Evaluation of the financial performance of existing hardwood plantations in north east New South Wales

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Disclaimer

Executive summary

Background

In recent decades, large areas of state owned native forests have been transferred from wood production to conservation uses. This has been largely motivated, directly, or indirectly, by the development of Regional Forest Agreements (RFA's) This decreased access to public native forests for harvesting prompted the establishment of large areas of hardwood plantations (Clark, 2004).

Unfortunately, in many regions, including the north east of New South Wales, plantations were established prior to the formation of silvicultural guidelines (Smith and Brennan, 2006), without the robust stakeholder engagement (Leys and Vanclay, 2011; Loxton, 2012) and lacking an established or proven market. This has led to poor plantation management, poor relationships with rural communities (Leys and Vanclay, 2011) in turn leading to poor uptake of the investment and weak justification for the investment.

For timber production to become part of the local rural economy in the north east region of NSW the establishment of a plantation estate will need to be economically viable.

The relatively recent establishment of the hardwood plantation estate in north east NSW means that data availability is relatively scarce in terms of regional coverage of species, geographical location, management practices and biometrics. As the plantations established in the mid 1990s and early 2000s are close to mid rotation it is timely to assess the current state of the plantations and consider the mix of products that will be available in the future and their potential value.

This study aimed to assess the financial viability of existing hardwood plantations in the north east of NSW based on timber value estimated using log size and form at the current age. The study also sought to identify biophysical and management factors influencing species performance (product volume and quality).

Data

The data from 26 plantations was used to represent the spread of species, management and climatic conditions within the study area. Of particular importance was to match similar plantations that had received differing levels of silvicultural treatment. The data was sourced from private and publicly owned plantations greater than 15 years of age. The data combines field data collected specifically for the study and inventory data provided by private plantation owners and Forestry Corporation of NSW.

Modelling

Height and diameter of the measured trees were extrapolated to age 40 using Vanclay's (2010) single parameter height and diameter models. Individual models were created for each location, species and management (thinned/unthinned) combination. The model for each location, species, management combination was used to create an 'average' tree at age 40.

Log taper equations (Bi, 2000) were used to determine underbark diameter along the log for merchandising. Stand volumes were calculated by multiplying the log volume for the average tree by stand stocking to determine the volume in each log class ha^{-1}.

Current Forestry Corporation of NSW stumpage price schedules that account for both species and the geographic origin of forest products were used to calculate log prices. The individual log volumes and values by size class for each plot were summed and the figures were extrapolated based on plot size to calculate values ha^{-1}.

Average annual rainfall and Australian Soil Classification type were used to assess the effect of site on productivity for the select and key species in the data set (blackbutt, Gympie messmate and spotted gum).

Results and discussion

The results of the study reiterate information about the resource that is widely available: subtropical eucalypt plantations need to be managed to promote the growth of quality timber.

The most limiting impact on plantation value in this study was log quality, represented as the form score. Lower stem counts, either because of thinning or natural self-sorting and mortality, was positively related to both diameter at breast height and stem form. Low stem counts also affected MAI, this is thought to be due to the plantations not reaching full site capacity. The cost of silvicultural management has been seen as a hurdle to management (Stephens and Grist, 2004; Cassidy et al, 2012), however the cost of not managing is far greater. This analysis shows that the average cost of providing two thinning events and two pruning events is 0.38% of IRR. Comparatively the average cost of poor form was 4%.

The availability of two site and species combinations to assess the impacts of thinning in this study points to the lack of silviculture being practiced in the region. Comparing the returns of the thinned versus unthinned plantations of the same species in the same, or comparable region, found the impact on return to be 4.13% (Gympie messmate) and 11.25% (spotted gum). The cost of silviculture being exceeded by the returns.

Species selection is crucial to plantation value. Species nominated as 'select' and 'key' species by Forestry Corporation of NSW are the highly sort after native forest species in the region, offering the greatest return to the grower. Species selection for plantations should consider log values and marketability at the end of the rotation (Venn, 2005; Nolan et al, 2005, Smith and Brenna, 2006, Cassidy et al, 2012). Shining gum grown in the Central Tablelands region exemplifies this; the log volume and form were both high for this species, but the low market value of the timber negates further perusal of the species for plantation establishment.

Reviewing the value of hardwood logs may be necessary to support the expansion of the privately owned plantation estate in the north east of NSW. Across NSW most hardwood logs come from public land so the price is largely set by the government who is represented by the Forestry Corporation of NSW (FCNSW). FCNSW's hardwood log pricing system was originally based on a residual stumpage model that supported industry and employment however it now seeks to represent a market based price by estimating customers' 'willingness-to-pay'. One of the challenge for plantations logs is that the prices determined through the 'willingness-to-pay' model are based on native forest logs that are older and larger.

With the continued pressure on native forest harvesting in the rest of the country (Kanowski, 2017), the Australian timber market's dependence on native hardwood is becoming less reliable. This may support increased pricing of plantation grown hardwood and enable consideration of the cost of their production as proposed by Cassidy et al, 2012; Whittle et al, 2019; and Cacho et al, 2001.

Prices used in this study from Forestry Corporation NSW are less than the prices paid for logs grown on private property (J. Rankin, 2024, personal communication, 31 May). Even so, when considering the best performing species, management and region combination: thinned Gympie messmate grown in the Coastal North region (1.66% IRR), increasing the value of the logs by 200% provides a return of 5.03%, unsurprisingly three times the modelled value. Alternately, if better genetics (Henson and Smith, 2007) or silvicultural management (Smith and Brennan, 2006), was available and the time to grow the same product was reduced to 30, rather than 40 years the return to the producer would be 2.67%, 1.6 times the modelled value. The governments Support Plantation Establishment Program (DAFF, 2023) offers \$2000 ha^{-1} towards establishment cost. Factoring this potential funding to reduce upfront cost could change the rates of return above to 2.13% over 40 years or 3.38% over 30 years (1.28 and 2.04 times the modelled value respectively).

The available data did not contain enough replicates to make detailed site species matching inferences, however, some useful insights were gained. Regression analysis confirmed a significant relationship between MAI and stocking and MAI and rainfall ($p = 0.01$ and $p = 0.05$ respectively). No soil type provided an obvious disadvantage to growth for any of the three select or key species. The significant relationship between MAI and stocking suggests growth on these sites was not attributed to site productivity, rather stocking and site occupation.

Conclusion

The interactions of site, species and management on the factors that affect log value: species, size and form are intricate. The need to understand such interactions for successful plantation management supports the need for further research with a focus on high value species and the application of optimum silviculture. Intricacies of growing and management costs and returns and the effect of the current log value system requires further consideration. However, this study highlights the importance of management for log size and quality outcomes. The price returned for logs needs to account for growing costs. To provide a full account of plantation worth the exploration of the environmental values offered by plantations need to be highlighted regardless of their monetisation. Plantation growth is correlated with rain fall, and site occupation should be managed for optimum productivity. To expand the plantation estate current and potential resource owners will require clear technical advice during establishment and management and access to secure markets in the future.

1. Introduction

In recent decades, large areas of state owned native forests have been transferred from wood production to conservation uses. This has been largely motivated, directly, or indirectly, by the development of Regional Forest Agreements (RFA's) brokered between state and federal governments. These agreements aimed to secure long term forest management, providing industry access whilst protecting environmental and cultural values (Commonwealth of Australia, 1995). This decreased access to public native forests for harvesting prompted the establishment of large areas of hardwood plantations (Clark, 2004).

Unfortunately, in many regions, including the north east of New South Wales, plantations were established prior to the formation of silvicultural guidelines (Smith and Brennon, 2006), without the robust stakeholder engagement (Leys and Vanclay, 2011; Loxton, 2012) and lacking an established or proven market. This has led to poor plantation management, poor relationships with rural communities (Leys and Vanclay, 2011) in turn leading to poor uptake of the investment and weak justification for the investment.

For timber production to become part of the local rural economy in the north east region of NSW the social and environmental landscape must be successfully navigated. Regardless of environmental and social licence, the establishment of a plantation estate will still hinge on the economic viability of the venture.

Is the economics of planting trees on private property a barrier to landholders taking part in growing trees for timber production?

Plantation value is determined by the sum total of the timber and environmental services available minus the cost of establishment and management and the discount rate on capital invested (Venn, 2005; Nolan et al., 2005; Smith and Brennan 2006; Cassidy et al., 2012). Product yield, growth rate and timber quality will be determined by species choice, management and site quality (Gerrand et al., 2003; Venn 2005; Smith and Brennan, 2006). The log price depends on product quality access to the market based on haulage distance, market demand and purchaser pricing (Leskinen and Kangas, 1998).

Hardwood mills buy logs based on diameter and length; the relationship between log size and price is not always linear (Cassidy et al, 2012). Mills use specifications to determine the grade of the log, which is correlated with both size and monetary value of the log to the seller. Log value is determined by size (girth), length, form, internal defect, and species (James, 2001; Montagu et al, 2003; Palmer, 2010). The hierarchy of product values, determined by the end use, from most to least valuable is poles and girders, veneer, sawlogs, and pulp logs (James, 2001).

Environmental services provided by timber plantation include biodiversity, soil and watershed protection (O'Grady and Mitchel, 2018; Marais et al, 2019); agricultural co-benefit values (Barker at al, 2018; Fleming et al., 2019); and carbon sequestration (Monckton and Mendham, 2022; Wall, 2022).

Most costs for forestry plantations are incurred at the beginning of the venture with no return on investment until a commercial thinning event, if there is a market for the thinned product, or the end of the rotation. It is important to consider the cost of capital for the investment, the interest paid on money borrowed to set up the plantation, or interest forgone on money spent. Therefore, when considering the cost of the venture compared to the estimated benefit, the cost of interest must be included (Cassidy et al., 2012). The optimum rotation length is the age when discounted returns are maximised (Maraseni and Cockfield, 2011). It is generally accepted that a 6% return on capital is required for long term investment (Ibbotson and Chen, 2003). Previous studies (Venn, 2005; Maraseni and Cockfield, 2011; Cassidy et al., 2012) have shown that plantation return is sensitive to not only establishment and management costs but site quality and environmental factors.

The relative recent establishment of the hardwood plantation estate in north east NSW means that data availability is relatively scarce in terms of regional coverage of species, geographical location, management practices and biometrics. As the plantations established in the mid 1990s and early 2000s are close to mid rotation it is timely to assess the current state of the plantations and consider the mix of products that will be available in the future and their potential value.

This study aims to assess the viability of timber plantation establishment in the north east of NSW based on timber value estimated using log size and form. The study also seeks to identify appropriate species for different sites and optimum management in terms of product volume and quality.

2. Methods

2.1 Study area

The study location mimics the North East NSW RFA Region. The area covered by the North East NSW RFA stretches from the Queensland boarder in the north to the edge of the Sydney basin in the south. It covers close to 10 million Ha, of which about two thirds (6 314 922 ha) is privately owned land and one third (3 005 738 ha) forested public land (Dept of Agriculture Water and the Environment, ND).

2.1.1Climate

The climate of the area varies from Subtropical (warm humid summer, mild winter) in the north east to Warm Temperate from Port Macquarie south along the coast. The Climate inland along the range is mild temperate, except for Armidale Shire which has a cool temperate climate (Figure 1) (Australian Building Codes Board, 2019).

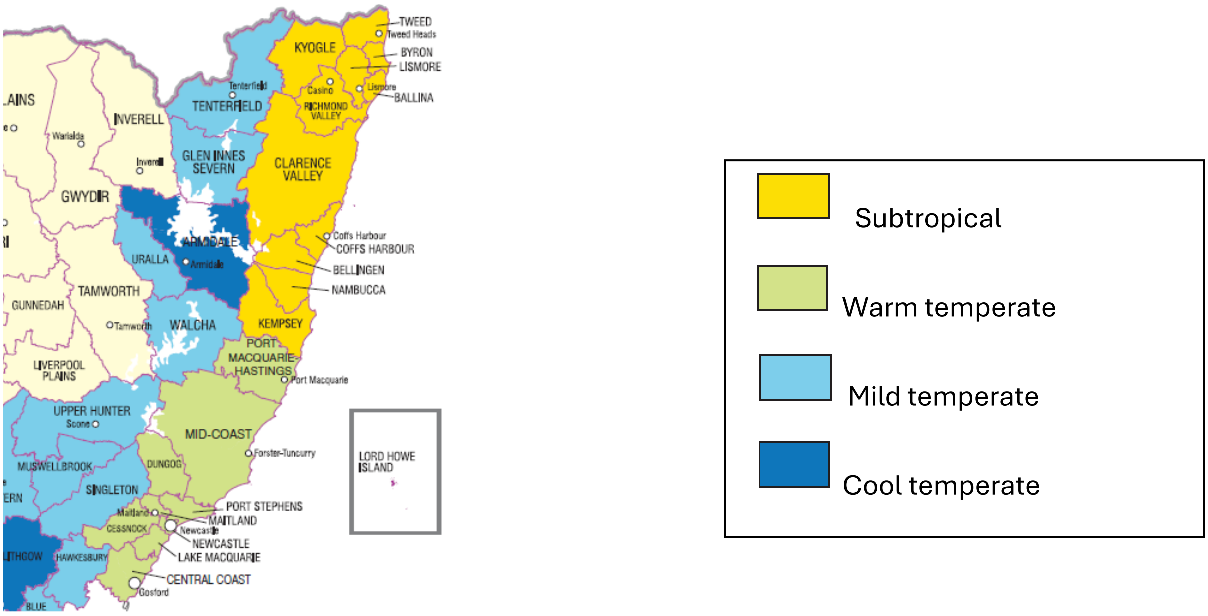


Figure 1. Climate range of the study area (Adapted from, Australian Building Codes Board, 2019).

2.2 Data

The data for the study aims to represent the spread of species, management and climatic conditions within the study area. Of particular importance was to match similar plantations that had received differing levels of silvicultural treatment. The data was sourced from private and publicly owned plantations greater than 15 years of age. The data combines field data collected specifically for the study and inventory data provided by private plantation owners and Forestry Corporation of NSW. Maps of the Forestry Corporation NSW forest regions may be seen in Appendix 1.

2.2.1 Field Measurements

Plots

Circular plots were established at each location to a density of 0.1% of the plantation area. Plot size was established to capture a minimum of 10 trees and increased in diameter until the standard deviation of the diameters at breast height (DBH) of the trees within the plot was less than 10%. Plot locations were chosen to cover the aspect, elevation and species at individual plantation sites. All plots were positioned at least 2 rows away from gaps and edges. The radius of the plot was measured using a Nikon forestry 550 laser rangefinder to an accuracy of 0.1 m.

Tree measurements

The top height and the clear bole length; defined as the height to the lowest large persistent branch that would limit the length of the merchantable log, were measured for each tree within the plot to an accuracy of 0.1m using a Nikon forestry 550 laser rangefinder. The DBH (1.3 m) was measured using a diameter tape to the nearest millimetre (Figure 2).

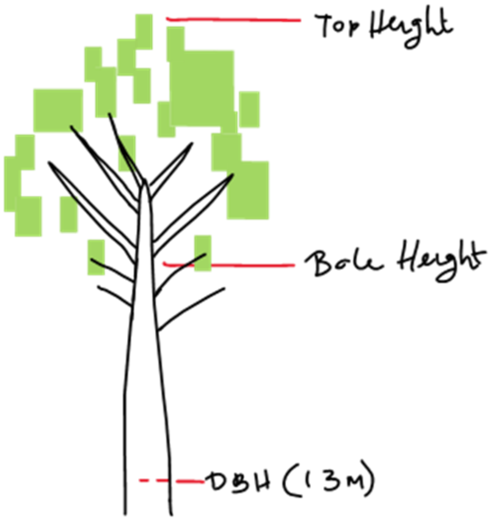


Figure 2. Representation of height and diameter measurement locations.

Each measured tree was allocated a form score, this score translates to the quality of the potential log products available at harvest (Table 1). Additional information about the tree vigour, disease, presence of double or snapped leaders and fire damage were also recorded.

2.2.2 Inventory Data

Inventory data was collected from both private and public. All plantations had data collected from an area equal to at least 0.01% of the plantation area and representative of the plantation e.g. up and down slope, differing aspects. For FC data this was achieved by matching inventory data with mapping information.

The inventory data provided by Forestry Corporation of NSW includes plot location, size, species, planting date, measure age and silvicultural history. DBH and stem merchandising with quality ratings were provided for all trees within the plots, and plot specific predominant height. The merchandising and quality ratings were used to estimate bole height and a form score between 1 and 5.

Table 1. Tree form ratings

Score	Description	Potential grade
1	Straight and clean bole. Minimum length 6 m	Pole
2	Minor bend, but clean bole	High quality large
3	Minor bend/s or branch defects that will imply cross cutting with no significant waste	High quality small
4	Multiple bends or other defect implying multiple crosscuts with some waste	Low quality
5	Malformations or defects implying no merchantable saw logs/sections	Waste

2.2.3 Report data

This report presents the data for 26 plantations and eight species commercial eucalypts. The plantations are both privately and publicly owned. The data for nine plantations was collected specifically for the project, four from privately owned plantation forest inventory and the remainder of the data was derived from the inventory data provided by Forestry Corporation of NSW

Only three plantation datasets contained known thinned and unthinned plot data, two sets of spotted gum and one set of Gympie messmate. This data is utilised for assessing the benefits of thinning. The stocking density and related size and form information for all location, species and treatment combinations are refenced in the results and discussion. Plantation locations can be seen in Appendix 2, see Table 5 for related information.

2.3 Modelling

2.3.1 Height and diameter

Height and diameter of the measured trees were extrapolated to age 40 using Vanclay's (2010) single parameter height and diameter models. Individual models were created for each location, species and management (thinned/unthinned) combination. The model for each location, species, management combination was used to create an 'average' tree at age 40.

Height

$$H = \beta_1 (t - 0.5)^{0.5}$$

H= Height
β_1= parameter to be found
t= age in years

Diameter

$$D = \beta_2 (H - 1.3)/\ln N$$

D= Diameter
β_2= parameter to be found
H= Height
t= age in years
N = Stocking

2.3.2 Merchantable log length

The measured tree height and height of the clear bole; or predominant height and merchandising assessment from the supplied inventory data, were used to determine the merchantable portion of each stem. The average merchantable portion from each set of model data, calculated as bole height/total height x 100 or, merchantable product length/predominant height x 100, was used with the modelled average height to determine the merchantable log length at age 40.

2.3.3 Log taper

Log taper equations (Bi, 2000) were used to determine under bark diameter along the log for merchandising. A generic Eucalypt species equation was used for all species except for E.pilularis and C. maculata; equations specifically derived for those species were used.

2.3.4 Log and Stand Volume

The modelled plantation average merchantable log length, diameter at breast height over bark (DBHOB) and modelled under bark taper were used to estimate stand volume. Using modelled under bark diameters the logs were merchandised for optimum financial return using current Forestry Corporation of NSW log mid diameter specifications and standard log lengths of 3, 3.6, 4.2, 4.8, 5.4 and 6m. Smalian's sectional volume equation (West, 2004) was used to determine log volume (m^3) in each log category for each location, species, management combination.

Stand volumes were calculated by multiplying the log volume for the average tree by stand stocking to determine the volume in each log class ha^{-1}. The stocking rate recorded at the time the measurements were taken were used for volume and value calculations, no thinning or mortality modelling have been used.

2.3.5 Stand value

Current Forestry Corporation of NSW stumpage price schedules that account for both species and the geographic origin of forest products were used to calculate log prices (see Appendix 3 for full schedule). The individual log volumes and values by size class for each plot were summed and the figures were extrapolated based on plot size to calculate values ha^{-1}.

The Forestry Corporation of NSW price data was used as it is accessible, consistent and set by the government. Logs sourced from private resources are often purchased at a higher price however, using this set and accessible list of figures that allows for species, size and location figures was used in an effort to limit discrepancies in the analysis.

Table 2 lists the species in this report and their respective species group. Figure 3 (below) represents the relationship between log size diameter and species group baseline pricing (Forestry Corporation of NSW, 2017).

Table 2. Species value group, common name, botanical name and code (Forestry Corporation of NSW, 2017).

Species group	**Common name**	**Botanical name**	**Code**
Select hardwoods	Gympie Messmate	*Eucalyptus cloeziana*	GMM
Key hardwoods	Blackbutt	*Eucalyptus pilularis*	BBT
	Spotted gum	*Corymbia maculata* *Corymbia citriodora*	SPG
High value hardwoods	Flooded gum	*Eucalyptus grandis*	FLG
	Silvertop stringybark	*Eucalyptus laevopinea*	STS
	Sydney blue gum	*Eucalyptus saligna*	SBG
Mixed hardwoods	Blue-leaved stringybark	*Eucalyptus agglomerata*	BLS
High country hardwoods	Shining gum	*Eucalyptus nitens*	SHG

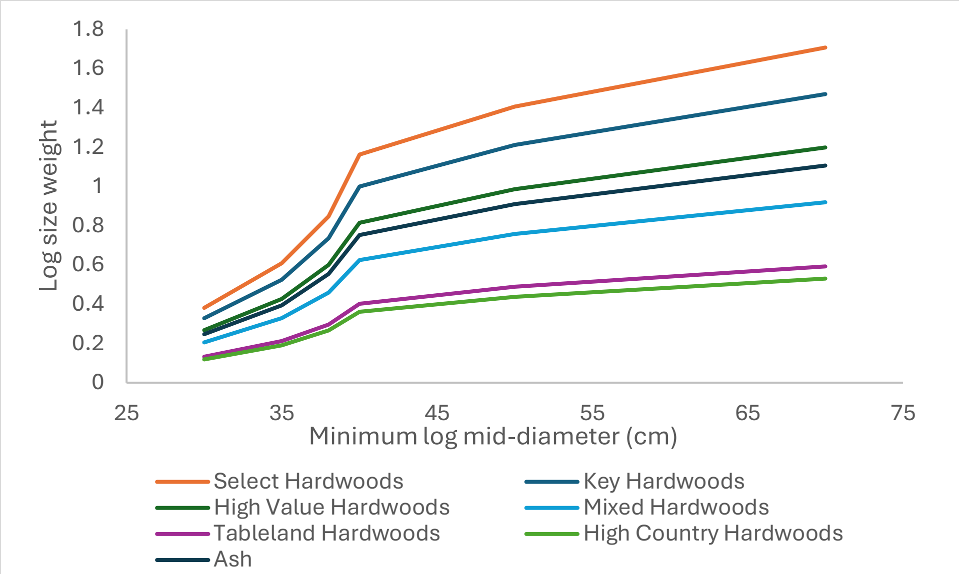


Figure 3. The relationship between minimum log mid diameter, log size weighting applied to log value and species group (Forestry Corporation of NSW, 2024).

2.3.6 Form weighting

A form weight was calculated using the values representative of native forest products classed by both size and form. The $/m^3 values used to inform the form weights were sourced from Palmer (2022). The data was collected across multiple native forest operations in the study region and averaged to provide a regional average value.

To convert the information from Palmer (2022) to a weight index, each form class was matched with the relevant product grade. To convert the dollar value to an index the dollar value for each product was divided by the dollar value for poles, returning a representation of each category as a proportion of the highest value product (Table 3).

Table 3. Product class, form score, cubic meter price and derived form weight (adapted from Palmer 2022).

Product	Form Score	Average $/m^3	Form weight
Pole	1	135.45	1.00
HQ Large[a]	2	128.01	0.95
HQ Small[b]	3	76.19	0.56
Low qual	4	24.80	0.18
Waste	5	0	0

[a] centre log diameter under bark >40cm
[b] centre log diameter under bark <40cm

The derived weight and the related form scores (1-5) were graphed and a non-linear equation, 3rd order polynomial, was fit to the data (Figure 4). The equation was used to create a form weight based on the average form score for each location, species, management combination. The values of merchandised logs ha^{-1} for each location, species, management combination was multiplied by the form weight to account for differences in plantation form quality. Accounting tree and log form in the plantation valuation aims to provide a representation of value based on log conversion and expected waste, as well as glean the value of silvicultural inputs on product availability and value.

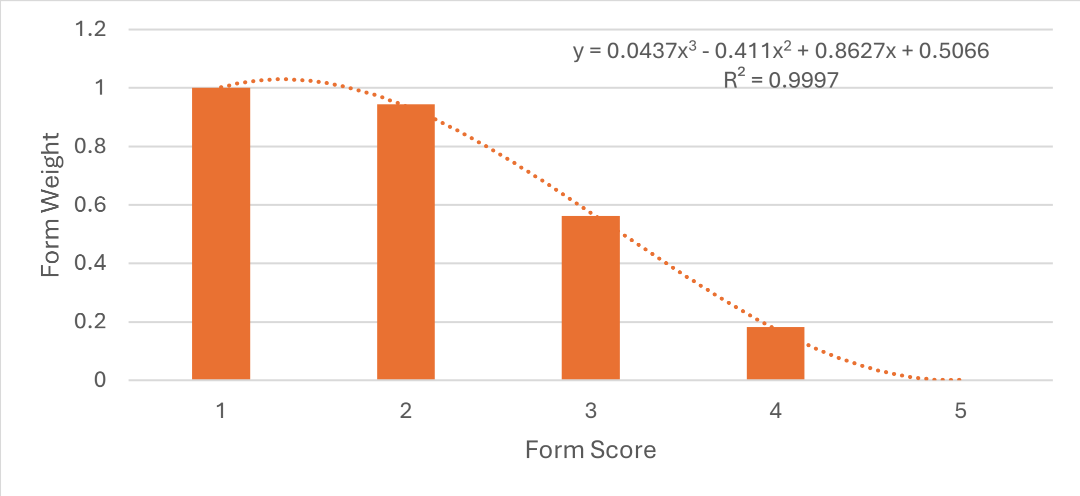


Figure 4. Non linear relationship between form weight and form score (adapted from Palmer 2022).

2.4 Financial analysis

The data available for this analysis covers a range of species, locations and management regimes sampled within the study area. Timber volumes and values were interrogated using the management variables thinning and pruning

Log values ha^{-1}, establishment and management costs were used to calculate internal rate of return (IRR) to assess the value and viability of timber production across species, locations and management combinations across the study region.

2.4.1 Establishment and management costs

Estimates of establishment and management costs were acquired from discussions with private plantation growers in the region. Costs for thinning and pruning assume generic per hectare thinning or pruning cost. Two thinning events, and two pruning events have been factored into management costs. Thinning at age 3 was costed at \$1000 ha^{-1}, a second commercial thin was assumed to be cost neutral i.e. the returns for the timber produced was equal to the cost of thinning. Pruning events were costed at \$1000 ha^{-1}. The profitability of the plantations was assessed with and without the pruning at ages 3 and 7. The list of costs and the year each cost has been applied may be seen in Table 4.

2.5 Interrogating site quality and management

Plot locations were partitioned as per Forestry Corporation of NSW's grouped price zones. Forestry Corporation of NSW price zones are aligned with site quality factors such as rainfall and climatic variations for growing different species. Plots were further analysed based on management to include presence or absence of thinning and pruning.

Plot data for each location, species, management combination were analysed to examine the trends in DBH, Clear bole length, individual log volume and volume ha^{-1}. Financial returns ha^{-1}

were analysed across species, silvicultural treatments and plot locations, to explore differences in plantation returns across the plantation estate in north east NSW. Forestry Corporation NSW grouped price zone maps are attached as Appendix 1.

Table 4. Modelled establishment and maintenance costs for private eucalypt plantations in the north east of New South Wales and year they incur.

Year	Event	Cost ha^{-1}
0	Establishment	$6100
1	Post plant weed spray	$100
2	Post plant weed spray	$100
3	Precommercial thin	$1000
3	Form prune	$1000
7	Form prune	$1000
Annual	Maintenance	$200

2.5.1 Site Species Matching

Average annual rainfall and Australian Soil Classification type were used to assess the effect of site on productivity for the select and key species in the data set (blackbutt, Gympie messmate and spotted gum).

Average annual rainfall figures were obtained using the ANUCLIM Annual Mean Rainfall raster layer (State Government of NSW and NSW Department of Climate Change, Energy, the Environment and Water, 2020).

The Australian Soil Classification (ASC) Soil Type map of NSW (Department of Planning, Industry and Environment, 2021) was used to find Australian soil classification types for each location.

Productivity was assessed using the modelled mean annual increment at age 40 (m^3) for each site. Regression analysis was preformed to assess if there was relationships between productivity rainfall.

3. Results

The results represent eight commercial eucalypts species collected from 26 plantations across 7 grouped price zones. The plantations are both privately and publicly owned. The data used in the analysis was collected specifically for the project or sourced from inventory data from private plantations and Forestry Corporation of NSW.

3.1 Height and diameter

Models for height and diameter were produced using Vanclay (2010) single parameter models for each individual species, location and treatment combination. The modelled heights and diameters at age 40 are presented in Table 5.

The average proportion of merchantable stem (bole height) measured in the field, or calculated from merchandising data for each species, location and treatment combination was applied to the corresponding modelled average tree at 40 years old (Table 5). Stocking, DBH, total height and bole height for each species and region is presented as Figure 5. The relationship between DBH, total tree height and merchantable height can be seen in Figure 6. The data shows a positive relationship between DBH and total height and DBH and bole height.

Table 5. Modelled diameter at breast height (cm), total tree height (m) and merchantable log length (m).

Region	Region code	Forest code	Species code	Stocking ha^{-1}	DBH[a] (cm)	Height (m)	Bole height (m)
Coastal North	1	1-1	GMM_T[b]	280	51.3	46.9	26.1
Coastal North	1	1-2	BBT[c]	700	37.2	36.2	13
Coastal North	1	1-7	BBT	610	35.4	37	15
Coastal North	1	1-9	BBT	530	39.5	40.9	15.9
Coastal North	1	1-8	BBT	530	45.9	45.5	12.7
Coastal North	1	1-4	SPG[d]	320	34.2	34.4	15.5
Coastal North	1	1-6	SPG	320	32.1	37.7	14.2
Coastal North	1	1-3	SPG	400	32.8	31.5	17.2
Coastal North	1	1-1	SPG_T[e]	270	42.5	36.3	12.3
Coastal North	1	1-6	SPG_T	290	37	35.7	16.1
Coastal North	1	1-5	SBG[f]	680	33.4	26.3	12.2
Coastal North	1	1-9	SBG	400	35.5	33.6	12.9
Coastal North	1	1-8	SBG	700	41.6	42	5.8
North east up river	2	2-4	GMM[g]	680	37.8	37.2	21.1
North east up river	2	2-5	GMM	500	37	37.4	13.5
North east up river	2	2-1	BBT	360	52.9	49.7	19
North east up river	2	2-3	BBT	630	42.1	43.9	18.9
North east up river	2	2-2	BBT	480	43	41	12.8
North east up river	2	2-6	SPG	340	39.8	28.8	9
North east up river	2	2-1	SBG	520	48.4	40.4	16.5
Northen Foothills	3	3-1	BBT	460	41.1	43.9	15.7
Central Foothills	4	4-4	GMM	440	48.3	33.9	14
Central Foothills	4	4-4	BBT	550	46.7	37.4	16.2
Central Foothills	4	4-4	BLS[h]	520	42.8	32.1	14.1
Central Foothills	4	4-1	STS[i]	455	39.6	34.9	19.2
Central Foothills	4	4-3	STS	160	45.7	32.8	14.7
Central Foothills	4	4-2	STS	570	33.9	29.1	14.3
Central Foothills	4	4-1	SBG	460	37.9	40.2	17.3
Central Foothills	4	4-3	SBG	290	34.6	30.6	13.3
Central Foothills	4	4-2	SBG	520	32.1	33.4	16.1
Central Tablelands	5	5-1	SHG[j]	440	55.8	41.4	26.5
Central Up River	6	6-1	BBT	570	54.7	42.7	19.8
Central Up River	6	6-2	BBT	220	59.2	42.5	23
Central Up River	6	6-3	BBT	530	37.4	37.9	9.6
Central Up River	6	6-1	FLG[k]	580	38.6	35.6	17.5
Central Up River	6	6-2	FLG	470	47	46	27.9

Region	Region code	Forest code	Species code	Stocking ha^{-1}	DBH[a] (cm)	Height (m)	Bole height (m)
Central Up River	6	6-1	BLS	730	46.5	33.3	15.9
Coastal South	7	7-1	GMM	160	46	31.6	15.5
Coastal South	7	7-2	GMM	740	35.4	37.6	13.2
Coastal South	7	7-1	BBT	280	51.4	38	19.5
Coastal South	7	7-2	BBT	630	37.9	40.2	15.6
Coastal South	7	7-1	FLG	110	54.5	45.5	23.5

[a] Diameter at breast height [b] Gympie messmate, thinned [c] Blackbutt [d] Spotted gum
[e] Spotted gum, thinned [f] Sydney blue gum [g] Gympie messmate
[h] Blue-leaved stringybark [i] Silvertop stringybark [j] Shining gum [k] Flooded gum

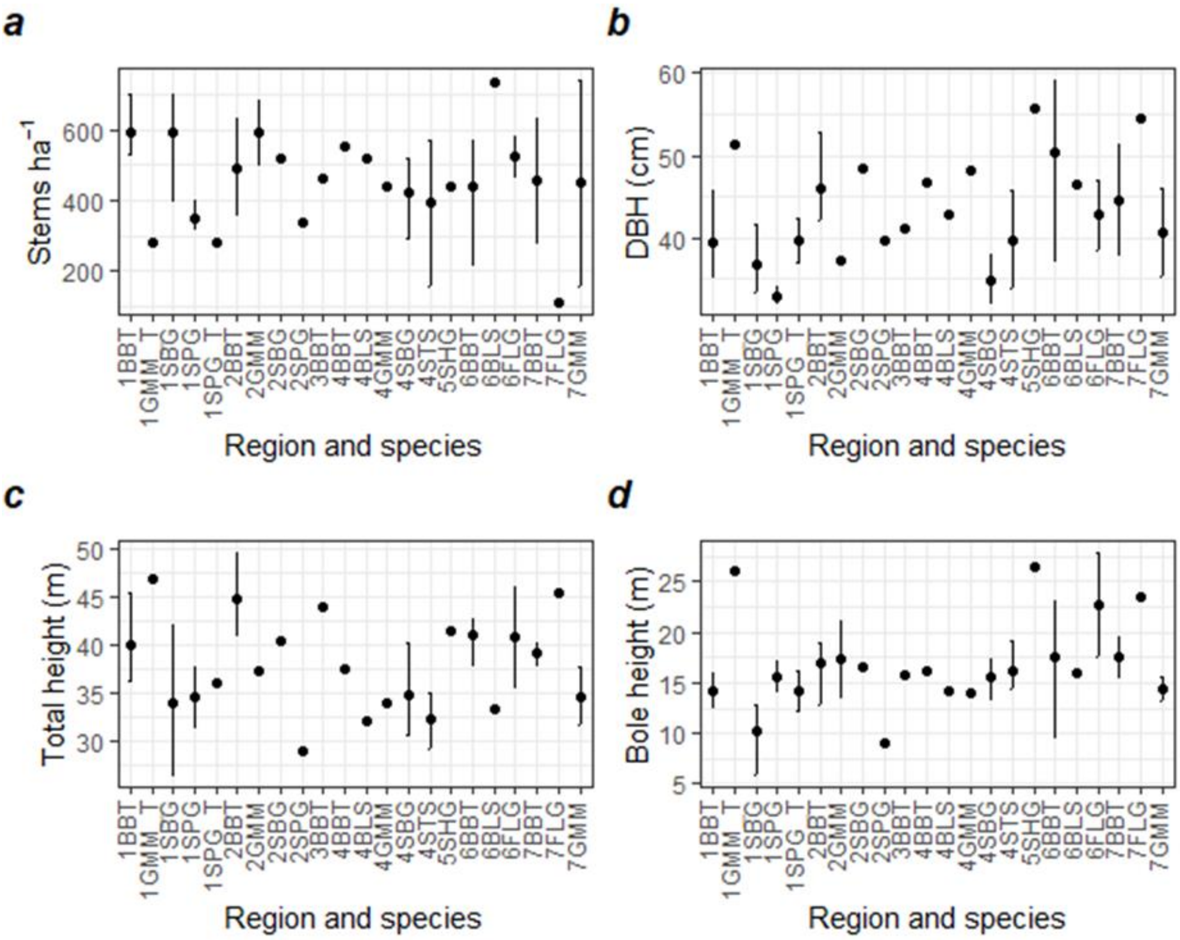


Figure 5. a) Plantation stocking by region and species, b) Modelled diameter at breast height (cm) at age 40 by region and species, c) Modelled total height (m) at age 40 by region and species, d) Modelled clear bole height (m) at age 40 by region and species. Black dots represent the average for the region and species combination, the bar represents the range of the data above and below the average. Where there is only a dot, only a single plantation was measured for that region and species combination.

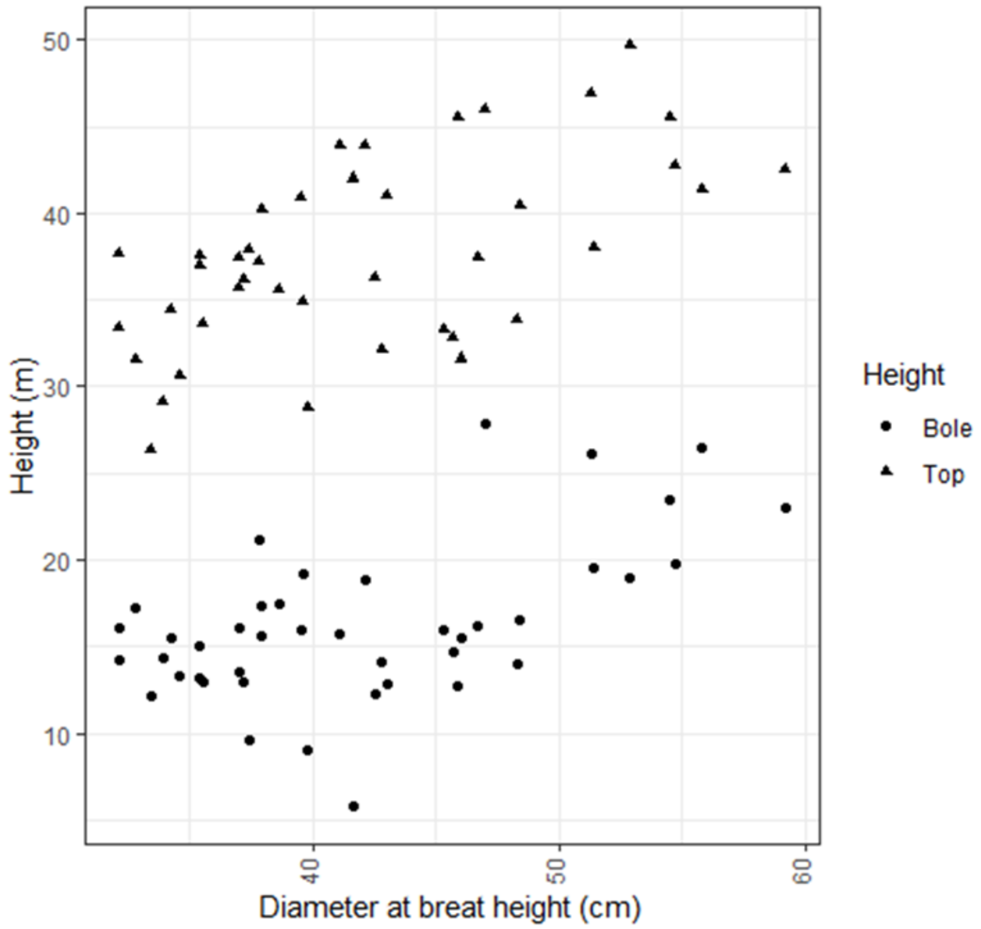


Figure 6. The relationship between diameter at breast height (cm), total height (m) and merchantable log length (m) at age 40. The figure shows the modelled average trees for each plantation, not average region and species groups.

3.2 Mean Annual Increment

Mean annual increment (Figure 7) varied from 2.24 m^3 ha^{-1} for spotted gum grown in the North Coast region to 13.9 m^3 ha^{-1} for shining gum grown in the Central Up River region. The average MAI for all species and regions is 7.3 m^3 ha^{-1}. The greatest variation for a single species and region was Sydney blue gum in the North Coast region, 8.2 m^3 ha^{-1}.

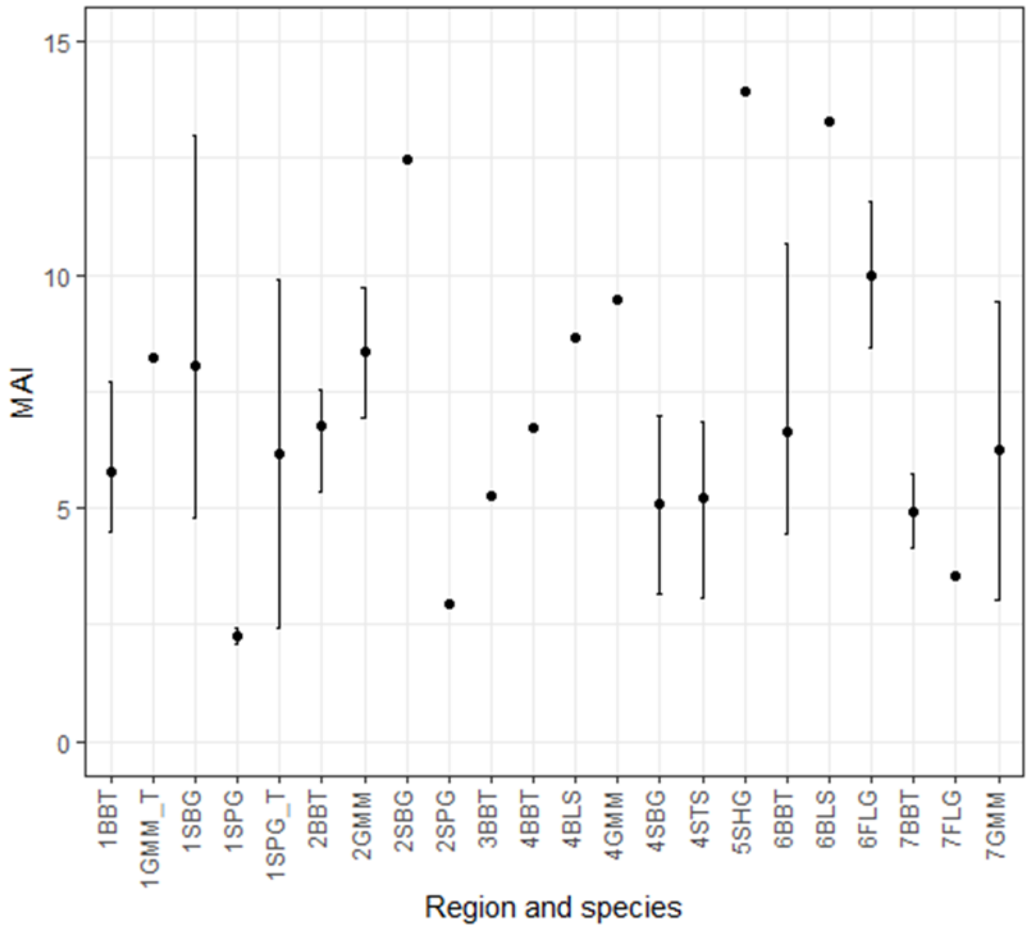


Figure 7. Modelled mean annual increment (MAI) m^3 ha^{-1} by region and species at age 40. Black dots represent the average for the region and species combination, the bar represents the range of the data above and below the average. Where there is only a dot, only a single plantation was measured for that region and species combination.

3.3 Log and Stand Volume

Merchantable log volumes by size class modelled at 40 years show a positive relationship between DBH, log size and merchantable volume ha^{-1} (Figure 8). The stands with the largest modelled volume m^3 ha^{-1} are blue-leaved stringybark grown in the Central Up River region and shining gum grown in the Central Table Lands region. Both of these plantations had logs modelled in the higher size classes and higher stocking rates (730 and 440 stems ha^{-1} respectively). The two lowest yielding plantations were both spotted gum grown in the Coastal North region, stocked at 400 and 320 stems ha^{-1}.

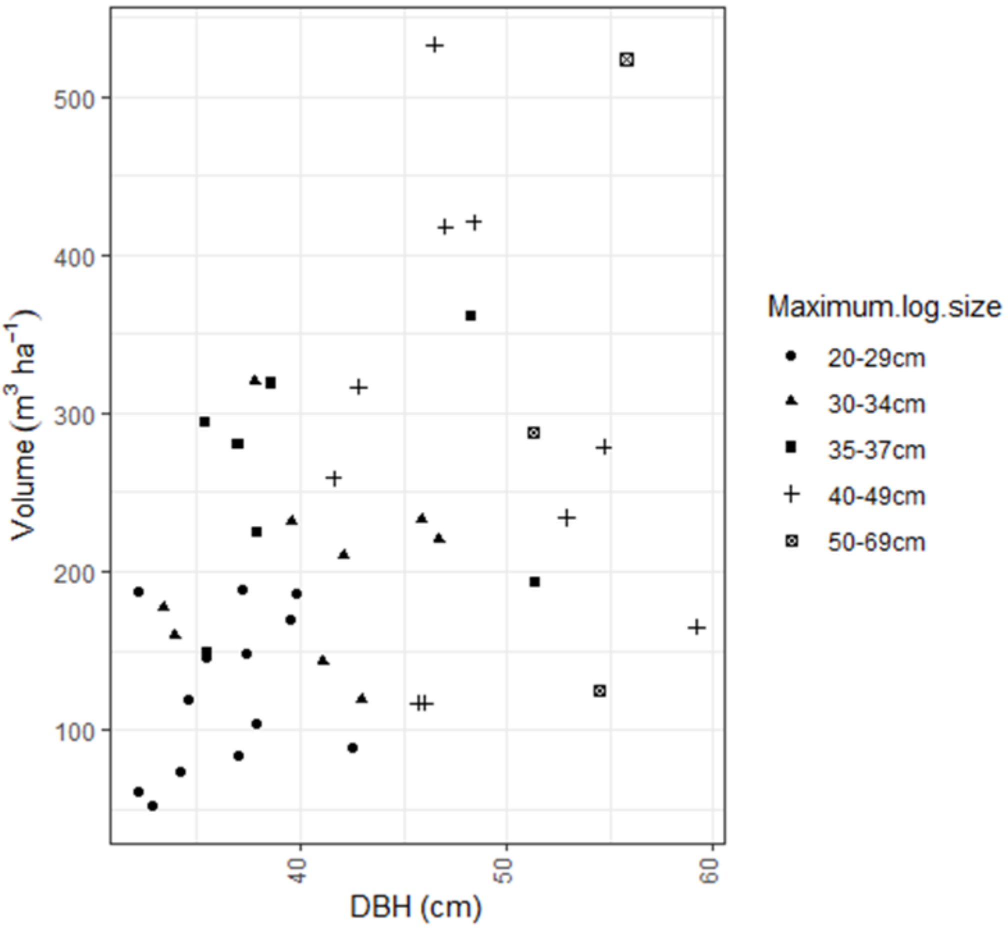


Figure 8. The relationship between diameter at breast height (DBH), merchantable log volume ha^{-1} and maximum log size for modelled 40 year old average trees. The figure shows the modelled average trees for each plantation, not average region and species groups.

The average merchantable log volume is 215 m^3 ha^{-1}, the range in merchantable log volume is 471m^3 ha^{-1} (Figure 9). The largest merchantable volume was modelled for blue-leaved stringybark grown in the Central Up River region (533 m^3 ha^{-1}), the least was spotted gum grown in the North Coast region (62 m^3 ha^{-1}). No logs were produced from any species or region with a mid-diameter of 70+ cm.

Figure 10 shows the modelled individual tree log volumes by log size class. The figure illustrates the range of individual log volumes within the single size classes. Differences in log volumes are due to the variable lengths of the logs; each tree was mechanised to produce the highest financial gain.

Log volume availably ha^{-1} by size class is presented in Figure 11. Species and region combinations with lager modelled DBH's generally produced larger logs, however volume ha^{-1} is also affected by stand stocking (Figure 8); this relationship is variable. Looking at the most and least densely stocked forests, blue-leaved stringybark grown in the Central Up River region at 730 stems ha^{-1} returned the highest merchantable volume (533 m^3 ha^{-1}), whereas the second most densely stocked sample Sydney blue gum grown in the North Coast region at 593 stems ha^{-1} returned 195 m^3 ha^{-1}, the 11th highest volume of merchantable logs. The least stocked plantation flooded gum grown at 110 stems ha^{-1} in the Coastal South region produced 125 m^3 ha^{-1}, the third lowest volume overall. Plantations with logs in the 50-69 cm mid DBH range were thinned Gympie messmate grown in the coastal North region, Shining gum grown in the Central Tablelands region and flooded gum grown in the Coastal South region. These plantations were grown at 280, 440 and 110 stems ha^{-1} respectively and returned the 8th, 2nd and 19th highest volumes overall.

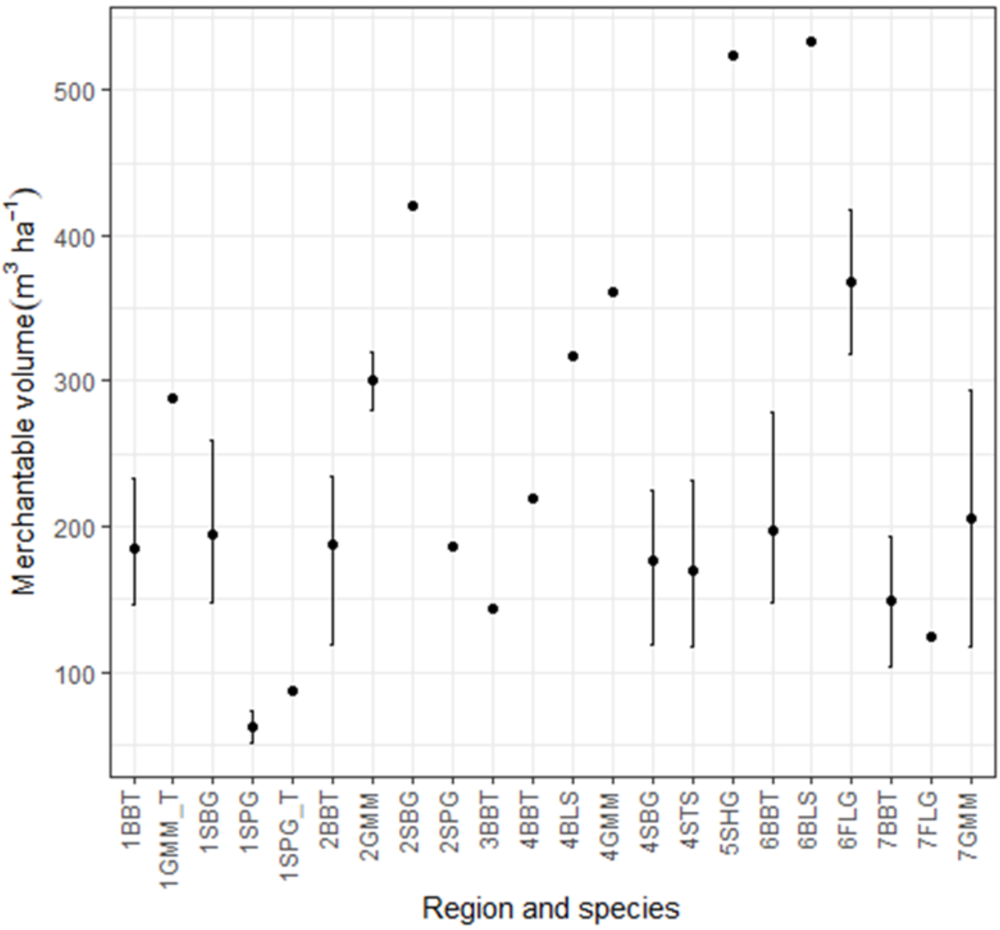


Figure 9. Modelled merchantable log volume by size class (m^3 ha^{-1}) grouped by region and species at age 40. Black dots represent the average for the region and species combination, the bar represents the range of the data above and below the average. Where there is only a dot, only a single plantation was measured for that region and species combination.

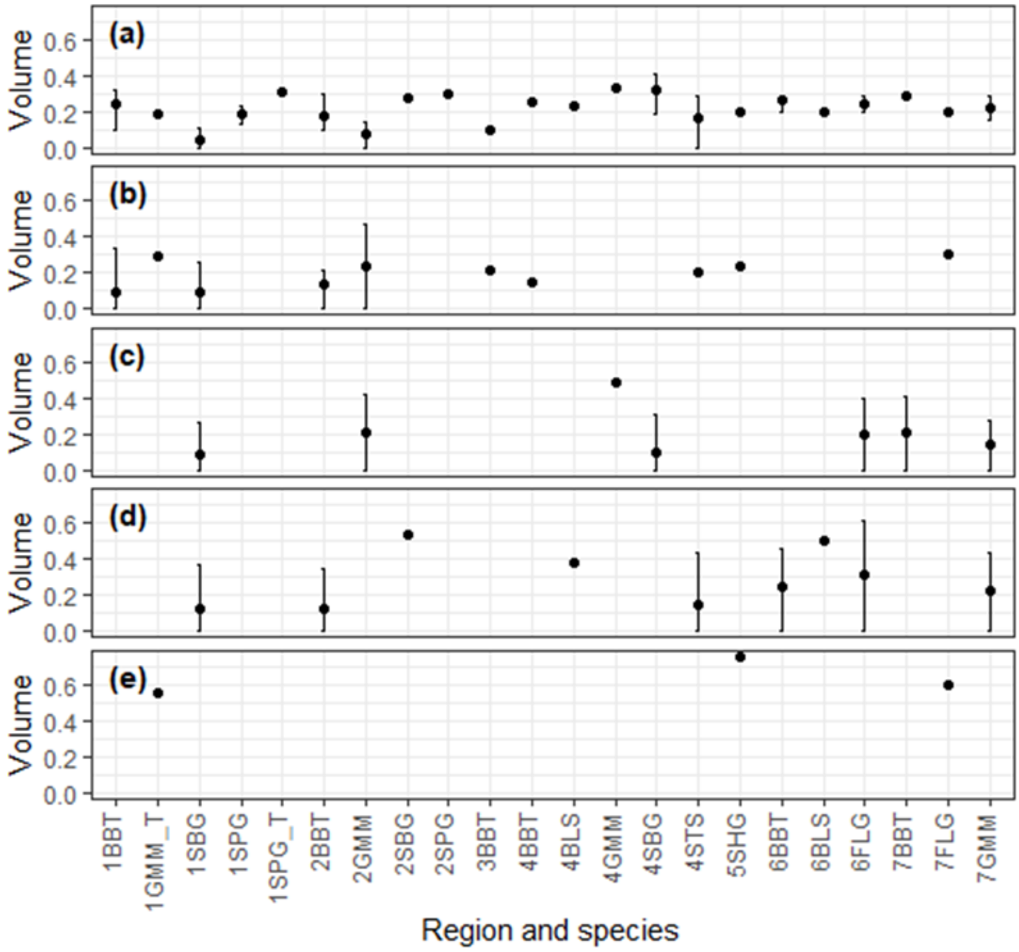


Figure 10. Modelled merchantable log volume per tree by size class (m[3]) grouped by region and species at age 40. a) log mid diameter 20-29 cm, b) log mid diameter 30-34 cm, c) log mid diameter 35-37 cm, d) log mid diameter 40-49 cm, e) log mid diameter 50-69 cm. N.B. no logs were merchandised in the size classes 38-39 cm or 70+ cm. Black dots represent the average for the region and species combination, the bar represents the range of the data above and below the average. Where there is only a dot, only a single plantation was measured for that region and species combination.

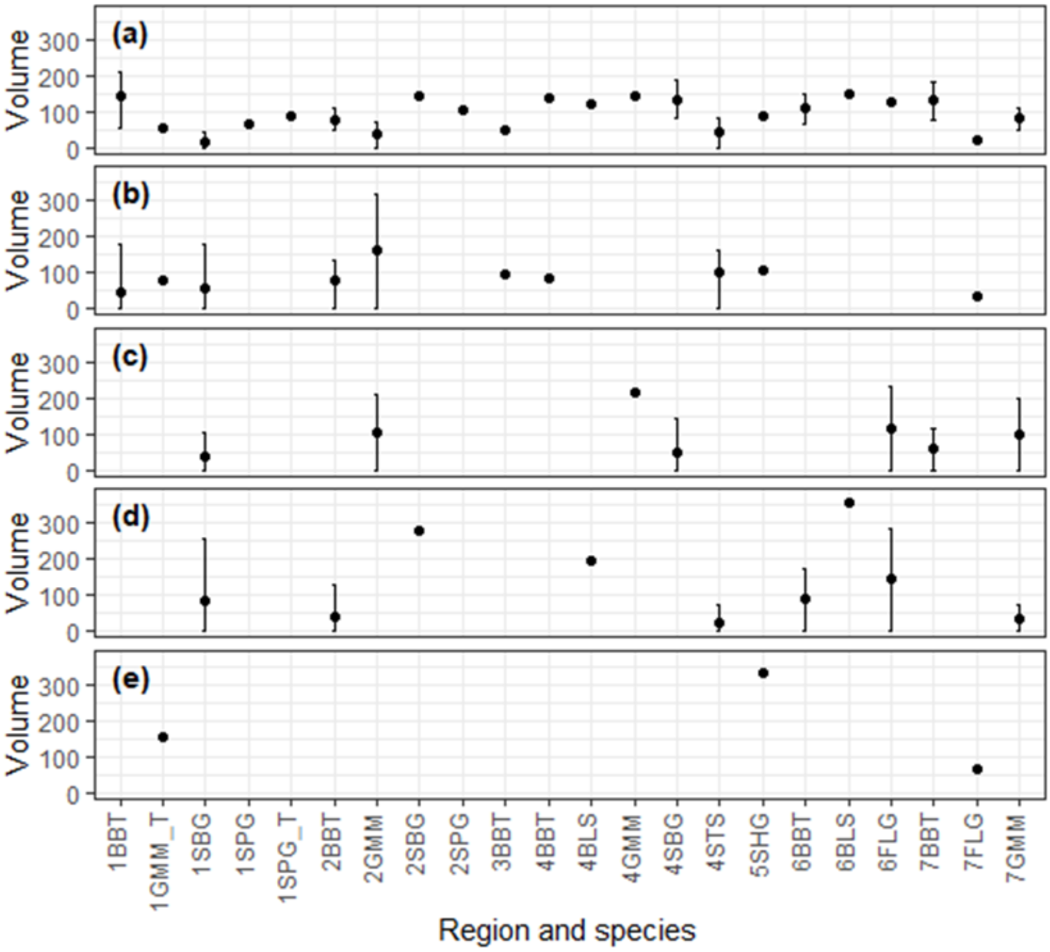


Figure 11. Merchantable log volume(m^3 ha^{-1}) by size class modelled at age 40. a) log mid diameter 20-29 cm, b) log mid diameter 30-34 cm, c) log mid diameter 35-37 cm, d) log mid diameter 40-49 cm, e) log mid diameter 50-69 cm. N.B. no logs were merchandised in the size classes 38-39 cm or 70+ cm. Black dots represent the average for the region and species combination, the bar represents the range of the data above and below the average. Where there is only a dot, only a single plantation was measured for that region and species combination.

3.4 Log and stand value

The non linear relationships between log size and value (see Figure 3), and form and value (See Figure 4), as well as the differences in value attributed to different species groups (Figure 3), contribute the financial outcomes for plantations. Thus, plantation species, location and management all attribute to long term financial results.

3.4.1 Form weighting

Incorporating a form measurement in the data set provides the opportunity to value the plantations beyond standard species or volume assumptions. The form weight provides an indication of expected product recovery or waste. Viewing the data in this way provides a further step to understanding resource value and management opportunities.

Figure 12, below, shows the form scores for each species and region combination. Close to 70% of form scores fall between 2.5 and 3.5, the overall average is 2.9. Thinned Gympie messmate in the North Coast region has the lowest average form score (2.1); Sydney blue gum in the same region has the highest (3.9). Blackbutt grown in the Central Up River region had the greatest range in form score (1.8 – 3.8).

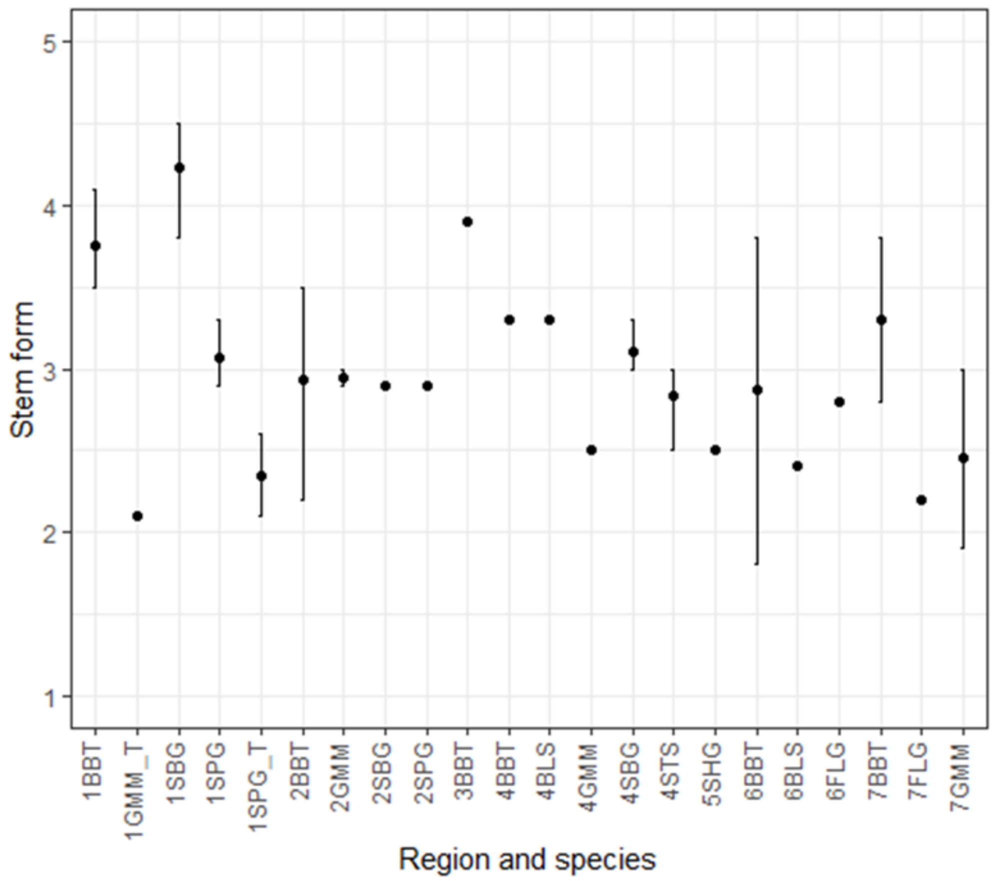


Figure 12. Tree form rating by region and species. Black dots represent the average for the region and species combination, the bar represents the range of the data above and below the average. Where there is only a dot, only a single plantation was measured for that region and species combination.

Figure 13, below, shows the relationship between stems ha^{-1} and form score. Generally, stands with lower stocking have lower form score, indicating a lower overall portion of trees containing defect or trees with consistently low occurrence of defect. This pattern is reflected in Figure 14, showing stands with lower DBH have a higher form score i.e. higher occurrence of defect or non-commercial stems.

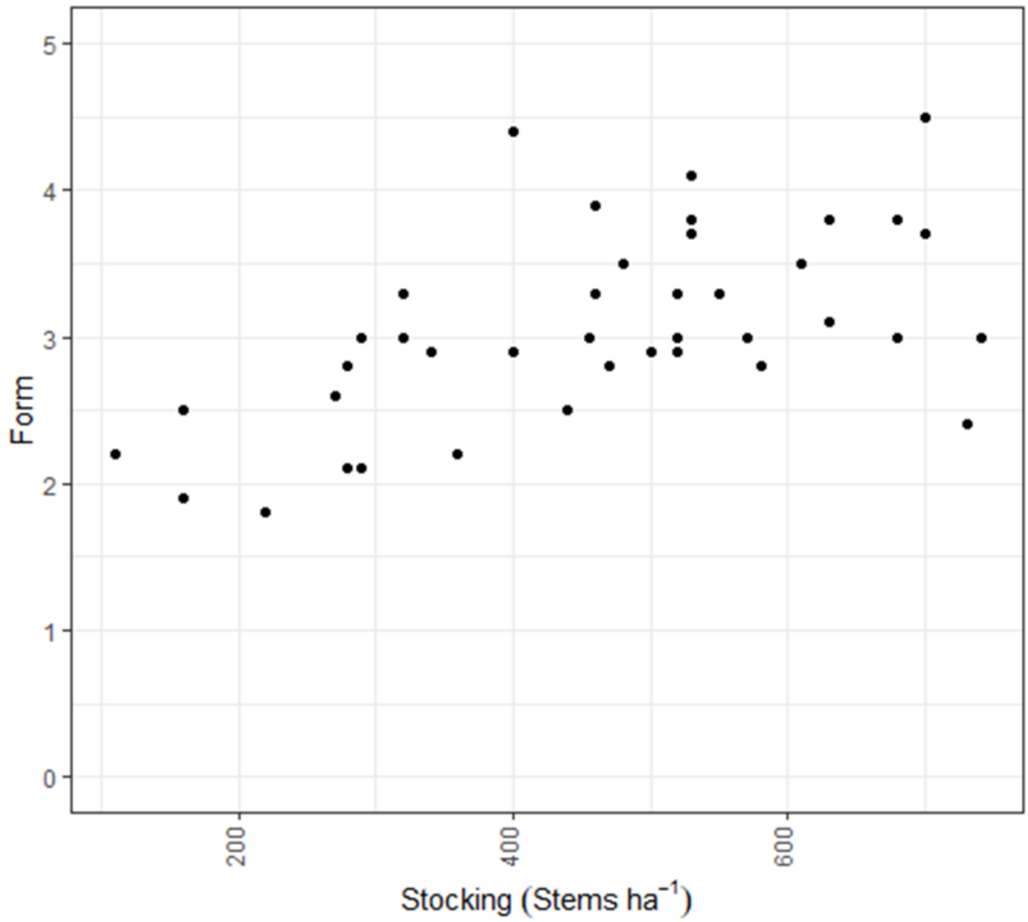


Figure 13. The relationship between stocking (stems ha^{-1}) and form score. The figure shows the modelled average trees for each plantation, not average region and species groups.

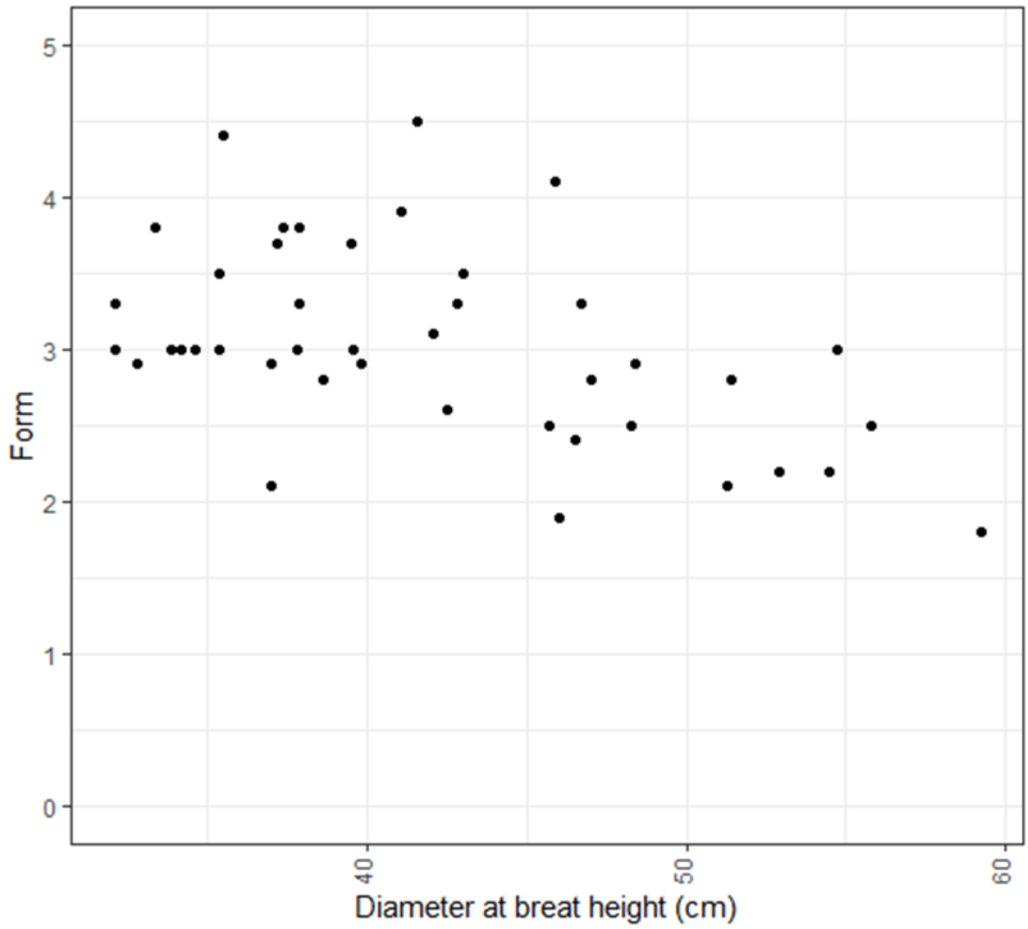


Figure 14. The relationship between diameter at breast height (cm) at age 40 and form score. The figure shows the modelled average trees for each plantation, not average region and species groups.

Applying the form weight to the modelled stand values provides an expected value for the stand incorporating defect and down grade. The effect of the form score on stand value is shown in figure 15. Differences between weighted and unweighted values are smallest when the form score and value are low, becoming more impactful where the initial value and form score are high.

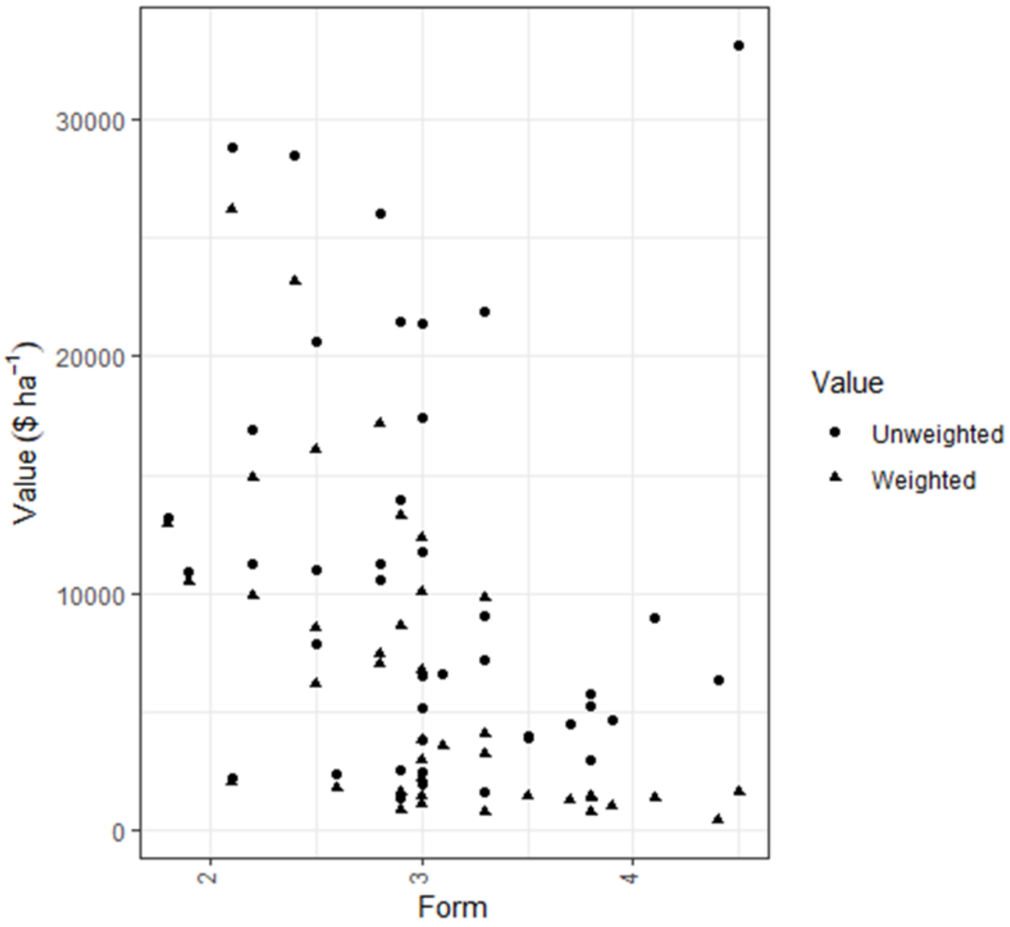


Figure 15. The relationship between form score and weighted and unweighted log value ($ ha^{-1}) at age 40. The figure shows the modelled average trees for each plantation, not average region and species groups.

The relationship between weighted and unweighted value ha^{-1} is linear (R^2=0.69) (Figure 16). This indicates the more extreme weights placed on poorer formed trees are in stands of already low value (see Figure 8); applying more extreme form weights on already low value stands has less affect than if placed on larger and therefore higher value logs. The exception is Sydney Blue Gum grown in the North Coast region, the unweighted value of $33154 ha^{-1} and weighed values of $1597 ha^{-1}.

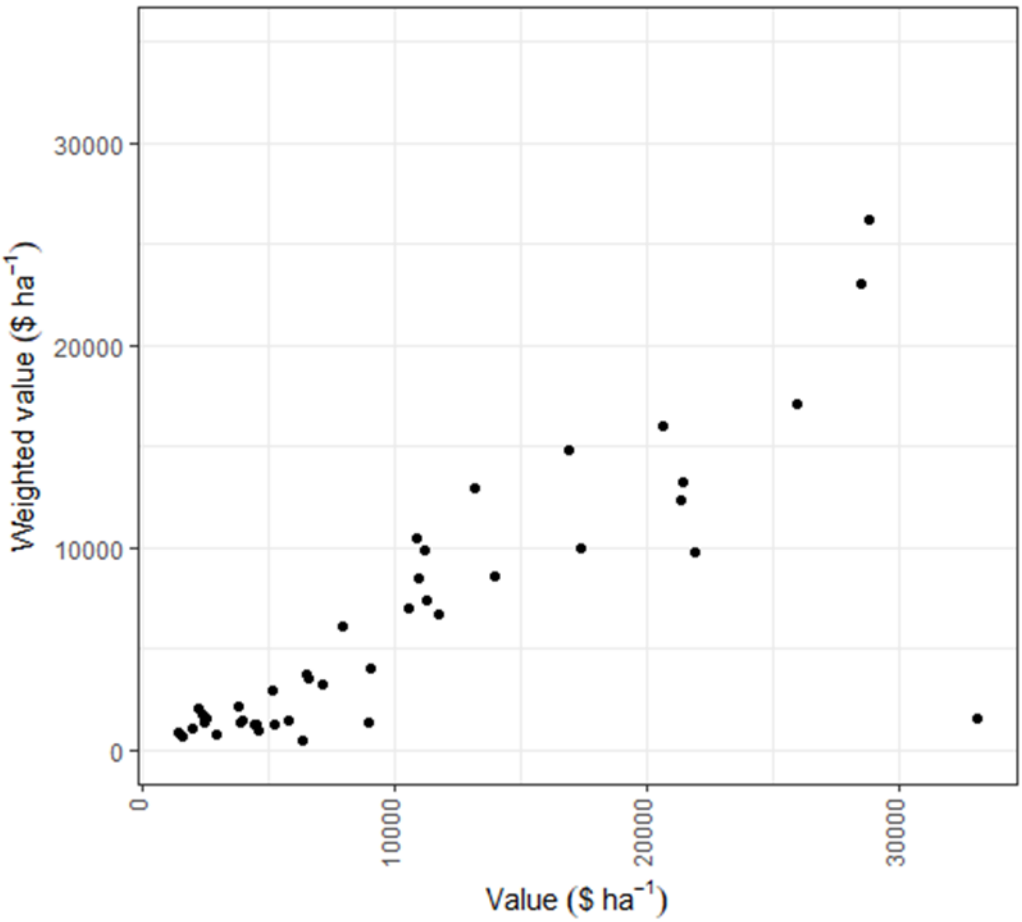


Figure 16. The relationship between weighted and unweighted value ($ ha^{-1}) at age 40. The figure shows the modelled average trees for each plantation, not average region and species groups.

3.4 2 Weighted and unweighted stand values

Weighted and unweighted stand values for the modelled stands show the impact of stand quality on overall financial value (Figure 17). The greatest downgrade in value is for Sydney blue gum grown in the North Coast region (96%). The downgrade on the thinned stands was 8.5% for Gympie messmate and 17.7% for spotted gum. The management to reduce stems favoured keeping trees with good form and low defect for the final crop.

Thinned Gympie messmate grown in the North Coast region and blue-leaved stringybark grown in the Central Up River region returned the greatest values both before and after the form weight has been applied. The Thinned Gympie messmate was grown at 280 stem ha^{-1} whereas the blue-leaved stringybark was grown at 730 stem ha^{-1}. Gympie messmate is a select species, priced at the highest rate; blue-leaved stringybark is classed as the mixed hardwood, has the 5th highest value rating.

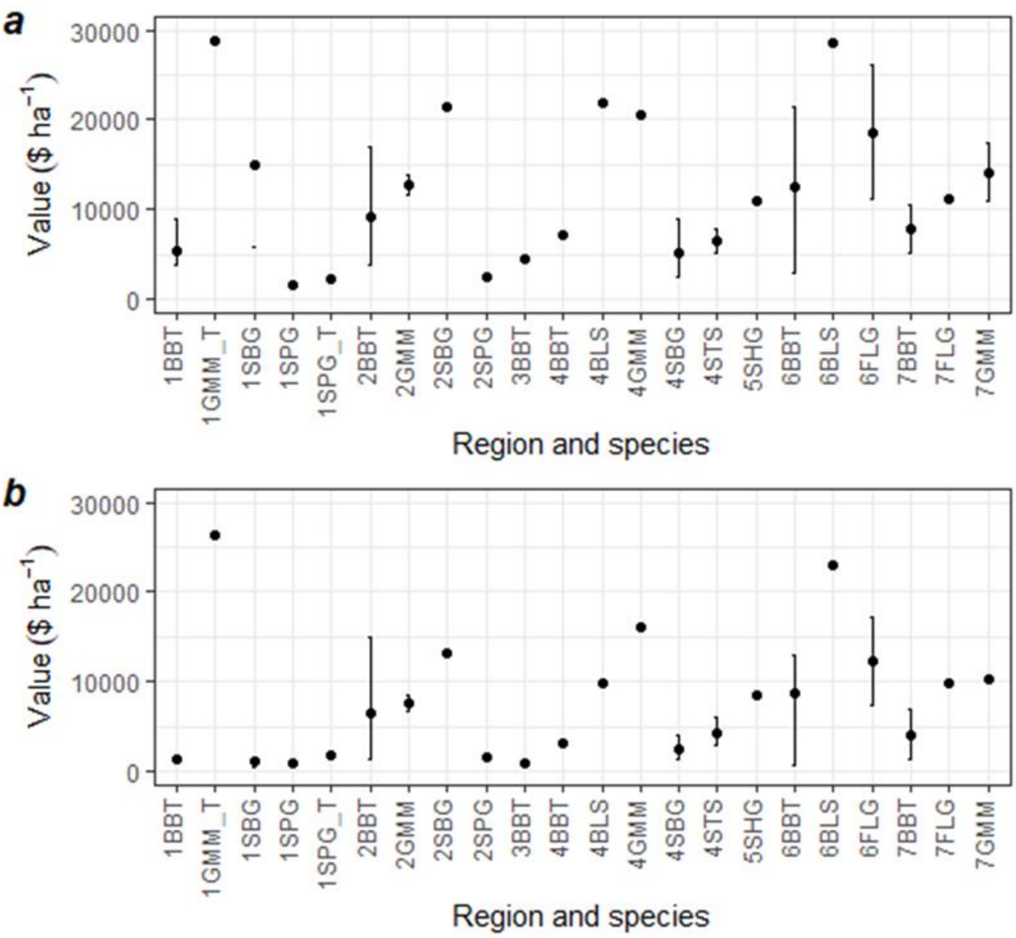


Figure 17. Value ($ ha^{-1}) by region and species modelled at age 40. a) Unweighted value b) Weighted value. Black dots represent the average for the region and species combination, the bar represents the range of the data above and below the average. Where there is only a dot, only a single plantation was measured for that region and species combination.

3.4.3 Species and value implications

Figure 18 shows merchantable volume (m^3 ha^{-1}) (a), unweighted value ($ ha^{-1}) (b) and weighted value ($ ha^{-1}) (c) ordered by Forestry Corporation species value groups (see Table 2 and Figure 3). The figure highlights the importance of species choice. Shining gum grown in the Central Tablelands region was one of only two species and region combinations that achieved a merchantable volume greater than 500 m^3 ha^{-1}, the other being blue-leaved stringybark grown in the Central Up River region (524 and 533 m^3 ha^{-1} respectively). Shining gum is in the High Country Hardwoods value group, the least profitable group overall. The unweighted value returned for shining gum was $10 975 ha^{-1}; blue-leaved stringybark returned $28 587 ha^{-1}. Comparatively, Gympie messmate is classed in the Select Hardwoods value group, the most profitable species group. Gympie messmate grown in the Coastal North, North East Up River, Central Foothills and Coastal South regions produced 288, 300, 361 and 206 m^3 ha^{-1} respectively; retuning $28 811, $12 834, $20 651 and $14 154 ha^{-1}.

Gympie messmate from the Coast North region produced the least volume (288 m^3 ha^{-1}), but the greatest return for the species ($28 811 ha^{-1}). This stand had been thinned; the volume available attributed to a lesser number of larger trees. The effect of thinning on the quality of the available trees is illustrated further when comparing the effect of form weighting on values (b and c panels). The effect of thinning on volume and value can been seen for thinned and unthinned spotted gum. The thinned spotted gum grown in the Coastal North region produced slightly more volume than the unthinned spotted gum in the same region but less than the unthinned spotted gum grown in the North East Up River region (87, 62 and 186 m^3 ha^{-1} respectively). However, when viewing the values the thinned spotted gum is worth close to the same as the unthinned spotted gum grown in the North East Up River region when unweighted ($2282 and $2553 ha^{-1} respectively) and more when the form weight is applied ($1877 and $1577 ha^{-1}), despite the unthinned plantation producing more than double the merchantable volume.

Blackbutt, the species grown across the most sites in the study ranged in volume production from 143 m^3 ha^{-1} in the Northern Foothill regions to 220 m^3 ha^{-1} in the Central Foothills region, returning values of $12488 ha^{-1} and $4610 ha^{-1} unweighted and $8657 ha^{-1} and $978 ha^{-1} weighted.

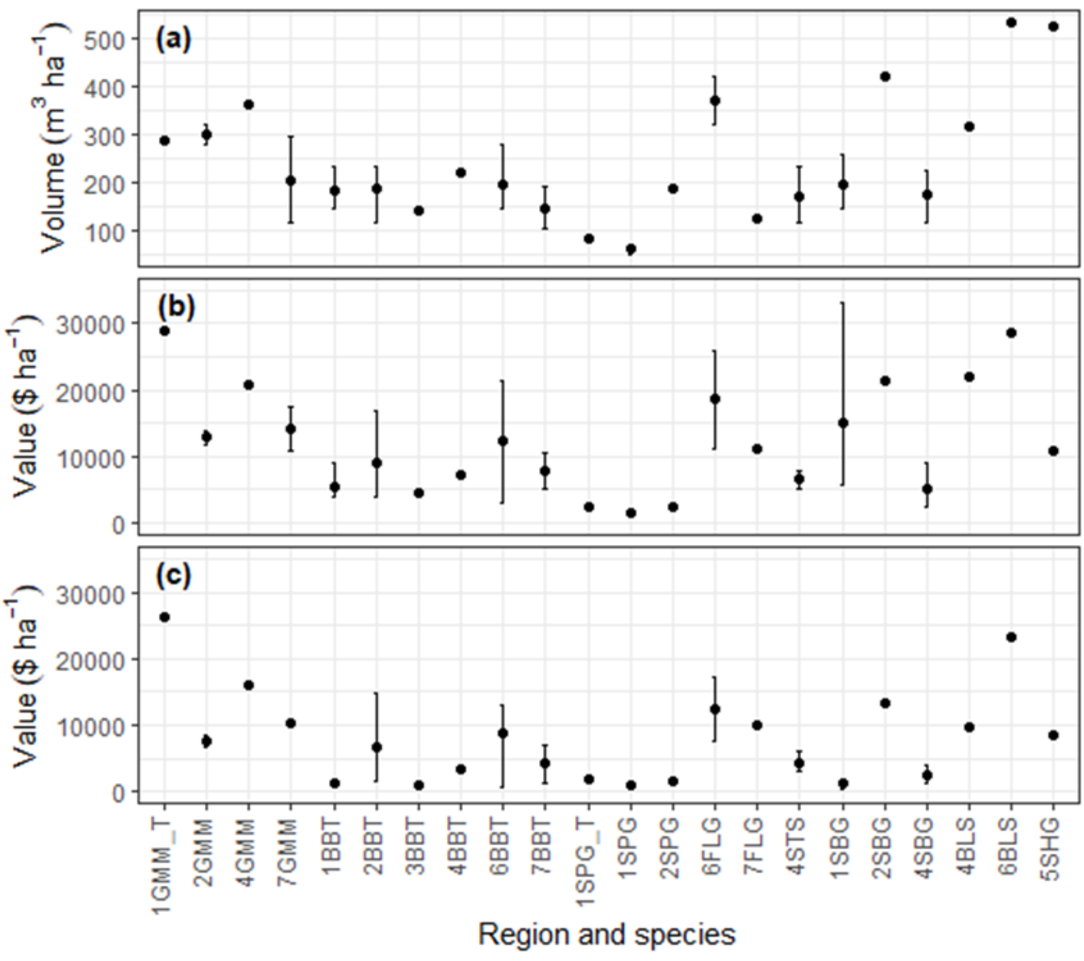


Figure 18. a) Merchantable volume (m^3 ha^{-1}) modelled at age 40; b) unweighted value ($ ha^{-1}) modelled at age 40, and c) weighted value ($ ha^{-1}) modelled at age 40. Figures are ordered by Forestry Corporation species value groups from the highest to lowest value group. Black dots represent the average for the region and species combination, the bar represents the range of

the data above and below the average. Where there is only a dot, only a single plantation was measured for that region and species combination.

3.5 Financial analysis

Internal rate of return (IRR) for timber was calculated for each location, species and treatment combination. The analysis was completed utilising two management approaches: without pruning events at ages 3 and 7 (Figure 19), and with pruning events at ages 3 and 7 (Figure 20). The ‘a’ graphs show the unweighted values and ‘b’ the weighted values.

The modelled returns calculated without pruning costs (Figure 19) show the highest average IRR, Gympie messmate grown in the North Coast region, was 2.08 % unweighted and 1.78 % weighted. Spotted gum grown in the Coastal North region returned the lowest average IRR, -12.46 %, and -22.40% once the form weighting was applied. Thinned spotted gum grown in the North Coast region returned one of the lowest IRRs (-9.23 %), however, as the combination also had a low form rating, the weighted value out preformed 4 combinations with higher unweighted IRR’s.

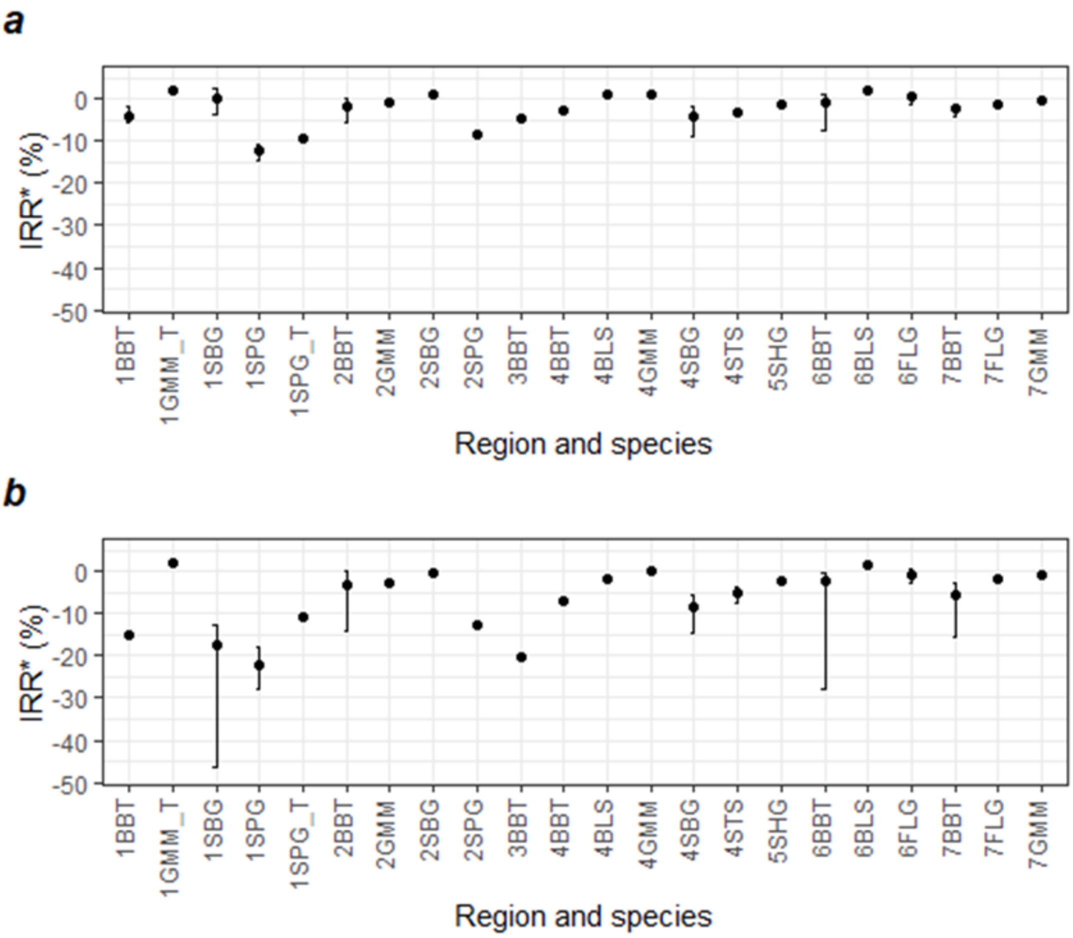
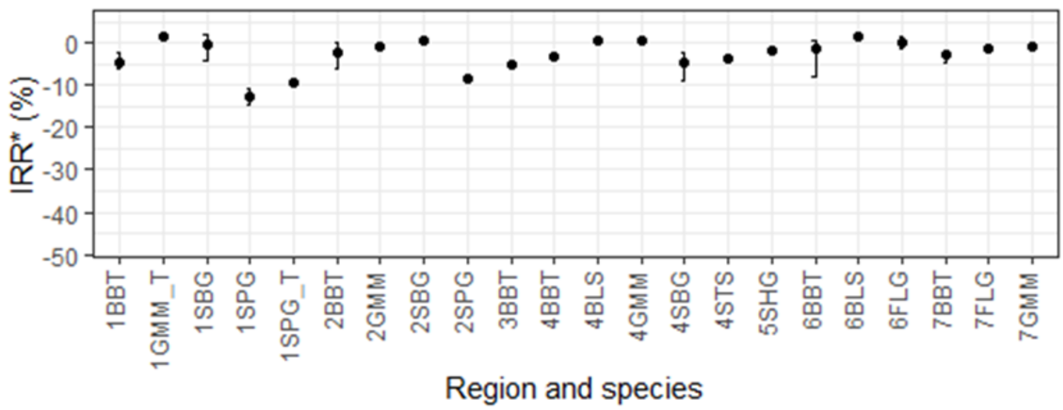


Figure 19. Internal rate of return (IRR) (%) without including the cost of pruning, by region and species modelled at age 40. a) Unweighted value b) Weighted value. Black dots represent the average for the region and species combination, the bar represents the range of the data above and below the average. Where there is only a dot, only a single plantation was measured for that region and species combination.

Figure 20 shows the weighted and unweighted returns for the plantations with the cost of two pruning events. The unweighted and weighted returns for the best preforming combination, Gympie messmate grown in the North Coast region, were 1.66% and 1.36% respectively. Spotted gum grown in the Coastal North region returned the lowest average IRR, -12.59 %, and -22.41% once the form weighting was applied (Figure 20).

Including the two pruning events had an average impact on mean IRR figures for each species and region combination of – 0.38%. Comparatively the average effect of poor form, expressed through the form rating, had an impact of close to 4% (4.08% unpruned and 3.90% pruned).

a



b

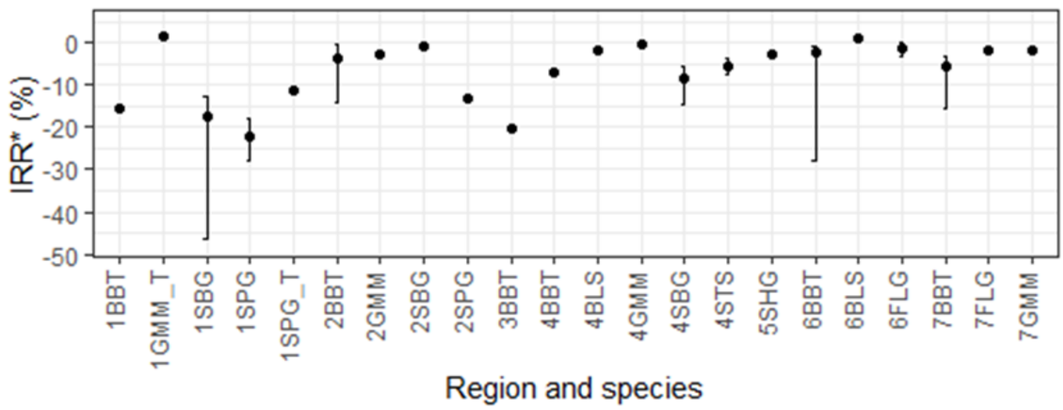


Figure 20. Internal rate of return (IRR) (%) including the cost of pruning, by region and species modelled at age 40. a) Unweighted value b) Weighted value. Black dots represent the average for the region and species combination, the bar represents the range of the data above and below the average. Where there is only a dot, only a single plantation was measured for that region and species combination.

3.6 Site Species Matching

The data for the three select and key species in the dataset was available across 26 sites. The available data did not contain enough replicates to make detailed site species matching inferences, however, some useful insights were gained.

Rainfall ranged from 1000 to 1600 mm yr^{-1} with a mean of 1245 mm yr^{-1}. Blackbutt sites received the highest average rainfall (1329 mm yr^{-1}), followed by Gympie messmate (1291 mm yr^{-1}), then spotted gum (1158 mm yr^{-1}). A rainfall map of the study region is attached as Appendix 4.

Figure 21 shows the relationship between modelled MAI at age 40, stocking and rainfall level. The figure shows a positive trend between MAI and stocking, and higher productivity with higher rainfall. This relationship was confirmed with regression analysis finding a significant relationship between MAI and stocking and MAI and rainfall ($p = 0.01$ and $p = 0.05$ respectively).

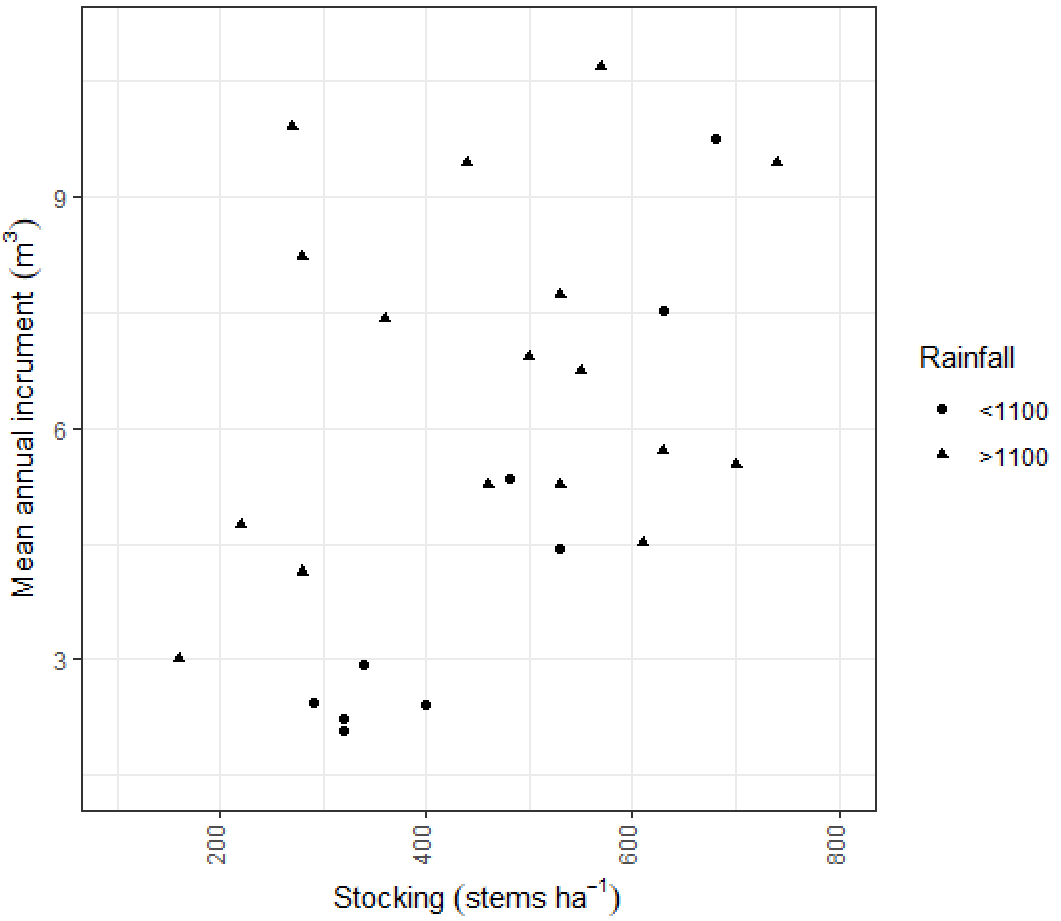


Figure 21. The relationship between stocking (stems ha^{-1}), mean annual increment (m^3) and average annual rainfall (mm yr^{-1}) at age 40. The rainfall has been separated into two groups low rainfall (<1100 mm yr^{-1}) and high rainfall (>1100 mm yr^{-1}). The figure shows the modelled averages for each blackbutt, Gympie messmate and spotted gum plantation, not average region and species groups.

The dermosols and kurosols dominated the soil types present across the study area. The list of soils present and a description may be found in Table 6.

Table 6. Australian Soil Classification, code, and description of soils present in the data set (Adapted from Isbel, R., 2016)

Soil classification	Code	Description
Dermosols	DE	soils with B2 horizons that have grade of pedality greater than weak throughout the major part of the horizon.
Kurosols	KU	Clear but abrupt textural B horizon and in which the major part of the upper 0.2 m of the B2t horizon (or the major part of the entire B2t horizon if it is less than 0.2 m thick) is strongly acid.
Sodsols	SO	Clear but abrupt textural B horizon and in which the major part of the upper 0.2 m of the B2t horizon (or the major part of the entire B2t horizon if it is less than 0.2 m thick) is sodic and is not strongly subplastic.
Kandosols	KA	Have B2 horizons in which the major part has a grade of pedality that is massive or weak, **and** Have a maximum clay content in some part of the B2 horizon which exceeds 15% (ie. heavy sandy loam [SL+] or heavier).
Rudosol	RU	negligible (rudimentary), if any, pedologic organisation apart from the minimal development of an A1 horizon or the presence of less than 10% of B horizon material (including pedogenic carbonate) in fissures in the parent rock or saprolite. The soils have a grade of pedality of single grain, massive or weak in the A1 horizon and show no pedological colour change apart from darkening of an A1 horizon. There is little or no texture or colour change with depth unless stratified or buried soils are present. Cemented pans may be present as a substrate material.

Figure 22 shows the relationship between modelled MAI at age 40, stocking and soil type. The figure shows a positive trend between MAI and stocking, but no relationship between soil type and productivity.

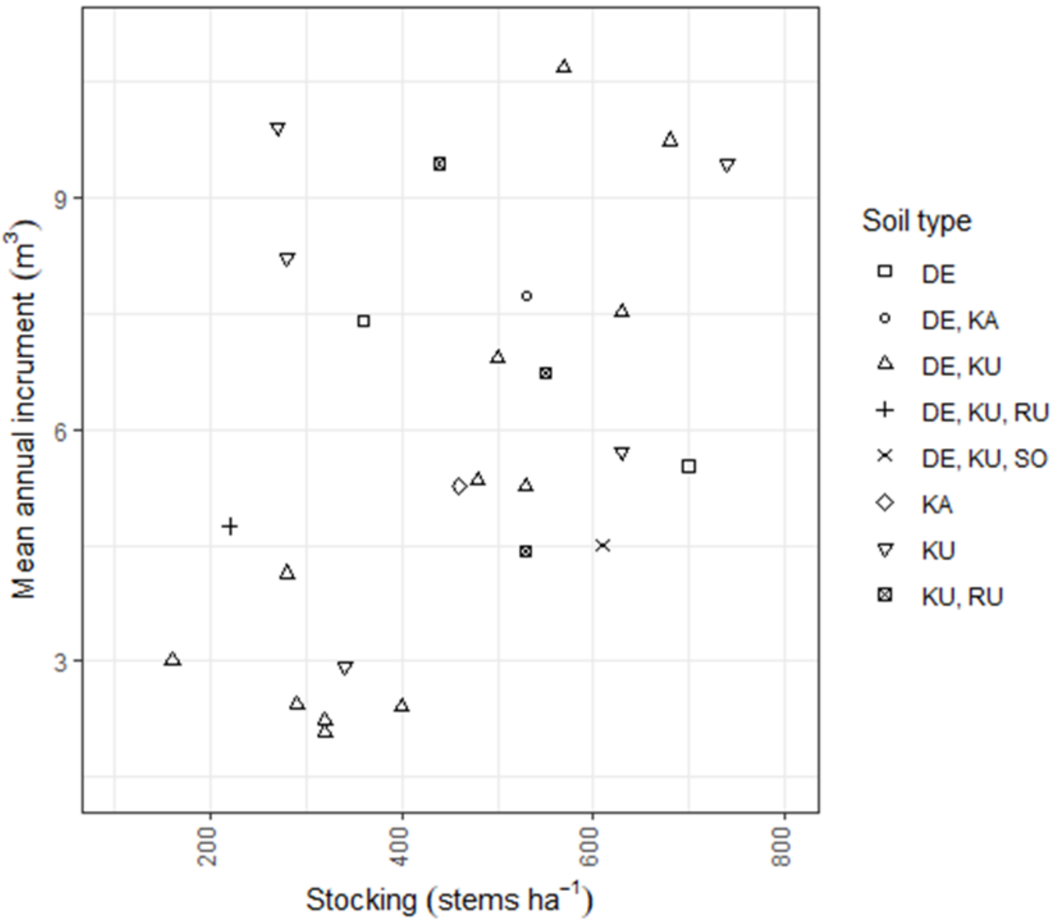


Figure 22. The relationship between stocking (stems ha^{-1}), mean annual increment (m^3) and soil type (Australian Soil Classification) at age 40. The figure shows the modelled averages for each blackbutt, Gympie messmate and spotted gum plantation, not average region and species groups.

DE: Dermosol, KU: Kurosols, SO: Sodsols, KA: Kandosols, RU: Rudosol

4. Discussion

This study provides the opportunity to assess the timber value of the hardwood plantation estate in the north east region of NSW. The estate is close to 20 years in age, 50% of the assumed 40 year rotation. The study drew data from a range of sources and species within the region to model growth and financial outcomes. The modelled outcomes aim to provide the basis for discussion about the current estate and future plantation establishment and management in the region for quality log production.

The results of the study reiterates information about the resource that is widely available: subtropical eucalypt plantations need to be managed to promote the growth of quality timber (Monague et al, 2003; Smith and Brennan, 2006; Cassidy et al, 2012; West and Smith, 2020; Carias and Page, 2023); site and species selection is crucial to positive timber and value outcomes (Garrand et al. 2003; Evans and Turnbull, 2004; Venn, 2005; Nichols et al, 2010; Paul et al, 2013; Carias and Page, 2023); and, the price of logs requires augmenting to incorporate the cost of growing trees (Cassidy et al., 2012).

Silviculture to promote the growth of less, but better quality trees through thinning or longer clear boles through pruning is largely absent from the data set. The resource in the north east of NSW planted in the late 1990's or early 2000's has been largely left unmanaged (Clark, 2004). Plantations established on private property have mostly been removed or left unmanaged. Some, mostly established by now defunct managed investment schemes such as Forest Enterprises Australia have been managed as brown field plantations and have been retrospectively thinned and pruned by new owners (A. Hurford, 2024, personal communication, 03 March)

The most limiting impact on plantation value in this study was log quality, represented as the form score. Lower stem counts, either because of thinning or natural self sorting and mortality, was positively related to both diameter at breast height and stem form. The cost of silvicultural management has been seen as a hurdle to management (Stephens and Grist, 2004; Cassidy et al, 2012), however the cost of not managing is far greater. This analysis shows that the average cost of providing two thinning events and two pruning events is 0.38% of IRR. Comparatively the average cost of poor form was 4%. It is notable that most subtropical eucalypt plantations are planted from unimproved genetic sources; improvements to tree genetics would likely see gains in form and therefore value.

The availability of two site and species combinations to assess the impacts of thinning in this study points to the lack of silviculture being practiced in the region. Comparing the returns of the thinned versus unthinned plantations of the same species in the same, or comparable region, found the impact on return to be 4.13% (Gympie messmate) and 11.25% (spotted gum). The cost of silviculture being outshone by the returns.

Species selection is crucial to plantation value. Species nominated as 'select' and 'key' species by Forestry Corporation of NSW are the highly sort after native forest species in the region, offering the greatest return to the grower. Species selection for plantations should consider log values and marketability at the end of the rotation (Venn, 2005; Nolan et al, 2005, Smith and Brenna, 2006, Cassidy et al, 2012). Shining gum grown in the Central Tablelands region exemplifies this; the log volume and form were both high for this species, but the low market value of the timber negates further consideration of the species for plantation establishment.

Reassessing the value of plantation grown logs will be necessary to support the expansion of the privately owned plantation estate in the north east of NSW. Historically prices set buy government have been such to support industry and employment, not reflective of the cost to grow trees (Cassidy et al, 2012). Potentially, the logs produced in long rotation managed plantations will be of higher and more consistent quality, the cost of harvest lower and haulage distances less due to planting on preciously cleared land.

With the continued pressure on native forest harvesting in the rest of the country (Kanowski, 2017), the Australian timber market is to become more reliant on plantation grown logs or imported products. The market will need to consider the cost of timber production (Cassidy et al, 2012; Whittle et al, 2019; Cacho et al, 2001).

Prices used in this study from Forestry Corporation NSW are less than the prices paid for logs grown on private property (J. Rankin, 2024, personal communication, 31 May). Even so, when considering the best preforming species, management and region combination: thinned Gympie messmate grown in the Coastal North region (1.66% IRR), increasing the value of the logs by 200% provides a return of 5.03%, unsurprisingly three times the modelled value.

Alternately, if better genetics or silvicultural management was available and the time to grow the same product was reduced to 30, rather than 40 years the return to the producer would be 2.67%, 1.6 times the modelled value. The government's Support Plantation Establishment Program (DAFF, 2023) offers $2000 ha^{-1} towards establishment cost. Factoring this potential funding to reduce upfront cost could change the rates of return above to 2.13% over 40 years or 3.38% over 30 years (1.28 and 2.04 times the modelled value respectively). The high cost of plantation establishment, compared to other plantation timber such as pine. Cost are higher due to challenges such as terrain and weed control, some cost could be mitigated in the future due to the economies of scale should there be higher demand. Improvements in genetics (Henson and Smith, 2007) and silviculture (Smith and Brennan, 2006) may also yield higher gross product recovery during processing and contribute to reduced establishment and maintenance costs by reducing the number of trees planted and thinned non commercially at an early age (Cassidy et al, 2012). The improved economics of these contributions can't be estimated however, without data to support this suggestion. Despite that, there is the potential to underwrite the necessary log price adjustments to support the investment.

As the estate is reaching 20 years of age thinnings logs are being harvested for commercial products. Chip based products are not viable in the region due to lack of local market and distance to the nearest port for export (Cassidy et al., 2012). Thinnings products are predominantly small poles and firewood. These value adding activities will increase profitability beyond the figures modelled in this study for producers with the capability to access such processes. Indeed, value adding processes for both thinning and final harvest products will change the financial viability for plantation grown eucalypts in the region. However, the capacity to value add is beyond many current or would be plantation owners, and out of scope for the largest plantation owner, Forest Corporation of NSW. Investment into thinnings market creation or cooperative processing facilities for small private producers may prove helpful for encouraging the expansion of the hardwood estate in the region. Market certainty and transparency for logs harvested at the end of the rotation is also needed (Keenan et al, 2019).

Additional plantation values are beyond the scope of this report but are not insignificant. They include environmental and biodiversity values (O'Grady and Mitchel, 2018; Marais et al, 2019); agricultural co-benefit values (Barker at al, 2018; Fleming et al., 2019); and, carbon. Carbon sequestration benefits may be monetised as Australian Carbon Credit Units (ACCU's) (Monckton and Mendham, 2022; Wall, 2022) and the income has the potential to offset some of the establishment and management costs for the plantation and increase the overall financial performance of the investment. Wall (2022) suggests growing plantation eucalypts in the north east of NSW could return $4100 - $6800 ha^{-1} in carbon credit revenue (assuming $18/unit).

The effect of site and species match was evaluated for the most financially viable species in the data set only; the select (Gympie messmate) and key (blackbutt and spotted gum) species. The data consisted of 26 sites for the 3 target species. Whilst there wasn't enough data to reach conclusions on site and species matching, the data did provide some useful insights.

The rainfall variation in the data set is representative of the spread of rainfall in the east of the study area. The lowest rainfall in the dataset (1000mm yr^{-1}) is quite substantial. Given the significant relationship between rainfall and productivity lesser performance would be expected with lesser rainfall. Planting on sites with rainfall lower than 1000mm yr^{-1} should be done with caution, adding further replicates to the data set with lower rainfall averages would provide further certainty on productivity.

The target species were tolerant of the range of soils in the data set. Several of the soil combinations only occurred once or twice in the set, adding further sites to the data set would enable further discussion on the effect of soils on productivity. No soil type provided an obvious disadvantage. The significant relationship between MAI and stocking suggests growth on these sites was not attributed to site productivity, rather stocking and site occupation.

5. Conclusion

The interactions of site, species and management on the factors that affect log value: species, size and form are intricate. The need to understand such interactions for successful plantation management supports the need for further research with a focus on high value species and the application of optimum silviculture. Intricacies of growing and management costs and returns and the effect of the current log value system requires further consideration. However, this study highlights the importance of management for log size and quality outcomes. The price returned for logs needs to account for growing costs. To provide a full account of plantation worth the exploration of the environmental values offered by plantations need to be highlighted regardless of their monitorisation. Plantation growth is correlated with rain fall, and site occupation should be managed for optimum productivity. To expand the plantation estate current and potential resource owners will require clear technical advice during establishment and management and access to secure markets in the future.

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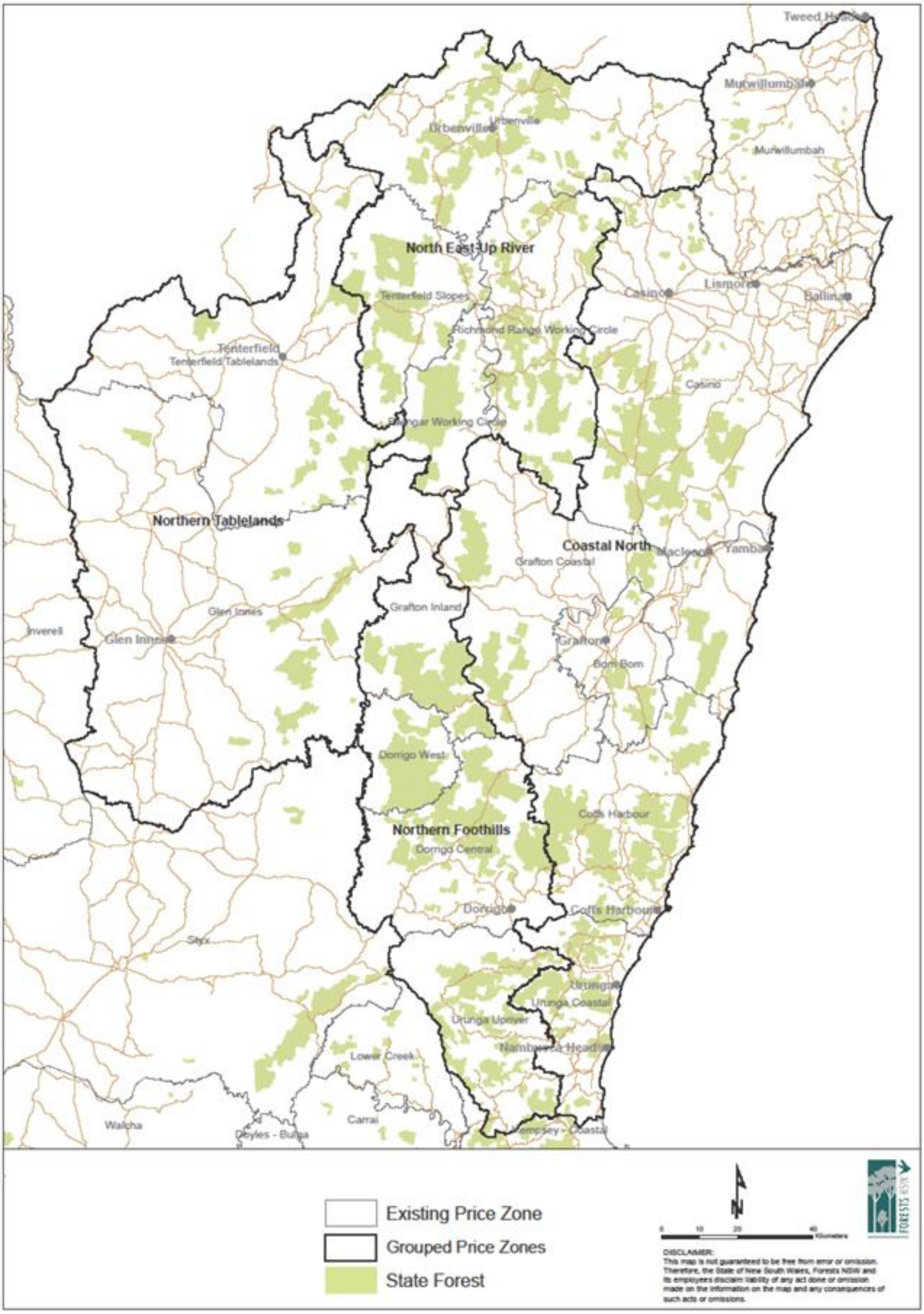
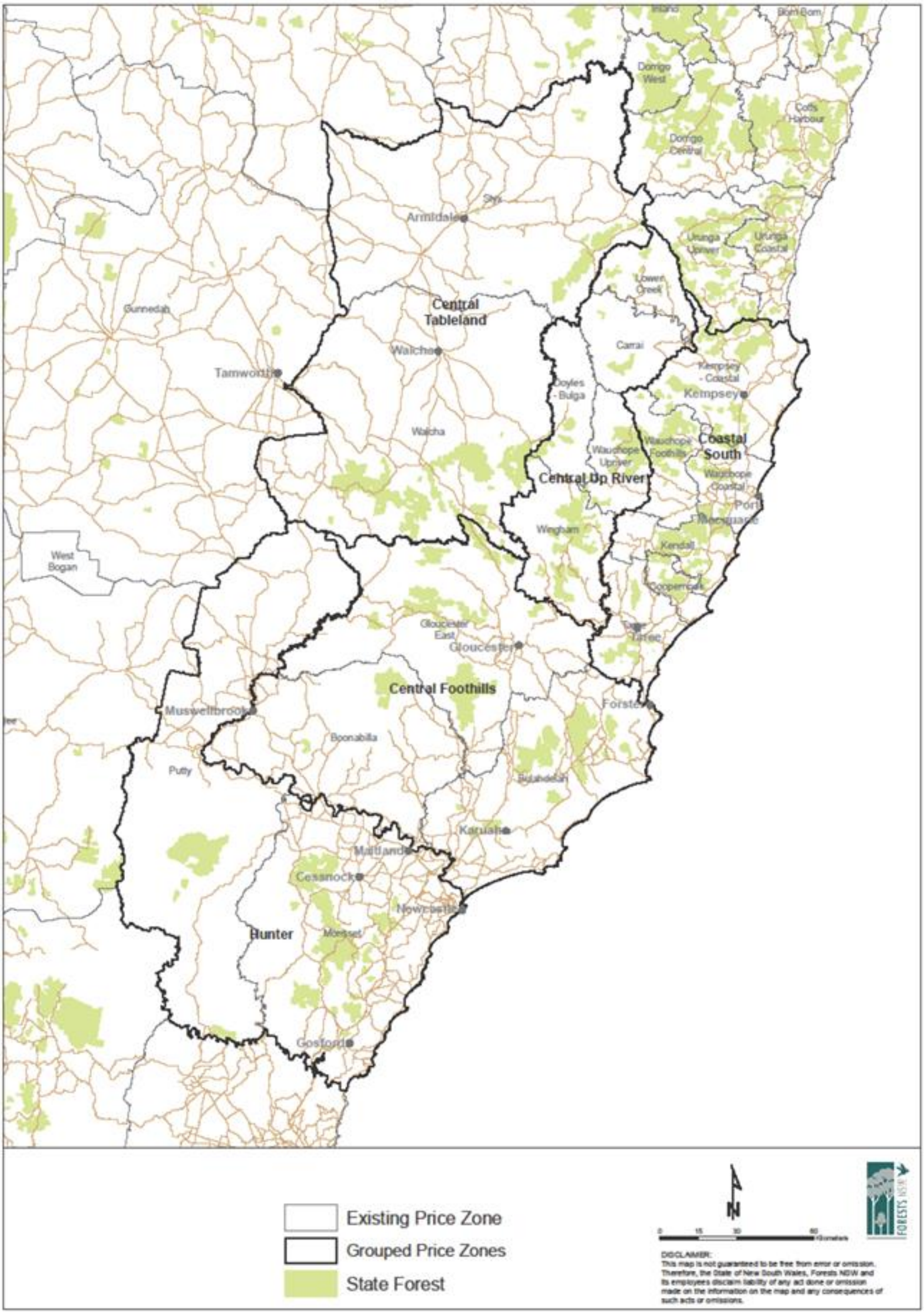
Appendix 1. Forestry Corporation NSW price zone maps

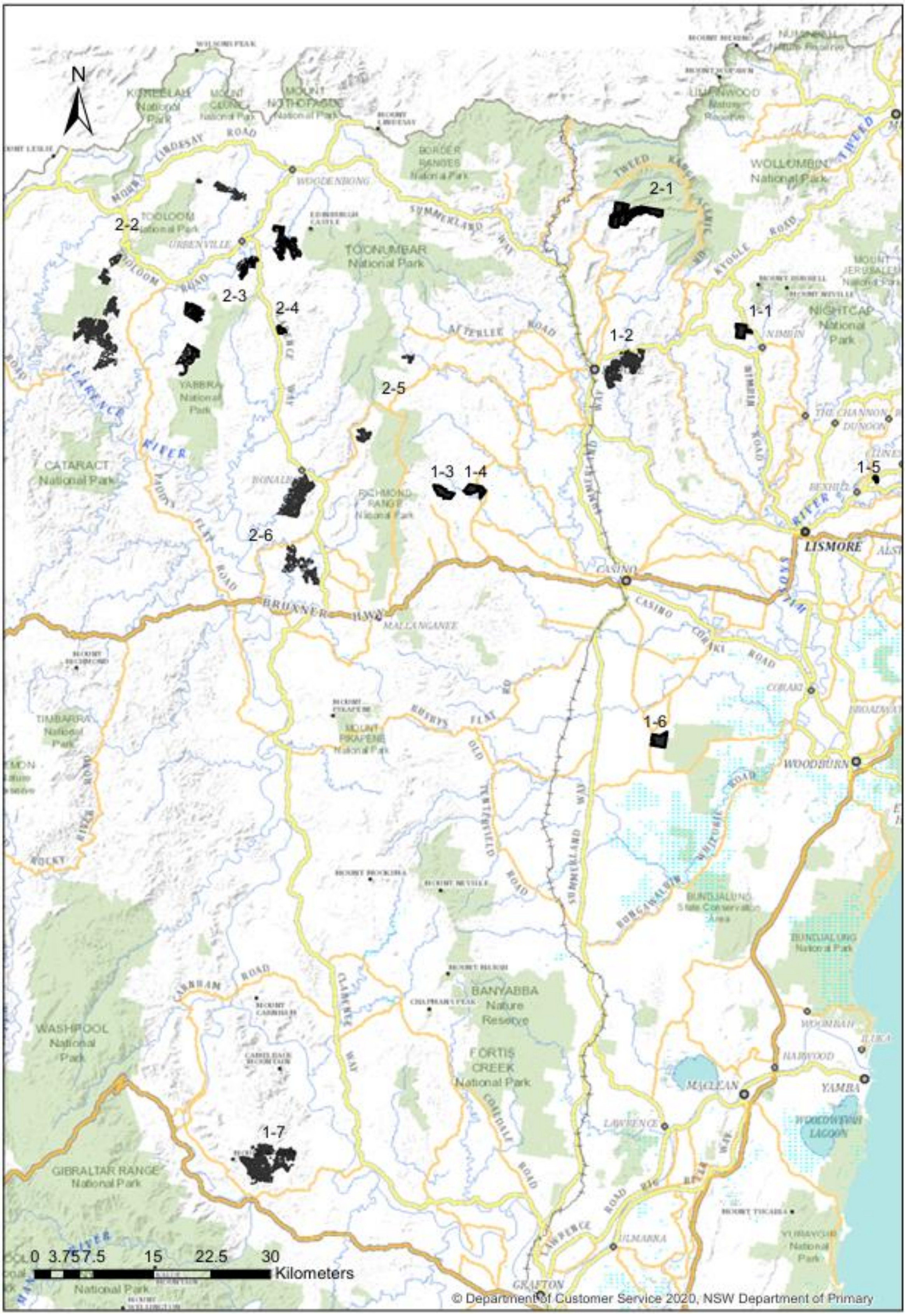


Map 1.1. North East Region (Forestry Corporation NSW, 2017)

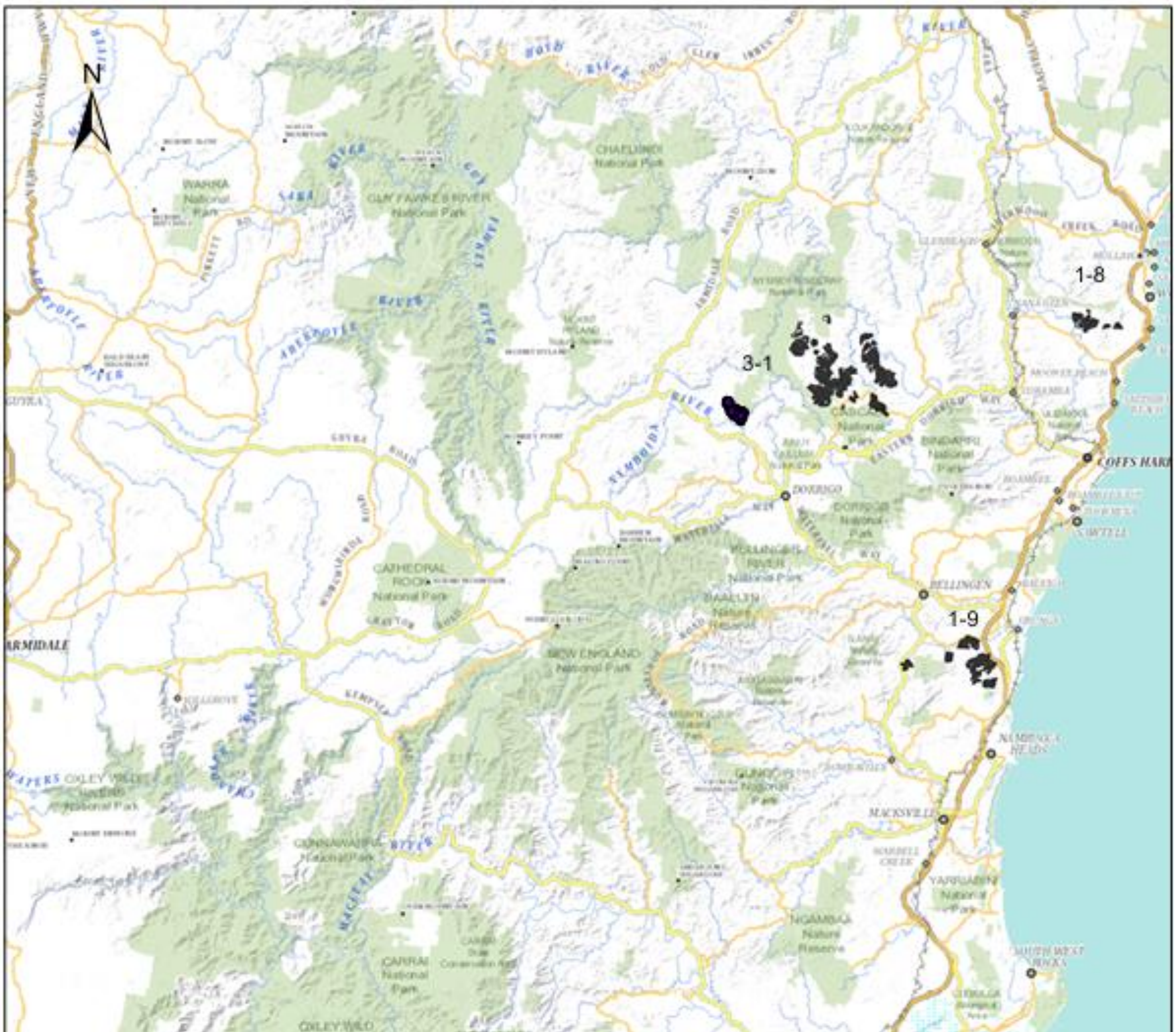


Map 1.2. Central Region (Forestry Corporation NSW, 2017)

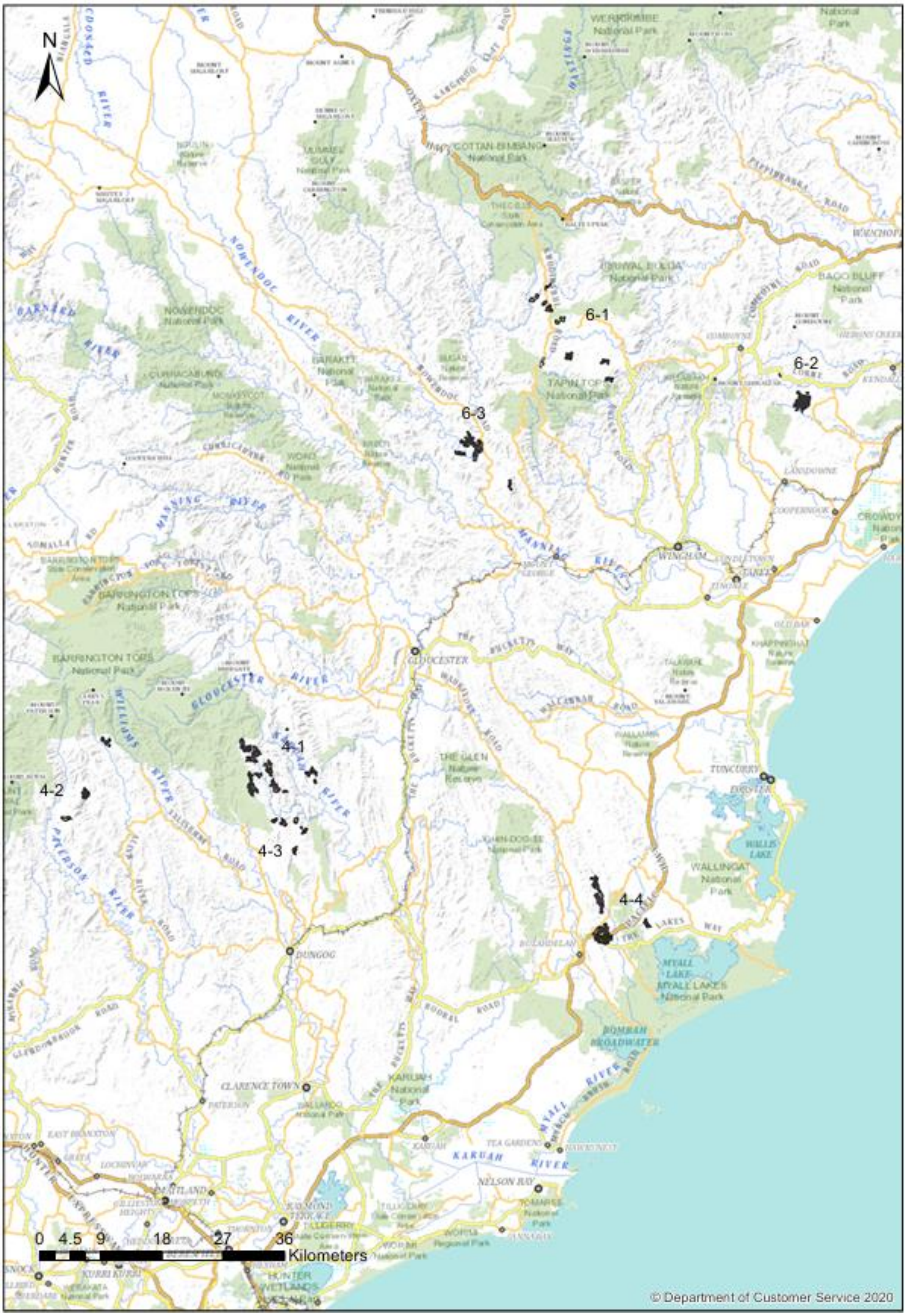
Appendix 2: Plantation locations



Map 2.1. Plantation locations in regions 1 and 2



Map 2.2. Plantation locations in regions 1, 3, 5 and 7.



Map 2.3. Plantation locations in regions 6 and 4.

Appendix 3: Stumpage price schedule

Log prices by species, size and region (Forestry Corporation of NSW, 2024.

Price Zone	Species Group	Size Classes						
		20-29	30-34	35-37	38-39	40-49	50-69	70+
Coastal North	Select Hardwoods	$26.49	$42.20	$67.42	$93.92	$128.66	$155.68	$189.13
	Key Hardwoods	$26.35	$41.99	$67.08	$94.08	$128.01	$154.89	$188.17
	High Value Hardwoods	$20.46	$32.60	$52.09	$73.06	$99.40	$120.28	$146.12
	Mixed Hardwoods	$18.19	$28.98	$46.30	$64.94	$88.35	$106.91	$129.88
	Tableland Hardwoods	$11.19	$15.76	$25.17	$36.46	$50.78	$64.25	$79.11
	High Country Hardwoods	$12.19	$19.42	$31.02	$43.52	$59.21	$71.64	$87.03
North East Up River	Select Hardwoods	$23.05	$36.72	$58.66	$81.72	$111.95	$135.46	$164.57
	Key Hardwoods	$23.47	$37.39	$59.73	$83.78	$113.99	$137.93	$167.56
	High Value Hardwoods	$14.26	$22.72	$36.29	$50.90	$69.25	$83.80	$101.80
	Mixed Hardwoods	$7.73	$12.31	$19.67	$27.59	$37.54	$45.42	$55.18
	Tableland Hardwoods	$9.31	$14.82	$23.68	$33.21	$45.18	$54.67	$66.42
	High Country Hardwoods	$9.98	$15.89	$25.38	$35.60	$48.43	$58.60	$71.19
Northern Foothills	Select Hardwoods	$24.31	$38.74	$61.89	$86.22	$118.11	$142.92	$173.63
	Key Hardwoods	$23.06	$36.74	$58.70	$82.33	$112.02	$135.54	$164.67
	High Value Hardwoods	$16.81	$26.78	$42.79	$60.02	$81.66	$98.81	$120.04
	Mixed Hardwoods	$15.84	$25.24	$40.33	$56.57	$76.96	$93.12	$113.13
	Tableland Hardwoods	$10.55	$16.80	$26.85	$37.66	$51.23	$61.99	$75.31
	High Country Hardwoods	$9.62	$15.32	$24.48	$34.34	$46.72	$56.53	$68.68
Northern Tablelands	Select Hardwoods	$20.51	$36.76	$57.68	$79.40	$109.41	$135.51	$164.22
	Key Hardwoods	$21.06	$37.07	$59.35	$82.58	$113.32	$141.47	$174.34
	High Value Hardwoods	$16.78	$26.74	$42.71	$59.91	$81.51	$98.63	$119.82
	Mixed Hardwoods	$12.98	$24.77	$39.14	$52.92	$72.03	$86.75	$111.67
	Tableland Hardwoods	$11.78	$18.76	$29.96	$42.03	$57.18	$69.19	$84.05
	High Country Hardwoods	$8.32	$13.25	$21.17	$29.69	$40.39	$48.88	$59.38
Central Foothills	Select Hardwoods	$29.76	$47.41	$75.74	$105.52	$144.55	$174.91	$212.49
	Key Hardwoods	$26.64	$42.44	$67.80	$95.10	$129.39	$156.56	$190.21
	High Value Hardwoods	$20.31	$32.36	$51.70	$72.51	$98.65	$119.37	$145.02
	Mixed Hardwoods	$20.78	$33.11	$52.89	$74.19	$100.94	$122.14	$148.38
	Tableland Hardwoods	$11.24	$17.90	$28.60	$40.12	$54.58	$66.05	$80.24
	High Country Hardwoods	$8.93	$14.22	$22.72	$31.86	$43.35	$52.46	$63.73
Central Tablelands	Select Hardwoods	$18.33	$32.86	$51.57	$70.98	$97.81	$121.14	$146.81
	Key Hardwoods	$18.82	$33.14	$53.06	$73.82	$101.30	$126.47	$155.86
	High Value Hardwoods	$15.00	$23.90	$38.18	$53.56	$72.87	$88.17	$107.12
	Mixed Hardwoods	$11.60	$22.15	$34.99	$47.31	$64.39	$77.55	$99.83
	Tableland Hardwoods	$8.28	$13.19	$21.07	$29.56	$40.22	$48.66	$59.12
	High Country Hardwoods	$4.99	$7.94	$12.69	$17.80	$24.22	$29.30	$35.60
Central Up River	Select Hardwoods	$24.67	$39.31	$62.80	$87.49	$119.85	$145.02	$176.18
	Key Hardwoods	$23.70	$37.76	$60.32	$84.60	$115.11	$139.28	$169.21
	High Value Hardwoods	$17.07	$27.19	$43.44	$60.93	$82.90	$100.31	$121.87
	Mixed Hardwoods	$13.20	$25.20	$39.81	$53.82	$73.26	$88.23	$113.58
	Tableland Hardwoods	$10.27	$16.36	$26.13	$36.65	$49.87	$60.34	$73.31
	High Country Hardwoods	$7.89	$12.56	$20.07	$28.16	$38.31	$46.35	$56.31
Coastal South	Select Hardwoods	$28.08	$44.75	$71.49	$99.59	$136.43	$165.08	$200.55
	Key Hardwoods	$28.55	$45.49	$72.67	$101.93	$138.68	$167.80	$203.86
	High Value Hardwoods	$23.29	$37.12	$59.30	$83.17	$113.16	$136.92	$166.35
	Mixed Hardwoods	$17.54	$27.95	$44.65	$62.63	$85.21	$103.10	$125.26
	Tableland Hardwoods	$16.23	$25.84	$41.28	$57.90	$78.78	$95.32	$115.81
	High Country Hardwoods	$12.42	$19.79	$32.65	$47.00	$65.71	$75.02	$78.43

Appendix 4: Rainfall map

Map 4.1. Rainfall distribution across study area