ARC Centre for Forest Value

Tasmania's submerged timbers: An assessment of potential resource volumes and the physical properties

October 2019

A report to the Department of State Growth, prepared by the ARC Training Centre for Forest Value.

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CHAPTER 1:

Resource assessment of Special Species Timbers located in hydro storages

Executive Summary

Five West Coast hydro impoundments have been investigated for their resource production potential being Lakes Gordon, Mackintosh, Burbury, Pieman and Murchison. It is estimated that a volume of up to 300 000 cubic metres of wood may lie beneath these lakes. The available volumes from Lakes Gordon, Pieman and Macintosh are significant. Limited volumes are available from Lakes Burbury and Murchison.

This volume estimate has been derived from a desktop analysis, informed by aerial photograph interpretation, vegetation mapping and expert opinion. As most of the available volume is submerged, precise estimates are impossible. The confidence limits around the estimate are unknown but are assumed to be significant.

The proportion of this wood by species is unknown, however some inferences or assumptions can be made based on location and historical records. The timber recovered from Lake Pieman to date is broadly one third eucalypt, one quarter celery-top pine, one quarter myrtle, with some quantities of blackwood, Huon pine, sassafras and leatherwood also being recovered.

Early estimates of the volume of wood that was recoverable from the hydro impoundments focussed on the special species timbers, as it was considered unlikely that the eucalypt component could be recovered economically. This has proven not to be so, and the eucalypt component at present, as above, is significant.

The proportion of wood that is recoverable and/or useable is unknown. For example, the wood that is currently submerged in Lake Gordon has been exposed to the air at times of very low water level. The impact that this may have had on the levels of decay in this wood is unknown. In addition, constraints may be imposed on access to recoverable and/or usable resources as a result of water level management by Hydro Tasmania.

Recovery of logs during the current operations on Lake Pieman have shown large differences between the early estimates, and the actual recovery, particularly by species. With time, the rates of recovery of timber from these operations will help to refine the forecasts. This will only apply to Lake Pieman.

Introduction

Prior to inundation, the areas that the hydro dams are now located within contained a wide array of vegetation communities ranging from buttongrass dominated sedgelands to tall wet eucalypt forest to cool temperate rainforest.

The resource assessment targeted those forest types that are known to contain eucalypt sawlog and/or a range of special species timbers (SST), that is, tall wet eucalypt forest communities dominated by one or more of *Eucalyptus delegatensis*, *E. obliqua*, *E. regnans* or *E. nitida*, and cool temperate rainforest.

The resource assessment of the logs available for salvage for the areas inundated by hydro schemes utilised the photo-interpreted coverage, GIS data, and vegetation mapping information that is available for the lake areas being investigated. Appendix 1.1 Maps 1 and 2 shows the sections of Lake Pieman with the current photo-interpreted (PI) typing shown surrounding the dam area. Using this information combined with old aerial photography images allowed extrapolation of the forest types into the inundated area to provide areas of interest for salvage operations (Figure 1). Lake Pieman can be seen fully classified in Appendix 1.1 Maps 3 and 4. Areas were mapped as high, medium or low potential to produce suitable logs from each lake (also referred to herein as 'suitability zones').

Aerial PI coverages of the hydro-dams and surrounding areas were obtained where available from Forestry Tasmania (now Sustainable Timber Tasmania). Using a stereoscope to view overlapping pairs of photographs, interpreters divide the vegetation into patches which appear to be visually homogeneous and boundaries are drawn where the canopy structure or species composition changes significantly (Stone 2010). Accurate photo-interpretation mapping of vegetation requires experience and great skill – it is not always obvious where one vegetation type merges into another. This is particularly true where rainforest intergrades with mature mixed forest, in which the density of emergent eucalypts can be quite variable. The PI coding system used is detailed in Appendix 1.2. For a complete description of the PI system see Stone (2010).

Areas mapped as 'High' were those areas with the greatest height potential including all tall eucalypt forest (E1 - E+3) with high densities (>=c) and tall rainforest (M+). Recoverable volumes in these forest types are estimated to range between 150 - 300 m^3/ha. However only some proportion (10 to 20%?) of this volume is likely to be suitable for sawing.

Areas mapped as 'Medium' were those areas of tall eucalypt forest with low density, and short rainforest (M-). Recoverable volumes in these forest types are estimated to range from 100 - 200 m^3/ha of total wood.

Areas mapped as 'Low' are all other forest PI codes including fire damaged (f'd) and cut-over (c'o) forest; volumes in this classification are highly variable, but as proved by timber salvaged in the initial trial, salvageable logs exist within previously cut-over areas.

Where possible the estimated volumes were confirmed through the use of sonar. Bathymetric surveys were also used to map lake depths. Lake depths were taken from the relevant Full Supply Levels.

The volume estimations are deliberately conservative. The log specifications for the recovered wood has no comparison to the log classifications system applied in routine terrestrial operations. The current maximum salvage depth for the active operation in Lake Pieman is 26 m. Volumes and areas have been assessed to a depth of 40 m to allow for variable lake levels.

A similar approach as described above was then applied to the other lakes considered to have resource potential for the current project, being Lakes Gordon, Macintosh, Burbury and Murchison. The areas were digitised onto GIS coverages for each of these lakes. GIS coverages produce area statements for each of the high, medium or low suitability zones, to the nearest tenth of a hectare. This implies a level of accuracy that is not supported by the nature of the approach. In the following tables areas have been rounded.

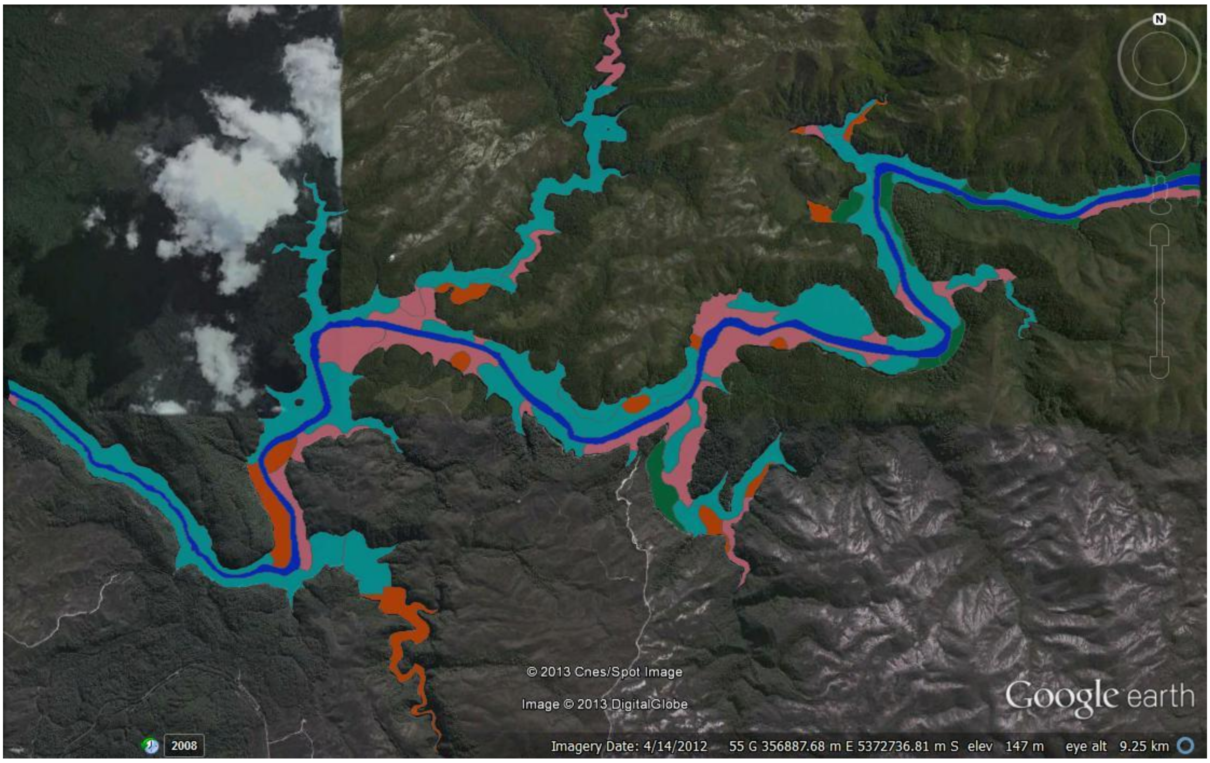


Figure 1: Lake Pieman inundation area classified into forest types through extrapolation of PI types and aerial photography.

Based on the PI typing areas were classified for suitability to the project as High (light blue), Medium (pink), Low (green), None (red) or River (dark blue). The classification allowed volume estimates of timber to be made for calculating a likely annual volume cut for salvage operations. Based on the analysis of Lake Pieman the following classification breakdown was achieved.

Table 1: Classification Breakdown of Lake Pieman in suitability classes for log salvage operations. Note that are areas shown have been rounded compared to the figures produced by the GIS.

Suitability	**Hectares**
High	500
Medium	700
Low	400
None	234
River	358
Total	2,190

Further details are provided for all five lakes: Gordon, Mackintosh, Burbury, Pieman and Murchison, in the tables that follow.

Resource estimates

Resource estimates are problematic given that the logs are under water, which means that estimates of standing volume cannot be based on individual stem assessments, stems cannot be assigned to particular species, nor can estimates be made of the recoverable volume from each stem. The original estimates of volumes were made from anecdotal estimates of sawlog volumes expected from various forest types and estimates made when conducting the early log salvage operations on Lake Pieman. Table 2 shows the predicted volumes based on the preliminary assessments. This is necessarily a conservative estimate of the volumes expected to be available for recovery in the salvage areas.

Table 2: Original resource estimate – Lake Pieman

Species	**Estimated % Composition**	**High Suitability (50 m^3/ha by 500 ha)**	**Medium Suitability (20 m^3/ha by 700 ha)**	**Total (m^3)**
Myrtle	70%	17640	10010	27650
Eucalyptus spp.	15%	3780	2145	5925
Other SST	15%	3780	2145	5925
Total	100%	25215	14280	39490

Table 3 shows the actual recovery of logs to date. The important point to note from this table is the degree of difference between the original estimates, as above, that were based on the best available information at the time, and the actual recovery. This illustrates very clearly the difficulties in forecasting the available volumes, and the degree of caution that must be applied when interpreting the resource assessments for the other impoundments under consideration. Note that early estimates of the volume of wood that was recoverable from the hydro impoundments focussed on the special species timbers, as it was considered unlikely that the eucalypt component could be recovered economically. This has proven not to be so, and the eucalypt component at present is significant.

Table 3. Actual recovery of logs from Lake Pieman to date (Andrew Morgan personal communication)

Species	Proportion
Eucalyptus spp.	33%
Celery-top pine	24%
Myrtle	23%
Blackwood	14%
Other SST	6%
Total	100%

'Other SST' is Huon pine, sassafras and leatherwood.

GIS analysis of potentially productive areas within each of Lakes Gordon, Mackintosh, Burbury, Pieman and Murchison

Table 4a. Lake Gordon, GIS analysis of suitability zone by depth (ha)

	Depth		
Suitability zone	**0-40 m**	**All**	**Total**
High	300	550	550
Medium	2600	4100	4100
Low	2000	2600	2600
Not classified			6400
None			13300
Existing water			125
Total	4900	7250	27075

Currently Lake Gordon is the only lake considered to have recoverable volume below 40 m depth, as Lake Gordon has historically had a very wide operating range. The impact that the significant fluctuations in the water levels of the lake may have had on the quality of wood submerged or otherwise in the lake remains unknown.

Table 4b. Lake Gordon, potential recovery by suitability zone by species (m^3/ha)

	Suitability zone		
Species	**High**	**Medium**	**Low**
Eucalypt	60	40	10
Myrtle	20	10	5
Sassafras	10	5	0
Celery Top	5	5	0
Total	95	60	15

Table 4c. Lake Gordon, potential production by species and suitability zone, 0 to 40 m depth (m^3)

	Suitability zone			
Species	**High**	**Medium**	**Low**	**Total**
Eucalypt	18000	104000	20000	142000
Myrtle	6000	26000	10000	42000
Sassafras	3000	13000	0	16000
Celery Top	1500	13000	0	14500
Total	28500	156000	30000	214500

Table 4d. Lake Gordon, potential production by species and suitability zone, all depths (m^3)

	Suitability zone			
Species	**High**	**Medium**	**Low**	**Total**
Eucalypt	33000	164000	26000	223000
Myrtle	11000	41000	13000	65000
Sassafras	5500	20500	0	26000
Celery Top	2750	20500	0	23250
Total	52250	246000	39000	337250

Table 5a. Lake Mackintosh, GIS analysis of suitability by depth (ha)

Suitability zone	All Depths
High	250
Medium	150
Low	90
Not classified	
None	
Existing water	2500
Totals	2990

There is no potential in Lake Mackintosh for areas deeper than 40 m.

Table 5b. Lake Mackintosh, potential recovery by suitability zone by species (m3/ha)

	Suitability zone		
Species	**High**	**Medium**	**Low**
Eucalypt	40	30	10
Myrtle	50	20	10
Sassafras	10	5	0
Celery Top	2	0	0
Total	102	55	20

Table 5c. Lake Mackintosh, potential production by species and zone, all depths (m3)

	Suitability zone			
Species	**High**	**Medium**	**Low**	**Total**
Eucalypt	10000	4500	900	15400
Myrtle	12500	3000	900	16400
Sassafras	2500	750	0	3250
Celery Top	500	0	0	500
Total	25500	8250	1800	35550

Table 6a. Lake Burbury, GIS analysis of suitability zone by depth (ha)

Suitability zone	All depths
High	0
Medium	150
Low	400
Not classified	1724
None	106
Existing water	2488
Total	4868

There is no potential in Lake Burbury for areas deeper than 40 m.

Table 6b. Lake Burbury, potential recovery by suitability zone by species (m3/ha)

	Suitability zone		
Species	**High**	**Medium**	**Low**
Eucalypt	10	10	10
Myrtle	10	10	10
Sassafras	10	5	0
Celery Top	2	0	0
Total	32	25	20

Table 6c. Lake Burbury, potential production by species and zone, all depths (m3)

	Suitability zone			
Species	**High**	**Medium**	**Low**	**Total**
Eucalypt	0	1500	4000	5500
Myrtle	0	1500	4000	5500
Sassafras	0	750	0	750
Celery Top	0	0	0	0
Total	0	3750	8000	11750

Table 7a. Lake Pieman, GIS analysis of suitability by depth (ha)

Suitability	**All Depths**
High	500
Medium	700
Low	400
Not classified	
None	234
Existing Water	358
Total	2192

There is no potential in Lake Pieman for areas deeper than 40 m.

Table 7b. Lake Pieman, potential recovery by suitability zone by species (m3/ha)

	Suitability zone		
Species	**High**	**Medium**	**Low**
Eucalypt	30	15	5
Myrtle	20	15	10
Sassafras	5	5	0
Celery Top	10	8	0
Total	65	43	15

Table 7c. Lake Pieman, potential production by species and zone, all depths (m3)

	Suitability zone			
Species	**High**	**Medium**	**Low**	**Total**
Eucalypt	15000	10500	2000	27500
Myrtle	10000	10500	4000	24500
Sassafras	2500	3500	0	6000
Celery Top	5000	5600	0	10600
Total	32500	30100	6000	68600

Table 8a. Lake Murchison, GIS analysis of suitability by depth (ha)

Suitability	All depths
High	60
Medium	60
Low	20
Not classified	260
None	0
Existing Water	38
Total	438

There is no potential in Lake Murchison for areas deeper than 40 m.

Table 8b. Lake Murchison, potential recovery by suitability zone by species (m3/ha)

	Suitability zone		
Species	**High**	**Medium**	**Low**
Eucalypt	40	15	10
Myrtle	10	5	5
Sassafras	5	5	0
Celery Top	0	0	0
Total	55	25	15

Table 8c. Lake Murchison, potential production by species and zone, all depths (m3)

	Suitability zone			
	High	**Medium**	**Low**	**Total**
Eucalypt	2400	900	200	3500
Myrtle	600	300	100	1000
Sassafras	300	300	0	600
Celery Top	0	0	0	0
Total	3300	1500	300	5100

Resource Assessment, volumes and areas, all lakes.

Table 9a. Total potential production, all lakes combined, 0 to 40 m depth (m3)

	Suitability zone			
Species	High	Medium	Low	Total
Eucalypt	45400	121400	27100	193900
Myrtle	29100	41300	19000	89400
Sassafras	8300	18300	0	26600
Celery top	7000	18600	0	25600
Total	89800	199600	46100	335500

Table 9b. Total potential production, all lakes combined, all depths (m3)

	Suitability zone			
Species	High	Medium	Low	Total
Eucalypt	60400	181400	33100	259900
Myrtle	34100	56300	22000	96000
Sassafras	10800	25800	0	33350
Celery top	8250	26100	0	33850
Total	113550	289600	55100	422700

Table 10. Summary of salvageable area by suitability zone (ha)

	Depth		
	10 - 40 m	**40 m +**	**Total**
High	1130	260	1390
Medium	3730	1500	5230
Low	2,930	630	3560
Total	7790	2390	10180

References

Forestry Tasmania (2010) Silvicultural systems for native eucalypt forests. Native Forest Silviculture Technical Bulletin No. 5. Forestry Tasmania, Hobart.

Stone, M. (1998) Forest-type mapping by photo-interpretation: A multi-purpose base for Tasmania’s forest management. Tasforests 10, 15-32.

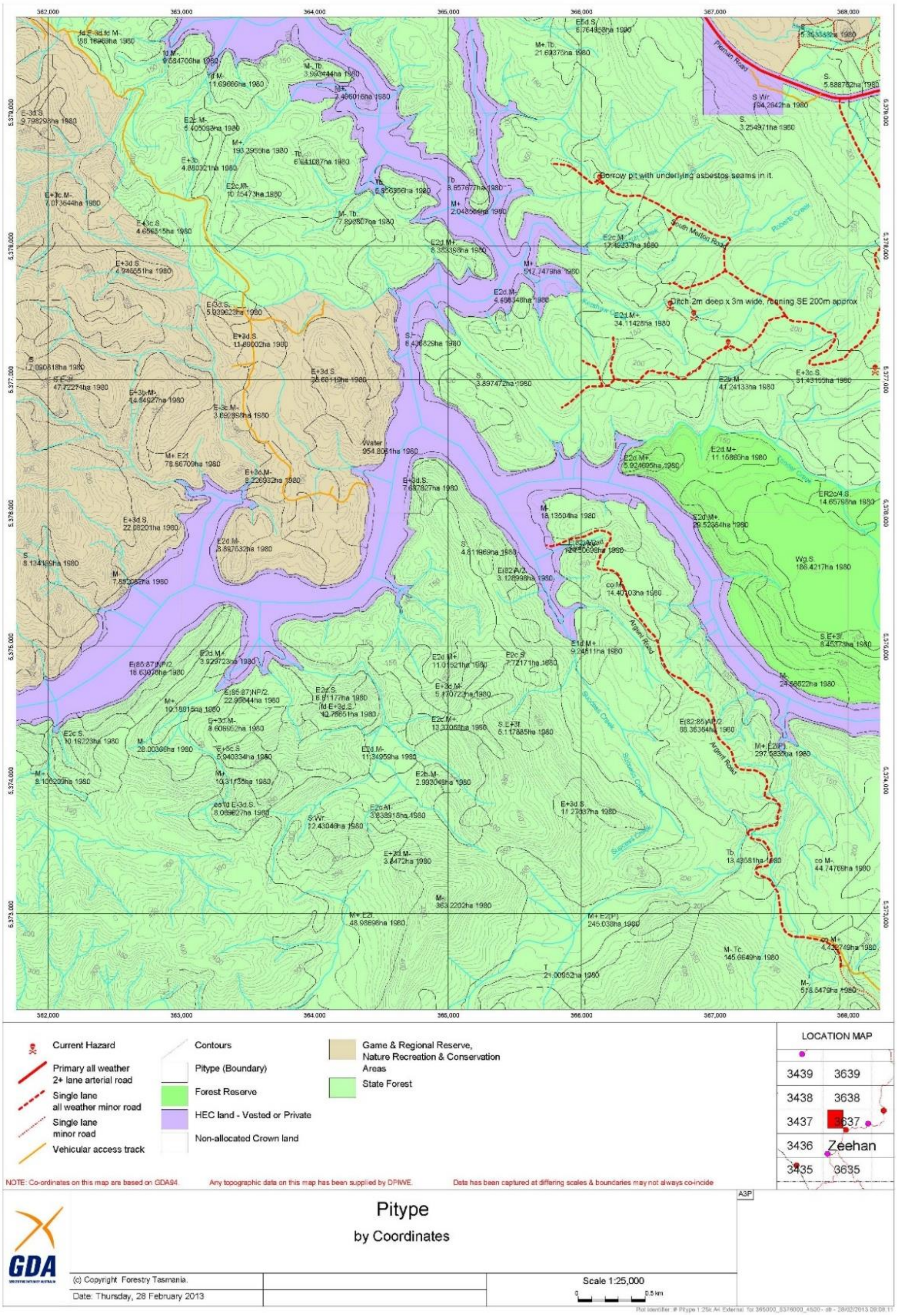
APPENDIX 1.1 Lake Pieman Resource Assessment

Map 1. Western section of Lake Pieman showing current photo-interpretation (PI) typing. Current salvage operations are based at the end of Argent Road, see the dotted red line ending just to right of map centre.

Map 2. Eastern section of Lake Pieman showing current photo-interpretation typing.

Map 3. Western section of Lake Pieman showing PI types and suitability zones as mapped during the resource assessment project.

Map 4. Eastern section of Lake Pieman showing PI types and suitability zones as mapped during the resource assessment project.



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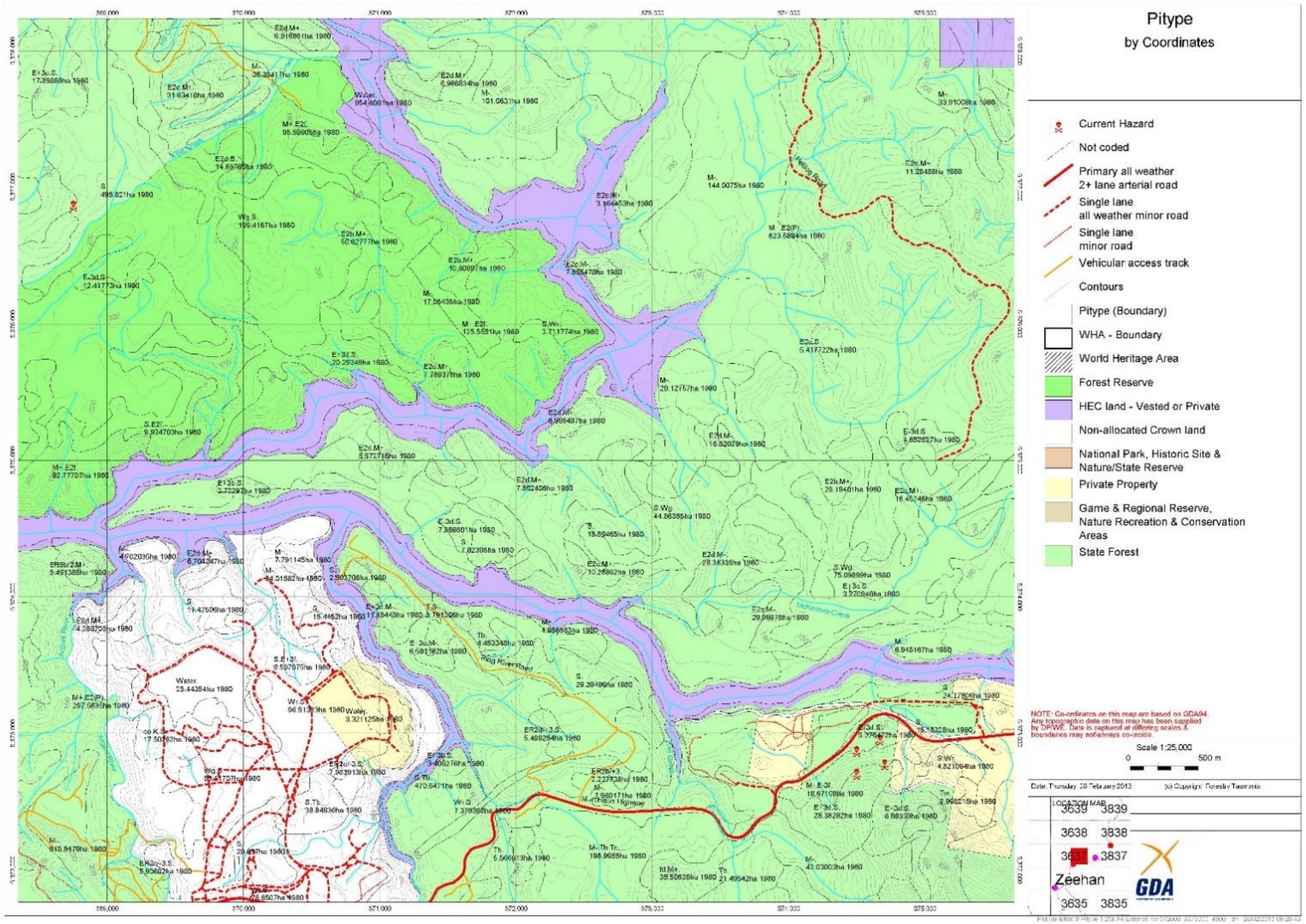

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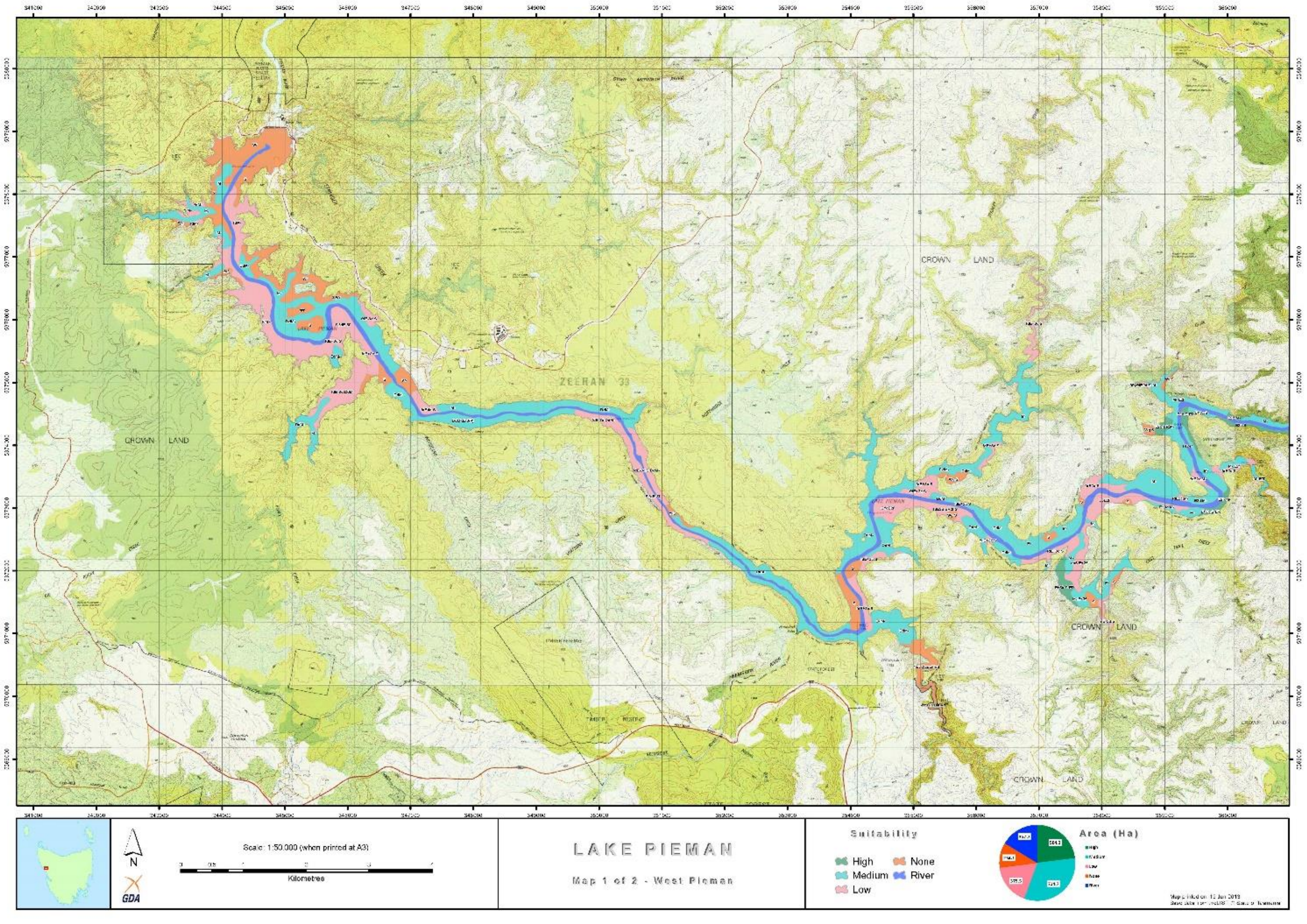
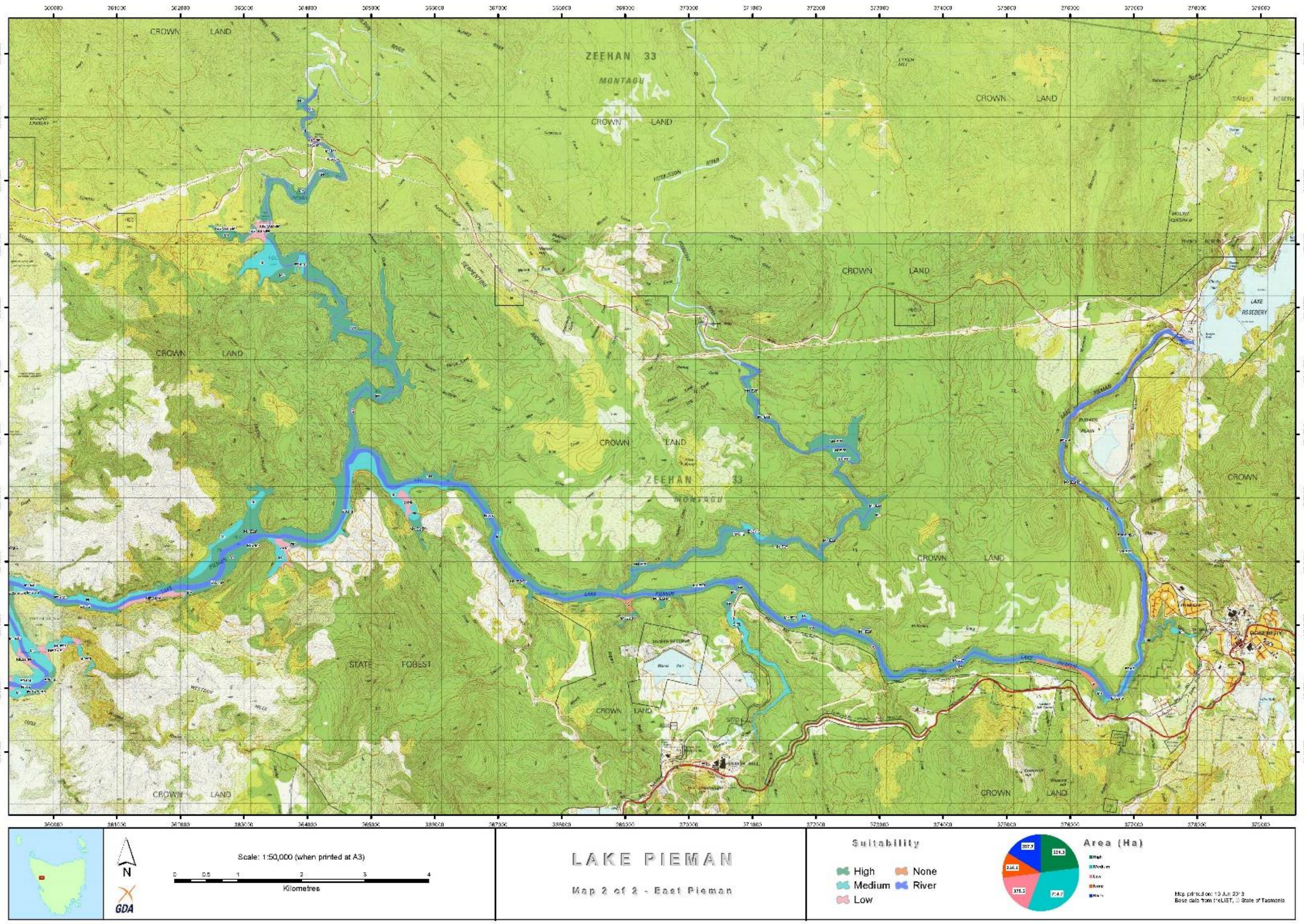


Map 3. Western section of Lake Pieman showing PI types and suitability zones as mapped during the resource assessment project.



Map 4. Eastern section of Lake Pieman showing PI types and suitability zones as mapped during the resource assessment project.

APPENDIX 1.2 PI-type codes. Extract from Forestry Tasmania (2010).

A PI-type code is composed of a series of stand elements, each delimited with a full stop, and each representing a single species-group/age-class component of the stand being described. The order in which the elements are listed reflects their relative significance (i.e. the element which is most abundant or likely to determine the current management of the stand is listed first).

PI-types may be preceded by a condition-class code, indicating that the stand is dead, severely fire-damaged, over-mature, thinned, or cut-over in past selective logging.

Eucalypts are subdivided according to growth stage, each with stand height and percentage crown cover estimates where possible. Myrtle-dominated rainforest is separated by growth stage and crown size, with height class recorded only for regrowth stands.

Other native forest species are generally grouped as *other species* (if taller than 15 m) or *scrub*. However, locally important species (e.g. wattle) are coded as separate elements.

Whenever a forest patch does not contain a mature eucalypt element, evidence of the height of any previous mature eucalypts on the site is recorded as an indication of the growth potential of current and future eucalypt regrowth stands. The height-potential class may be measured from isolated mature trees, dead stags or fallen trees. In the case of stands regenerated after clearfelling, height-potential boundaries are transferred from older maps or from photographs of the original forest.

Table 11.1. PI type codes.

Condition Classes		
co cut-over fd severely fire-damaged	th thinned dd dead	om over-mature
Mature eucalypt		
Height classes		
E1* average height > 76 m	E+3 average height 34–41 m	E4 average height 15–27 m
E1 average height 55–76 m	E-3 average height 27–34 m	E5 average height < 15 m
E2 average height 41–55 m	E3 average height 27–41m	
Live crown density-classes		
a 70–100% crown cover	c 20–40% crown cover	f < 5% crown cover
b 40–70% crown cover	d 5–20% crown cover	(P) Patches or scattered
Dead stem-count classes		
A* > 60 stems/ha	B 25–39 stems/ha	D 2–14 stems/ha
A 40–60 stems/ha	C 15–24 stems/ha	F < 2 stems/ha
Regrowth eucalypt		
Height classes		
ER1 average height < 15 m	ER3 average height 27–37 m	ER5 average height 44–50 m
ER2 average height 15–27 m	ER4 average height 37–44 m	ER6 average height > 50 m
Density-classes		
a 90–100% crown cover	c 50–70% crown cover	f 1 – 10% crown cover
b 70–90% crown cover	d 10–50% crown cover	(P) Patches or scattered
Mature height potential		
/1*, /1, /2, /3, /+3, /-3, /4, /5 as per eucalypt mature height classes		
Aged regeneration		

E(yy)m Eucalypt regeneration, where yy is year of regeneration in 1900s (yyy = 2000s), m is method.
Regeneration-method codes **A** Artificially seeded **P** Planted (not for intensive plantation) **N** Natural seeded **W** Wildfire-seeding
Plantation Ph(yy) Hardwood plantation (planting year yy or yyy for post 2000) Ps(96) Softwood plantation (1996)
Non-eucalypt species S Scrub (< 15 m tall) M+ Tall myrtle rainforest M- Low myrtle rainforest Tr Radiata pine (wild) Tb Blackwood T Secondary species (> 15 m tall) Mr1 Myrtle rainforest regrowth < 15 m tall Mr2 Myrtle rainforest regrowth > 15 m tall Sb Bauera scrub Sh Horizontal scrub St Tea-tree scrub Tc Celery-top pine Tl Leatherwood Th Huon pine Tk King Billy pine Ts Sassafrass Tt Tea-tree Tw Wattle
Non-forest K Bracken V Grazing Vc Cultivated land Vo Orchard Vz Rough grazing Vp Pasture W Waste, bare Wg Buttongrass Wr Rock Wm Mountain moor
Unstocked forest site U/p Un-regenerated forest site (with eucalypt potential p) Z/S Un-regenerated former scrub site Z/W Un-regenerated former waste site

CHAPTER 2:

Testing the physical properties of submerged and terrestrial wood

Executive summary

During the past five years commercial salvage harvest of logs from water storages in Tasmania and the subsequent production of sawn timber, has developed rapidly from a concept to a successful business. The speed of development has resulted in a range of questions about the sustainability of this new supply, the material and performance characteristics of the new resource, and the possible impacts on existing supply arrangements and markets.

This project was funded to make preliminary assessments of the first two of these sets of questions, namely:

1. How accurately can we estimate the extent of the underwater resource and can we predict future available volumes by location, year and species? and
2. Can we determine whether there are differences in the material characteristics of the underwater resource compared to the terrestrial resource and can we draw any consequent conclusions about the suitability for performance requirements in various end uses.

This chapter focusses on the second of these questions, and reports on a series of tests designed to compare and contrast the in-service performance of both submerged wood and terrestrial wood.

'Submerged wood' is timber from logs that have been salvaged from Lake Pieman, a hydro storage on the west coast of Tasmania. Terrestrial wood is wood harvested from conventional harvesting operations. In this study, three different woods were tested: celery-top pine, myrtle and eucalypt. The testing was divided into two sections: Part 1) Expansion on soaking and shrinkage on drying, and Part 2) Wood properties testing.

For all three species tested, both radial and tangential swelling on soaking in water was greater for submerged wood than for terrestrial wood. The other differences between the submerged and terrestrial myrtle and eucalypt were generally minor and inconsistent. There were no consistent, strong trends. The submerged celery-top pine had lower modulus of elasticity, lower modulus of rupture, higher moisture content, higher drying stress, lower density and lower screw withdrawal resistance than terrestrial celery-top pine.

For the testing reported here it must be kept in mind that variation in the sawing, air drying, kiln drying, and storage of each piece of wood following harvesting can result in variation in the performance of that piece of wood through the tests described within. Also, with experience, management of the sawing and drying processes can significantly improve the performance of the finished timber over time. The material being tested and reported here is a small sample of the total volume of wood that was in the market place at one point in time. Variations in the performance of the wood in testing are to be expected, and caution is required in arriving at general conclusions regarding the relative performance of wood from different sources, sourced at different times.

The findings of this report should be viewed in conjunction with a previous chapter titled *"Resource assessment of Special Species Timbers located in hydro storages"* that addressed question (1) of this project. That report concluded that while a significant amount of submerged wood may be available as a resource, the exact proportion of wood that is recoverable and/or useable is currently unknown. This second report indicates that when comparing physical properties of submerged and terrestrial wood there were differences in how these two sources of wood performed. However, performance was not consistent across tests. There were also differences between the three species in performance for some characteristics and, consequently, there was not a clear and consistent reportable difference in performance between submerged and terrestrial wood. Further testing across a wider sourced resource and in different sampling periods will further test the questions assessed in this report and may identify consistent differences between the two wood sources.

Introduction

During the past five years commercial salvage harvest of logs from water storages in Tasmania and the subsequent production of sawn timber, has developed rapidly from a concept to a successful business. The speed of development has resulted in a range of questions about the sustainability of this new supply, the material and performance characteristics of the new resource, and the possible impacts on existing supply arrangements and markets. This project was funded to make preliminary assessments of the first two of these sets of questions, namely:

1. How accurately can we estimate the extent of the underwater resource and can we predict future available volumes by location, year and species? and
2. Can we determine whether there are differences in the material characteristics of the underwater resource compared to the terrestrial resource and can we draw any consequent conclusions about the suitability for performance requirements in various end uses.

This chapter focusses on the second of these questions.

The submerged wood referred to in this report is timber from logs that have been salvaged from Lake Pieman, a hydro storage on the west coast of Tasmania. Logs are harvested from under the water, taken to a local sawmill for processing, air dried for about 6 months, and then kiln dried, skip dressed, and taken to market. In broad terms about 70% of the wood currently being produced from Lake Pieman is eucalypt, 20% myrtle and 10% celery-top pine. Small volumes of sassafras are also produced. While this project was being established, the available timber comprised eucalypt, myrtle and celery-top pine. The eucalypt timber is of unknown species, although it is likely that it is a mix of *Eucalyptus obliqua* and *E. nitida*. This timber is referred to in this report as submerged wood.

The terrestrial wood referred to in this report is wood harvested from conventional harvesting operations. In order to test material that was comparable to the submerged wood, eucalypt, myrtle and celery-top pine boards were sourced from a sawmill in northwest Tasmania. The eucalypt is known to comprise boards of *Eucalyptus obliqua* and *E. nitida*. Due to the difficulty of distinguishing the eucalypt species for the submerged wood, the two terrestrial eucalypt species were often grouped together to provide a more direct comparison. However, in some circumstances the two species were treated separately. This timber is referred to in this report as terrestrial wood.

The wood was tested at two different locations; the Sandy Bay campus of the University of Tasmania where the expansion on soaking in water and contraction on drying was tested (Part 1 of this report), and the Centre for Sustainable Architecture with Wood, at the Inveresk campus of the University, where a range of tests were conducted (Part 2 of this report). Ideally, the wood would have been tested 'blind', that is, the practitioners would not have known whether each piece was of terrestrial or submerged wood origin, but this was not really possible as the timber had to be delivered by truck from sawmiller to testing location and arrived clearly packaged and labelled. This is not considered a problem for the testing program as most of the testing reported here was empirical or mechanical.

The chapter is divided into two parts, each detailing the methods, results and conclusions of the tree testing procedures undertaken. The two parts of this report are;

Part 1: Expansion on soaking and shrinkage on drying

Part 2: Wood properties testing

A third aspect to this work was to examine the chemical properties of submerged wood. The first stage was to complete a review of the literature and speak with a wood chemical expert (Dr Alieta Eyles, University of Tasmania) to determine if this was a valuable line of enquiry. A review of the literature highlighted that very little work has examined wood chemical differences between submerged and terrestrial wood in any species, with little to no previous work on celery-top pine and myrtle. Despite this knowledge gap, Dr Eyles indicated that due to the chemical variability that is likely to exist within a tree, between trees matched with the unknown background of the wood made available for testing (e.g. age, provenance, period of submersion etc) it is unlikely that a short-term study would reveal any results of value as the variability in the data would be too high. A longer-term study (e.g. PhD project) would be required to begin to elucidate some of these questions. Consequently, it was determined that no further investigation into the chemical properties of submerged wood would be conducted at this stage.

Part 1. Expansion on soaking and shrinkage on drying

This part of the project was completed in the glasshouse complex at the School of Natural Sciences, University of Tasmania.

Methods

The submerged and terrestrial wood sourced for this project comprised boards of about 100 mm wide and 25 mm thick and of random lengths. From these boards small lengths were prepared for the expansion/shrinkage testing. The boards were dressed to 100 mm by 22 mm, and then a sample 125 mm long was taken from each board. The number of samples for each species by source varied from 10 to 45 due to timber availability. Each sample at the commencement of the testing was nominally 125 mm long, 100 mm wide and 22 mm thick (Photo 1), although there was some variation. The submerged wood is predominantly backsawn but included some quartersawn and mixed sawn material. The terrestrial material was a mixture of backsawn, quartersawn and mixed sawn (Photo 2). The sawing orientation of each sample was recorded before testing.

Photo 1. A selection of the pieces prepared for water testing. Myrtle (left), celery-top pine (rear), Eucalyptus obliqua (right) E. nitida (front).

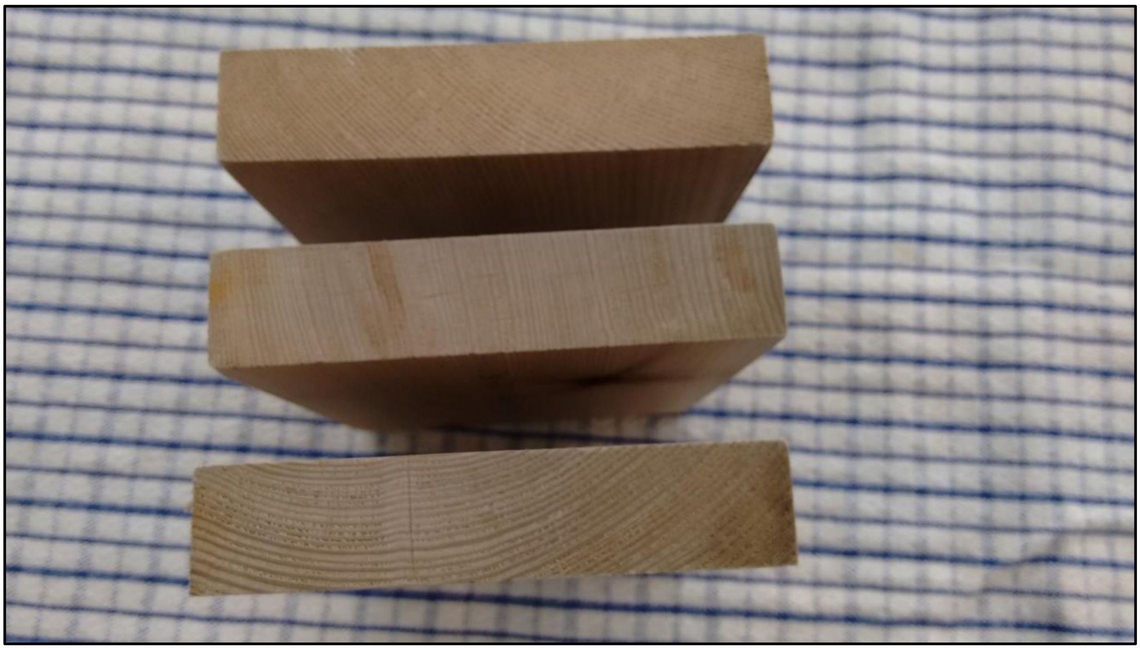


Photo 2. Top to bottom, mixed sawn, quartersawn, and backsawn pieces of celery-top pine.

The samples were measured prior to soaking for length, width and thickness, using digital callipers accurate to one hundredth of a millimetre, and weighed using digital scales accurate to one hundredth of a gram. Measurement locations were recorded from the same position on the board for all subsequent measurements. The samples were then placed in plastic tubs, which were filled with water. Bricks were used to hold the samples down, such that they were completely submerged, and care was taken to ensure that the samples were all freely exposed to the water on all sides except the bottom. The samples were arranged longitudinally in the tubs such that the end grain was exposed at both ends (Photo 3).

Photo 3. Wood samples in water. The bricks were needed to keep the samples wholly submerged.

The samples were then re-measured at set time periods as described below. To ensure accurate measurement particularly of the sample weights, the samples were removed from the tubs and allowed to drip dry until there was no free water on the surface. Free water was also found to interfere with the accuracy of the digital callipers. They were measured daily from Day 1 to Day 11, every second day from Day 11 to Day 23, and then approximately every third or fourth day from Day 23 to Day 99. From about day 23, it was noticed that the samples were becoming slimy to the touch, of unknown cause, so thereafter the samples were scrubbed weekly in clean water. Ongoing remeasurement was planned until the samples stopped taking up water but it became clear that although the rate of uptake slowed to very low levels, the samples were still taking up water at Day 99. The samples were removed from the water and drying commenced.

The terrestrial wood samples were dried for three weeks (21 days) in a controlled atmosphere of 80% relative humidity and 25°C. The aim of maintaining a controlled atmosphere was so that all the samples were dried under constant and controlled conditions. However, two problems emerged shortly after the drying cycle was commenced. 1) The high relative humidity meant that the samples were subjected to intense and frequent misting, which was distributed unevenly across the samples, which were drying out unevenly, and 2) the terrestrial wood had commenced soaking earlier than the submerged wood, that is, while the terrestrial wood was drying, the submerged wood was still soaking, and it was considered that all of the samples should be subjected to the same drying regime. Consequently, the terrestrial wood was put back into, and allowed to reabsorb, water until the submerged wood had been soaking for 100 days. The terrestrial wood recovered much of the water lost to drying but did not reach the same level of saturation as it had reached at Day 99.

With the benefit of the knowledge gained from the repeated measuring of the terrestrial wood, the submerged wood was measured less frequently through the soaking cycle. The samples were measured on commencement (Day 1), then Days 2 and 4, then every third or fourth day until Day 42, then weekly until Day 98, at which point both sets, that is, all the terrestrial and all the submerged wood were removed from the water and arranged on racks in a controlled atmosphere. Having found that a relative humidity of 80% resulted in frequent and uneven misting of the wood samples, the relative humidity was set at 50%, and the temperature maintained at 25°C. At this lower level of humidity, the mist was much less frequent, and more evenly distributed. The samples were rearranged after each remeasurement to ensure that they all received as similar a drying regime as possible. No issues were observed during the drying cycle. Both sets of samples were remeasured 1, 2, 4, 7, 11, 14, 21, 28, 35 and 42 days after removal from the water, by which stage the rate of drying was almost negligible.

Analysis

As noted earlier, the samples comprised backsawn, quartersawn and mixed sawn material. Each piece was measured for weight, length, thickness and width. For the analysis, the rate of expansion on soaking and of shrinkage on drying was converted from length, width and thickness, to longitudinal, radial and tangential, as these are known to be different in timber. Generally speaking, longitudinal expansion and/or shrinkage tends to be minimal, whilst radial expansion/shrinkage tends to be in the range 3 to 6%, and tangential expansion/shrinkage tends to be in the range 6 to 12% (Skaar 1988).

Differences in the effects of soaking and drying between terrestrial and submerged wood were examined graphically for each of the three species tested. Average weight, radial, tangential, and longitudinal dimensions were calculated per measurement day as well as the standard error of the species group. To aid comparison across species and wood type, values are reported as a percentage change from pre-soaking weight for the results from the soaking experiment and as percentage change from the hydrated rate for the drying experiment.

The initial size of each piece at the commencement of the trial was also compared to the final size of each piece at the completion of the trial, that is, following 99 days of soaking and 42 days of drying.

Results

Weight gain on soaking to near saturation

Comparing the submerged wood to the terrestrial wood showed that there was no significant difference in the rate of weight gain due to soaking in celery-top pine and eucalypt by source. However, the submerged myrtle expanded more than the terrestrial myrtle with the difference between the two becoming evident early in the soaking cycle (Fig. 1). The rate of weight gain also differed between the species examined with the eucalypt gaining the most weight in both the terrestrial and submerged samples (Fig. 1).

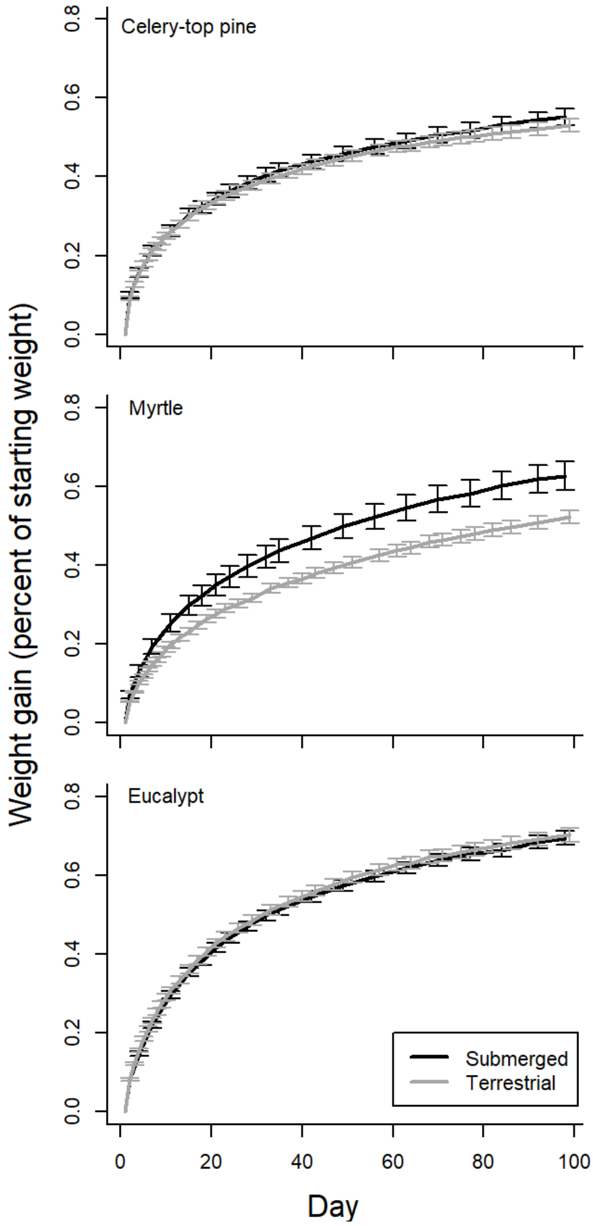


Figure 2: Change in weight due to soaking, reported as percentage gained from pre-soaking weight. Results are reported for both submerged (black) and terrestrial wood (grey) for the three different species. Error bars shown are standard errors.

Weight loss on drying.

As observed for the soaking samples, there were no significant differences in weight loss from drying between the terrestrial and submerged samples for the celery-top pine and eucalypt but there were small differences observed for myrtle (Fig. 2). The submerged myrtle lost more weight and did so quicker than the terrestrial. However, the differences between the two myrtle sets was only minor and not as pronounced as that observed during soaking; in part this may be because the submerged myrtle had gained more weight during soaking and, therefore had a greater amount to lose.

Weight loss under drying was quicker than the weight gain from soaking, the majority of weight was lost within the first 10 days of drying.

The minor differences in the early rates of drying in both the celery-top pine and eucalypt are likely due to the loss of weight that was associated with the first drying of the terrestrial timber. After re-soaking the samples were still around 9% below their initial near-saturated capacity so the first few days of drying encompass both weight loss due to drying and the weight that was not re-absorbed.

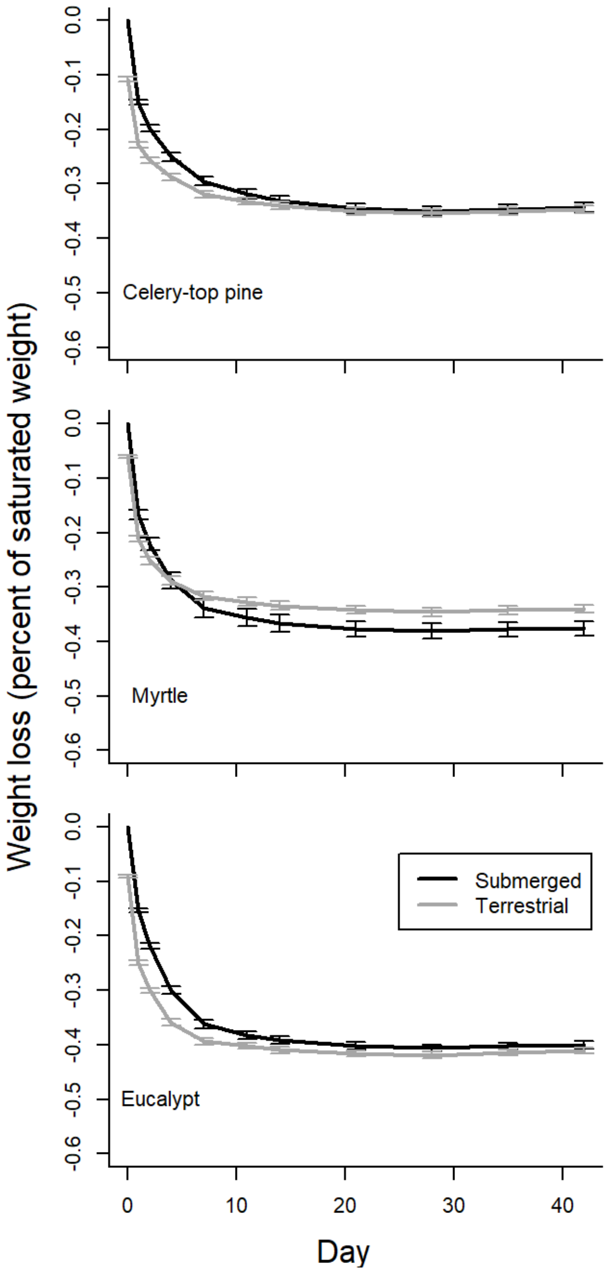


Figure 3: Change in weight due to drying, reported as percentage lost from weight at near saturation point. Results are shown for both submerged (black) and terrestrial wood across the three different species. Error bars are standard errors.

Longitudinal swelling/shrinkage with soaking/drying

Consistent with all previous experience of timber in service there is no significant longitudinal swelling of the timber on soaking, nor longitudinal shrinkage of the timber on drying. This result was consistent across both submerged and terrestrial wood and for all species (Fig. 3, 4).

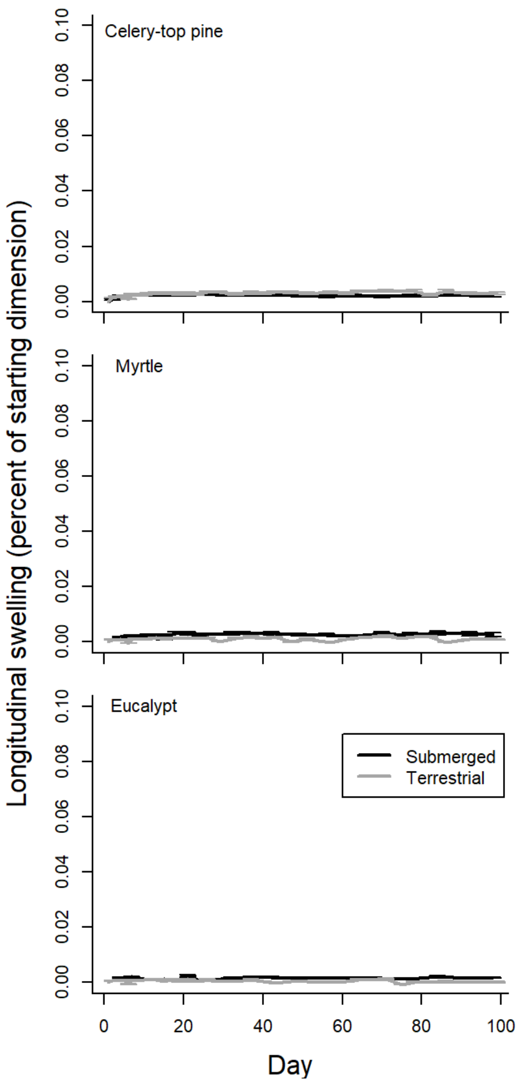


Figure 4: Longitudinal swelling due to soaking. Reported as percentage gain from starting size. Results are shown for submerged (black) and terrestrial wood (grey) across the three different species.

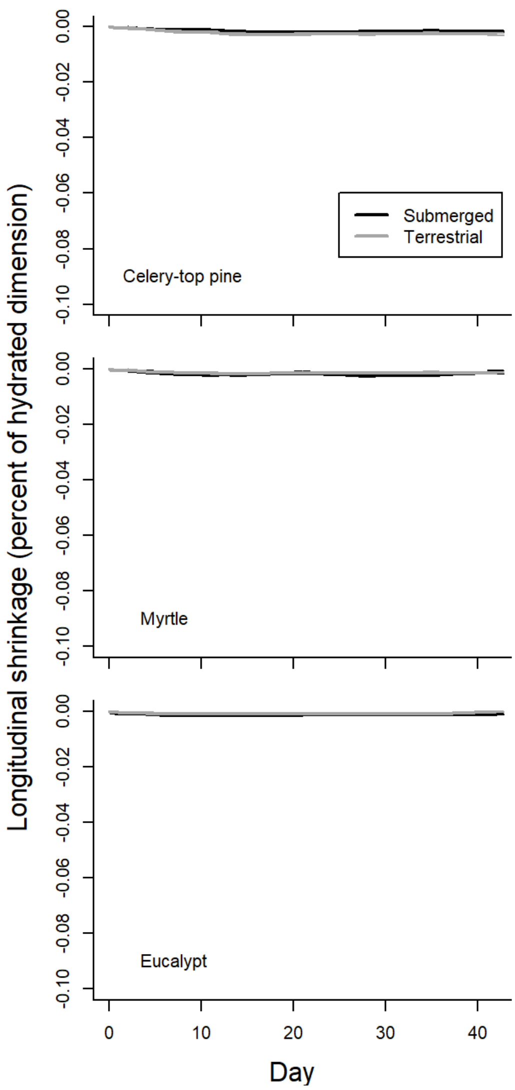


Figure 4: Longitudinal shrinkage due to drying. Reported as percentage loss from near-saturated size. Results are shown for submerged (black) and terrestrial wood (grey) across the three different species.

Radial swelling on soaking to near saturation

Examination of radial swelling on soaking showed that the submerged and terrestrial wood differed in their responses. Across all species the submerged wood exhibited greater swelling over the 99 days of soaking and swelled at a faster rate than the terrestrial. The time over which the swelling occurred was similar across both groups with the eucalypt and myrtle reaching maximum swelling after around 20 days of soaking and celery-top pine reaching maximum swelling in under 10 days. While the celery-top pine was the fastest to reach maximum swelling, overall it swelled the least compared to the myrtle and the eucalypt (Fig. 5).

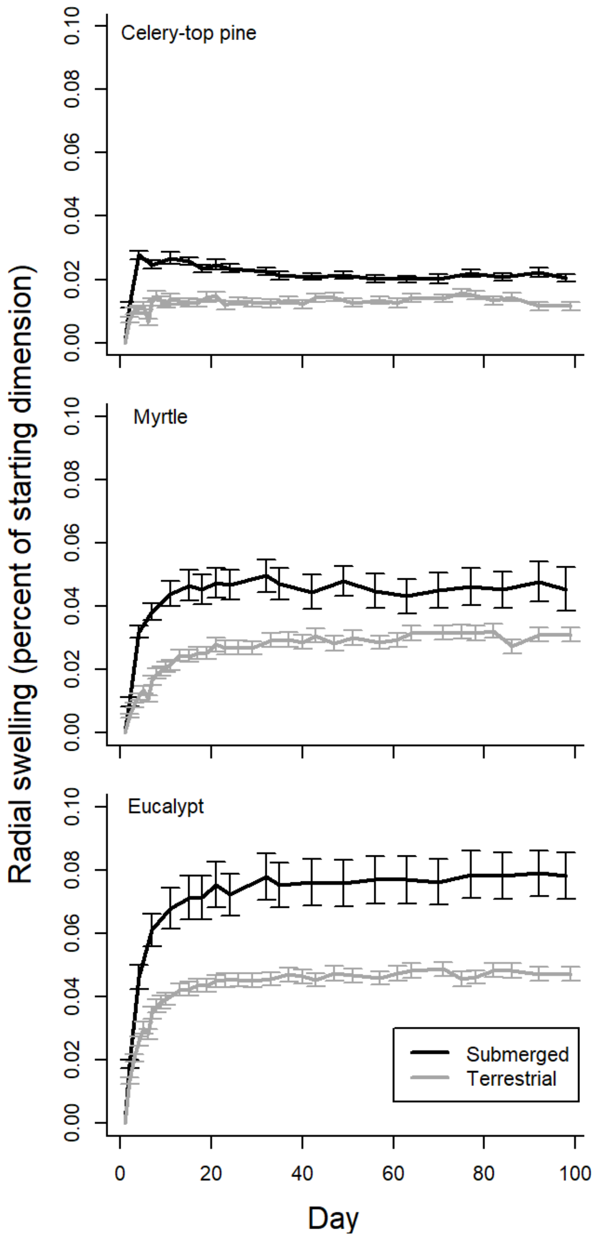


Figure 5: Radial swelling due to soaking. Reported as percentage gain from starting size. Results are shown for submerged (black) and terrestrial wood (grey) across the three different species. Error bars are standard errors.

Tangential swelling on soaking to near saturation

Tangential swelling exhibited very similar patterns to the radial swelling, with submerged wood showing both faster rates of swelling and greater levels of swelling over the 99 days of soaking (Fig. 6). The time to maximum swelling was slower tangentially than radially, particularly for the submerged myrtle and eucalypt, which were still exhibiting small increases in size after 99 days of soaking. Celery-top pine showed the least swelling and eucalypt the most.

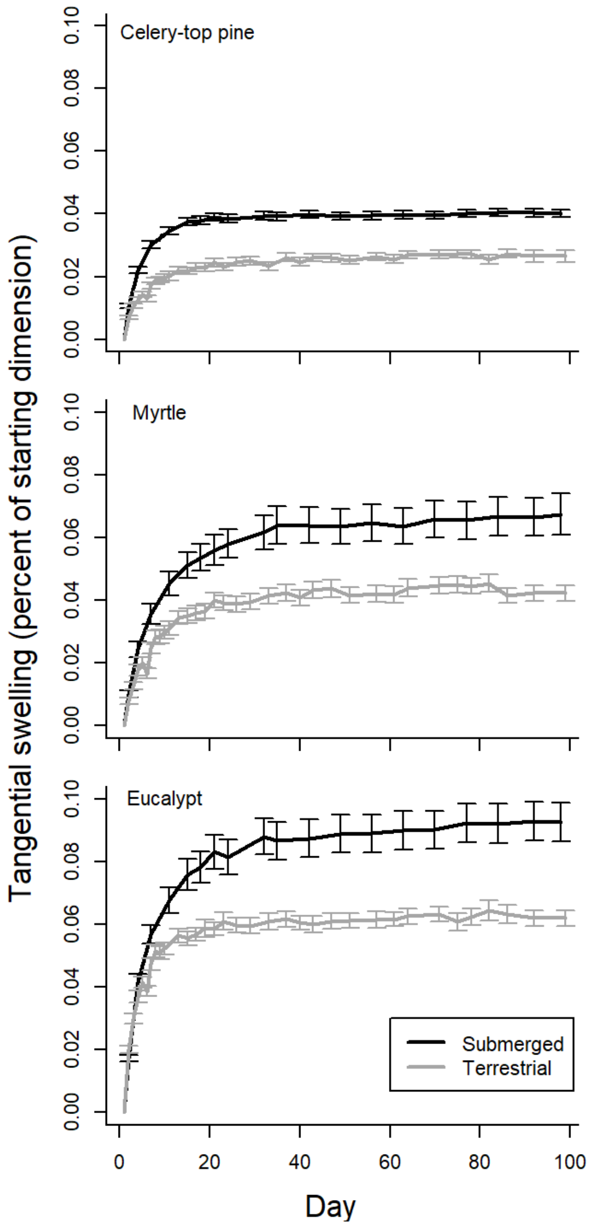


Figure 6: Tangential swelling due to soaking. Reported as percentage gain from starting size. Results are shown for submerged (black) and terrestrial wood (grey) across the three different species. Error bars are standard errors.

Radial shrinkage on drying

The radial shrinkage in the terrestrial celery-top pine was small but significantly greater than the radial shrinkage in the submerged celery-top pine, but the differences were negligible in the other two species (Fig. 7). Between species, the eucalypt shrank the fastest and to the greatest extent while the celery-top pine shrunk the least, this is a similar pattern as observed for the radial swelling.

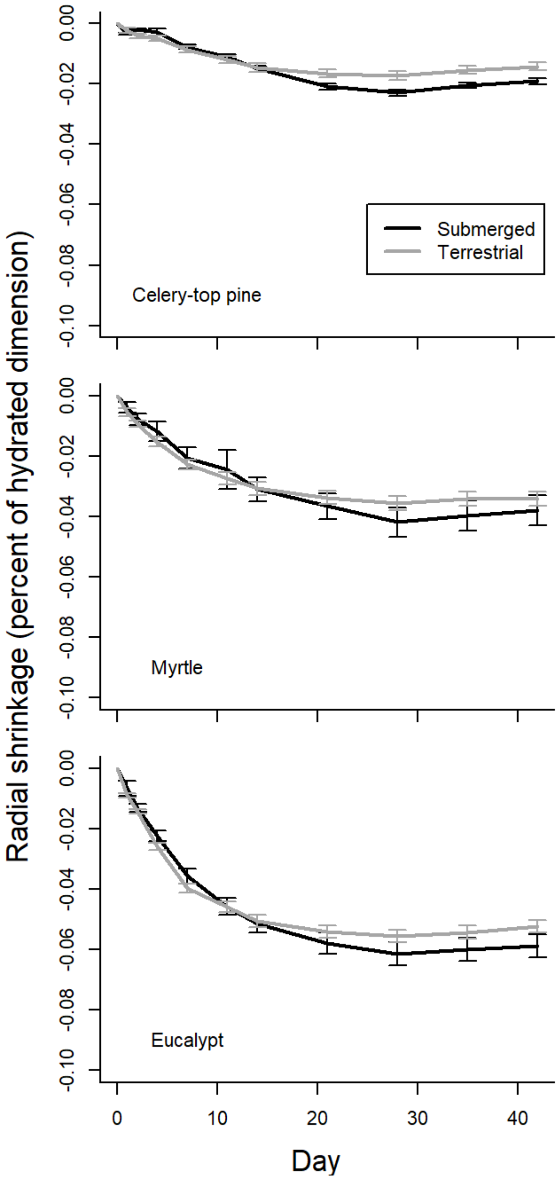


Figure 7: Radial shrinkage due to drying. Reported as percentage loss from near-saturated size. Results are shown for submerged (black) and terrestrial wood (grey) across the three different species.

Tangential shrinkage on drying

The tangential shrinkage in the terrestrial celery-top pine was small but significantly greater than the tangential shrinkage in the submerged celery-top pine, but differences were negligible in the other two species (Fig. 8). The pattern across the different species is similar to that for the radial shrinkage with celery-top pine exhibiting the least shrinkage and eucalypt the most.

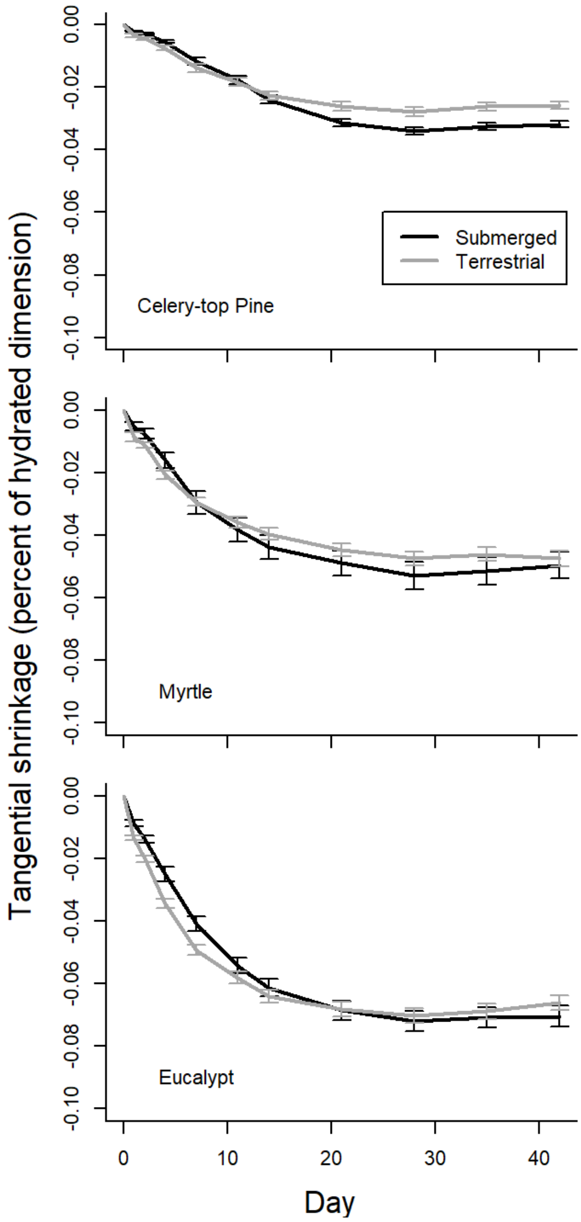


Figure 8: Tangential shrinkage due to drying. Reported as percentage loss from near-saturated size. Results are shown for submerged (black) and terrestrial wood (grey) across the three different species.

Initial size by source and species compared to final size by source and species

A comparison of the dimensions and weight of the timber samples pre-soaking to post drying showed that after the soaking and drying treatments the timber samples returned to their original size in most circumstances (Table 1). The only notable difference was that the submerged timber samples did not quite shrink to their original width, this pattern was consistent across all three species. There was no major difference between the start and finish characteristics in the terrestrial wood.

Table 1: Pre-soaking (start) and post-drying (finish) weights and dimensions for the terrestrial and submerged wood samples. Results are shown separately for the three species examined.

		Submerged			Terrestrial		
		Celery-top	Myrtle	Eucalypt	Celery-top	Myrtle	Eucalypt
Length	Start	125.34±0.02	125.71±0.04	125.79±0.01	125.18±0.02	125.18±0.02	125.22±0.01
	Finish	125.39±0.02	125.91±0.04	125.88±0.01	125.26±0.02	125.20±0.02	125.32±0.01
Width	Start	98.93±0.02	99.20±0.02	98.09±0.24	99.19±0.16	99.16±0.16	99.33±0.22
	Finish	99.60±0.05	100.59±0.24	99.68±0.26	99.27±0.16	98.92±0.17	98.89±0.23
Thickness	Start	21.31±0.03	21.71±0.05	21.38±0.03	21.12±0.02	21.15±0.03	21.26±0.02
	Finish	21.33±0.03	21.84±0.07	21.64±0.1	21.07±0.02	20.99±0.04	20.97±0.03
Weight	Start	171.45±3.77	191.69±8.85	191.85±5.35	174.00±2.8	181.26±2.78	177.92±3.03
	Finish	173.69±3.81	193.81±8.76	194.23±5.44	173.52±2.91	181.63±2.75	177.66±2.9

Degrade on drying

During the soaking and drying phases, it was observed that there were notable changes to the characteristics of the timber, particularly the expansion and contraction of internal checks (Photo 4, 5). Unfortunately, no formal assessment of the visual qualities of the wood samples was undertaken during the drying cycle. Note that this wetting and drying cycle was more stringent than would usually apply to timber in service. The samples were taken from being fully saturated in water, to a constant regime of 25°C and 50% relative humidity. Consequently, they dried out very quickly, and in a shorter time frame than it took to reach saturation, as described above.

A formal assessment was not undertaken after two weeks of drying (Photo 4) because it was assumed that the degrade that was evident after two weeks of drying would continue to get worse. But in fact after four weeks of drying the degrade did not appear to become markedly worse (Photo 5), although the checks that are evident in photo 4 are still present, they have just closed up. The checking after two weeks is presumably the result of the outside of each piece of wood drying faster than the core, resulting in a strong differential in the moisture content of the core versus the shell, whereas after four weeks of drying the core had dried out significantly and the differential was less. After four weeks (about 28 days) the samples had reached equilibrium with the controlled atmosphere, and the visible degrade was largely restricted to the rare defects that were visible at the commencement of the trial.

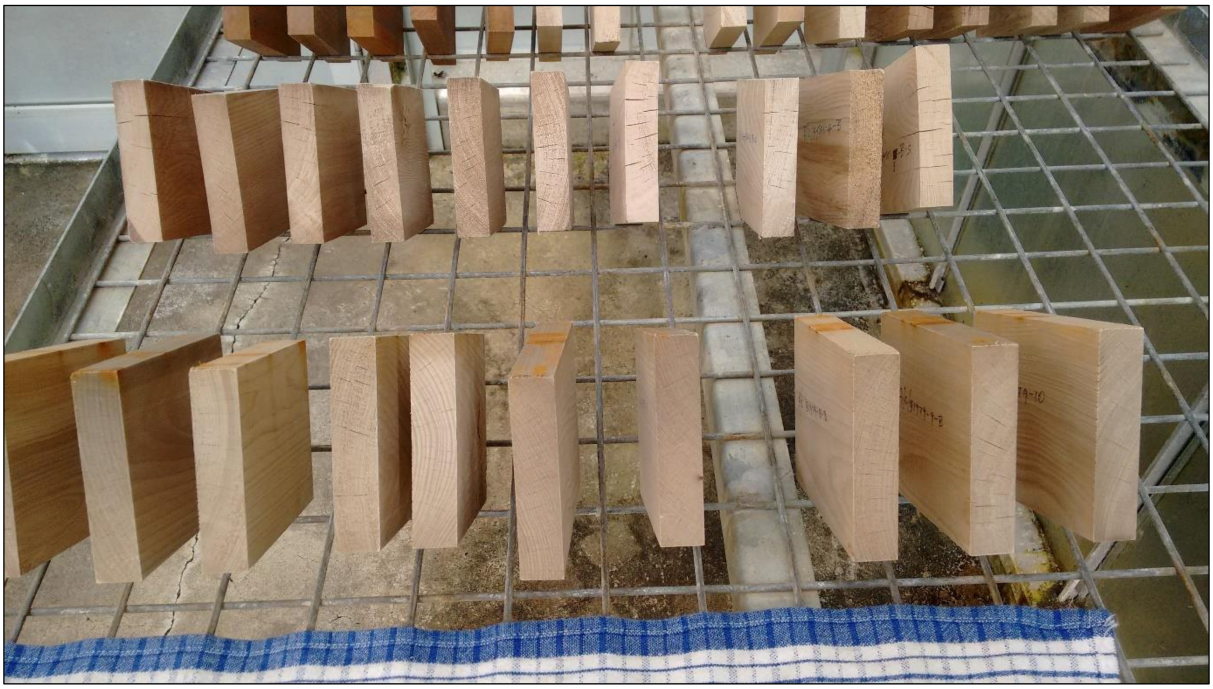


Photo 4. Randomly selected samples of celery-top pine after two weeks of drying. Terrestrial wood at front and submerged wood at rear. The degrade appears to be worse in the submerged wood, with numerous checks in most samples, whereas there are only scattered checks in the terrestrial wood.

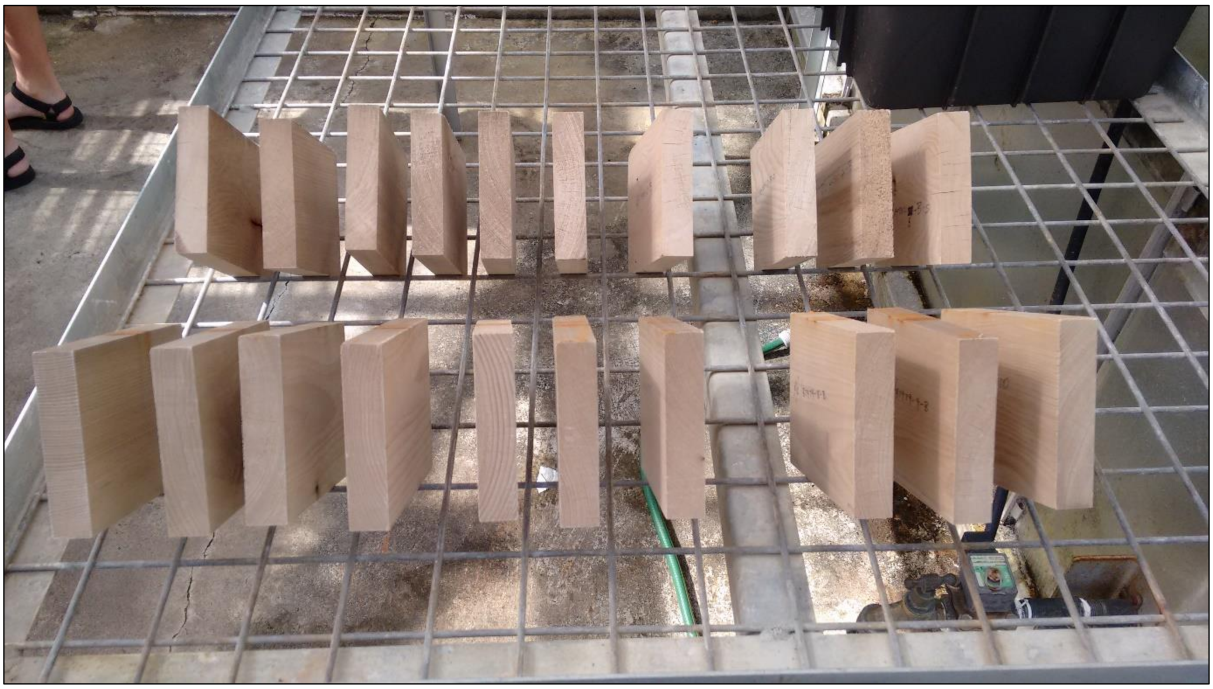


Photo 5. The same set of samples as in photo 4, after four weeks of drying. The degrade is now much less evident.

Conclusions

The results of the soaking and drying tests showed differences in the performance of the submerged wood versus the terrestrial wood. The main findings from these tests were:

1. The submerged wood swelled radially more than the terrestrial wood on soaking across all species tested.
2. The submerged wood swelled tangentially more than the terrestrial wood on soaking across all species tested.
3. Longitudinal swelling in all species tested by both sources was negligible.
4. The radial shrinkage in the terrestrial celery-top pine was greater than the radial shrinkage in the submerged wood celery-top pine, but the differences were negligible in the other two species.
5. The tangential shrinkage in the terrestrial celery-top pine was greater than the tangential shrinkage in the submerged wood celery-top pine, but differences were negligible in the other two species.
6. The submerged wood myrtle took up water faster than the terrestrial myrtle. The submerged wood and terrestrial celery-top pine and eucalyptus species took up water at very similar rates.
7. Both the submerged wood and terrestrial samples dried out more quickly (c. 21 days) than they took up water (100 days to near saturation).
8. The degrade on drying appears to be a little worse in the submerged wood, but this was not formally tested.

References

Skaar, C. 1988. Wood-Water Relations. In: Springer Series in Wood Science. Eds. T. E.

Timell. Springer-Verlag, Berlin Heidelberg. pp. 283.

Part 2 Wood properties testing

This part of the work was completed at the Centre for Sustainable Architecture with Wood (CSAW) at the Inveresk campus of the University of Tasmania

Introduction

The timber used in this part of the testing procedures was part of the same packs of timber that were supplied and used in the testing described in part 1 of this report. It is important to note that due to sourcing of the submerged and terrestrial timbers from different locations we could not control the sawing or drying of the timber post-harvest. Therefore, for the procedures reported below it must be kept in mind that variation in the sawing, air drying, kiln drying, and storage of each piece of wood can result in variation in the performance of that piece of wood through the tests described below. Also, with experience, management of the sawing and drying processes can significantly improve the performance of the finished timber over time. The material being tested and reported here is a small sample of the total volume of wood that was in the market place at one point in time. Variations in the performance of the wood in testing are to be expected, and caution is required in arriving at general conclusions regarding the relative performance of wood from different sources, sourced at different times.

The testing at CSAW covered:

- Visual grading
- Bending properties (Modulus of Rupture, MOR, and apparent Modulus of Elasticity, MOE)
- Moisture content (MC) and gradient
- Residual drying stress
- Density
- Janka hardness
- Screw withdrawal resistance
- Machinability (workability)

Visual grading

All the timber received met the highest rating for appearance grade standards at the time of purchase. These standards were AS 2796.2 and AS 4785.2 for the terrestrial timber and Hydrowood grading rules for the submerged timber. Upon receiving the timber, the appearance grading was re-checked and in the large majority of cases the timber matched the original grading. The point of checking the original grading was to ensure that all of the timber tested in the following tests was of a consistently high standard, and it was.

Bending properties (MOR and MOE)

Methods

The Modulus of Rupture (MOR) and apparent Modulus of Elasticity (MOE) of each sample set was determined by tests conducted on 10 samples each of celery-top pine, myrtle and mixed hardwood for both submerged and terrestrial wood as well as a set of 10 *E. obliqua* samples. The terrestrial myrtle was boards that were 25 mm thick by 125 mm wide by 2250 mm span length. All the other species were boards 25 mm thick by 105 mm wide by 1890 mm span length.

The wood was tested to:

- AS/NZS 4063.1:2010. Characterization of Structural Timber – Test Methods for bending strength, apparent MOE and MOR.
- AS/NZS 2878:2000 Timber – Classification into strength groups.

The apparent Modulus of Elasticity in bending (MOE) is determined from the measurement of the vertical displacement of the centre point of the test piece whilst under a load that is being increased at a constant and standard rate (Photo 6). The Modulus of Rupture is determined from the load being applied and the measured displacement at the moment that the sample piece failed.

The MOE and MOR of the boards were calculated using Equation 3 and Equation 4 from AS 4063.1:2000, (Standards Australia 2010).

$$MOE = \frac{23L^3(F_2-F_1)}{108bd^3(\varphi_2-\varphi_1)} \qquad (3)$$

$$MOR = \frac{F_{max}\,L}{bd^2} \qquad (4)$$

where b and d are the thickness and the width of boards (mm); L is the span length (mm); F_2 and F_1 are respectively 40% and 10% of the maximum load (F_{max}) at failure point (N); φ_2 and φ_1 are maximum displacement (mm) at F_2 and F_1 loads, respectively.

Analyses

The difference between the submerged and terrestrial timber for both MOE and MOR was tested using Students t-test (two-tailed) for comparing two samples with equal variances. For each variable three t-tests were conducted; submerged myrtle compared to terrestrial myrtle, submerged celery-top pine compared to terrestrial celery-top pine and submerged eucalypt vs terrestrial eucalypt.

Results

There were differences between submerged and terrestrial timber for both Modulus of Elasticity (MOE) (Table 2) and Modulus of Rupture (MOR) (Table 3). However, differences were species dependent with the submerged celery-top pine showing lower MOE and MOR than terrestrial celery-top pine and submerged myrtle showing higher MOR and MOE than terrestrial myrtle. There was no significant difference between submerged and terrestrial eucalypts, this includes testing against both non-identified terrestrial eucalypt species and terrestrial *E. obliqua*.

Table 2: Modulus of Elasticity (n = 10) between submerged (S) and terrestrial wood (T). The E. obliqua samples were compared to both the terrestrial eucalypt and the submerged eucalypt and the lower P value is reported.

Species	**Celery-top pine**		**Myrtle**		**Eucalypt**		**E. obliqua**
Source	**S**	**T**	**S**	**T**	**S**	**T**	**T**
MOE (GPa)	10.3	12.8	14.4	12.5	18.5	17.8	16.8
T-test	**P = <0.001**		**P = 0.027**		P = 0.690		P = 0.373
	Sig.		Sig.		Not sig.		Not sig.

Table 3: Modulus of Rupture (n = 10) between submerged (S) and terrestrial wood (T). The E. obliqua samples were compared to both the terrestrial eucalypt and the submerged eucalypt and the lower P value is reported.

Species	**Celery-top pine**		**Myrtle**		**Eucalypt**		***E. obliqua***
Source	**S**	**T**	**S**	**T**	**S**	**T**	**T**
MOR (MPa)	36.5	64.5	56.4	38.8	66.3	65.7	61.2
T-test	**P = <0.001**		**P = 0.027**		P = 0.945		P = 0.548
	Sig.		Sig.		Not sig.		Not sig.

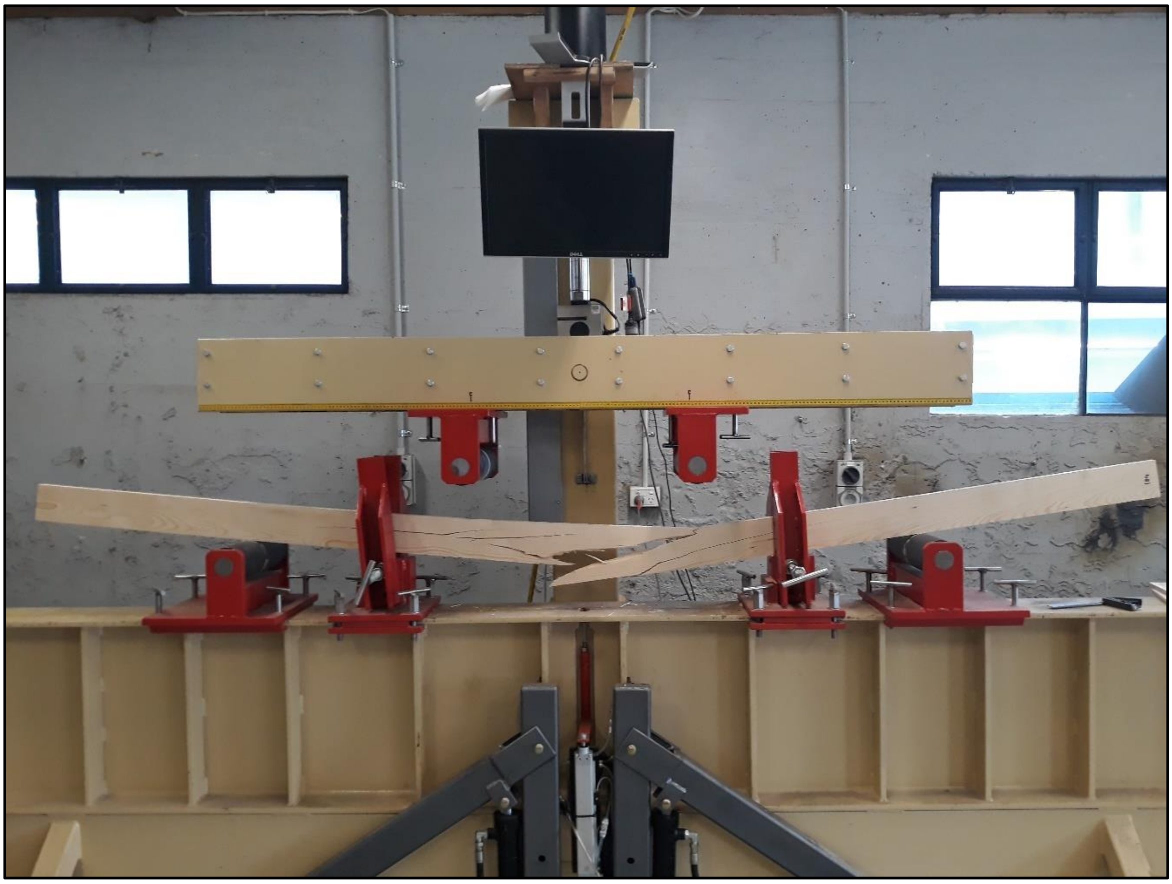


Photo 6. Testing rig for determining apparent MOE and MOR. The sample piece is supported on the black rollers left and right, and the load is applied at a constant rate via the two rollers mounted below the top beam. The red uprights retain the test piece from any lateral movement whilst the load is applied, and also help to stop material flying around the room when the piece fails.

Moisture content (MC)

Methods

Moisture content was tested as per AS/NZS 1080.1: 2012. Timber – Methods of Test – Moisture Content.

Samples were tested in three formats from one section taken 450 mm from the end of each board, and tested for capacitance, resistance and oven dry density in that order, each of which are different ways of measuring the water content of the sample material. Oven dry density was tested to AS 1080 for both initial test and case to core split. 15 boards per species per group was used for each of the three moisture content tests

The resistance meter was uncorrected for species but corrected for temperature. Moisture meters normally have a species conversion for testing the moisture content of a board, but no tables exist for Tasmanian timber species so the default, which is for Douglas fir, had to be used. Testing oven dry density is an empirical measure and this is the most reliable test. Capacitance meter measurements were also taken as they are used by many furniture makers not wanting to use destructive pins on this type of high dollar material. Capacitance measurement is challenging with changing density and grain structures. Again, oven-dry density is the most reliable measure.

Analyses

Difference between the submerged and terrestrial timber for oven dry-moisture content, J2000 moisture content and Delhorst capacitance moisture content were tested using Students t-test (two-tailed) for comparing two samples with equal variances. For each variable three t-tests were conducted; submerged myrtle compared to terrestrial myrtle, submerged celery-top pine compared to terrestrial celery-top pine and submerged eucalypt vs terrestrial eucalypt.

Results

Moisture content testing showed that across all species the submerged timber had a small but significant higher moisture content (Table 4, 5, 6). As noted above, oven-dry density is the most reliable of these three tests, however, the pattern of the difference was identical between the three tests and only the Delhorst capacitance test did not show a significant result for all species (Table 6). The results also indicate that all the material tested was below the usual market expectation of around 12% moisture content. The material had been stored in an air-conditioned building for some months prior to testing, and this could have resulted in the relatively low moisture contents.

Table 4: Oven dry moisture content measured for both submerged wood (S) and terrestrial wood (T). N = 15 for each group.

Species	**Celery-top pine**		**Myrtle**		**Eucalypt**	
Source	**S**	**T**	**S**	**T**	**S**	**T**
% m c	10.42	9.39	11.31	9.76	10.73	9.50
	P = 0.003		**P = < 0.001**		**P = 0.002**	
	Sig.		Sig.		Sig.	

Table 5: J2000 moisture content measured for both submerged wood (S) and terrestrial wood (T). N = 15 for each group.

Species	**Celery-top pine**		**Myrtle**		**Eucalypt**	
Source	**S**	**T**	**S**	**T**	**S**	**T**
% m c	11.78	10.18	11.59	10.33	10.75	9.61
	P = 0.005		**P = 0.008**		**P = 0.020**	
	Sig.		Sig.		Sig.	

Table 6: Delhorst capacitance moisture content measured for both submerged wood (S) and terrestrial wood (T). N = 15 for each group.

Species	**Celery-top pine**		**Myrtle**		**Eucalypt**	
Source	**S**	**T**	**S**	**T**	**S**	**T**
% m c	10.93	10.41	11.97	10.40	11.47	9.83
	P = 0.290		**P = 0.005**		**P = < 0.001**	
	Not sig.		**Sig.**		**Sig.**	

Moisture gradient

Methods

Moisture gradient was tested as per AS/NZS 1080.1: 2012. Timber – Methods of Test – Moisture Content. Case to core testing is conducted to measure the difference between the centre ‘core’ of a test piece and the outside ‘case’. It is desirable for timber being presented to market to have an even moisture content across the piece, that is, for core and case moisture content to be similar.

For moisture gradient testing a section of board was taken at least 450 mm from the end of the board, as end grain is known to dry more quickly than face grain, and then the test piece was split using a custom-made splitter, so as to extract a sample piece from the core of the section, and a sample piece from the case of the same section. The pieces were then weighed, placed in an oven for 24 hours, weighed again, and then weighed every 6 hours until their weight stopped changing, that is, until they were completely dry. Initial moisture content of each piece was then calculated.

Results

The results indicate that the core material generally was at a higher moisture content than the case material. The pattern of higher moisture content within the core was consistent across all species examined and did not change depending on submerged or terrestrial wood (Table 7). Higher core moisture was also consistently observed independent of which case was examined. As for the moisture content testing above, all material was found to be at less than 12% moisture content. As mentioned previously, the drier condition of the case material could well be the result of the wood being stored for some time in an air-conditioned environment.

Analyses

Difference between the case and core moisture content was tested using Students t-test (two-tailed) for comparing two samples with equal variances. For each species per group a t-test was conducted on core versus both outer cases.

Table 7: Average moisture content, core v case, % for submerged wood (S) and terrestrial wood (T) (n = 5).

Species	**Celery-top pine**		**Myrtle**		**Eucalypt**	
Source	**S**	**T**	**S**	**T**	**S**	**T**
Case 1	8.82	9.09	8.98	9.58	8.60	7.64
Core	11.25	10.74	11.58	10.87	11.49	8.70
	P = 0.003	**P = 0.017**	**P = 0.028**	P = 0.066	**P = 0.020**	P = 0.076
	Sig.	**Sig.**	**Sig.**	Not sig.	**Sig.**	Not sig.
Case 2	8.00	8.91	9.57	9.54	9.34	7.63
Core	11.25	10.74	11.58	10.87	11.49	8.70
	P = 0.001	**P = 0.008**	P = 0.104	P = 0.028	**P = 0.034**	P = 0.050
	Sig.	**Sig.**	Not sig.	Not sig.	**Sig.**	Not sig.

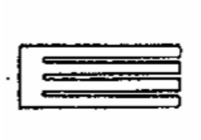
Residual drying stress

Methods

Residual Drying Stress was assessed using the standard stress prong test. Whilst the prong test is an industry standard, it is not an empirical test but an observational one. Nothing is measured, but distortion is observed immediately, and then 24 hours, after cutting. Samples are scored based on the assessment sheet (Fig. 9). The residual drying stress should be examined together with the results of the moisture gradient tests (Table 7). Again, this may be more an indicator of process/handling during the seasoning phase than product but is in reality a strong indicator of how the material will perform in use.

The procedure for a prong test is:

1. Cut 4 defect-free cross section about 30 mm wide at least 400 mm from the end of the board.
2. Number the pieces for identification.
3. Using a bandsaw, cut about 3 saw cuts (for 25 mm thick timber) from one edge parallel to the face, stopping 10 mm from an edge for each sample. See the sketch below.



Take care pulling the cross section back through the saw cut as stressed piece may pinch and pull the bandsaw blade.

4. Photograph and measure the initial movement in each sample.

The central two prongs can be broken out to show cases of severe stress.

5. Assess the level of stress using Figure 11.

(The above provided by CSAW and comes from “3. Residual stress Workshop session: Timber properties KDA 503-335: Timber, its origin and characteristics”, used with permission).

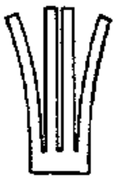
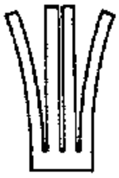
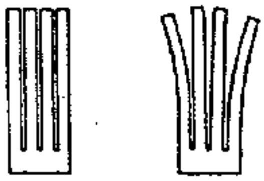
Immediately after cutting	After Standing for 24 hours		
 **1. Turn out** Surface in tension and centre in compression	 **1A Turn in** Indication of unequal moisture content distribution: surface drier than centre. Occurrence: Early stages of drying. Remarks: No need to steam, may need to raise humidity.	 **1B Does not change** Indication of practically equal moisture content distribution. Surface in tension & centre in compression. Occurrence: After over steaming at low mc. Remarks: Steaming has been too severe.	
 **2. Turn In** Surface in compression and centre in tension	 **2A Pinch tighter** Indication of unequal moisture content distribution: surface is drier than centre. Occurrence: After the centre dries below fibre saturation point. Remarks: Advantageous point to relieve stresses by steam treatment.	 **2B Become straight of turn out** Indication of unequal moisture content distribution: centre is drier than surface. Occurrence: After steaming but before redrying. Remarks: Prongs cut after re-drying should remain practically straight.	
 **3. Remain straight** Free from stresses	 **3A Remain straight** Indication of equal moisture content distribution and freedom from stresses. Remarks: Correct final condition.	 **3B Turn in** Indication of unequal moisture content distribution: surface is drier than centre. Remarks: A short steaming treatment to balance moisture content should also relieve stresses.	 **3C Turn Out** Indication of unequal moisture content distribution: centre is drier than surface. Occurrence: During some period of redrying after steaming.

Figure 9. Assessment sheet for grading test samples using the prong test.

Results

The submerged samples exhibited greater drying stress compared to terrestrial samples. This pattern was consistent across all three species examined. This pattern was also present both straight after cutting and 24 hrs post-cutting (Table 8). Overall the terrestrial eucalypt samples showed the least residual drying stress (86% showed no movement after 24 hours) followed by the terrestrial celery top pine (85% no movement after 24 hours) and the terrestrial myrtle (71% no movement after 24 hours). In comparison after 24 hours only a small percentage of the submerged samples had exhibited no movement; eucalypt (14%), myrtle (29%), celery-top pine (50%).

As previously noted, any tendency in the material for the case to be drier than the core, could be the result of the material being stored in an air-conditioned building.

Table 8: The prong test results of the submerged and terrestrial timber samples

Species	**Resource type**	**N**	**Prong Shape**	
			Initial	**After 24h**
Celery top pine	Submerged	15	3/1, 5/2, 7/3	3/1^{a}, 5/2^{b}, 7/3^{a}
	Terrestrial	15	2/1, 1/2, 12/3	2/1^{a}, 1/2^{b}, 12/3^{a}
Myrtle	Submerged	15	7/1, 4/2, 4/3	7/1^{a}, 4/2^{a}, 4/3^{a}
	Terrestrial	15	1/1 , 14/3	1/1^{b}, 10/3^{a}, 4/3^{b}
Eucalypt	Submerged	15	12/2, 3/3	12/2^{a}, 2/3^{a}, 1/3^{b}
	Terrestrial	15	1/1, 14/3	1/1^{b}, 12/3^{a}, 2/3^{b}

Dry Density

Methods

Dry density was measured at 12% moisture content and followed the methods as per AS/NZS 1080.3: 2000. Timber – Methods of Test – Density.

This test was per the standard with material taken from the end of the board at approximately 600 mm in to give some consistency, with the original 20 samples upped to 30 to give better representation.

Analyses

Difference in dry density between submerged and terrestrial timber were analysed using students t-test (two-tailed) for comparing two samples with equal variances. Three t-tests were conducted that compared; submerged celery-top pine to terrestrial celery-top pine, submerged myrtle to terrestrial myrtle and submerged eucalypt to terrestrial eucalypt.

Results

The submerged celery-top pine and eucalypt samples were significantly less dense than the terrestrial wood. No significant differences were observed between the submerged wood and terrestrial wood in the myrtle samples (Table 9).

Table 9: Dry density (kg/m3) measured for submerged (S) and terrestrial (T) samples (n = 30).

Celery-top pine		Myrtle		Eucalypt	
S	T	S	T	S	W
591	619	653	680	605	650
P = 0.018		P = 0.070		**P = 0.004**	
Sig.		Not sig.		**Sig.**	

Janka hardness

Methods

The Hardness testing was conducted according to the procedures described in ASTM (American Society for Testing and Materials) D1037. There is no Australian Standard for hardness testing, and the procedure followed is recognised globally.

The set up for testing is as illustrated below (Fig. 10). A constant load is applied to a ball bearing 11.3 mm in diameter until the ball bearing has penetrated the test sample to half the diameter of the ball bearing. The amount of force required to achieve the target penetration is reported in Newtons.

Test pieces were prepared from the boards provided with each test piece being 125 mm by 25 mm by nominal lengths. Each piece was tested four times on each of the radial and tangential faces to give eight values from which an average was determined. The average scores were then compared for ten samples for each species by each source.

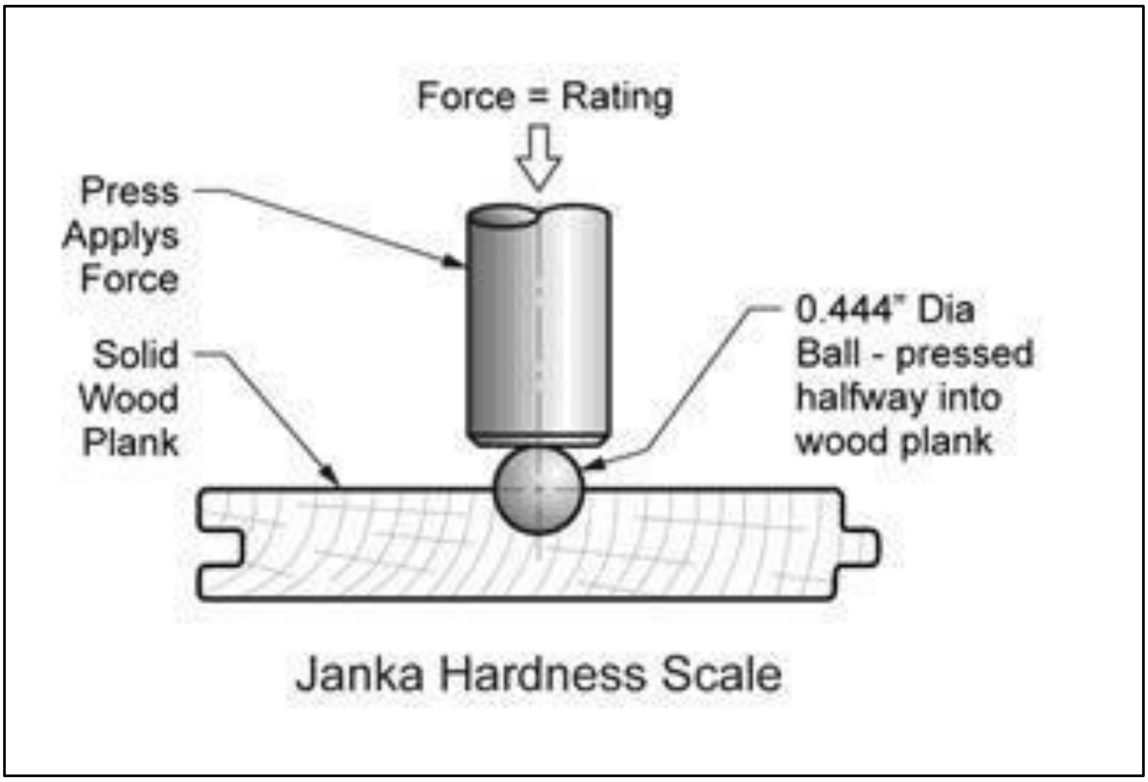


Figure 10. The set up for testing Janka hardness.

Analyses

Difference in Janka hardness between submerged and terrestrial timber were analysed using students t-test (two-tailed) for comparing two samples with equal variances. Three t-tests were conducted that compared; submerged celery-top pine to terrestrial celery-top pine, submerged myrtle to terrestrial myrtle and submerged eucalypt to terrestrial eucalypt.

Results

There was no significant difference in the hardness of any species by source. The celery-top pine is softer than the myrtle and the eucalypt (Table 10).

Table 10: Janka hardness (N) for submerged (S) and terrestrial wood (T) reported for celery-top pine, myrtle and eucalypt species (n = 10).

Species	**Celery-top pine**		**Myrtle**		**Eucalypt**	
Source	**S**	**T**	**S**	**T**	**S**	**T**
Force (N)	4.73	4.37	5.42	5.68	5.18	5.40
T-test	P = 0.092		P = 0.068		P = 0.471	
	Not sig.		Not sig.		Not sig.	

Screw withdrawal resistance

Methods

Fastener withdrawal tests were conducted according to Australian Standard AS 1649-2001 – Timber – Methods of Test for Mechanical Fasteners using fastener sizes and types relevant to the required application. The Standard describes the test and analysis of the data in detail. Each board was again 125 by 25 mm by nominal length to fit the testing rig, pictured below (Photo 7). The test procedure is as follows:

"Each fastener shall be withdrawn by means of a tensile load applied axially to the fastener in a testing machine of suitable capacity. The specimen shall be supported firmly, and means provided for pulling the fastener by a grip shaped to fit the base of the fastener head."

Six gauge, 30 mm needle point woodscrews were used for all tests. Screws are considered to provide a more reliable and repeatable test result than nails. For each test specimen two screws were inserted and then withdrawn from both the radial and tangential faces of the specimen, using a new screw for each test. The reported data is in kilo Newtons, and is the average force required to withdraw the screw from the two faces of each of fifteen specimens, except for the terrestrial *E. obliqua* for which only ten specimens were available.

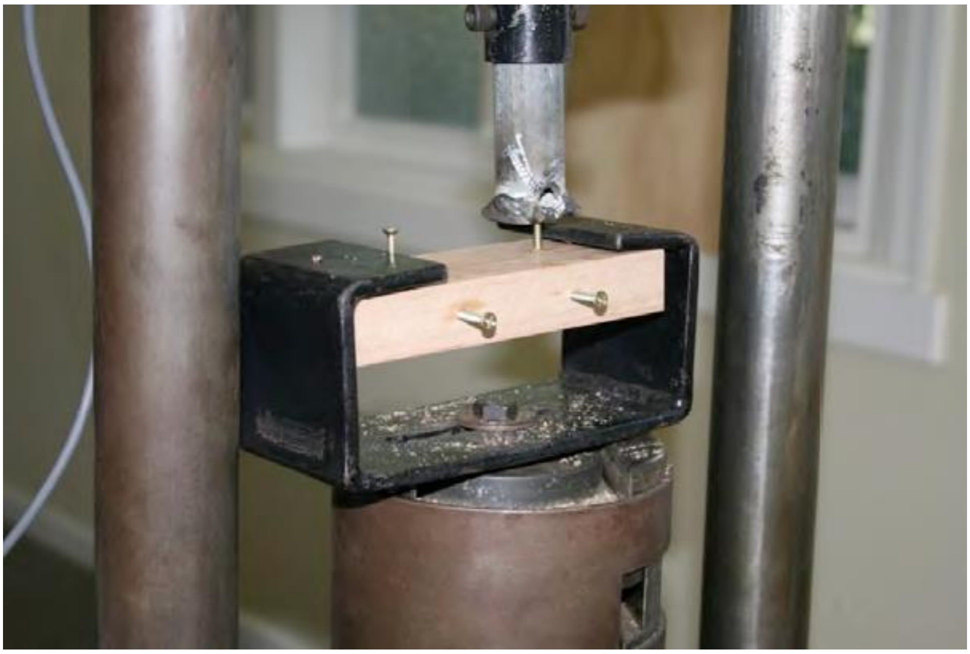


Photo 7. Testing rig for fastener withdrawal.

Analyses

Difference in screw withdrawal resistance between submerged and terrestrial timber were analysed using students t-test (two-tailed) for comparing two samples with equal variances. Three t-tests were conducted that compared; submerged celery-top pine to terrestrial celery-top pine, submerged myrtle to terrestrial myrtle and submerged eucalypt to terrestrial eucalypt.

Results

The fastener withdrawal resistance tests showed that the only significant difference between the submerged wood and the terrestrial wood occurred in the celery top pine where the submerged wood was demonstrated to be much softer (Table 11). For the myrtle and eucalypt species there was no significant difference between the two samples. Overall the celery-top pine was softer compared to the myrtle and the eucalypt (Table 11).

Table 11: Fastener withdrawal resistance for submerged (S) and terrestrial wood (T) for each of three species (n = 15). Significance tested using Students t-test (two-tailed) for comparing two samples with equal variances.

Species	**Celery-top pine**		**Myrtle**		**Eucalypt**		***E. obliqua***
Source	**S**	**T**	**S**	**T**	**S**	**T**	**T**
Force (kN)	1.56	1.99	2.09	2.08	2.12	2.18	2.11
T-test	**P = 0.043**		P = 0.926		P = 0.656		P = 0.531
	Sig.		Not sig.		Not sig.		Not sig.

Machinability (workability)

Methods:

Workability testing was conducted to the American Society for Testing and Materials (ASTM) 1666 – 11 (2011): Standard Test Methods for Conducting Machining Tests of Wood and Wood – Base Materials. The tests include assessment of planing, routing/shaping, boring (Photo 8). The machinability testing was conducted on the three species (celery-top pine, myrtle and eucalypt), plus samples of *E. obliqua*.

The machining tests were performed on dressed all round boards of 305 x 76 x 19 mm, using a computer numerical control (CNC) machine. 25 boards of each species per source were examined. The boring properties of the studied timber were visually examined for any crushing, tear-outs, fuzziness and smoothness of cut. The routed groove properties of the samples (both on side grain and end grain) were also visually examined for any raised grain, chipped grain, fuzziness and rough-end grain. The following grading system was used to classify the machinability properties of the samples:

Grade 0: No defects

Grade 1: Excellent

Grade 2: Good

Grade 3: Fair

Grade 4: Poor

Grade 5: Very poor

Results

All the timber samples across species and timber source were defect free all boring characteristics (crushing, tearout and smoothness) and exhibit no defect or excellent results for boring fuzziness (Table 12). Chipped grain and rough-end grain also exhibited limited defects across all samples with only a few minor instances of fair or poor results. All of the timber samples showed some tendency for raised grain when routing the side grain. This occurred in all species and results do not appear to be distinguishable between submerged and terrestrial samples, although raised grain occurred least in the terrestrial myrtle whereas the submerged myrtle had 10 instances of good or fair results (Table 12).

Table 12: The machinability grades of the timber species tested in this study. Results are reported for both terrestrial and submerged wood across three species. For reported results the first digit represents the total number of samples and the second digit indicates the grade (as listed in the methods).

		Routing (side grain)		Routing (end grain)	Boring
Species	**N**	**Raised grain**	**Chipped grain**	**Rough-end grain**	**Fuzziness**
Submerged celery-top pine	25	2/0, 13/1, 5/2, 5/3	25/0	25/0	15/0, 10/1
Terrestrial celery-top pine	25	5/0, 9/1, 10/2, 1/4	25/0	25/0	25/0
Submerged myrtle	25	2/0, 13/1, 8/2, 2/3	23/0, 1/2, 1/3	25/0	25/0
Terrestrial myrtle	25	20/0, 5/1	25/0	25/0	25/0
Submerged eucalypt	25	7/0, 5/1, 7/2, 6/3	24/0, 1/3	25/0	15/0, 10/1
Terrestrial eucalypt	25	1/0, 16/1, 8/3	25/0	20/0, 5/2	25/0
E. obliqua	25	16/2, 9/3	25/0	25/0	14/0, 11/1

Photo 8: Machinability testing on timber samples.

Conclusions

The wood properties testing revealed some differences between the submerged and terrestrial wood samples. The celery-top pine samples showed significantly different wood properties in six of the eight characteristics tested between submerged vs terrestrial wood. The myrtle and eucalypt samples only exhibited key differences in three of the eight characteristics.

Celery-top pine

The submerged celery-top pine was less stiff (MOE) and had lower strength (MOR) than the terrestrial samples. The submerged celery-top pine also exhibited greater drying stress, had higher moisture content, was less dense and was softer as measured by the screw withdrawal test, but note that there was no difference to terrestrial wood as measured by Janka hardness. There was also no difference in the machinability between submerged and terrestrial samples.

Myrtle

The submerged myrtle exhibited greater stiffness and strength compared to terrestrial myrtle. The submerged myrtle had a higher moisture content than the terrestrial samples. No differences could be detected between submerged and terrestrial samples for the other wood properties, including machinability.

Eucalypt

There were no detectable differences in strength and stiffness between the terrestrial and submerged eucalypt samples. However, the submerged eucalypt exhibited greater drying stress, higher moisture content and was less dense then the terrestrial wood. There were no other significant differences between submerged and terrestrial eucalypt samples.

APPENDIX 2.1 Dry cleavage of glued joints

Introduction and objective

This report describes the comparative performance of two glue types commonly used for special species timbers sawn from terrestrial and submerged resources which are currently available to the market. The species include celery-top pine, myrtle, and mixed hardwood. The material was tested in accordance with AS/NZS1328.1 which is attached at the rear of this report.

The testing aimed to compare the effect of glue bond properties on special species timbers from terrestrial and submerged resources. The testing was structured to assess the materials potential suitability for glue bond adhesion for general appearance application in residential and commercial fit-out using a quality polyvinyl acetate (PVA) glue and the suitability in marine and boatbuilding applications by the introduction of a waterproof polyurethane (PUR) type glue as used in commercial structural applications.

There are a range of variables including drying regimes, storage, handling as well as log handling and identification which may partially cloud whether the differences in performance of glue bonds found between sets are due to submersion, natural variation, or other factors. As far as possible, the material was prepared to be as consistent as possible, as described below in the methods section.

Methods

Species

Six species sets were tested: two species (celery-top pine and myrtle) and one species group (mixed hardwoods) from two resources (terrestrial and submerged) by two glue types (PVA and PUR). The submerged hardwood is reportedly a combination of Messmate, *E. obliqua*, and Smithton Peppermint, *E. nitida*. As the properties of these species can be significantly different, ideally they should have been tested separately. However, separation of the species in log or board with certainty requires expensive microscopic examination and is not part of the commercial realities for the product. As terrestrially milled hardwoods are also a mix of species, comparisons between sample sets of terrestrial and submerged boards must be treated with caution.

Sample and board size

Nominal 100 mm x 25 mm boards were re-sawn then machined to 24 mm finished product. All the material was then graded to clear grade as per AS2796 to give a consistent comparison. The material tested was selected randomly from amongst the available timber but only those pieces that made clear grade as above were used.

Tests were conducted in accordance with the relevant cleavage test in AS1328.1 (see pages appended at rear). This test measures the cleavage characteristics of face-bonded glued joints parallel to the direction of the grain. This method was employed because of the lack of any standard glue tests for appearance grade products and is widely used as a reliable in-house test in the continuous quality control on the glue line for glue-laminated timber structural products.

All the timber used was conditioned to an average of 11 ± 1% moisture content to minimise variability in both glue application and potential performance. While this is not required in the standard it was decided to apply this level of rigor for the purpose of comparison. All samples were checked for moisture content using a resistance meter in accordance with AS1080.1 and confirmed with an oven dried sub set (1 sample per set).

The timber was glued as per B4.2 in the standard in groups of 6 boards 80 mm wide x 50 mm long and 24 mm thick (depth was increased to 50 mm for more consistent evaluation as per the suggestion in the standard).

Samples were machined and laid up within three hours of machining using production wind up clamps from a commercial multi-point glue lamination. This was shorter than the 24-hour period suggested by two alternate glue manufacturers, but the shorter time frame was suggested by the PUR glue manufacturer as a safe window without any potential effect on glue bond strength.

Glue was applied as per manufacturers instructions on volume and time and left clamped for 24 hours to be consistent. Samples were then prepared as per figure B4.2 and each joint was cut to a uniform depth of 10 mm using a radial arm saw. Each glue line was then cleaved using a brick bolster and hammer as per Figure B3. All glue lines were cleaved and assessed individually.

Each glue line was visually assessed for wood failure percentage to the nearest 5% and reported below giving individual line and sample percentages for the six species and the two glue types. Note that a wood failure rate of 100% indicates that the glue failure rate was 0%. Consequently the higher the reported figure the better the glue bonding.

Acceptance criteria for dry cleavage tests were determined in accordance with appendix B of AS1328.1 wherein the average wood failure for all the glue lines in a specimen shall not be less than 60% and any glue line having a wood fibre failure of less than 30% fails the specimen. These criteria above are for structural elements potentially under differing loads and not for typical appearance product but were used as a high baseline for comparison of species and glue types.

All testing was conducted in a constant temperature and humidity environment, at 16ºC and 60% relative humidity.

Glue types

PUR

Purbond is a moisture curing, 100% solids, polyurethane adhesive. It reacts with surface moisture on any substrate, especially semiporous materials, which initiates its curing reaction. In the process of this reaction, Purbond foams and expands slightly, forcing its way into gaps, unevenness, or pores on each of the mating surfaces, thus enhancing the contact area of the joint. It has high shear strength and is creep resistant.

PVA

Biokil Crown fast-set wood adhesive is designed as a one-pack, ready-for-use, woodworkers adhesive fast-set to meet the requirements of category D3/3 and D3/4 of EN204 and in addition it gives a fast rate of bond strength development. Category D3 of EN204 covers the use of wood adhesives in applications where joints may be subjected to short term water contact or exposure to high humidity, for example as in kitchen work surfaces, window frames, doors and stairs. In addition, Biokil Crown fast-set wood adhesive meets the resistance to sustained load (creep test) requirements of BS 4071 "Polyvinyl Acetate (PVA) Emulsion Adhesives for Wood".

Analyses

Analysis of variance (ANOVA) was used to determine if there were statistically significant differences in cleavage rates depending on glue type and resource type. A model was run separately for each species and included source (submerged and terrestrial) and each glue type (PVA and PUR); models were run on the average cleavage rate of the board (n = 12).

Results

There were no statistical differences in average cleavage rate between submerged and terrestrial timber in any of the three species tested (myrtle $P = 0.822$; celery-top pine $P = 0.114$; hardwood $P = 0.737$). For all species glue type had a significant impact on average cleavage rate (all species $P < 0.001$). Across all species the PUR glue had higher average cleavage rates than the PVA glue. For submerged and terrestrial samples combined PUR glue in the celery-top pine averaged 84.0 compared to 69.7 for the PVA; for the myrtle PUR averaged 80.0 compared to 63.1 in the PVA and in the hardwood PUR averaged 91.2 compared to 72.2 for the PVA.

Table 1. Wood failure rate (%) for submerged wood glued with PVA

Species	Line 1	Line 2	Line 3	Line 4	Line 5	Line 6	Average
Myrtle	65	60	55	60	60	60	60
Myrtle	75	65	60	55	55	70	63.3
Myrtle	70	65	60	60	50	70	62.5
CTP	70	75	70	70	55	75	69.2
CTP	70	55	75	60	60	55	62.5
CTP	75	70	70	70	75	75	72.5
Hardwood	75	75	70	70	70	70	71.6
Hardwood	75	70	75	75	70	65	71.6
Hardwood	80	80	70	80	75	70	75.8

Table 2. Wood failure rate (%) for terrestrial wood glued with PVA

Species	Line 1	Line 2	Line 3	Line 4	Line 5	Line 6	Average
Myrtle	55	65	60	65	65	65	62.5
Myrtle	55	70	55	65	60	60	60.8
Myrtle	65	60	80	70	65	75	69.2
CTP	75	70	70	60	80	75	71.6
CTP	70	70	75	75	65	70	70.8
CTP	80	65	65	70	75	75	71.6
Hardwood	65	80	75	75	75	75	74
Hardwood	55	55	80	75	80	70	69.2
Hardwood	75	70	75	75	60	70	70.8

Table 3. Wood failure rate (%) for submerged wood glued with PUR

Species	Line 1	Line 2	Line 3	Line 4	Line 5	Line 6	Average
Myrtle	65	75	80	80	80	80	76.6
Myrtle	80	75	100	90	80	80	84.1
Myrtle	75	85	80	70	95	80	80.8
CTP	80	80	80	80	85	80	80.8
CTP	85	90	80	80	80	70	80.8
CTP	80	80	80	85	95	95	85.8
Hardwood	100	90	90	90	85	90	90.8
Hardwood	100	100	95	90	80	75	90
Hardwood	90	100	90	90	90	90	91.6

Table 4. Wood failure rate (%) for terrestrial wood glued with PUR

Species	Line 1	Line 2	Line 3	Line 4	Line 5	Line 6	Average
Myrtle	70	75	70	70	70	80	72.5
Myrtle	85	80	80	80	80	75	80
Myrtle	90	80	100	85	80	80	85.8
CTP	85	80	80	80	85	90	83.3
CTP	90	85	90	100	85	85	89.2
CTP	85	85	85	90	80	80	84.2
Hardwood	100	100	100	90	90	85	94.1
Hardwood	95	95	85	85	80	100	90
Hardwood	85	95	95	90	90	90	90.8

Conclusions

After assessing the effects of glue bond by dry cleavage all material has passed the base line criteria (60%) for a structural glue-laminated product (Tables 1 to 4). No difference was observed between the glue bond strength in submerged versus terrestrial timber. The work has shown in this instance that PUR glues have a stronger bonding effect than PVA.

APPENDIX 2.2 Abstract from AS/NZS 1328.1

APPENDIX B

METHODS OF TEST—CLEAVAGE OF GLUED JOINTS

(Normative)

B1 SCOPE

This Appendix describes a method for measuring the cleavage characteristics of face and edge bonded glued joints parallel to the direction of the grain in glulam. The Standard is applicable in the field of continuous quality control on the glueline.

B2 PRINCIPLE

B2.1 Procedure

A specimen consisting of a full cross section of glulam is cleaved apart in the plane of the glueline and the percentage of wood failure is recorded.

B2.2 Conditioning

The specimen can be conditioned as follows:

(a) Under ambient conditions in accordance with B4.3.1.

(b) Under wet conditions in accordance with B4.3.2.

B3 APPARATUS

The following apparatus is required:

(a) A chisel with a wedge angle and thickness such that the tip of the blade does not touch the bottom of the saw cut in the specimen, before cleavage failure occurs. The width of the chisel shall exceed the width of the test specimen.

NOTE: A bricklayers bolster is suitable.

(b) Bricklayers hammer or mallet.

(c) Radial arm saw or similar.

(d) For wet conditioning, an autoclave or similar vessel designed to withstand safely a pressure of at least 500 kPa, equipped with a vacuum pump capable of drawing a vacuum of at least 500 mm Hg of mercury in the vessel, and a pump or other device to provide a pressure of at least 500 kPa.

B4 PREPARATION OF TEST SPECIMENS

B4.1 Procedure

Specimens shall be cut as detailed in Figure B1 and shall be a minimum of 25 mm long.

B4.2 Glueline

Each glueline shall be cut uniformly to a depth of 10 mm, on the glueline as shown in Figure B2.

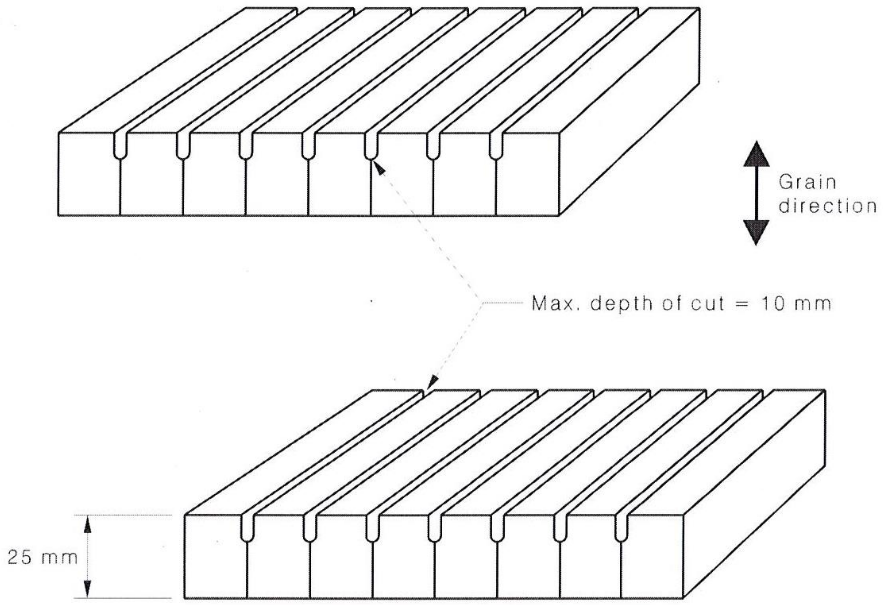


FIGURE B2 CUTTING GLUELINE

NOTE: Specimens can be cut longer than 25 mm as the larger specimens are easier to evaluate the wood failure percentage.

B4.3 Conditioning of specimens

B4.3.1 *Ambient conditioning*

Ambient conditioning of specimens shall involve storage inside the factory at prevailing conditions of temperature and humidity of not less than 2 hours.

B5 PROCEDURE

The procedure shall be as follows:

(a) Cleave each glueline by means of the chisel and hammer. Refer Figure B3.

At least three gluelines in each of the lower, middle and upper part shall be tested. If there are less than ten laminations all gluelines shall be tested.

(b) Visually assess each individual glueline wood failure percentage to the nearest 5%. Express the result as an average of all the individual gluelines.

NOTE: Light at an oblique angle such as from a fluorescent desk lamp has been found to be beneficial in the assessment of wood failure.

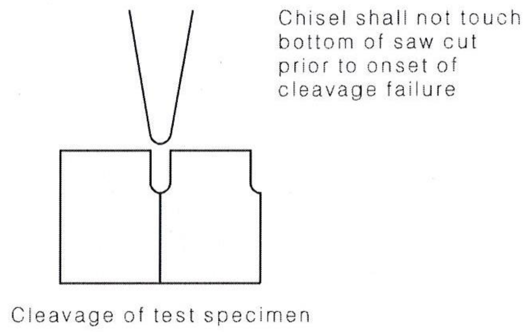


FIGURE B3 CLEAVAGE OF TEST SPECIMEN

B6 RESULTS

The following information shall be reported:

(a) The identification mark on the specimen.

(b) Wood failure percentage (WFP) of the individual gluelines.

(c) Determine the average wood failure percentage.

(d) Determine the minimum wood failure percentage.

(e) Note whether the specimen passes or fails the test.

2.6.6 Acceptance criteria for cleavage tests after both ambient and wet conditioning

When determined in accordance with Appendix B, the average wood failure for all gluelines in a specimen shall not be less than 60%. Any glueline having a wood fibre failure of less than 30% shall fail the specimen.

2.6.7 Retest

In the event of a specimen failing Clause 2.6.6, 2 further specimens from the failed glueline shall be tested in accordance with Appendix B. The results of these 2 specimens shall be averaged and should the results fail to comply with the requirements of Clause 2.6.6 then the batch represented by the sample shall be rejected. In the assessment of wood failure, areas influenced by the presence of wood defects shall be disregarded.

APPENDIX 2.3 Technical data sheets

maxbond PVA Woodworking Adhesive

Description

maxbond PVA Woodworking Adhesive is a cross linking, water resistant (D3 standard), high solids, high viscosity adhesive that resists soaking into end grain. The resulting joints have greater strength and resilience than those made with conventional PVA adhesives.

Benefits

- High solids – high strength
- Will accept most oil based stains
- Sandable
- Water clean up.
- Fast setting
- High viscosity – gap filling
- Will accept most stains and lacquers
- D3 standard water resistance

Uses

- Bonding particleboard
- Bonding plywood
- Bonding MDF Panel
- Bonding most species of timber
- Laminating
- Cabinetmaking
- Craft Work

Compatible Substrates

Pasteboard	MDF
Timber	Plywood

Performance Summary

Full cure	Typically 24 hours depending on conditions.
Colour	Off white when liquid, opaque when cured

Surface Preparation

Ensure that temperature is above 10°C. Surfaces must be close fitting, sound, dry, free from dust, oils, waxes and contamination. Use iron free tools and containers as iron will blacken the adhesive. Hardwoods must be bonded immediately after sanding or planing and should be wiped with White Spirits to remove any oily residues.

Application

Apply a thin and uniform coating to one surface by squeezing the bottle or use a glue spreader, glue roller, notched trowel or brush for larger areas. If higher water resistance is required, apply to both surfaces. Press surfaces together within 5 minutes and clamp tightly for a minimum of 2 hours. Maximum strength is attained after 24 hours. The open assembly and setting times are affected by working conditions including temperature, moisture, absorbency of surfaces and amount of adhesive used. Light articles need only be clamped for 15 minutes. Sand after 30 minutes to one hour, depending on conditions. For heavier articles or heavy sanding, chiseling, routing etc, best results are achieved if clamped overnight.

Cure Time

Keep clamped for minimum of 2hours. Full strength is usually reached in 24 hours

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Thailand
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Clean Up

Wash up tools in warm water while adhesive is still wet. Excess, wet adhesive can be removed from joint lines using a slightly damp cloth. Dry adhesive may be cleaned up with hot, soapy water. Cured material can be removed by trimming with a knife or scraper.

Limitations

- Do not apply at temperatures below 10°C.
- Do not use in wet areas
- Do not use on applications where the joints will be permanently immersed in water
- Must be clamped for maximum strength.

Safety Information

maxbond PVA Woodworking Adhesive is not classified as hazardous according to criteria of Worksafe Australia. A Material Safety Data Sheet is available from the H.B. Fuller representative your state, HB Fuller Australia customer service, or downloadable from the HB Fuller web site, www.hbfuller.com.au

Disclaimer

This technical data sheet summarises at the date of issue to the best technical knowledge of HB Fuller Australia. Since HB Fuller Australia cannot anticipate or control the conditions under which the product may be used, each user must, prior to usage, review this technical data sheet in the context of how the user intends to handle and use the product in the workplace. If clarification or further information is needed to ensure that an appropriate assessment can be made, the user should contact this company. Our responsibility for the products sold is subject to our standard terms and conditions, a copy of which is sent to our customers and is also available on request.

Version 1
TDS Date: 17/01/2017

DRIVE Marine Services

A single pack waterproof polyurethane adhesive

Purbond is a new adhesive manufactured by BoatCraft Pacific for bonding timber, semiporous and non-porous surfaces. Features of **Purbond** are

- high adhesive strength
- no long term creep in stressed joints
- suitable for use on damp surfaces
- can be applied direct from the bottle
- application is to one surface only, coverage 200 - 250 ml per square metre
- invisible in close fitting gule lines
- contains no volatile or flammable ingredients
- sand easily and *dose not blunt cutting tools*
- 100% waterproof, withstands 72 hour boiling water test.sets in 1 - 2 hours, fully cured in 24 hours

TECHINCAL DATA

Purbond is a moisture curing, 100% solids, polyurethane adhesive. It reacts with surface moisture on any substrate, especially semiporous materials, which initiates its curing reaction. In the process of this reaction, **Purbond** foams and expands slightly, forcing its way into gaps, unevenness, or pores on each of the mating surfaces, thus enhancing the contact area of the joint. It has high shear strength and is creep resistant.

Purbond can be used for bonding most materials including timber, plywood, fibre and particle boards, foamed plastics, concrete, even metals. While a strong bond will be formed to most substrates, it may not be structural with all materials. The bond is stronger than all timbers softer than pine and oregon, especially Western Red Cedar, and breaks the timber grain of them. Harder timbers will be bonded with equal strength, but the glue line may break before the timber. In test pieces we have obtained 100% wood failure with hard timbers such as Rosewood and Tasmanian Oak.

Purbond is recommended for wooden boat building applications including both timber laminating and cedar strip planking, where its ease of use will be particularly appreciated. It is suitable for all interior and exterior joinery and fitting out, and wherever surfaces are imperfectly mated. It is not recommended for gap filling of open joints, where the glue can expand out of the joint, or for joints subject to forces of peel or direct tension. For such applications, use Bote-Cote® Epoxy adhesive.

PREPARATION AND APPLICATION

Surfaces to be bonded must be sanded, clean, and free from dust, grease or other contaminants. Timber and concrete generally have adequate surface moisture to initiate cure. Other dry surfaces may be dampened with water before application by wiping with a damp cloth.

Apply **Purbond** directly from the bottle to one surface only. Spread with a scraper to a thin layer, then join and clamp the parts. Application rates will vary with the roughness of the surface. On an average surface, coverage will be 200 - 300 ml per square metre. Clamps may be removed when the exudate is hard, generally after 2 - 3 hours unless temperatures are very cold. At temperatures below 10 deg C, allow 5 - 6 hours for cure.

Some adhesive will expand out of the joint. It is best left to harden, and cut off or sanded after it has cured. Purbond sands easily without clogging the paper. It does not blunt cutting tools such as chisels and planes.

DRIVE Marine Services

SOME USES OF PURBOND

Purbond is most effective in sliding type (“shear”) joints, but is less effective in peel or tensile joints. Some examples of its best usage are:

- Laminating beams especially curved beams and similar moderately stressed laminates Mortise and tenon and biscuit joints
- Glueing dowels
- Bonding plywood e.g. to make thick ply panels, or to timber reinforcing strips Laminating bench tops
- Boat building using cedar strip planking
- Glueing to aluminium
- Glueing to concrete
- Glueing Stainless Steel to MDF and Plywood
- Glueing foams including expanded polystyrene, PVC, polyurethane, or polyethylene

PURBOND FOR CEDAR STRIP PLANKING

Purbond is especially useful for the Strip Planking method of boat building, and great efficiency will be obtained by using it with Quickstrip profiled strips.
Assemble Quickstrip planks onto the boat with the **tongue uppermost**. Place each fresh strip in a glueing jig with its groove uppermost, and simply run a bead of Purbond along the groove direct from the bottle. Spread the bead out into the groove with a suitably shaped wooden spatula. Then flip the strip over, and mount it onto the tongue of the previously fitted strip. Fasten at each station in the usual way, nailing into the upper half of the strip to force it down onto the station.

STORAGE AND HANDLING

Purbond is moisture sensitive, and containers must be kept sealed after use. If left unsealed, a skin may form, but the rest of the product will remain useable. If the bottle is stored upside down, this skin will then be at the bottom, and cannot prevent Purbond being squeezed out of the bottle. Shelf life is at least one year.
Always wear rubber gloves when using Purbond. Contact with the skin will cause temporary blackening which cannot be removed by washing. Prolonged contact may induce allergenic reactions such as rashes or breathing congestion in sensitive people.
Clean up with most solvents such as acetone. Do not thin Purbond with solvents.

PROPERTIES OF PURBOND

Chemical type	Moisture curing polyurethane
Colour	Honey colour
Solids content	100 %
Specific Gravity	1150 kg/m^3
Viscosity	3000 mPa.sec
Spread rate	200 – 300 gm per m2
Open time	45 – 60 minutes
Set time	2 hours
Full cure time	24 hours
Temperature resistance	120 Deg C
Boil resistance	72 hours
Flammability	Non flammable
Flash Point	>200 Deg C
Shear strength	exceeds 10 MPa