Special Timbers Resource Assessment on Permanent Timber Production Zone Land

A report to Department of State Growth and Ministerial Advisory Council Special Timbers Subcommittee

Forestry Tasmania

September 2015

Executive Summary

This report provides an assessment of the special timbers resource on 812,000 ha of Permanent Timber Production Zone (PTPZ) land managed by Forestry Tasmania. Existing inventory and models were used along with new inventory plots and newly developed LiDAR-based imputation models to predict potential yields of blackwood, myrtle, sassafras, celery-top pine, silver wattle and Huon pine over the next 200 years.

Blackwood is the most abundant special species timber, followed by myrtle and celery-top pine. Only small amounts of sassafras and silver wattle are expected to be available, particularly in the longer-term. Available volumes of all special species timbers will drop from 2027, when a large proportion of the mature native forest in the eucalypt zone (which currently produces some special timbers) is expected to be replaced by regrowth forest in the harvest schedule. The majority of the resource is located in the northwest region of Tasmania.

A summary of the cat 4 plus utility sawlog resource for the target species over defined timeframes is contained in the following table.

	Estimated volume cat 4 plus utility sawlog (m^3/year) by time period	
Species	2015/16 to 2026/27	2027 onwards
Blackwood	4,275	3,095
Celery-top pine	130	10
Myrtle	270	225
Sassafras	90	50
Silver wattle	70	-
Total	**4,835**	**3,380**

Additionally, there is an estimated 3,545 m^3 of Huon pine sawlog (all classes) remaining in ‘accessible’ areas in the special timbers Huon pine zone. If this resource was salvage-harvested over the next 12 years (up to 2026/27) then 295 m^3 could be salvage-harvested each year.

Estimated volumes in this report are lower than previously reported targets for special timbers due to a reduction in the available landbase, longer rotations used for some species and more accurate volume estimates resulting from the rainforest modelling work using LiDAR.

It should be noted that:

- Reported volumes are estimates.
- Reported volumes are from within ‘provisionally couped up’ areas which are deemed to be suitable for harvesting. Obvious steep slopes, streamside reserves and areas requiring protection from harvesting have been excluded.
- Discounts have been applied to the modelled volumes to reflect the area within provisional coupes that is not actually harvested due to factors identified during detailed operational planning.
- Log product recovery factors have been applied to the modelled volumes to allow for levels of defect within special timbers trees that cannot be seen during field based forest assessment.
- Harvesting in the special timbers rainforest zone is assumed to be ground-based only.
- Commercial viability of accessing and harvesting the resource has not been reported and was not used as a limiting factor.
- Yield estimates are based on strategic (long-term) modelling of potential harvest levels over the next 200+ years, and any short-term estimates are indicative only. Forestry Tasmania’s annually updated three year wood production plan (http://www.forestrytas.com.au/forest-management/3yp) provides a more operationally feasible view of special timbers availability over the short-term.

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Background

The signatories to the Tasmanian Forest Agreement ("the TFA", signed on 22 November 2012) agreed at Clause 9 thereof that further work was required to define the resource and future supply for special timbers. This work was to be overseen by the Special Council, which convened a Special Timbers Subcommittee.

In order to assess the special timbers resource and supply options, the Subcommittee requested that Forestry Tasmania produce "a review and outline of options regarding methodology, assumptions and data requirements for resource identification and assessment by cost, timeframe and other issues" (Forestry Tasmania, 2013a).

Subsequently, the (then) Department of Infrastructure, Energy and Resources contracted Forestry Tasmania to produce an assessment of future potential wood volumes for special species timbers across Permanent Timber Production Zone (PTPZ) land and special timbers contingency areas under the TFA Act. This assessment was based on the resource assessment methodology (Forestry Tasmania, 2013a) agreed with the Special Timbers Subcommittee of the Special Council. Initially the scope of this assessment included the special timbers contingency areas established under the *Tasmanian Forests Agreement Act 2013* (now repealed); however, under the *Forestry (Rebuilding the Forest Industry) Act 2014* these areas were reclassified as Future Potential Production Forest and are now administered by the Crown Lands Minister and the Department of Primary Industries, Parks, Water and Environment (DPIPWE). The special timbers contingency areas are no longer recognised and this report focuses solely on PTPZ land.

Following the disbandment of the Special Council, Forestry Tasmania has continued with the resource assessment in accordance with the methodology agreed with the Special Council and in accordance with the contract with the Department of State Growth. The report is intended to inform the Department and be provided to the recently established Ministerial Advisory Council Special Timbers Subcommittee.

Introduction

This report provides an assessment of future potential wood volumes for special timbers across Permanent Timber Production Zone (PTPZ) land. Within the PTPZ there are five management zones which produce special timbers:

- Special Timbers Blackwood Zone (StBwd)
- Special Timbers Huon Pine Zone (StHpm)
- Special Timbers Rainforest Zone (StRft)
- Eucalypt Forest rich in Special Timbers Zone (StEuc)
- Eucalypt Zone (Euc)

The first three of these zones are managed specifically for the production of special timbers. The StEuc zone is managed for production of both eucalypt and special timbers, while the eucalypt zone consists of native forest which is managed principally for the production of eucalypt timber. The extent and location of each of the zones on PTPZ land is shown in Figure 1. Forestry Tasmania's field planners review all areas of PTPZ land to identify those areas that are both available and suitable for harvesting. This process ('couping up') is usually completed as an office-based exercise and excludes obviously un-harvestable areas such as steep slopes, streamside reserves and areas of special values requiring protection under the Forest Practices Code (Forest Practice Authority, 2015). The resulting area is called a provisional coupe. The area of provisional coupes in each of the management zones is generally less than the total area of production forest (Table 1) and it is this area that is used for modelling yields in the first instance.

Table 1. Total area of production forest within PTPZ land in each management zone and area of forest that is provisionally 'couped up' and potentially suitable for harvesting in each zone.

	Management Zone				
	StBwd	StHpm	StRft	StEuc	Euc
Production forest (ha)[1]	8,600	2,700	38,000	6,140	517,000
Provisional Couped Up Area (ha)[2]	6,900	1,400	14,200	6,140	338,000

1. Excludes plantations and areas zoned as protection under FT's Management Decision Classification System.
2. The area actually harvested is dependent on a detailed coupe level assessment to account for natural and cultural values and operational issues.

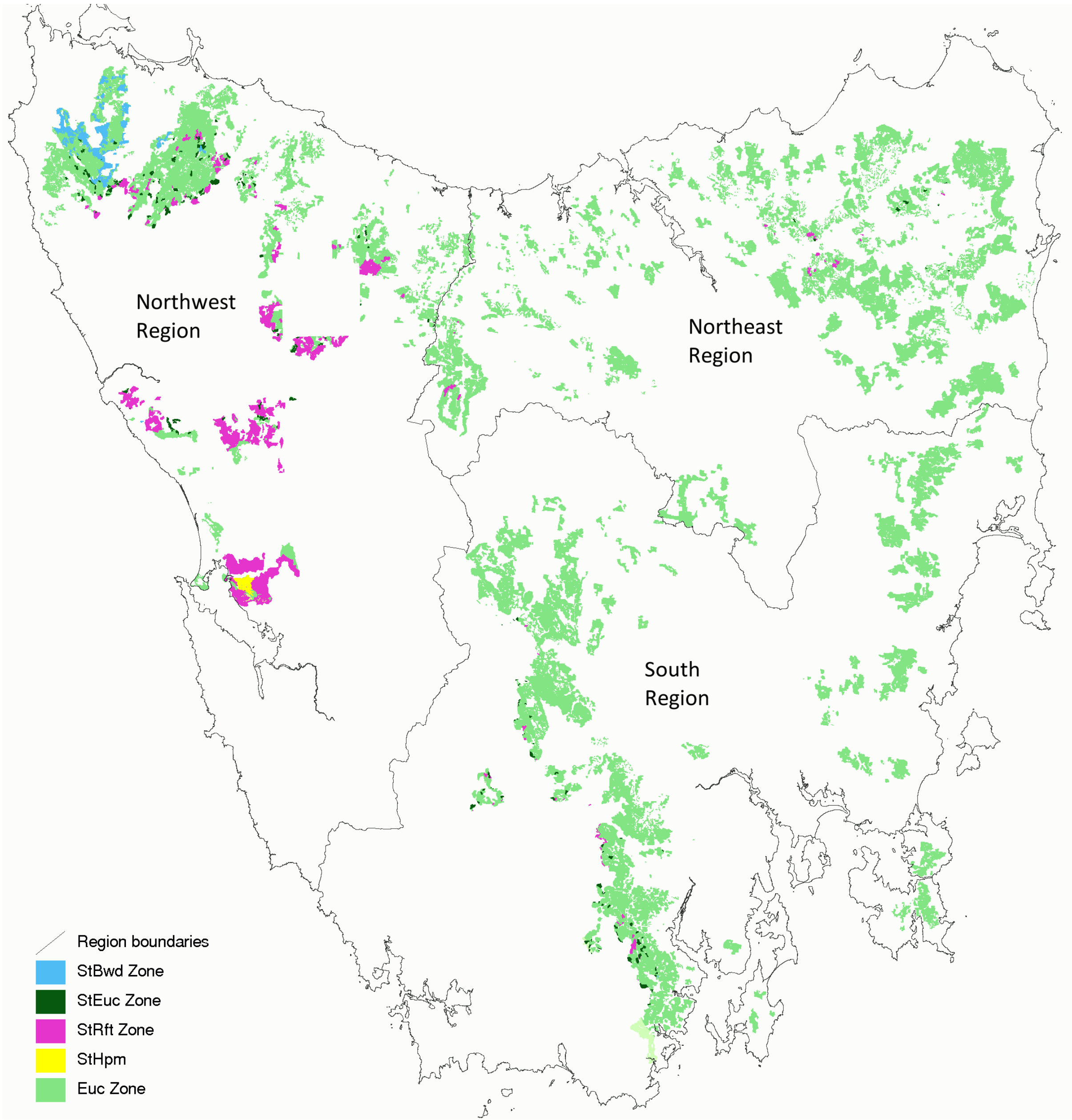

Figure 1. Location and extent of the management zones which produce special timbers. This map shows the area of production forest in each zone (see Table 1).

The methodology adopted for this resource assessment is largely as described in Forestry Tasmania (2013a). The proposed scope and methodology was independently reviewed by Prof. Andrew Robinson (Robinson, 2014), resulting in a number of recommendations which were largely adopted. This report provides details on the establishment and analysis of additional inventory plots, the use of remote sensing technology (LiDAR) to improve the resolution of mapped data for the relevant areas, and the modelling of future yields of special timbers for PTPZ land.

LiDAR is an airborne remote sensing technology that uses laser range finding to precisely measure forest canopy structure and the underlying terrain. Forest canopy measurements, together with traditional inventory plots, can be used to develop imputation models that, when applied across the landscape, provide an inventory of the forest with greater precision and at a finer spatial scale than could be achieved with inventory plots alone. The fine scale terrain measurements provide very detailed information about topographic features that are useful in operational planning for road access and harvest.

As noted in Forestry Tasmania (2013a), the scope of this assessment is PTPZ land managed by Forestry Tasmania and does not include forests on private property, or forests on public land that are managed by agencies other than Forestry Tasmania (including Future Potential Production Forest).

This report does not speculate about any potential for helicopter harvesting or underwater salvage, nor does it include any assessment of eucalypt logs and eucalypt craftwood that might be of interest to the relevant market. It also does not make any assessment of the commercial viability or costs associated with harvesting and/or extraction operations for the volumes identified.

This report adopts the definition of special timbers that is given in s. 3 of the *Forestry (Rebuilding the Forest Industry) Act 2014*, i.e.

(a) blackwood (*Acacia melanoxylon*);

(b) myrtle (*Nothofagus cunninghamii*);

(c) celery-top pine (*Phyllocladus aspleniifolius*);

(d) sassafras (*Atherosperma moschatum*);

(e) Huon pine (*Lagarostrobos franklinii*);

(f) silver wattle (*Acacia dealbata*); and

(g) any other timber that is prescribed by the regulations,

noting that, pursuant to (g), no other species of timber had been prescribed as a special timber at the date of this report.

Forestry Tasmania has recently concluded a review of the sustainable sawlog supply from the special timbers blackwood zone in north-west Tasmania (Forestry Tasmania, 2013b), and as such, no additional work has been done in this assessment to model yields from this zone. Volumes reported in the results section for this zone are sourced directly from the 2013 Review of Sustainable Blackwood Supply (Forestry Tasmania, 2013b).

As recommended in Forestry Tasmania (2013a), this report estimates yields separately for each species and, where possible, differentiates between Category 4 sawlog, utility log, outspec log and craftwood (see Appendix 1 for log specifications). This report does not attempt to provide meaningful forecast yields for any particular colour / grain subset of a species (e.g., deep red myrtle).

It should be noted that the yield estimates in this report are based on strategic (long-term) modelling of potential harvest levels over the next 200+ years, and any short-term estimates are indicative only. Forestry Tasmania's annually updated three year wood production plan (http://www.forestrytas.com.au/forest-management/3yp) provides a more operationally feasible view of special timbers availability over the short-term.

Methods

Since the special timbers resource is located within a number of different management zones distinct approaches to modelling yields from the various zones were necessary (Table 2). The general approach involves the use of inventory data to estimate gross volumes which are then discounted to account for operational constraints and actual recovered volumes (Figure 2). Inventory plot data is then projected forward using growth models, providing estimates of sustainable yield over time. A more comprehensive description of the methods used in each zone is provided below. The method used for the special timbers rainforest zone has highly technical elements relating to the use of LiDAR data which are fully described in Appendix B.

Table 2. Summary of methods used for estimating special timbers resource by zone.

Management Zone	**Overview of Method**
Special Timbers Rainforest (StRft)	Imputation of plot data based on complex analysis and modelling of LiDAR information.
Eucalypt (Euc)	Summary of special timbers resource forecast as arisings from the Eucalypt Zone in the Sustainable Yield Review No. 4 (Forestry Tasmania, 2014).
Eucalypt Forest rich in Special Timbers (StEuc)	Summary of special timbers resource forecast as arisings from the Eucalypt Forest rich in Special Timbers Zone in the Sustainable Yield Review No. 4 (Forestry Tasmania, 2014).
Special Timbers Huon Pine (StHpm)	Use of LiDAR topography and canopy information and analysis of recovered volume to refine the Huon pine resource review (Forestry Tasmania, 2005).
Special Timbers Blackwood (StBwd)	Volumes reported for the Special Timbers Blackwood Zone are sourced directly from the 2013 Review of Sustainable Blackwood Supply (Forestry Tasmania, 2013b) and do not include any volume from Fenced Intensive Blackwood coupes.

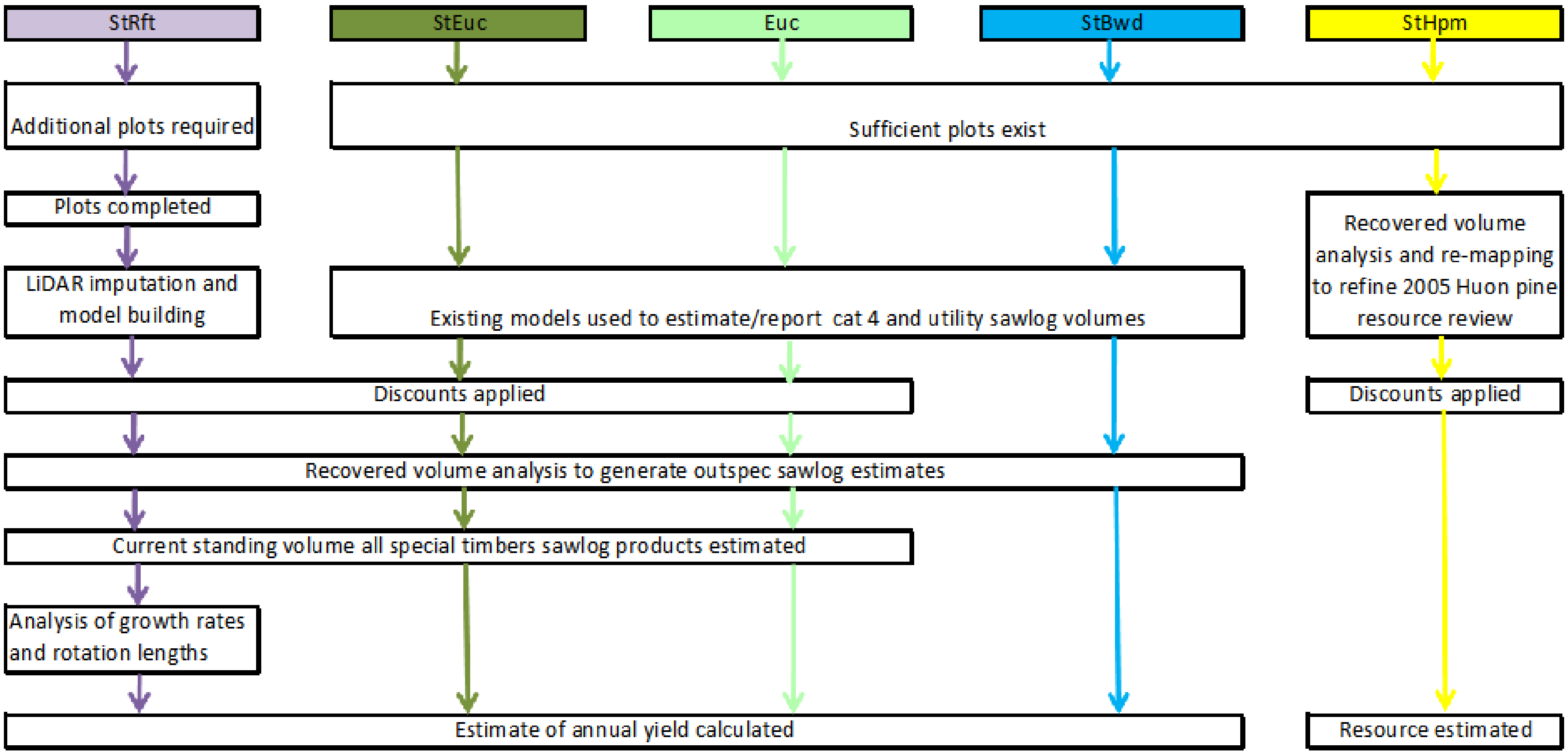

Figure 2. Flowchart summarising methods used for estimating special timbers resource by zone.

Special Timbers Rainforest Zone (StRft)

The goal of the rainforest inventory was to quantify the standing merchantable timber of each species and to map the distribution of these resources across the special timbers rainforest zone. To achieve this we combined forest inventory field data with remotely-sensed LiDAR data using machine learning methods. In this process, we imputed (or assigned) the library of forest inventory field plots across the study area in a statistically rigorous way, constructing raster-based maps at moderate resolution that defined the forest area and quantified the forest attributes. A general overview of the method follows, with more detailed methods and results of the inventory available in Appendix B.

Overview

As noted in Forestry Tasmania (2013a), the number of existing inventory plots in the special timbers rainforest zone was very low compared to the other zones, therefore an additional 150 field plots were established and measured (Figure 3). LiDAR data already existed for some of the area, and an additional 90 000 ha of LiDAR coverage was obtained. The full suite of LiDAR inventory plots (n=1603) were then used to build a forest classification model (Rainforest/Blackwood/Eucalypt/Non-forest) to assign each inventory plot to one of the classes. Imputation models were then constructed. During this process, known values from measured areas (inventory plots) are imputed, or assigned, to areas where these values are unknown (all couped up forest areas outside the plots) according to a computer-based algorithm. Predictor variables were based on LiDAR data and were derived at a 10 m cell resolution. Once the imputation model had predicted which plot was most suited to represent each 10 m x 10 m square of couped up forest in the special timbers rainforest zone, the volume of special timbers by species was estimated by collating the volumes predicted from the inventory plots across the zone. Field visits were made to a number of coupes in the special timbers rainforest zone to confirm that data generated by the imputation model was representative of the forest in reality.

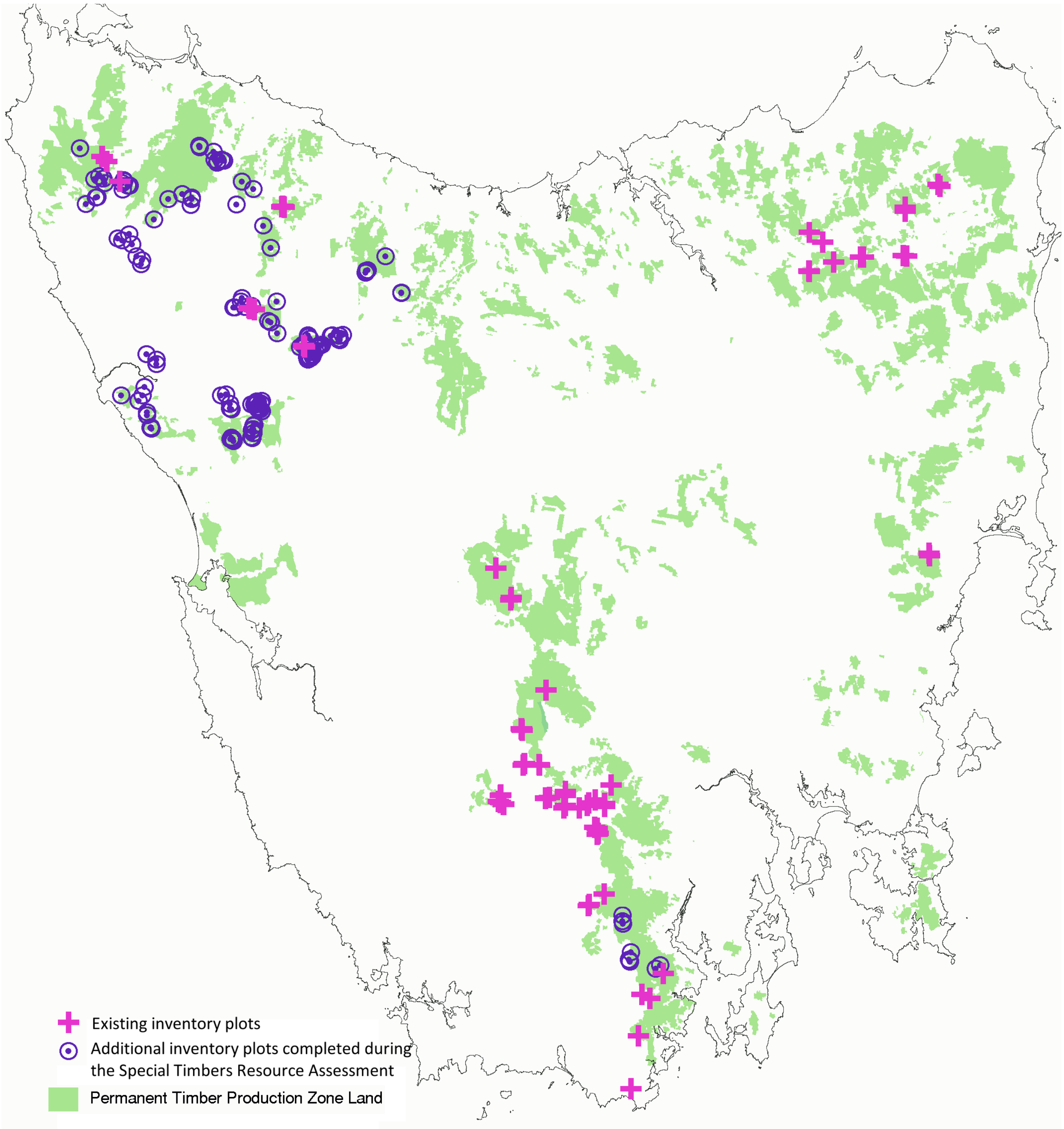

Figure 3. Location of special timbers rainforest zone inventory plots and PTPZ land.

An example of the classification applied to a 25 hectare area is provided in Figure 4. The area includes 2500 pixels (i.e., each pixel represents 10 m x 10 m). The map displays clumps of eucalypt forest embedded within a rainforest matrix. Very small pockets of non forest and blackwood forest also occur.

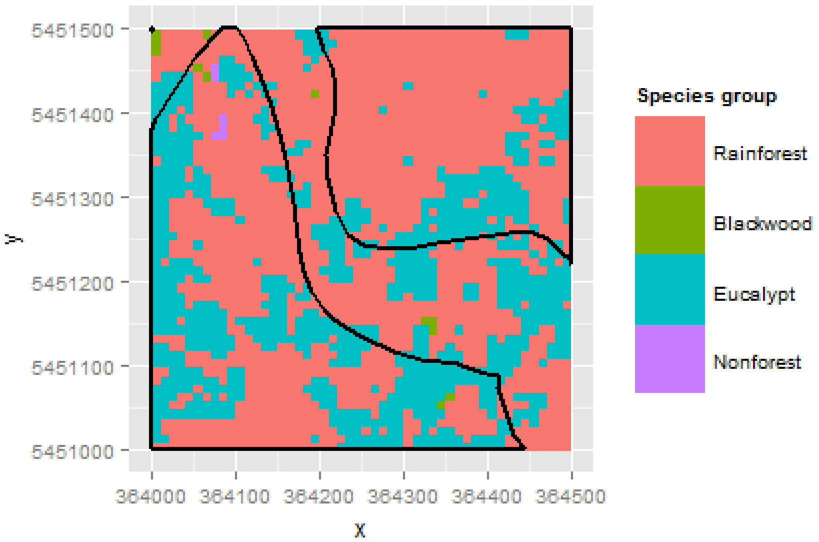

Figure 4. Mapped species group on a 25 hectare sample of LiDAR data with an overlay of special species coupe boundaries.

The imputed unique plot identifiers applied to the same 25 hectare area are shown in Figure 5. Over 200 unique plots are imputed into the area, indicating a high degree of variability in forest condition.

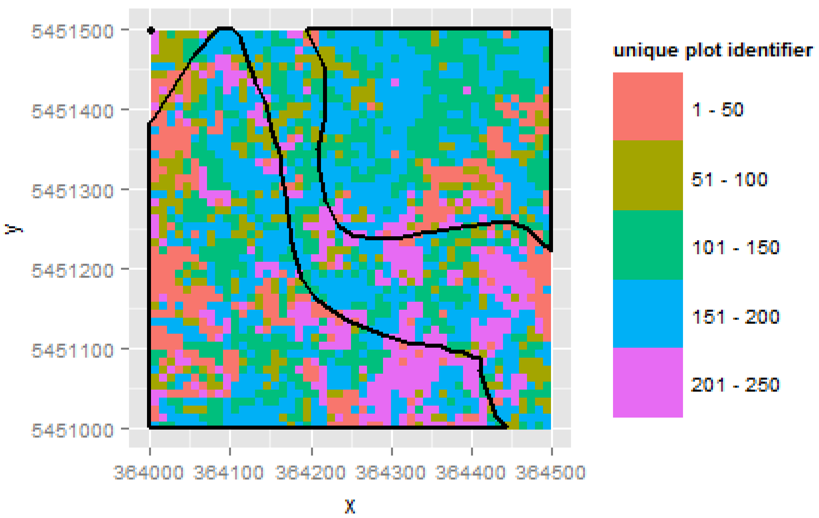

Figure 5. Mapped unique plot identifiers on a 25 hectare sample of LiDAR data with an overlay of special species coupe boundaries

Discounts

When estimating sustainable yield, both an area discount and a recovery factor are applied. Area discounts are applied to capture the area within the 'couped up' area that cannot be harvested for various reasons (e.g., previously unmapped streams, rocky ground or karst features). Historically, about 25% of eucalypt coupe area is discounted at the strategic planning level. For the special timbers rainforest zone an area discount of 10% was applied. The discount used for these coupes is smaller because an additional in-depth review of the harvest boundaries was conducted based on topographic information provided by LiDAR, identifying most of the areas to be excluded. In particular, all areas with slope greater than 19 degrees were excluded from the special timbers rainforest zone coupes, to ensure these coupes would be suited to conventional ground-based harvesting. Additional areas containing geomorphological features, biodiversity and/or archaeological values may still be identified during detailed pre-harvest field inspections and it is these areas that the 10% discount is designed to account for.

Log product recovery factor is a discount applied to assessed timber volumes in order to account for undetected internal defect. Forestry Tasmania maintains records of the production and sale of all its forest products, and records of actual recovered volumes are used to refine volume estimates derived from visual assessment of standing trees during plot measurement.

Mesibov (2002), discussed recovery factors for myrtle as follows:

> "Studies have shown that it is almost impossible to estimate ocularly the degree of defect in standing myrtle trees. An apparently sound myrtle may be shown to be almost entirely rotted when felled. Conversely, a myrtle which from ocular assessment would be judged to be rotten, can be shown to be sound when felled. A study of the ability of forest assessors to predict internal defect reliably from external appearance, showed that experience is of little value and a blind guess was as good as the considered opinion of an experienced assessor in most cases (FORTECH, 1982).
>
> In the 1970s and 1980s, Forestry Tasmania carried out several assessments of the myrtle resource in northwest Tasmanian rainforest (Davis 1998). The aim in each case was to improve both the accuracy and the precision of volume estimates. Assessments of gross bole volume and pulpwood volume were generally reliable, but sawlog results were very disappointing. Thirty-two of the 60 plots referred to above were

> included in a defect analysis carried out in 1985/86...The ratio of recoverable sawlog to assessed sawlog volume on the 32 plots averaged only 0.43."

An analysis comparing LiDAR-predicted volumes and actual recovered volumes for special timbers was conducted on six coupes which had a LiDAR surface captured prior to harvest. This analysis showed a ratio of recovered sawlog volume to predicted sawlog volume of 0.34. Based on this analysis and the myrtle recovery factor of 0.43 reported above, a log product recovery factor of 0.4 was applied for all species in the special timbers rainforest zone.

Growth rate and rotation length

The sustainable yield for a given species depends on its growth rate. When combined with a desired log diameter, growth rate can be used to determine the length of time needed to grow a commercial log (also known as the rotation length). Sustainable yield can then be calculated by dividing the current standing volume of each species by the rotation length of that species. Table 3 shows the desired log diameters and growth rates used in the calculation of the sustainable yield for the special timbers rainforest zone coupes. Growth rates for each species are based on expert opinion and were derived from an examination of FT tree growth data (4274 measured trees), published literature (Allen, 2002; Tyquin, 2005; Wood *et al.*, 2010) and unpublished data (Kathy Allen, pers. comm.).

Table 3. Desired log diameters and growth rates used in the calculation of the sustainable yield in the Special Timbers Rainforest Zone.

Species	Desired Log Diameter at Large End (cm)	Growth Rate (cm/year)	Rotation Length (Years)
Myrtle	90	0.30	300
Sassafras	45	0.15	300
Celery-top Pine	45	0.15	300
Blackwood	50	0.50	100
Silver Wattle	50	0.62	80

Log diameters used here reflect the approximate log sizes that are preferred by industry, rather than the minimum specifications for an acceptable sawlog. The specified diameter for Cat 4 myrtle logs is larger than for the other species since the deeper red colouring in myrtle correlates with older, larger trees. Larger diameter myrtle logs are also more likely to have larger volumes of heartwood free of rotten core (Mesibov, 2002).

Eucalypt Zone (Euc)

The forecast yields of special timbers sawlogs (Category 4 and Utility) from the eucalypt zone are as arisings from the scheduling of coupes for the harvest of high quality eucalypt sawlogs and eucalypt peeler logs. The harvest schedule used in this resource assessment for the eucalypt zone is as reported in the Sustainable Yield Review No. 4 (http://cdn.forestrytasmania.com.au/uploads/File/pdf/pdf2014/sustainable_yield_report_4_270314.pdf). Note that this harvest schedule reduces the proportion of mature forest harvesting in the eucalypt zone beyond 2026/27 and therefore is unlikely to yield any significant quantities of special timbers beyond this time.

The estimate of special timbers sawlogs follows the same method of estimating high quality eucalypt sawlogs (see Attachment 3 in the TFA Yield Estimates Methodology Report at http://cdn.forestrytasmania.com.au/uploads/File/pdf/pdf2014/tfa_yield_report_270314.pdf). This method involves inventory plot measurements at a point in time grown into the future by a growth model, where these plot measurements are available, otherwise expert opinion, and all estimates subsequently calibrated with historical harvest yields and area discounts applied. The historical harvest yields are also used to estimate the species distribution of special timbers sawlogs. Finally, regional planning staff assessed and adjusted some forest block estimates based on their local knowledge of the forest.

Eucalypt Forest Rich in Special Timbers Zone (StEuc)

The method used to model yields for this zone is the same as for the eucalypt zone described above. However, it is assumed that after the initial harvest the eucalypt forest rich in special timbers zone will be managed on a rotation length that is appropriate to the long-term supply of special timbers rather than eucalypt.

Calculation of Outspec Sawlog volumes

In the eucalypt, eucalypt forest rich in special timbers and special timbers rainforest zones, values for cat 4 and utility sawlog were calculated from mathematical models using current log specification measurements (Appendix A; Forestry Tasmania, 2008). Outspec sawlogs are special timbers logs that do not meet the cat 4 or utility log specification but are still desired by sawmills. Since there are no set specifications, the quantity of outspec logs cannot be calculated from models. Recovered volume data for the three years from 2012/13 to 2014/15 was used to calculate the ratio of cat 4 plus utility sawlog to outspec sawlog for each species. These ratios were then used to calculate an estimate of the amount of outspec sawlog based on the estimated amount of cat 4 plus utility sawlog across all relevant management zones.

Special Timbers Huon Pine Zone (StHpm)

Small quantities of salvaged Huon pine logs are recovered in the special timbers Huon pine zone coupes at Teepookana. This supply is augmented from time to time by very small quantities recovered from Macquarie Harbour and other beaches and estuaries. The other source of Huon pine is from the stockpile arising from the salvage of the Lake Gordon floodplain in the 1970s. This assessment includes only recovered volumes from Teepookana, and is based on an analysis of sales records from 1999 to 2013, a recouping of the salvageable area based on LiDAR topography information and a revision of the Huon pine resource review (Forestry Tasmania, 2005).

An accurate boundary of salvage/harvest areas from 1999 to 2013 was digitised based on LiDAR data, and volumes of Huon pine produced in the 1999 to 2013 period were obtained. Based on these figures, the recovered volume of Huon pine per hectare was calculated.

The report on Special Timbers Resources at Teepookana (Forestry Tasmania, 2005) was reviewed. For this report, areas of "Proven up", "Inferred" and "Prospective" Huon pine resource were mapped at a 'broadscale' based on aerial photos, photo interpretation to classify forest types, contour lines and drainage lines. Assessment data from 1987/88, based on a 5% of area on-ground inventory program, was compared with recovered volume data from the same year to refine the 1987/88 assessment estimated volumes.

When comparing the 'actual harvest area 1999-2013' sourced from LiDAR canopy mapping with the 2005 'broadscale' mapping of potential Huon pine resource, it became evident that only portions of the area defined by 'broadscale' mapping were being harvested. Actual harvest boundaries were constrained by site-specific factors such as steep slopes, unmapped streams and gutters, and areas of low or nil volume of Huon pine. An area discount figure was therefore calculated, and applied to the actual harvest area to predict how many hectares would have been harvested at the 'broadscale' mapping level.

The recovered volumes (1999-2013) were divided by the predicted 'broadscale' harvested area figure to generate revised volume per hectare estimates that could be applied to the remaining areas identified by the 2005 broadscale mapping.

An additional classification of “Steep” was added to the stratification of the 2005 potential Huon pine areas. The potential areas are now as follows:

- Accessible. The area is accessed by a current road and is suited to ground-based salvage / harvest operations.
- Difficult. The area is currently not accessed by road and may contain some areas of steep slopes and/or the ground is broken by numerous gutters.
- Steep. The majority of these areas have slope greater than 19 degrees and are not suited to ground-based salvage / harvest operations. Resource in this section was further reduced by 50% as a reflection of operational constraints.

Results

The estimated volumes of each species per year is reported below and classified into two time periods. The time periods reflect a short to medium and long-term view. The year 2026/27 was chosen to split the short to medium and long-term views since Forestry Tasmania's current contractual commitments to supply high quality eucalypt sawlog are until 2027 and correspond with a decrease in special timbers produced as arisings from eucalypt forest harvesting.

Blackwood is the most abundant special species timber, with 9,305 m^3/year available up until 2027, and 6,105 m^3/year available thereafter (Table 4). The main source of blackwood in both the short- and long-term is the special timbers blackwood zone (StBwd). The volume of blackwood estimated from the special timbers rainforest zone (StRft) is relatively small compared to the volume expected to be produced from the eucalypt zone (Euc) and eucalypt forest rich in special timbers zones (StEuc) up until 2027.

Table 4. Estimated volume (m^3/year) of blackwood sawlogs available from each of the relevant management zones by time period. Note that the cat 4 plus utility StBwd volumes are sourced from Forestry Tasmania (2013b) and do not include areas of Fenced Intensive Blackwood.

Blackwood		Volume by time period	
		2015/16 to 2026/27 (m^3/yr)	2027 onwards (m^3/yr)
Cat 4 plus utility	StBwd	3,000	3,000
	StRft	95	95
	StEuc	140	0*
	Euc	1,040	0**
Subtotal cat 4 + utility		4,275	3,095
Outspec	StBwd	2,850	2,850
	StRft	160	160
	StEuc	240	0*
	Euc	1,780	0**
Subtotal outspec		5,030	3,010
Total sawlog		**9,305**	**6,105**

* A small volume of blackwood may be produced from several StEuc coupes in the period 2027 onwards.
** A small volume of blackwood sawlogs may be produced in the period 2027 onwards from the Euc zone.

Myrtle is the second most abundant special species, with 750 m^3/year of myrtle sawlogs estimated to be available until 2026/27, and a small reduction in the volume available thereafter (Table 5). About one-third of the estimated volume consists of cat 4 plus utility sawlogs, with the remainder consisting of outspec logs. The majority of the myrtle resource is located in the special timbers rainforest zone, and from 2027 onwards, all myrtle sawlogs are sourced from this zone.

Table 5. Estimated volume (m^3/year) of myrtle sawlogs available from each of the relevant management zones by time period.

Myrtle		Volume by time period	
		2015/16 to 2026/27 (m^3/yr)	2027 onwards (m^3/yr)
Cat 4 plus utility	StRft	225	225
	StEuc	10	0
	Euc	35	0
Subtotal cat 4 + utility		270	225
Outspec	StRft	400	400
	StEuc	20	0
	Euc	60	0
Subtotal outspec		480	400
Total sawlog		**750**	**625**

The remaining special timbers species are much less abundant than blackwood and myrtle, and are more variable in supply. A total of 150 m^3/year of sassafras sawlog are estimated to be available until 2026/27, with a reduction in the volume available thereafter to 85 m^3/year (Table 6). For the period 2015/16 to 2026/27, 43% of the available sassafras resource will be produced from the harvest of coupes in the eucalypt and eucalypt forest rich in special timbers zones.

Table 6. Estimated volume (m^3/year) of sassafras sawlogs available from each of the relevant management zones by time period.

Sassafras		Volume by time period	
		2015/16 to 2026/27 (m^3/yr)	2027 onwards (m^3/yr)
Cat 4 plus utility	StRft	50	50
	StEuc	10	0
	Euc	30	0
Subtotal cat 4 + utility		90	50
Outspec	StRft	35	35
	StEuc	5	0
	Euc	20	0
Subtotal outspec		60	35
Total sawlog		**150**	**85**

Similarly, 290 m^3/year of celery-top pine is estimated to be available until 2026/27, but only a small volume available from 2027 onwards (20 m^3/year, Table 7). About 45% of this total volume consists of cat 4 plus utility sawlog. The cat 4 plus utility sawlog volume estimated to be available from the special timbers rainforest zone is only 10 m^3/year. There is considerably more celery-top forecast to be produced from the eucalypt and eucalypt forest rich in special timbers zones up until 2027.

Table 7. Estimated volume (m^3/year) of celery-top pine sawlogs available from each of the relevant management zones by time period.

Celery-top pine		Volume by time period	
		2015/16 to 2026/27 (m^3/yr)	2027 onwards (m^3/yr)
Cat 4 plus utility	StRft	10	10
	StEuc	40	0
	Euc	80	0
Subtotal cat 4 + utility		130	10
Outspec	StRft	10	10
	StEuc	50	0
	Euc	100	0
Subtotal outspec		160	10
Total sawlog		**290**	**20**

All silver wattle volume identified in this study was found within the eucalypt zone (Table 8). No commercial volumes of silver wattle exist in the special timbers rainforest zone or the eucalypt forest rich in special timbers. In total, 70 m^3/year of silver wattle sawlog is estimated to be available until 2026/27. Traditionally there has not been a demand for outspec silver wattle and Forestry Tasmania has no records of sales of outspec silver wattle in the last three years. Since outspec volumes in this report are calculated from the ratio of cat 4 plus utility sawlog to outspec sawlog sold over the last 3 years, the amount of outspec sawlog predicted for this species is zero.

Table 8. Estimated volume (m^3/year) of silver wattle sawlogs available from each of the relevant management zones by time period.

Silver wattle		Volume by time period	
		2015/16 to 2026/27 (m^3/yr)	2027 onwards (m^3/yr)
Cat 4 plus utility	StRft	0	0
	StEuc	0	0
	Euc	70	-*
Subtotal cat 4 + utility		70	0
Outspec	StRft	0	0
	StEuc	0	0
	Euc	0	0
Subtotal outspec		0	0
Total sawlog		**70**	**0**

*The volume of silver wattle sawlogs produced in the period post 2027 was not quantified in this assessment.

A summary of the volumes available by region shows that the majority of the resource is situated in the northwest region of Tasmania (Table 9). In the period up to 2026/27 there is about 90 m^3 per year to be produced in the northeast, most of which is blackwood, and about 430 m^3 per year spread across all species to be produced in the southern region. After 2026/27 there is very little volume, less than 10 m^3 per year, forecast to be produced in both the northeast and the south regions. The location of the regions is shown in Figure 1.

Table 9. Estimated volume (m^3/year) of special timbers sawlogs available by species, time period and region. See Figure 1 for extent of regions.

		Volume of cat 4 plus utility sawlogs (m^3/yr) by region			
Species	Time period	Northwest	Northeast	South	Total
Blackwood	2015/16 to 2026/27	4005	82	188	4275
	2027 onwards	3093	1	1	3095
Celery-top pine	2015/16 to 2026/27	25	0	105	130
	2027 onwards	8	0	2	10
Myrtle	2015/16 to 2026/27	232	5	33	270
	2027 onwards	215	5	5	225
Sassafras	2015/16 to 2026/27	48	2	40	90
	2027 onwards	47	2	1	50
Silver Wattle	2015/16 to 2026/27	0	3	67	70
	2027 onwards	0	-	-	-
Total	**2015/16 to 2026/27**	**4310**	**92**	**433**	**4835**
	2027 onwards	**3363**	**8**	**9**	**3380**

The results of the Huon pine assessment are presented as a finite resource. The Huon pine resource on PTPZ land at Teepookana Plateau consists predominantly of logs left on the forest floor following Huon pine harvesting about 100 years ago. In total, 5,315 m^3 of Huon pine sawlog and craftwood are currently estimated to be available in ‘Accessible’ areas, while a further 2,365 m^3 are located in ‘Difficult’ areas and 2,010 m^3 are from ‘Steep’ areas (Table 10).

Table 10. Estimated volume of Huon pine sawlogs available from the special timbers Huon pine zone.

Huon pine	Volume available		Supply period (years)	
	Sawlog (m^3)*	Craft (m^3)	Supply until 2026/27	At Average Volume since 1997
Accessible	3,545	1,770	12	21
Difficult	1,575	790	-	9
Steep	1,340	670	-	8
Annual Volume of Sawlog Supply (m^3)			295	168

*The quantities of sawlog reported include cat 4, utility and outspec in the percentages 57%, 33% and 10% respectively.

The annual volume supplied from the remaining Huon pine resource directly affects the number of years that Huon pine can continue to be supplied to industry. The two supply volumes outlined in Table 10 provide an indication of the potential longevity of the resource. If all of the 'accessible' volume was salvage-harvested over the next 12 years (up to 2026/27), then 295 m^3 could be salvage-harvested each year. Alternatively, if the rate of salvage harvest remains similar to that over the past 10 years (~168 m^3/year), 'accessible' volumes of Huon pine timber will last for 21 years.

Discussion

This report provides an assessment of the special timbers resource on 812,000 ha of Permanent Timber Production Zone land managed by Forestry Tasmania. Existing inventory and models were used along with new inventory plots and newly developed LiDAR-based imputation models to predict potential yields of blackwood, myrtle, sassafras, celery-top pine, silver wattle and Huon pine over the next 200+ years.

Blackwood is the most abundant special species timber, followed by myrtle and celery-top pine. Only small amounts of sassafras and silver wattle are expected to be available, particularly in the longer-term. Available volumes of all special species timbers will drop from 2027, when Forestry Tasmania's wood flow modelling reduces the proportion of mature forest harvesting in the eucalypt zone beyond 2026/27 (Forestry Tasmania, 2014). This zone is not expected to contribute significant volume for any species from 2027 onwards.

The Special Timbers Strategy (Forestry Tasmania, 2010) set a 10-year annual supply target of 500 m^3/year of cat 4 plus utility sawlog for myrtle, sassafras, celery-top pine and silver wattle. These figures were based on the larger available land base which was managed by Forestry Tasmania at that time (pre-TFA). By comparison, yields predicted until 2026/27 from this report are considerably lower: myrtle, 270 m^3/year; sassafras, 90 m^3/year; celery-top pine, 130 m^3/year and silver wattle, 70 m^3/year. Current prescriptions for special timbers management are based on a 200+ year rotation. However, our review of the growth rates for myrtle, celery-top and sassafras indicates that these species may require longer rotations to grow to commercial size. This has the effect of reducing the forecast annual yield from the forest that was derived in previous reviews of this resource.

The significant reduction from the targets set in the Special Timbers Strategy reflects the smaller landbase that is now available, longer rotations required for some species and more accurate volume estimates resulting from the rainforest modelling work using LiDAR.

LiDAR data has proven very useful in the course of this work, providing the basis for building imputation models as well as allowing a review of provisional coupe boundaries in the special timbers rainforest zone. Information from LiDAR-derived terrain products was also used to map the area of salvage-harvesting in the special timber Huon pine zone.

In the special timbers rainforest zone, areas with slope of greater than 19 degrees were excluded during a review of the provisional coupe boundaries to ensure that these coupes can be harvested using conventional ground-based machinery. Although cable harvesting of special timbers may be possible on some of the steeper ground, there is currently no experience with this type of harvesting in Tasmania.

Analysis of the resource available from the special timbers rainforest zone showed that myrtle and sassafras are often found together in the forest. There is also a loose correlation between the occurrence of celery-top and blackwood sawlogs. Silver wattle was predominantly found in areas that do not have sawlogs from the other special timbers species present.

Two key factors in quantifying the resource estimate from the special timbers rainforest zone were the area discount and the log product recovery factor. These two discount factors were derived from a combination of known data and expert opinion. In both instances the amount of quantifiable known data is small due to very small numbers of previous harvesting operations in representative forest. The accuracy of these two discount figures could be improved by collecting a number of years' worth of actual and representative data.

Although predicted yields of silver wattle in this assessment were low, growth data suggest that an 80 year rotation length would produce commercial sawlogs of this species. Since this species occurs commonly in dry eucalypt forest areas and rotation length is consistent with the rotation length of eucalypt forests, it is expected that silver wattle sawlog can be obtained from the Euc Zone on an ongoing basis.

For the special timbers Huon pine zone, at current average rates of salvage-harvest, the remaining resource will last for approximately 21 years (Table 10), although the supply of Huon pine to industry has been supplemented by logs from the Lake Gordon Huon pine stockpile and logs salvaged from Macquarie Harbour following flood events in the Gordon River. To further extend the period in which Huon pine can be supplied from the special timbers Huon pine zone, current ground-based salvage-harvest techniques would need to be modified to access the resource in the "Difficult" and "Steep" areas as defined above.

The majority of the special timbers rainforest zone is in the northwest region of the state. Approximately half of the coupes are remote and are not currently accessed by roads. During the process of refining coupe boundaries of the coupes within the special timbers rainforest zone, only topography within the coupe was considered. The specific rainforest type and potential volume of timber in the coupe along with the difficulty of building road access to the coupe were not used to influence the coupe boundaries. This assessment of special timbers volume focuses on the quantity of resource that could be harvested using ground-based harvesting equipment.

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Glossary of Terms and Acronyms

Category 4 sawlog	First-grade sawlog from special species timbers such as blackwood, myrtle, sassafras, celery top pine, Huon pine and silver wattle.
Coupe	For harvesting, Permanent Timber Production Zone Lands are subdivided into discrete areas called coupes.
Eucalypt Forest rich in Special Timbers Zone (StEuc)	These areas will be harvested by variable retention or clearfelling and regrown for at least 200 years. Includes eucalypt forest with an understorey rich in special timbers, which can be recovered during routine harvesting.
Eucalypt Zone (Euc)	The eucalypt zone is native forest which is managed for production of eucalypt timber.
Imputation	The process of replacing missing data with substituted values.
LiDAR	A remote sensing technology that uses light (laser) pulses to generate large amounts of data about terrain and landscape features.
Log product recovery factor	The ratio of recovered volume to estimated volume
Outspec logs	Outspec sawlogs are special timbers logs that do not meet the cat 4 or utility log specification tables but are still desired by sawmills.
Permanent Timber Production Zone (PTPZ) Land	Land managed by Forestry Tasmania under the *Forest Management Act 2013*.
Rainforest	Forest dominated by tree species such as myrtle, sassafras, celery-top pine and leatherwood, in which eucalypts comprise less than five per cent of the crown cover. Rainforest generally occurs in areas with high rainfall.
Silvicultural system/Silviculture	All the manipulations (e.g. harvesting, regeneration, thinning) carried out during the life time of forest stands or trees to achieve the management objectives of the landowner.
Special Timbers Blackwood Zone (StBwd)	Management for blackwood timbers production. Areas with tea-tree understorey are harvested by patch-clearfells whereas areas with myrtle understorey are selectively harvested. Includes blackwood swamps and fenced intensive blackwood.
Special Timbers Huon Pine Zone (StHpm)	Management for Huon pine production. Primarily salvage harvest of fallen trees and logs felled by the piners in the late 1800s and early 1900s. Protection from fire, disease and illegal harvesting
Special Timbers Rainforest Zone (StRft)	Management for special timbers production. Single tree and group selection (gaps are up to two tree lengths wide) harvests are prescribed and the majority of the canopy is retained at each cutting cycle. Nominal rotation lengths are at least 200 years. Protection from fire, disease and illegal harvesting
Sustainable yield	The level of commercial timber (or product mix) that can be maintained under a given management regime, without reducing the long-term productive capacity of the forest.
Utility logs	Logs which can be sawn but are below category 4 specification.

Appendix A. Special Timbers Sawlog Specifications

Special Species Timber Sawlog Sawlog Category 4 (Cat 4) and Utility		
Specifications for silver wattle, blackwood, sassafras, celery top pine, leatherwood, ti-tree and other special species timbers.		
Specification	**Cat 4**	**Utility**
Minimum Length	3.1 m	2.5 m
Minimum Small End Diameter	30 cm	25 cm
Limbs and Bumps[1]	3 of 4 faces clear (in 3.1m lengths)	2 of 4 faces clear (in 2.5 m lengths)
Spiral	1 in 8	1 in 8
Sweep	1 in 7	1 in 7
Scars[2]	¼ face - 3.1m in 3.1m	½ face - 2.5 m in 2.5 m
Borers[2]	Nil Evident	No significant evidence
End Defect		End-diameter < 30 cm u.b.-Nil.
	End-diameter 30-40 cm u.b. minimum of 10 cm radial ring clear of heart and sap.	End-diameter 30-40 cm u.b. minimum of 10cm radial ring clear of heart and sap.
	End-diameter > 40 cm u.b. as per Sawlog End Defect Limits Table.	End-diameter > 40 cm u.b. as per Sawlog End Defect Limits Table.

BLACKHEART (in sassafras)
To be classified Cat 4 or Utility sawlog, the blackheart **must be** visible in 1/3 of the radius in 3 of 4 quarters at **both ends** and extend from the core (pith) to beyond 1/2 of the radius at least twice at **one end**.

OUT-SPEC Special Species Timbers Logs

- Minimum length of 2.1 m

Special Species Timber logs, which cannot meet the specification tables, may be classified as OUT-SPEC.

Myrtle Category 4 (Cat 4) and Utility Sawlog

Myrtle logs with a mid diameter **= or >75 cm** will be classified as **Cat 4** and those **<75cm** will be classified as **Utility**.
Note: Myrtle Cat 4 and utility have the same "defect" criteria (listed below).

Specification	**Cat 4 and Utility**
Minimum Length	3.1 m
Min Small End Diameter	40 cm
Limbs and Bumps[1]	2 of 4 faces clear (in 3.1 m lengths)
Spiral	1 in 8
Sweep	1 in 7
Scars[2]	No 'old' scars evident
Borers[2]	Nil evident
End Defect	End-diameter < 40 cm u.b. Nil End-diameter > 40 cm u.b. as per Sawlog End Defect Limits Table.
Rot Pockets (in myrtle)	2 of 4 quarters clear

[1] Epicormic bumps on all species, and green limbs less than 5 cm in diameter on Celery Top Pine, are not considered to be bumps for the purposes of these specifications.

[2] Recent scars showing signs of callusing or borers are not considered to be a defect. No 'old' scars or borers are permitted for sassafras.

Sawlog Category 4 (Cat 4) **Huon pine and King Billy pine**		
SPECIFICATION	**CAT 4**	
Small End Diameter Class	40 cm	30 cm and < 40 cm
Minimum Length	1.8 m	3.0 m
Limbs, scars, holes and rot pockets	3 of 4 faces in each Minimum Length class shall be free of significant limbs[1], scars[2], holes[3] and rot pockets[4]. See **Notes** for definitions.	
Spiral	1 in 8. For example, not exceeding 30 cm of twist per 2.4 m log length.	
Sweep	Not exceeding 1/7 of the mid-diameter in each Minimum Length class or 2.4 m log length.	
End Defect	As per Eucalypt and Special Species Timber Sawlog End Defect Limit table.	
Hollow Logs[5]	If a log exceeds the End Defect Limit, but contains sound straight timber with a ring of solid wood **20 cm** in the radial direction at **both** ends, it will be classified as a CAT 4 Hollow Log (**C4-HL**).	
Flitches and Shells[6]	Sound, straight wood 1.8 m containing a slab/flitch free of defect where the average of the width (cm) + height (cm) is 27. Classified as a CAT 4 Flitch/Shell (**C4-FS**).	

Utility **Huon pine and King Billy pine**			
SPECIFICATION	**Utility**		
Small End Diameter Class	50 cm	40 cm and < 50 cm	25 cm and < 40 cm
Minimum Length	1.2 m	1.8 m	2.4 m
Limbs, scars holes and rot pockets	2 of 4 faces in each Minimum Length class length shall be free of significant limbs[1], scars[2], holes[3] and rot pockets[4]. See Notes for definitions.		
Spiral	Not applicable		
Sweep	Not applicable		
End Defect	- as per Eucalypt and Special Species Timber Sawlog End Defect Limit table.		
Hollow Logs[5]	If a log exceeds the End Defect Limit, but contains sound straight timber with a ring of solid wood **12 cm but <20 cm** in the radial direction at **both** ends, it will be classified as a Utility Hollow Log (**UT-HL**).		
Flitches and Shells[6]	Sound, straight wood 1.8 m containing a slab/flitch free of defect where the average of the width (cm) + height (cm) is 20. Classified as a Utility Flitch/Shell (**UT-FS**).		

Appendix B. Detailed inventory methods for the Special Timbers Rainforest Zone

Background

A two stage modelling approach was used to develop the inventory on rainforest coupes within the PTPZ. In the first stage a four-class forest classification model (Rainforest / Blackwood / Eucalypt / Nonforest) was constructed using data drawn from all native forests across the estate. In the second stage, imputation models were constructed for each special timbers bearing forest class. These models drew upon the relevant respective subsets of the data.

Data

Plot data comprised an existing library of LiDAR plots established across the full range of forest types that are present on the PTPZ, which were augmented by an additional set of plots that were placed in the rainforest coupes. The former were established using a random sampling schema that was pre-stratified by Forest Class (FC2011). The data were subsequently post-stratified based upon the observed forest type on the plot. The latter were targeted to known areas of rainforest to ensure that the available field data was representative of the resource. Plots were located within 300 m of drivable roads or tracks to enhance the efficiency of the inventory program.

Field plots were circular, with variable size to ensure an appropriate number of trees were measured. In mature and mixed-age eucalypt dominated forests and rainforests they had a radius of 20.0 m (1257 m^2). In pure regrowth and silviculturally regenerated forests they had a radius of 12.0 m (452 m^2). Field plot centres were geolocated using a Trimble GPS unit. At least 200 GPS points were recorded at each plot and these were differentially corrected in a post processing step that ensured sub-metre planimetric standard errors.

On each field plot, the magnetic bearing and horizontal distance to all trees with stem overbark diameter at 1.3m above ground (D) over 10cm was recorded. The tree species, total height and D of all trees over 10cm were recorded. All tree D were measured using diameter tapes. A Vertex ultrasonic hypsometer was used to measure total tree heights and tree distances from the plot centre. Ocular estimates of average canopy height and percentage canopy cover for all understory species with estimated canopy cover over 10% were also recorded. Three photos were taken from the plot centre facing north, south and vertically.

These provided a qualitative record of field plot conditions. Mean dominant height (H) was estimated as the weighted average of field measured tree heights (50 tallest trees/ha). Bark thickness was estimated from unpublished Forestry Tasmania models. Basal area was calculated using underbark D and stand stocking (S).

The LiDAR data were acquired using an Optech Pegasus discrete-return scanner. The maximum scan angle was set at 20° from nadir and the minimum point density was 200 points per 10 square meters. Up to four returns were recorded per pulse. The data were classified as ground or non-ground using proprietary algorithms and delivered in LAS 1.2 format (an open source binary standard data format). Each LAS file comprised a 600×600 metre tile with a 50 metre overlap to tiles adjacent. Vegetation height was calculated after interpolating a 1 metre resolution digital terrain model from the ground-classified returns using a multi-level B-spline (Lee et al. 1997).

LiDAR Data Processing

LiDAR returns with a 5 metre buffer that were spatially coincident to the field plots were extracted from the delivered data and range of candidate predictor variables then calculated by means of two separate processes. In the first process, the returns were clipped to the extents of the field plot boundaries and numerous grid-based candidate predictor variables were then extracted. These comprised percentiles and moments of both vegetation height and intensity, proportions of returns within vegetation height and intensity strata defined in both absolute and relative terms. In the second process, a 0.5 metre resolution canopy height model (CHM) was interpolated from the vegetation height data for each field plot. The CHMs were then clipped to the extents of the field plot boundaries and pixel metrics were then calculated from the CHM rather than the raw data in order to focus on the overstorey. The Tasmanian 1:25 000 elevation model was used to create a suite of terrain metrics, including topographic position and soil wetness. In total, 174 candidate predictor variables were available for modelling. One consequence of deriving such a large list is that it is likely to contain numerous spurious variables. In both stages of model building feature selection methods were used to identify important predictor variables and improve model accuracy.

An inspection of the LiDAR return profiles and tree height distributions for each plot identified a small number of outliers. These were removed from the analysis. Plot locations are mapped in Figure A1.

All LiDAR processing and modelling work was undertaken using open-source software. The principle software tool used was the R language and environment (R Core Team, 2014) with the additional packages: sp (Pebesma and Bivand, 2005; Bivand *et al.*, 2008), MBA (Finley and Banerjee, 2010), data.table (Dowle and Short, 2011), moments (Komsta and Novomestky, 2007), rgdal (Keitt *et al.*, 2010), foreach (Revolution Analytics, 2011) and doRedis (Lewis, 2012). The high computing load involved in generating large area rasters was accommodated using 48 Xeon cores in a virtual machine cluster that was managed using redis (Macedo and Oliveira, 2011) on an openSUSE 11.0 Linux operating system.

Forest classification methods and results

The full suite of LiDAR series plots were used to build a forest classification model. Trees within plots were assigned to one of four species groups. Plots were assigned to one of four classes according to the basal area proportions of each species group on the plot. A cross tabulation of inventory code versus plot species code appears in Table A1. Twenty-two of 243 LIRA plots contained a substantial eucalypt component and were classed as eucalypt plots. Fourteen of twenty LIWA plots (nominally measured in blackwood stands) contained a substantial myrtle/sassafras component and were classed as rainforest plots. Several further reclassifications were required.

Five modelling approaches were then tested in a 10-fold cross validation of the dataset.

- Approach 1 used a random forest (RF) algorithm (Breiman 2001, Liaw and Wiener 2002) to build the species group classification utilising all the candidate predictor variables.
- Approach 2 used a guided regularized random forest (GRRF) algorithm (Deng and Runger 2013) to build the species group classification utilising those candidate predictor variables identified in Approach 1 and their importance scores to tune the algorithm.
- Approach 3 used a gradient boosted machine (GBM) algorithm (Friedman 2001) to build the species group classification utilising all the candidate predictor variables.
- Approach 4 used a GBM algorithm to build the species group classification utilising those candidate predictor variables identified in Approach 1.
- Approach 5 used a GBM algorithm to build the species group classification utilising those candidate predictor variables identified in Approach 2.

These approaches were compared by inspecting contingency tables, and calculating accuracy and concordance measures for each approach. The accuracy and concordance measures (Dimitriadou *et al.*, 2008) arising from the analysis appear in Table A2. The accuracy statistic is a measure of the proportion of groups correctly classified averaged over all groups. The concordance measure compares the accuracy of the classification against that which would be classified by chance, with values of one indicating perfect agreement and values of 0 indicating lack of agreement. An inspection of these results indicates that the GRRF algorithm utilising a select list of variables displays greater accuracy and concordance than the RF algorithm. In contrast, the GBM algorithm performance declines as candidate variables are removed from the list (declining accuracy and concordance). Overall, the best result is obtained using the GBM algorithm with all candidate variables.

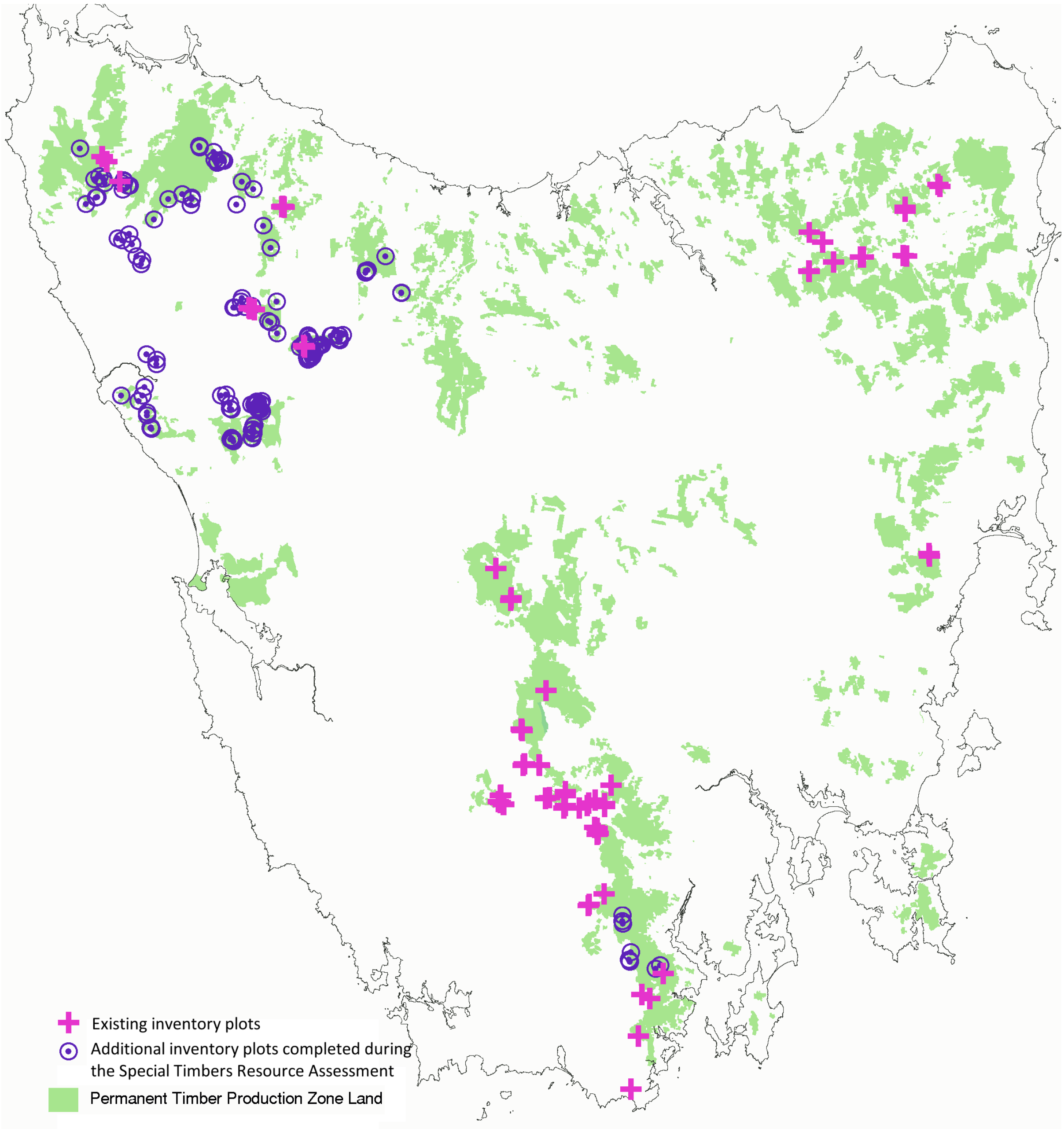

Figure A1. Location of special timbers rainforest zone inventory plots and PTPZ land.

Table A1. Crosstable of field plot inventory code versus field species group.

		Species group				
		Rainforest	Blackwood	Eucalypt	Nonforest	Total
LiDAR inventory series	LIRE	2	4	514	1	521
	LIMI	0	2	246	0	248
	LIMA	5	0	329	0	334
	LIWA	14	5	1	0	20
	LIRA	220	1	22	0	243
	LIFA	0	0	0	237	237
	Total	241	12	1112	238	

Table A1. Accuracy and concordance measures arising from the five modelling approaches applied to species group classification.

approach	Accuracy	Concordance
1	0.9108	0.811841
2	0.9364	0.86377
3	0.9507	0.89663
4	0.9482	0.891416
5	0.9414	0.877807

The contingency table arising from application of approach 3 appears in Table A3. The few blackwood plots are poorly predicted, whereas the other plots are comparatively well predicted. Behaviour of this type is typically observed when applying the GBM algorithm to unbalanced datasets.

Table A3. Contingency table arising from application of approach 3 showing observed numbers of plots of each species group versus the predicted number of plots of each species group

		Reference				
		Rainforest	Blackwood	Eucalypt	Nonforest	Total
Prediction	Rainforest	215	4	34	0	253
	Blackwood	0	1	3	0	4
	Eucalypt	26	7	1072	1	1106
	Nonforest	0	0	3	237	240
	Total	241	12	1112	238	

The confusion matrix arising from application of approach 3 appears in Table A4. The sensitivity metric for each species group is calculated as the proportion of *observed* plots that are correctly identified. The specificity metric for each species group is calculated as the proportion of *unobserved* plots that are correctly identified. The prevalence metric for each species group is calculated as the proportion of the total plots. The detection rate metric for each species group is calculated as the proportion of the total plots that are correctly identified. The detection prevalence metric for each species group is calculated as the proportion of the total plots that are identified. Taking the rainforest species group as an example, we can see that 89.2% of the rainforest plots were correctly identified as being rainforest (sensitivity = 0.892). 97.2% of the non-rainforest plots were correctly identified as being non rainforest (specificity = 0.972), i.e. 2.8% of the non-rainforest plots were incorrectly identified as rainforest. Rainforest plots made up 15.0% of the total sample (prevalence = 0.15). Rainforest was correctly identified in 13.4% of the sample (detection rate = 0.134) and identified in 15.8% of the sample (detection prevalence = 0.158).

Table A4. Confusion matrix arising from application of approach 3 showing sensitivity specificity, prevalence, detection rate and detection prevalence of each species group. See text for explanation of these terms.

	Rainforest	Blackwood	Eucalypt	Nonforest
Sensitivity	0.892	0.083	0.964	0.996
Specificity	0.972	0.998	0.931	0.998
Prevalence	0.150	0.007	0.694	0.149
Detection rate	0.134	0.001	0.669	0.148
Detection prevalence	0.158	0.002	0.690	0.150

Forest imputation methods and results

In the next stage, the same field plots were used to develop imputation models for the rainforest and eucalypt forest areas. The blackwood plots were subsumed into the Rainforest for this analysis. Gradient boosted machines are not suitable for classification problems with large numbers of classes so only the RF algorithm and GRRF algorithm were evaluated for this purpose.

In this stage, a feature selection procedure was applied to identify the candidate explanatory variables from the LiDAR data set that were most likely to have responded to the field observed data. This feature selection procedure entailed modelling a range of separate continuous response variables derived from the tree lists using the random forests algorithm. The performance of the models was inspected. Where models demonstrated efficacy in describing the continuous response variables, the list of explanatory variables contributing to the model was recorded. Having generated a reduced list of candidate variables through this feature selection procedure, we then built the imputation models. In the case of the rainforest species group plots, the modelled continuous response variables comprised mean dominant height (H), stocking (S), total basal area (G), blackwood basal area (BLA G), silver wattle basal area (WAT G), sassafras basal area (SAS G), celery-top pine basal area (CTP G), and myrtle basal area (SAS G). In the case of the eucalypt species group plots, the modelled continuous response variables comprised mean dominant height (H), stocking (S) and total basal area (G) only.

We used three statistics to evaluate the imputation models. These were calculated for each of the continuous response variables.

Mean deviation of the residuals, a measure of bias, was defined by:

$$MD = \frac{\sum_{i=1}^{n} y - \hat{y}}{n} \qquad (1)$$

Mean absolute deviation of the residuals, a measure of precision, was defined by:

$$MAD = \frac{\sum_{i=1}^{n} abs(y - \hat{y})}{n} \qquad (3)$$

Spearman's *rho* statistic, another measure of precision is given by:

$$\rho = 1 - \frac{6\sum(x_i - \hat{x}_i)}{n(n^2 - 1)}$$

Where *n* is the sample size, y_i and $\hat{y}_i$ are the observed and imputed continuous response variables respectively, and x_i and $\hat{x}_i$ are the ordered ranks of the respective variables.

Results of the imputation model evaluation appear in Table A5. The GRRF model results displayed the lowest bias (lower MD in 7 of 11 metrics), but the differences between the two approaches were minimal. The GRRF algorithm predicts individual species basal area with higher precision (lower MAD in 3 of 5 metrics and higher rho in 4 of 5 metrics), but at a cost to overall precision (higher MAD and lower rho in all 6 metrics). The Spearman's rho statistic was significant ($p < 0.001$) for every metric except CTP G ($p > 0.05$), indicating that application of either imputation model results in a higher precision inventory than one which can be achieved using the plots alone. On the basis of its superior performance as a generalist predictor of forest metrics the RF algorithm was chosen as to apply in the inventory.

Table A5. Imputation model evaluation results.

	Statistic	MD		MAD		Spearman's rho	
	Algorithm	RF	GRRF	RF	GRRF	RF	GRRF
Rainforest	H	0.021	-0.090	3.222	3.971	0.624	0.435
	S	-7.580	0.878	321.438	353.138	0.408	0.362
	G	-0.649	-3.164	21.711	22.241	0.383	0.335
	BLA G	0.128	-0.014	2.448	2.178	0.322	0.422
	WAT G	0.382	0.065	1.325	1.609	0.059 *	0.224
	SAS G	-0.364	-0.282	5.761	5.489	0.485	0.492
	CTP G	-0.013	-0.026	0.445	0.463	0.334	0.263
	MYR G	-0.512	-2.467	18.951	18.890	0.318	0.325
Eucalypt	H	0.370	0.248	4.029	5.067	0.869	0.766
	S	19.459	7.971	402.208	426.019	0.480	0.441
	G	-2.522	-2.380	24.774	27.013	0.777	0.669

* indicates non-significant result at the 0.05 level.

The candidate predictor variables together with the imputed plot identifier were derived over the study area at a 10 metre cell resolution. An example of the classification applied to a 25 hectare area is provided in Figure A2. The area includes 2500 pixels. The map displays clumps of eucalypt rich forest embedded within a rainforest matrix. Very small pockets of non-forest and blackwood-rich forest also occur.

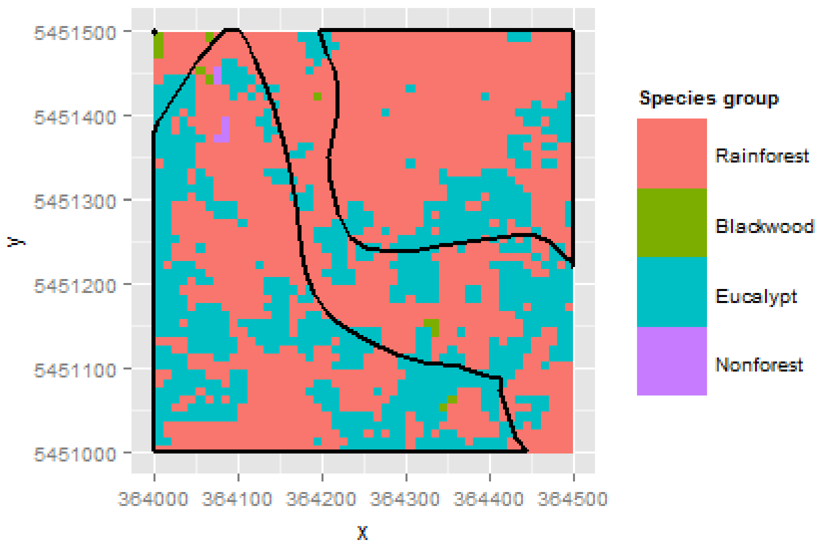

Figure A2. Mapped species group on a 25 hectare sample of LiDAR data with an overlay of special species coupe boundaries.

The imputed inventory series applied to the same 25 hectare area is shown in Figure A3. The eucalypt clumps through the centre of the area are predominately regrowth. Predominately mature eucalypts are found to the western and eastern boundaries.

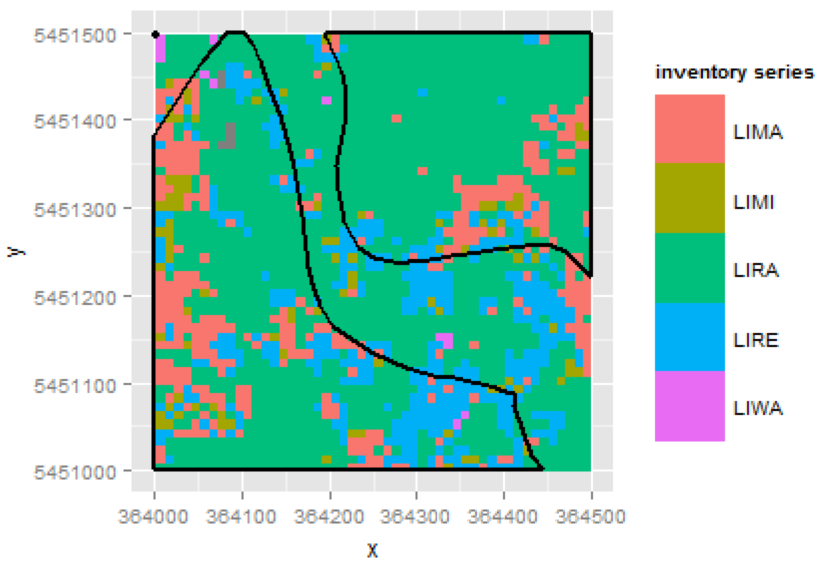

Figure A3. Mapped Inventory series on a 25 hectare sample of LiDAR data with an overlay of special species coupe boundaries.

The imputed unique plot identifiers applied to the same 25 hectare area appear in Figure A4. Over 200 unique plots are imputed into the area, indicating a high degree of variability in forest condition.

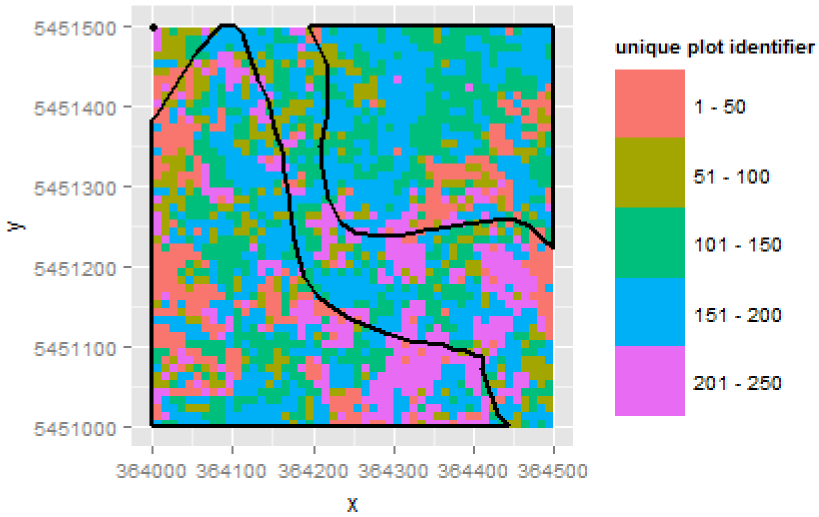

Figure A4. Mapped unique plot identifiers on a 25 hectare sample of LiDAR data with an overlay of special species coupe boundaries.

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