection timber harvesting regime, the initial 40-year regeneration period allowed the tree carbon stocks to recover to 46 tC/ha prior to the first harvest. The harvest event led to a 30% reduction in carbon stocks within the tree pool (reduced to 32 tC/ha), which is in line with the proportion of stems thinned from the forest. Regeneration occurring within the first 20-year return interval then allowed the tree pool to reach 50 tC/ha before the second harvest reduced stocks to 35 tC/ha. Tree carbon stocks then fluctuated between these values for each subsequent harvest cycle, indicating that a sustainable yield was being maintained for each site (Figure C1).

With only the stems removed from site to produce HWPs, the remaining harvest residues contributed to a temporary increase in the debris pool to 18 tC/ha. However, the application of a top disposal burn removed a proportion of these residues and returned the debris pool to close to its pre-thinning level, with carbon stocks generally maintained at around 15 tC/ha. The crop pool (pasture biomass) was unaffected by the harvesting event and remained stable at 6 tC/ha over the study period.

Scenario 3 – Maintaining pastures for intensive grazing:

With all tree growth suppressed from the commencement of this scenario, each site's carbon stocks are limited to the crops and debris pools. These remained stable over the study period at 6 tC/ha and 5 tC/ha respectively. The total scenario carbon stock of the site was therefore 11 tC/ha, less than 10% of the carbon sequestered by the undisturbed forest initially covering the site (Figure C1).

Scenario 4 – Native regrowth preserved for strict conservation:

Under the strict conservation scenario, native regrowth regenerates unabated over the study period reaching 102 tC/ha after 200 years, 91% of the carbon stored in the initially undisturbed forest (Figure C1). The proportions of carbon stored in the tree, debris and crop pools also replicated the initial forest structure.

Figure C1. Year-on-year carbon stock of each pool for all scenarios, averaged across all sites. The 100-year and 200-year long term average carbon stock is also depicted for Scenarios 1 and 2.

C.2 Ironbark woodland – Northern Qld Forestry Hub region

During Phase 1, carbon stocks had reached a relative steady state, with vegetation approaching the maximum biomass that could be supported on each site. At this point, the total site carbon stocks averaged across all sites was 68.7 tC/ha, 56% of which was stored in trees, while debris and pasture grasses stored the remaining 31% and 14%, respectively (Figure C2). The site's carbon stocks drop dramatically once the site was cleared and actively managed for low intensity grazing during Phase 2. Over this period the total carbon stocks fluctuated between around 19.8 tC/ha and 32.3 tC/ha on either side of each clearing event, thereby never exceeding more than 47% of that achieved by the undisturbed forest initially covering each site (Figure C2). During this period, the crop and debris pools remain relatively stable with the removal and regeneration of trees being the primary driver in carbon stock fluctuations.

Scenario 1 – Business as usual cyclical regrowth and re-clearing of native vegetation:

With Scenario 1 being a continuation of the Phase 2 management regime, carbon stocks followed the same trends over the entire study period (Figure C2). As there is no variation in management activities over this time, the long-term average carbon stocks over both 100- and 200-year periods were essentially the same at 24.8 tC/ha, approximately 36% of the site's initial forest carbon stock.

Scenario 2 – Native regrowth managed for selection timber harvesting regime:

When the sites shift to a selection timber harvesting regime, the initial 40-year regeneration period allowed the tree carbon stocks to recover to 21.2 tC/ha prior to the first harvest. The harvest event led to a 29% reduction in carbon stocks within the tree pool (reduced to 15.0 tC/ha), which is in line with the proportion of stems thinned from the forest. Regeneration occurring within the first 20-year return interval then allowed the tree pool to reach 22.7 tC/ha before the second harvest reduced stocks to 15.9 tC/ha. Tree carbon stocks then fluctuated around these values for each subsequent harvest cycle, indicating that a sustainable yield was being maintained for each site (Figure C2).

With only the stems removed from site to produce HWPs, the remaining harvest residues contributed to a temporary increase in the debris pool to 17.2 tC/ha. However, the application of a top disposal burn removed a proportion of these residues and returned the debris pool to close to its pre-thinning level, with carbon stocks generally maintained at around 15.8 tC/ha. The crop pool (pasture biomass) was unaffected by the harvesting events and remained at 9.6 tC/ha over the study period.

Scenario 3 – Maintaining pastures for intensive grazing:

With all tree growth suppressed from the commencement of this scenario, each site's carbon stocks were limited to the pasture and debris pools. These remain stable over the study period at 9.6 tC/ha and 8.9 tC/ha respectively. The total scenario carbon stock of the site is therefore 18.5 tC/ha, less than 27% of the carbon sequestered by the undisturbed forest initially covering the site (Figure C2).

Scenario 4 – Native regrowth preserved for strict conservation:

Under the strict conservation scenario, native regrowth regenerates unabated over the study period reaching 64.3 tC/ha after 200 years, 93.6% of the carbon stored in the initially undisturbed forest (Figure C2). The proportions of carbon stored in the tree, debris and crop pools also replicated the initial forest structure.

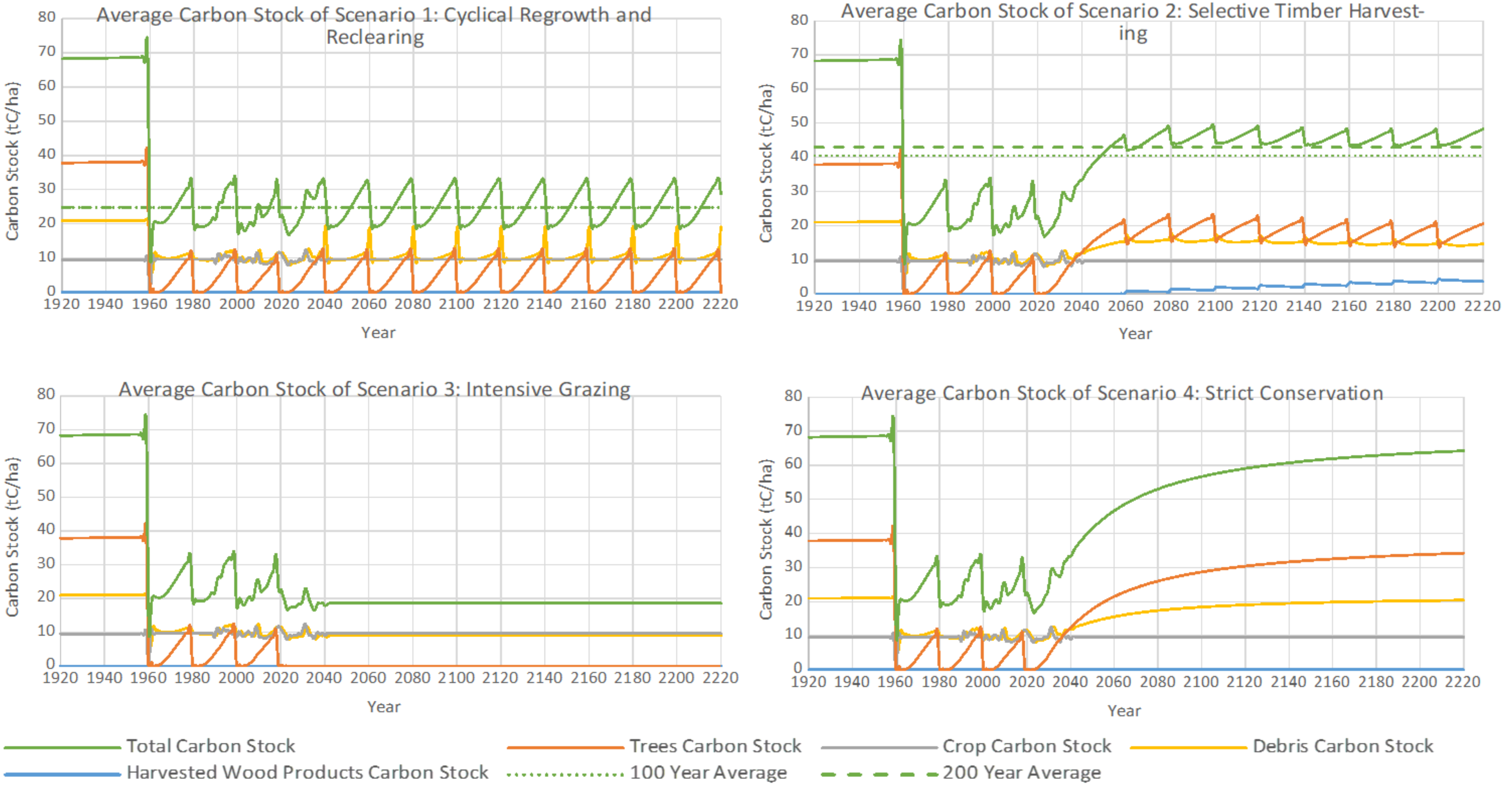

Figure C2. Year-on-year carbon stock of each pool for all scenarios, averaged across all sites in the Northern Queensland Hub region. The 100-year and 200-year long term average carbon stock is also depicted for Scenarios 1 and 2.

C.3 Coastal dry eucalypt forest – NE NSW Forestry Hub region

During Phase 1, carbon stocks had reached a relative steady state, with vegetation approaching the maximum biomass that could be supported on each site. At this point, the total site carbon stocks averaged across all sites was 143.1 tC/ha, 66% of which was stored in trees, while debris and pasture grasses stored the remaining 25% and 9%, respectively (Figure C3). The site's carbon stocks dropped dramatically once the site was cleared and actively managed for low intensity grazing during Phase 2. Over this period the total carbon stocks fluctuated between around 26.5tC/ha and 56.4 tC/ha on either side of each clearing event, thereby never exceeding more than 39% of that achieved by the undisturbed forest initially covering each site (Figure C3). During this period, the crop and debris pools remained relatively stable with the removal and regeneration of trees being the primary driver in carbon stock fluctuations.

Scenario 1 – Business as usual cyclical regrowth and re-clearing of native vegetation:

In this scenario carbon stocks followed the same trends as in Phase 2 over the entire study period (Figure C3). As there was no variation in management activities over this time, the long-term average carbon stocks over both 100- and 200-year periods were essentially the same at 38.7 and 38.8 tC/ha respectively, approximately 27% of the site's initial forest carbon stocks.

Scenario 2 – Native regrowth managed for selection timber harvesting regime:

When the sites shift to a selection timber harvesting regime, the initial 40-year regeneration period allowed the tree carbon stocks to recover to 54.4 tC/ha prior to the first harvest. The harvest event led to a 30% reduction in carbon stocks within the tree pool (reduced to 38.3 tC/ha), which is in line with the proportion of stems thinned from the forest. Regeneration occurring within the first 20-year return interval then allowed the tree pool to reach 59.2 tC/ha before the second harvest reduced stocks to 41.2 tC/ha (Figure C3). Tree carbon stocks then fluctuate around these values for each subsequent harvest cycle, indicating that a sustainable yield was being maintained for each site.

With only the stems removed from site to produce HWPs, the remaining harvest residues contributed to a temporary increase in the debris pool to 25.9 tC/ha. However, the application of a top disposal burn removed a proportion of these residues and returned the debris pool to close to its pre-thinning level, with carbon stocks generally maintained at around 23 tC/ha. The crop pool (pasture biomass) was unaffected by the harvesting events and remained stable at 12.4 tC/ha over the study period.

Scenario 3 – Maintaining pastures for intensive grazing:

With all tree growth suppressed from the commencement of this scenario, each site's carbon stocks were limited to the pasture and debris pools. These remain stable over the study period at 12.4 tC/ha and 11.0 tC/ha respectively. The total scenario carbon stock of the site is therefore 23.4 tC/ha, which is only 16% of the carbon sequestered by the undisturbed forest initially covering the site (Figure C3).

Scenario 4 – Native regrowth preserved for strict conservation:

Under the strict conservation scenario, native regrowth regenerates unabated over the study period reaching 131.1 tC/ha after 200 years, 92% of the carbon stored in the initially undisturbed forest (Figure C3). The proportions of carbon stored in the tree, debris and crop pools also replicated the initial forest structure.

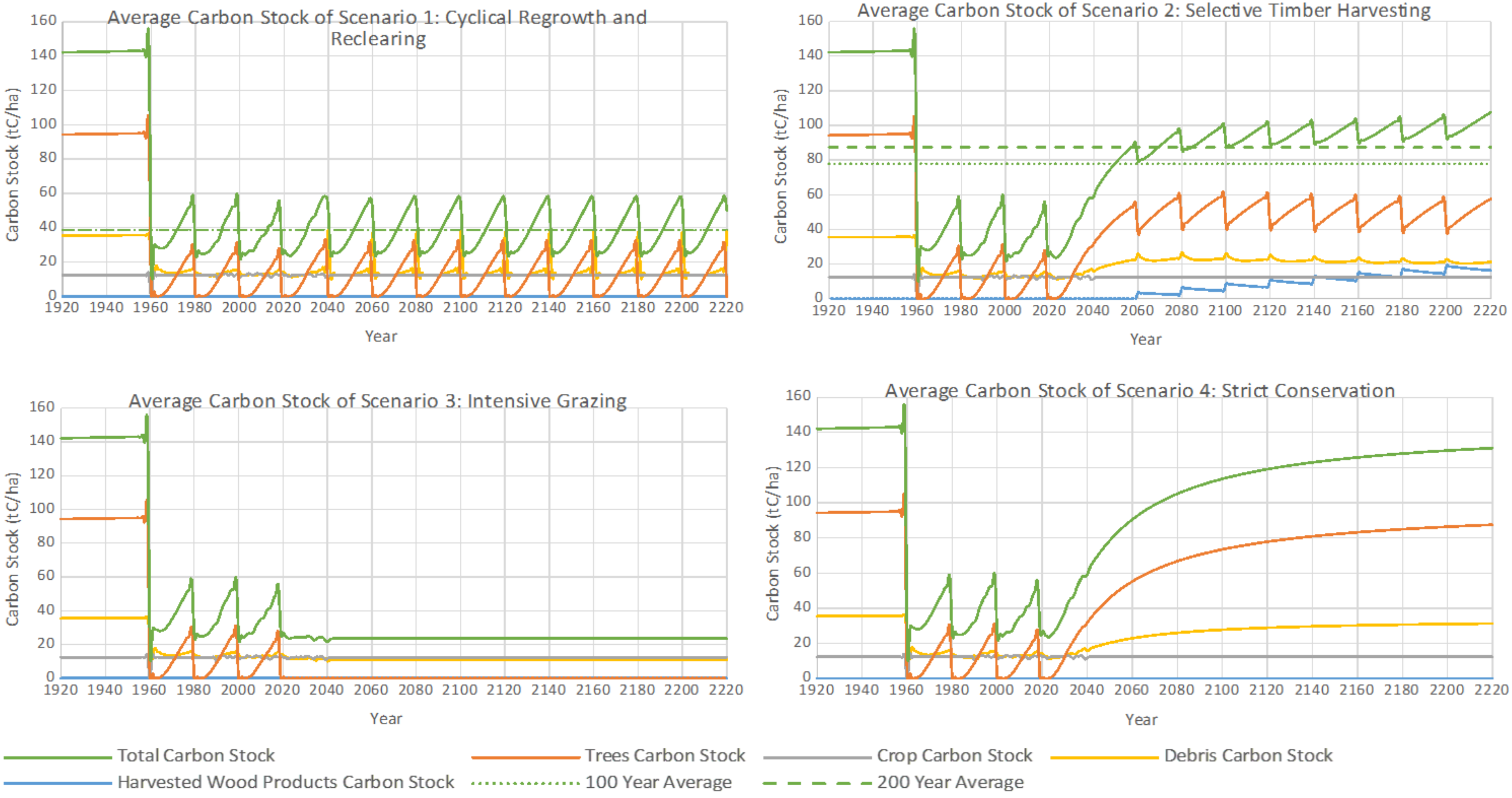

Figure C3. Year-on-year carbon stock of each pool for all scenarios, averaged across all sites in the North East NSW Hub region. The 100-year and 200-year long term average carbon stock is also depicted for Scenarios 1 and 2.

C.4 Coastal dry eucalypt forest – SE NSW Forestry Hub region

During Phase 1 of the modelling, carbon stocks had reached a relative steady state, with vegetation approaching the maximum biomass that could be supported on each site. At this point, the total site carbon stocks averaged across all sites was 213 tC/ha, 72% of which was stored in trees, while debris and pasture grasses stored the remaining 23% and 5%, respectively (Figure C4). The site's carbon stocks dropped dramatically once the site was cleared and actively managed for low intensity grazing during Phase 2. Over this period the total carbon stocks fluctuated between around 25.1 tC/ha and 73.6 tC/ha on either side of each clearing event, thereby never exceeding more than 35% of that achieved by the undisturbed forest initially covering each site (Figure C4). During this period, the pasture and debris pools remained relatively stable with the removal and regeneration of trees being the primary driver in carbon stock fluctuations.

Scenario 1 – Business as usual cyclical regrowth and re-clearing of native vegetation:

In this scenario carbon stocks followed the same trends as in Phase 2 over the entire study period (Figure C4). As there was no variation in management activities over this time, the long-term average carbon stocks over both 100- and 200-year periods were essentially the same at 44.6 and 44.8 tC/ha respectively, approximately 21% of the site's initial total carbon stock.

Scenario 2 – Native regrowth managed for selection timber harvesting regime:

When the sites shift to a selection timber harvesting regime, the initial 40-year regeneration period allowed the tree carbon stocks to recover to 88.0 tC/ha prior to the first harvest. The harvest event led to a 30% reduction in carbon stocks within the tree pool (reduced to 62.0 tC/ha), which is in line with the proportion of stems thinned from the forest. Regeneration occurring within the first 20-year return interval then allowed the tree pool to reach 95.9 tC/ha before the second harvest reduced stocks to 66.8 tC/ha (Figure C4). Tree carbon stocks then fluctuated around these values for each subsequent harvest cycle, indicating that a sustainable yield was being maintained for each site.

Scenario 3 – Maintaining pastures for intensive grazing:

With all tree growth suppressed from the commencement of this scenario, each site's carbon stocks were limited to the pasture and debris pools. These remained stable over the study period at 10.5 tC/ha and 9.5 tC/ha respectively. The total scenario carbon stock of the site was therefore 20.0 tC/ha, which is only 9% of the carbon sequestered by the undisturbed forest initially covering the site (Figure C4).

Scenario 4 – Native regrowth preserved for strict conservation:

Under the strict conservation scenario, native regrowth regenerates unabated over the study period reaching 194.5 tC/ha after 200 years, 91% of the carbon stored in the initially undisturbed forest (Figure C4). The proportions of carbon stored in the tree, debris and crop pools also replicated the initial forest structure.

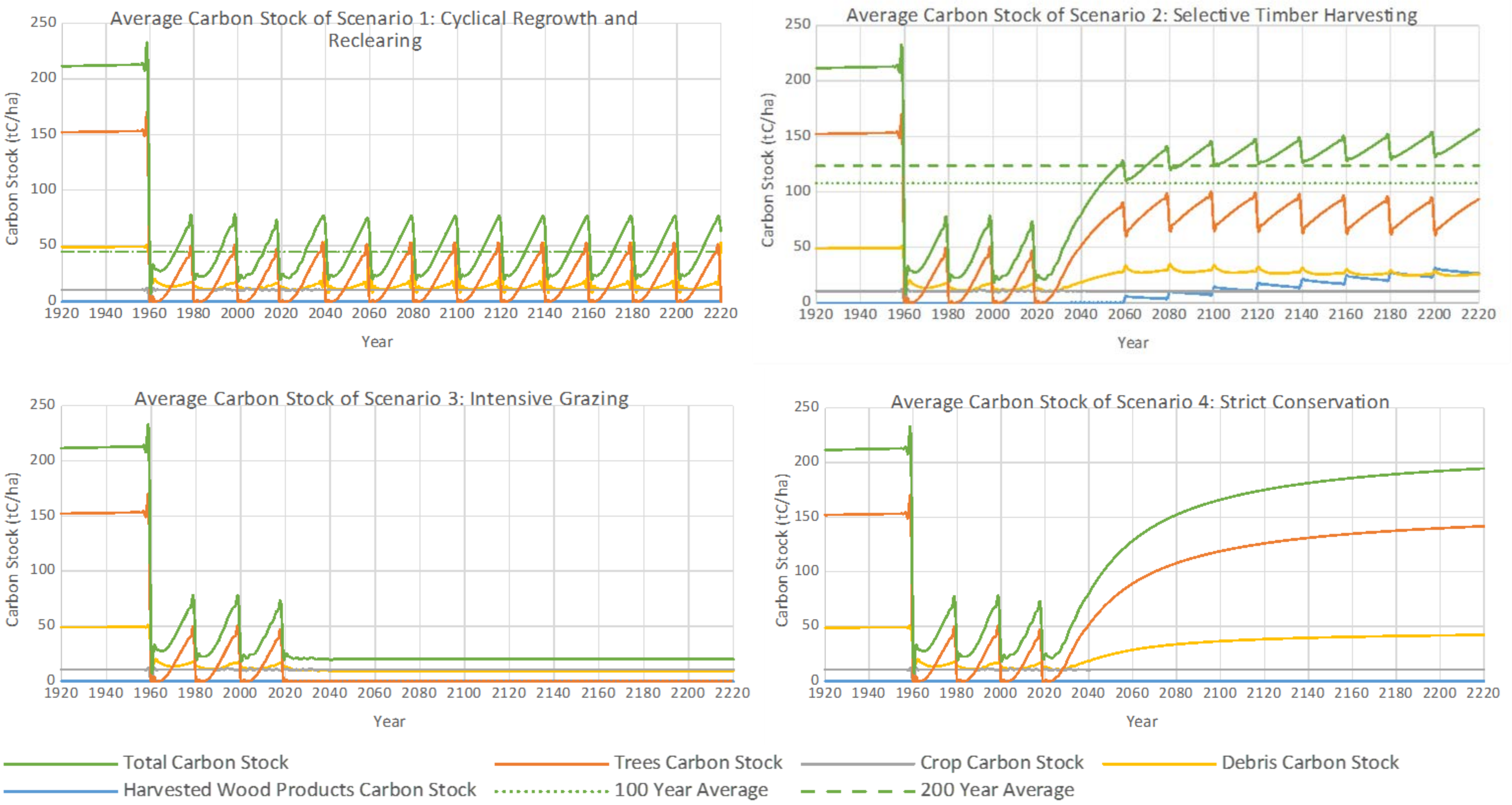

Figure C4. Year-on-year carbon stock of each pool for all scenarios, averaged across all sites in the South East NSW Hub region. The 100-year and 200-year long term average carbon stock is also depicted for Scenarios 1 and 2.

C.5 Variation among sites and Hub regions

Table C1 shows the total carbon stock of each site at year 2220, as well as average and standard deviation for each Hub region. This shows that there was significant variation among sites, both within a Hub region and among the different Hub regions. Site carbon stocks were generally lowest in the woodland ecosystems of the Northern Queensland Forestry Hub region and were highest in the SE NSW Hub region (Table C1). The degree of variation among sites was most pronounced for Scenario 4 (highest standard deviation), while Scenario 3 showed a low degree of variation among site carbon stocks. This indicated that the variation among sites was driven primarily by differences in the tree carbon pool, with the standard deviation of each scenario increasing as the relative contribution of the tree pool to the total carbon stocks increased. This can be explained by variation in each site’s maximum above-ground biomass (M), which is used as a proxy for site productivity by FullCAM, and is the key location-specific factor that influences tree growth. For scenarios that feature tree cover (scenarios 1, 2 and 4), carbon stock variation among sites aligned with the relative size of M (Table C1).

Table C1. The total carbon stocks of each site at year 2220 for each scenario. The average and standard deviation of carbon stocks for each scenario is also provided to depict the degree of variation among sites in a given hub region. Each site's maximum aboveground tree biomass (M) is also provided for reference.

Hub region / Site ID	1 – Business as usual	2 – Timber harvesting	3 – Livestock grazing	4 – Conservation	M (tdm/ha)
Southern and Central Qld					
Rathdowney	73.3	170.5	11.1	215	280.3
Gundiah	22.7	40.6	11.1	48.8	51.6
Gayndah	30.3	56.6	11.1	69.2	80.2
Gin Gin	30.4	60.6	11.1	74.4	86.3
Mean (Standard deviation)	**39.1 (23.1)**	**82.1 (59.6)**	**11.1 (0)**	**101.8 (76.2)**	**124.6 (104.9)**
Northern Qld					
East 1	27	70.9	15.1	52.2	41.8
East 2	33.9	30.3	29.2	67.9	66.1
West 1	22.4	53	14.8	38.5	26.4
West 2	49.7	39.2	29.2	92.9	71.6
Mean (Standard deviation)	**33.2 (11.9)**	**48.3 (17.7)**	**18.5 (7.1)**	**64.3 (23.9)**	**51.5 (21.2)**
NE NSW					
1	50.6	87.4	24.2	105.1	111.4
2	47.2	80.3	23.8	96.1	97.6
3	64.5	124.9	21.5	153.7	180.9
4	71.2	137.9	24.2	169.6	196.7
Mean (Standard deviation)	**58.4 (11.3)**	**107.6 (28.1)**	**23.4 (1.3)**	**131.1 (36.0)**	**146 (49.4)**
SE NSW					
5	94	198	19.1	247.8	312.2
6	78.9	161.8	20.1	201.2	245.2
7	87.3	182.2	20.1	227.5	279.6
8	47.1	84	20.9	101.6	109.2
Mean (Standard deviation)	**76.8 (20.8)**	**156.5 (50.6)**	**20.1 (0.8)**	**194.5 (64.8)**	**236.5 (89.2)**

Appendix D. Modelling Fire in Native Regrowth Forests