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NATIONAL INSTITUTE FOR FOREST PRODUCTS INNOVATION

New methods of reliably demonstrating species durability in commercially relevant time frames

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Launceston Centre

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NATIONAL INSTITUTE FOR
FOREST PRODUCTS INNOVATION
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New methods of reliably demonstrating species durability in commercially relevant time frames

Prepared for

National Institute for Forest Products Innovation

Launceston

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Executive Summary

This report outlines the overarching aims, methodology and results from the National Institute for Forest Products Innovation (NIFPI) project titled: 'New methods of reliably demonstrating species durability in commercially relevant time frames' (NT047/NIF108-1819).[1] This national research project was co-funded by the Australian and Tasmanian Governments, with cash and in-kind contributions from various timber industry and research collaborators. The project was led by Britton Timbers, with the University of Tasmania as the principal researcher.

The primary focus of this project was to identify accelerated methods of durability analysis for preservative treated or modified timber from *Eucalyptus* species that are of interest to the Australian timber industry. Durability tests typically investigate the efficacy of a candidate treatment (e.g. a new preservative chemical system) against fungal decay, insect and/or marine borer attack. The most reliable durability tests are field trials that closely mimic real-life decay scenarios, but these can take a very long time (sometimes several decades or more) to produce meaningful results. The original aim of this NIFPI project was to investigate and reduce the durability testing period required to produce useful results, rather than develop or investigate a new preservative treatment. The aim was to build on certified, well-understood accelerated testing approaches to increase their applicability in the Australian timber industry context.

However, this project relied on obtaining treated materials from other co-operators that could be used as the media for assessing accelerated test methods. Delays in the start date of the affiliated project and inherent difficulties with treating refractory (hard to treat), low durability *Eucalyptus* species made it difficult to obtain suitable test material and this prompted the incorporation of several other foci for the research.

Improving and accelerating the durability testing process for the Australian timber industry first requires development of preservative treatment processes that provide the media for subsequent accelerated durability investigations. An important part of this research project was the need to review treatment strategies for selected, representative species, outline how these strategies may impact the accelerated durability testing process and support the development of solutions as needed. This led to the development of the following modified research objectives:

- Establish and benchmark commercially viable durability assessment techniques suitable for use with Australian hardwoods
    - Start a long-term field trial to establish baseline natural (untreated) durability data on selected species for comparison with novel treatments
    - Establish which existing and novel durability treatment strategies are suitable for Australian hardwoods
    - Undertake treatment to provide materials for subsequent analysis
    - Identify which accelerated durability assessment techniques are most likely to be effective and reliable for testing successfully treated refractory Australian hardwoods

[1] The research relates directly to another NIFPI project titled 'Increasing the durability, and other material characteristics of Tasmanian hardwoods' (NT014/NIF078-1819). The preservative treatment work conducted as part of NIF078 is of direct relevance to the aims and outcomes of this project. It is advised that the final reports be read together.

A less explicit objective of the research was to help build durability analysis and testing knowledge and capacity in Tasmania and more broadly within Australia.

The research methodology involved a background literature review coupled with development of a series of strategic trials conducted by collaborative research teams at the University of the Sunshine Coast, the Danish Technological Institute, Oregon State University, the Department of Agriculture and Fisheries in Queensland, the University of Melbourne, the University of Queensland, and the University of Tasmania. The following strategies were trialled:

Trial 1 Accelerated and mid to long-term field trials
Trial 2 Initial preservative treatments
Trial 3 Accelerated laboratory trials

Significant outcomes from the research include:

- Establishment of a long-term (thirty year) field trial site in northern Tasmania that will be monitored and maintained by researchers at the Centre for Sustainable Architecture with Wood at the University of Tasmania, with matching material in a sister site at the Queensland Department of Agriculture and Fisheries Maroochy Research Station in Nambour, Queensland, that will be monitored and maintained by the National Centre for Timber Durability and Design Life at the University of the Sunshine Coast
- Multiple accelerated and mid to long-term field trials on treated and untreated material installed
- Improved capacity at the University of Tasmania's Centre for Sustainable Architecture with Wood to maintain, add material to, and collect data from the field trials
- Successful treatment and retention of biocides in the heartwood of Tasmanian plantation shining gum using supercritical carbon fluids (SCFs) as a carrier
- Iterative improvements on the use of conventional vacuum pressure impregnation (e.g. schedules, pressures) and a common preservative chemical (alkaline copper quaternary) in treating Tasmanian hardwoods of varying thicknesses
- Successful development of an accelerated decay chamber set up (i.e. using vermiculite bags) for larger scale samples in a laboratory-based setting
- Establishment of a PhD project at the University of the Sunshine Coast with aim to accelerate decay testing and durability analysis in treated refractory Tasmanian hardwoods

Industry/research partners:

Britton Timbers (project lead)
Sustainable Timber Tasmania
Neville Smith Forest Products
Porta Timber
McKay Investments Pty Ltd
Private Forests Tasmania
Koppers Performance Chemicals Australia
University of the Sunshine Coast (UniSC)
University of Tasmania (UTAS)

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Dr Anders Kjellow
Oregon State University:
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Standards referred to in this report

AS 5604:2005 – Timber natural durability ratings
AS/NZS 1604:2021 - Australian and New Zealand Standard for Preservative-treated wood-based products inclusive of Part 1: Products and treatment, Part 2: Verification requirements and Part 3: Test methods.
AS 3959:2018 - Construction of buildings in bushfire-prone areas.
AS/NZS 3837:1998 - Method of test for heat and smoke release rates for materials and products using an oxygen consumption cone calorimeter.
AS 5637.1.2015 - Determination of fire hazard properties.
AS ISO9705.2016 - Fire tests - Full-scale room test for surface products.
AS/NZS 3837.1998 - Method of Test for Heat and Smoke Release Rates for Materials and Products Using an Oxygen Consumption Calorimeter.
NCC 2019 – National Construction Code, Australia
AWPA - American Wood Protection Association, annual book of standards.
AWPC – Australasian Wood Preservation Committee / Protocols for assessment of wood preservatives

Glossary of terms

ACQ - alkaline copper quaternary system
Additive – adjuvant (see below)
Adjuvant (Adj) - a substance that is added to a pesticide product or pesticide spray mixture to enhance the pesticide's performance
AWPA – American Wood Protection Association
AWPA Standard E18-15 – Standard field tests for evaluations of wood preservatives to be used above ground (UC3B): Ground Proximity Test
AWPA Standard E7-15 – Standard field test for evaluation of wood preservatives to be used in ground contact (UC4A, 4B, 4C); Stake Test
AWPC – Australasian Wood Preservation Committee / Protocols for assessment of wood preservatives (used interchangeably)
BAL – bush fire attack level
BAE – boric acid equivalent
Blue Gum – *Eucalyptus globulus*
Boron – generally used in this document to refer to disodium octoborate tetrahydrate (DOT), or interchangeably used to refer to a boron-based preservative treatment
Chrome azurol S – an indicator spray that reacts to traces of copper
Cone calorimeter – used to assess fire performance of timber
CSAW – Centre for Sustainable Architecture with Wood
DAF – Department of Agriculture and Fisheries
Fomitopsis ostreiformis – an aggressive brown rot fungus found in Queensland
EN113 – European Standard test method for determining the protective effectiveness against wood destroying basidiomycetes
HRR – heat release rate
LOSP – light organic solvent preservative
Kop-Coat – a commercially available tank blend solution of Approved-Water-Based-Azole+permethrin with typical process chemicals and small amounts of a boron tracer
Koppers – Koppers Performance Chemicals
MCA – micronized copper azole
Nambour – field trial site at Maroochy Research Facility at Nambour
NCC – National Construction Code

NCTDDL - National Centre for Timber Durability and Design Life
NexGEN – proprietary water repellent coating system
NIFPI – National Institute for Forest Products Innovation
NT014/NIF078 – short-hand reference number for an affiliated project on durability titled: Increasing the durability, and other material characteristics of Tasmanian hardwoods
NT047/NIF108 – short-hand reference number for this project
PAN – preservative indicator that reacts to copper 1- (2-pyridylazo)-2-napthol
Radiata pine – *Pinus radiata*
UM – University of Melbourne
Upper Castra – field trial site at Sustainable Timber Tasmania seed orchard in Upper Castra
UQ – University of Queensland
UTAS – University of Tasmania
UniSC – University of the Sunshine Coast
Charge/Schedule/Cycle – all refer to the combination of vacuum and pressure cycles totalling to the length of time required in a treatment cylinder. These terms are used interchangeably.
SCF – Supercritical carbon dioxide treatment
Shining gum – *Eucalyptus nitens*
Spotted gum – *Corymbia spp.*
Superwood – SCF treatment facility in Denmark
Tasmanian oak – collective term for three species: *Eucalyptus regnans, Eucalyptus delegatensis* and *Eucalyptus obliqua*
TM – thermo-mechanical densification
VPI – vacuum pressure impregnation

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Introduction

Globally, new wood protectants go through a series of laboratory and field tests to show that they are effective before they are commercialised. These methods generally use easily treated pine sapwood so that the tests are evaluating the preservative not the ability of a given timber species to be uniformly impregnated. One of the major issues with developing new methods for protecting timber from fungal, insect or marine borer attack is the long time required to produce useful efficacy data. Field trials are broadly accepted as the most effective and accurate method because they closely imitate what will happen to the timber in real life. However, depending on the site, a field trial may take anywhere from as little as 2 to 3 years to as long as 30 years to produce relevant data. Clearly, prolonged testing is not commercially viable, but there are challenges associated with accelerating the testing timeframes.

The original aim of this project was to develop and assess methods for accelerating the generation of data on the performance of Tasmanian hardwoods that were treated with preservatives in the affiliated NIFPI project (NT014/NIF078). Nearly all global treatment standards focus on heavy treatment of the more permeable sapwood with a much lower expectation for heartwood treatment. Thus, almost all existing durability assessment methods are designed to test a novel chemical system that is thoroughly impregnated into easily treated sapwood samples (like pine). In refractory (hard to treat) species like certain Australian grown eucalypts, the treatment is likely to achieve only a shallow envelope or inconsistent treatment penetration along earlywood growth rings, as demonstrated by the trials in both this project and in the affiliated NIFPI report (NT014/NIF078).

The type of treatment that is achieved ultimately determines the type of durability test that is needed. For example, a shallow envelope treatment using a preservative that is already known to be effective, like alkaline copper quaternary (ACQ), would need to test the capacity of the shallow preservative barrier to protect a largely untreated core, and not the effectiveness of ACQ in preventing fungal decay. Thus many of the existing test methods to assess durability are inappropriate for Tasmanian hardwoods. The primary challenge for testing refractory Tasmanian hardwood species, is to create responsive and appropriate durability tests for novel hardwood-specific treatments as they are developed.

The secondary aim of this project was to build capacity in Tasmania for durability testing and evaluation. Strategies that may be used for durability evaluation range from highly specialised, small-scale, laboratory-based testing to medium and large-scale testing in field trial sites with specific climatic and environmental requirements. Laboratory-based testing requires a dedicated facility with the capacity to isolate and store fungal cultures and trained staff, while field trial sites need to be secure, and easily accessible, potentially for decades. The primary challenge for building capacity for durability testing and analysis is the need for space, an established facility where cultures can be stored and used safely, staffing capacity, long-term funding to support long-term data collection and site maintenance, and a safe and secure, accessible field trial site.

Background, challenges and strategies for durability testing

This research and the research in the affiliated NIFPI project (NT014/NIF07) focussed on plantation Tasmanian blue gum (*E. globulus* Labill.), plantation Tasmanian shining gum (*E. nitens*, [H. Deane & Maiden] Maiden*)*, and native regrowth Tasmanian oak, which is a mixture of three species (*E. regnans*, F. Muell, *E. delegatensis*, L'Hér, and *E. obliqua*, L'Hér). The Tasmanian hardwood species under investigation in this research have low natural durability with expected short lifespans in exterior exposures (Table 1). The Australian

Standard for preservative treatment AS/NZS 1604.1:2021 requires that hardwoods with low natural durability must be treated with a preservative if they are to be used in exterior applications.

The standards for preservative treatment are primarily developed using data derived from performance of treated pine sapwood. The presumption is that a given mass of chemical protects a given mass of pine timber, and that it will perform similarly on a hardwood, although there are some cases where more preservative is used to protect a hardwood species.

Treatment quality is normally determined by assessing the degree of the preservative penetration and the amount of chemical present (or retention). The penetration pattern and percentage of coverage is assessed by cutting a cross section from a treated board, and spraying it with an indicator spray that reacts to copper or some other chemical in the preservative system by changing the colour of the board. For example, chrome azurol S reacts by turning blue in the presence of copper. AS/NZS 1604.1:2021 specifies complete treatment of sapwood as well as an 8 mm minimum envelop treatment of the heartwood in boards greater than 35 mm thick, and a 5 mm minimum envelop treatment in boards less than 35 mm thick (most cladding boards are around 19-25 mm). Alternatively the standard states that: 'Unpenetrated heartwood shall be permitted, provided it comprises less than 20 % of the cross-section of the piece AND does not extend more than halfway through the piece from one surface to the opposite surface AND does not exceed 50 % of the width of the surface on which it occurs.'

Retention is typically assessed on the cross sections used to assess penetration. Sapwood and the outer 5 mm or 8 mm thick heartwood zone is ground to a fine saw dust which is extracted and analysed for chemical content using methods described in AS/NZS1604.3. Alternatively, retention can be calculated by determining the amount of treatable wood in a given charge, the average wood density, and then measuring the amount of chemical absorbed (uptake) to determine a net retention (also called gauge assay, or theoretical retention). In most cases, gauge assays are used on a regular basis, while chemical analysis is used on a very limited proportion of the total plant production (1 sample per 2000 pieces of a given material). Retention can generally be achieved by altering the strength of the treatment solution, but penetration, especially in heartwood, poses the greatest challenge since the process must overcome the inherent resistance of the wood to fluid ingress.

Table 1. Reported decay and termite resistance of the species tested[a]

Common name	Species	Termite Resistance	Decay Resistance	
			Above ground	In-Ground
Shining gum	*E. nitens*	Not resistant	D3 (7-15yrs)	D4 (0-5yrs)
Messmate (Tas oak)	*E. obliqua*	Not resistant	D3 (7-15yrs)	D3 (5-15yrs)
Blue gum	*E. globulus*	Not resistant	D2 (15-40yrs)	D3 (5-10yrs)
Mountain ash (Tas oak)	*E. regnans*	Not resistant	D3 (7-15yrs)	D4 (0-5yrs)
Alpine ash (Tas oak)	*E. delegatensis*	Not resistant	D3 (7-15yrs)	D4 (0-5yrs)
Radiata pine	*P. radiata*	Not resistant	D4 (0-7yrs)	D4 (0-5yrs)

[a]Ratings as per Australian Standard AS 5604.

Some existing testing strategies

Petri dish tests: Most initial assessments of novel chemical systems begin with some form of testing in Petri dishes containing a nutrient agar. The chemical under investigation is either added to the agar at increasing concentrations or paper disks are dipped into different concentrations of the chemical. Selected fungi are then exposed to the agar or paper. Responses are usually measured in terms of radial growth and these results are used to populate a dose-response graph. The fungi can be selected for different potential uses. For example, mould or stain fungi might be used where the goal is short term protection of freshly sawn timber against these fungi, while more robust decay fungi might be included for a preservative intended to protect timber for longer periods. Petri dish tests are inherently inaccurate, but they provide a simple method for rapidly assessing a large number of possible candidates. Petri dish tests can be completed in as little as four weeks (Zabel and Morrell, 2020).

Laboratory decay tests: The next step in the process is to evaluate the chemical in timber.[2] There are two primary methods for this process. The soil block test is used in North America and Australasia (Lebow & Clausen, 2010; AWPC, 2015), while the agar block method is used in Europe (EN113: CEN, 1996; Sarker, 2006) and, to a lesser extent, South America. Both tests impregnate a permeable timber such as pine sapwood with measured amounts (retentions) of the candidate preservative. These blocks are then weighed, sterilized and exposed to test fungi. The fungi used in block tests differ slightly between the methods but generally each includes aggressive white and brown rotters, some with known tolerance to specific groups of chemicals. Soil or agar block tests usually require fourteen to twenty or more weeks, depending on the test fungus and the timber substrate. The soil block test exposes the treated wood on the surface of a feeder strip inoculated with a decay fungus known to be aggressive under laboratory conditions. This approach is limited somewhat by the aggressiveness of the test, which means that it is not truly representative of above-ground conditions (Schultz and Nicholas, 2012). The agar block test exposes the blocks on glass rods over an agar medium inoculated with a decay fungus. Loss of wood mass is used as the measure of effectiveness and the results are compared with those for similar blocks treated with a known preservative as well as blocks containing no preservative (Stirling and Morris, 2015; Stirling et al., 2017). The agar block test is also limited by the artificial conditions, as the fungus to grow on a nutrient rich media before attacking the wood and the presence of other nutrients can abnormally stimulate the test fungus.

The results can be misleading with volatile chemicals or chemicals that leach at high levels from the wood, but the method can be modified to account for these anomalies, and both tests provide a measure of durability in a relatively short time (~ four months). These results can then be used to select the retentions that should be used for a field test.

Soft Rot Testing: The soil and agar block tests are less suitable for testing the third group of decay fungi, the soft rotters. These fungi generally require the addition of exogenous nutrients and higher moisture regimes to degrade timber. There is no universally agreed method for soft rot testing, but most use some form of burial to increase the moisture conditions (Nilsson, 1973; Zabel, et al., 1985). Some methods use non-sterile soil amended with compost while others add specific fungi to a sterile vermiculite mixture. Both test methods require four to six months to produce meaningful results.

[2] These tests would also work for modified timber that hasn't been chemically treated, for example, timber that has been thermally treated.

One drawback of soil block, agar block and soft rot tests is that they use mass loss from small blocks as the measure of decay. However, numerous studies have shown that wood properties such as toughness, tensile strength or flexural properties decline sharply at very early stages of decay. The use of direct measures of changes in wood properties can sharply shorten the test period. The AWPA Standards include several methods for using longitudinal compression strength or static bending to detect decay at the early stages. These methods also allow for manipulation of the exposure medium via addition of sand or organic matter to alter water uptake by the wood.

Fungus cellars: While laboratory trials are useful, some programs have also used fungal cellars which are a hybrid between laboratory and field tests. These are essentially greenhouses or climate-controlled rooms where timber stakes are exposed in soil beds. The stakes are removed periodically and visually evaluated for degree of decay. The conditions in the chamber can be varied in terms of temperature, nutrient levels, and soil moisture to encourage different decay types. The original fungal cellars were developed to assess soft rot decay, but subsequent research has shown that they can be used to evaluate a variety of different decay scenarios (Zabel and Morrell, 2020). In general, fungal cellars have proven to produce decay only marginally faster than field trials under severe decay conditions and their use has declined.

Field trials: The next step in the evaluation process is to expose samples under field conditions. There are innumerable exterior exposure methods that vary depending on the ultimate end-use and the climatic conditions (Meyer et al., 2016). The primary goal of a field exposure is to create conditions that are conducive to rapid fungal attack and, depending on the treatment type, termite attack. The test samples are typically chosen because they can be fully impregnated with the test chemical so that the procedures are assessing the ability of a novel preservative to protect a fully treated timber sample from degradation.

The most common method for assessing new preservatives is the stake test wherein small stakes are treated to varying levels with the candidate preservative along with a reference chemical and non-treated controls. These stakes are then inserted for half their length into the ground, usually in at least two locations with differing degrees of decay hazard. The stakes are removed and visually assessed for degree of fungal or insect attack on a regular basis. Stake sizes vary and decay rates can vary widely depending on soil and climate conditions. Stake tests typically require 3 or more years to produce relevant performance data. Stake tests are the primary method for assessing preservatives to be used in soil contact (Hazard Classes 4 and 5). Stake dimensions include 4 mm x 38 mm x 254 mm long Fahlstrom Stakes that have a high surface to weight ratio to encourage leaching, 19 mm square x 450 mm long stakes, 25 mm x 50 mm x 500 mm long stakes (also called International Union of Forestry Research Organizations or IUFRO stakes) and finally 100 mm x 50 mm x 460 mm long stakes. Each variation has advantages in terms of being representative while producing results in a short time period. The 19 mm stakes are widely used in North America, while the IUFRO stakes are more common in Europe. Some preservatives are also assessed using sawn or round posts, but these tests generally take far longer and are often installed for demonstration purposes rather than initial preservative approval.

While stake tests are widely used globally, this test creates severe conditions for fungal and insect attack that do not accurately represent the risk of degradation in larger timbers out of direct soil contact (Hazard Class 3). A variety of alternative methods have been developed for assessing the performance of timber out of direct soil contact (Meyer, et al., 2016). The common theme in all of these methods is to induce some form of water trapping joint that creates conditions conducive to fungal attack. There is no single above ground test method

employed worldwide although L-joints, ground proximity and decking tests appear to be most common (see Table 2). All these methods are very sensitive to wetting/drying conditions, which makes the exposure site selection especially critical. Researchers regularly refer to a Climate Index developed by T.C. Scheffer in the 1970's that uses weather station data for average temperature and number of days per month with measurable rainfall to create an index that generally ranges from 0 (no risk of decay) to 100 (high risk), although it can climb to well over 200 in some areas. The desire for more rapid results has led to the use of sites in sub-tropical or tropical areas with regular high amounts of rainfall. South Johnstone in Far North Queensland is preferred in Australia while Hilo, Hawaii is used for North America. There are also sites in Malaysia, Columbia, Panama and Costa Rica. There are definitely limits to the degree of decay acceleration that is possible with sites, especially in very wet climates where the timber might become too wet to decay.

Table 2. Examples of field trial tests used to assess preservative performance

Test	Description	Usage	Pros/Con
Stakes	Small timber pieces inserted 300mm in the soil	Widely used globally	Simple, but not intended for this application. If treatment works here, it is likely to work in H3 use.
L-joint test	Mortise and tenon joint in a painted timber to trap water	Widely used in Europe and North America	Traps moisture, but sample preparation is labour intensive
Post and rail	Small timbers are either bolted or nailed to a post. The connection traps water, enhancing fungal attack	Formerly used in North America	Simple to install, but assessment is difficult
Deck Tests	Decking material is exposed horizontally above ground	Used globally	Simple to install, but results can be slow in some climates
Ground proximity	Small blocks are placed on concrete blocks ~50 mm above ground and covered with shade-cloth	Widely used in North America and Australasia	Easy to install but creates very high decay hazard conditions that may not accurately represent all H3 applications
Sandwich	Three pieces of timber are attacked together and exposed with the joints upward to trap moisture	Used in North America	Simple, but requires more timber for each treatment.
Stack tests	Samples of untreated or treated timber are piled to create water trapping	European test	Simple, but requires a lot of treated material and can be slow to evaluate
Lap-joint	Treated pieces are clipped together to create a water trapping joint	Europe and North America	Cumbersome and clips can be costly

In general, accelerating the decay process using application-specific testing is possible but limited. Some approaches include:

- Using smaller timber samples that accentuate leaching and surface exposure: While this is useful, there are effective limits to using meaningful dimensions. Very small samples are likely to experience abnormally high leaching rates.
- Exposing samples under more severe conditions: As noted, exposing timbers in areas with higher rainfall and temperature can accelerate the decay process, but too much rain can result in very wet timbers such that oxygen is limited. Similarly, some exposures with very similar climate indexes can have very different rates of decay for reasons that remain poorly understood, clouding the results.
- Coatings: Several of the above-ground test methods coat surfaces and then create gaps that encourage moisture entry but slow drying, thereby accelerating the decay process. However, this is not realistic for materials that will be used without coatings.

- Adding specific fungi: inoculating timbers with a specific fungus might help accelerate decay, but the results have been mixed because the added fugus must compete with all of the other organisms that could invade naturally.
- Testing lower retentions: In general, laboratory and field trials use a range of retentions in an attempt to ensure that at least one of the chosen retentions is effective. Lower retentions will tend to fail more rapidly, leading to a temptation to use data from lower retentions to support a chemical. However, care must be taken with this approach, especially with preservatives that react with the wood (chromated copper arsenate is the best example). There is evidence that lower concentrations of these systems do not interact to the same degree as the actual use concentrations, resulting in less leach-resistant treatment.

Evaluating treatments in refractory species

The techniques described above are designed to test the efficacy of a novel chemical system in uniformly treated timber in terms of their resistance to insect and fungal attack. The tests do not evaluate how that chemical system behaves in different timber species. Thus, these methods are not appropriate for evaluating preservative/wood species combinations where the treatment cannot completely penetrate into the wood. In these instances, the goal is to develop a method that evaluates the ability of a thin barrier to exclude fungi from the largely untreated interior. As noted, for refractory timber, the Australian Standard for preservative treatment (AS/NZS1604.1:2021) requires minimum depths of heartwood penetration and places upper limits on the amount of allowable untreated heartwood, meaning that any attempts to accelerate the decay process must consider the fact that the timber is likely to be incompletely treated. In other words, tests are evaluating whether the amount and the behaviour of the chemical in the wood is effective, not the efficacy of the chemical itself. For example, in this scenario, a durability test on a preservative treated board with a 5 mm envelope of treatment surrounding an untreated core beneath, must essentially evaluate the ability of the preservative barrier to effectively protect the untreated wood beneath. This, the method must simultaneously examine the effect of barrier depth on fungal or insect exclusion and the probability that the wood will develop checks or splits that penetrate beyond the depth of treatment.

The test requirements for barrier treatments eliminate the use of well treated stakes or blocks. They also preclude the use of lower retentions to accelerate decay/leaching since the barrier must remain at effective at all levels. Conversely, when the final application of the timber is already known (e.g. for use as wall cladding), decreasing the specimen size to match the nominal thickness required for that application, could produce data more specific to the actual application.

In short, research on accelerated durability testing in the Australian timber industry context, needs to encompass the differences between application-specific and more generic timber durability treatment as well as the challenges of treating refractory species, while accepting that the preservatives have been vetted using other test methods.

Research in Canada (Ruddick, 1991), which has a preponderance of very difficult to treat softwood species, explored methods for assessing the effectiveness of a chemical barrier using small samples with known preservative treatments. The method most likely to be useful for evaluating barrier treatments in low durability *Eucalyptus* species involves treating small samples with a given biocide and the subjecting that sample to repeated wetting and drying to create micro-checks that potentially penetrate past the depth of the original treatment. These

blocks are then exposed to a decay fungus. The test assesses the ability of a given treatment to migrate into and protect otherwise untreated wood exposed in the check.

Another approach is to assess the effectiveness of a preservative barrier by exposing the treated surface to a large amount of fungal inoculum. This can be accomplished by inoculating untreated sapwood with a test fungus and allowing the wood to be thoroughly colonized. The fungal colonized wood is then attached to the treated block and incubated for varying periods of time. Mass loss is then used to assess the measure of protection. The advantage of this approach is that it creates a highly aggressive environment for the growth of the decay fungus and is relatively rapid (three to six months) but it also artificially enhances the ability of the fungus to penetrate the preservative barrier.

Both the Ruddick method and the mass inoculum approach artificially enhance the probability that a fungus will penetrate beyond the depth of the barrier. In both cases, the fungus is already actively growing on the surface so the primary mode of penetration will be fungal hyphae. This is unlikely to be the case in actual exposure where fungal spores or hyphal fragments carried by wind or rain land on the wood, germinate and then need to grow through the preservative barrier. This creates a more formidable barrier to the fungus in real life.

Research design and progression

This research project was a national, collaborative effort involving multiple research and industry partners. The project was directly linked to another Launceston-based NIFPI research project (NT014/NIF078) to improve the durability and fire performance of Tasmanian hardwoods.

Work began with a collaborative research planning meeting and subsequent literature review co-authored by the lead researchers across both projects, to establish the most viable potential strategies to achieve the project goals (Wood, et. al., 2020). The project research team collaboratively established a series of strategic trials that were then undertaken at the University of Tasmania, the University of the Sunshine Coast, and the Queensland Department of Agriculture and Fisheries.

It was originally intended that NT014/NIF078 would produce material that would subsequently be used in this project to develop new, accelerated testing processes, establish a secure field trial site and a mycological testing laboratory in Tasmania, and train researchers to be able to undertake durability tests and analysis.

The project started slowly due to changes in staffing and capacity at UTAS, difficulty recruiting suitable PhD candidates, and the onset of the COVID-19 pandemic and ongoing challenges caused delays throughout the project, including interstate travel restrictions, and short and often delayed timber supply, along with untimely disruption to CSAW's research operations caused by a relocation to Newnham because of the Northern Transformation Program at UTAS. As noted above, this project was heavily dependent on the production of treated materials in the affiliated Launceston-based NIFPI project NT014/NIF078, but delays in that project meant that treated material only became available for inclusion in field trials and laboratory decay studies early in 2022, while some of it was received after the project's final completion date. In terms of capacity building in Tasmania, while a new field trial site was able to be established in Tasmania, travel restrictions meant that other capacity building and training opportunities with key experts at the National Centre for Timber Durability and Design Life (NCTDDL) did not take place. Additionally, there was no dedicated facility from which a fungal culture laboratory could be safely set up at the University of Tasmania. In

2020-2021 the principal researcher on this project dedicated significant time alongside managing the active research trials to get approval for, fund, and renovate building T40 on the University of Tasmania's Newnham Campus, and relocate CSAW staff, students and activities to a more permanent home where a decay laboratory can potentially be established.

Despite the delays, challenges, and changes to the original objectives, the research trials have produced some significant successes and outputs. The lack of treated materials prompted a review of the research strategies for this project in early 2020, and several treatment options were undertaken under the auspices of this project, to generate some materials to test and evaluate. Some interesting treatment discoveries were made as a result.

Project teams met regularly to discuss progress and decide on next steps for the research as the iterative trials revealed new challenges and opportunities over the course of the project. Progress was also transmitted to industry partners through a series of milestone meetings, during which financial obligations were also reported on and signed off.

Document structure

This document is a compilation of work by various research teams. There have been a series of publications in conference proceedings and a (draft) journal article that directly resulted from the work reported on here. Rather than include the publications as appendices, this document uses the same material and references the relevant article in the title. Shorter summaries of the associated work are provided in the body of this report. Some segments of the writing from collaborator reports have been directly extracted and included in the main body of this report, and the authors/contributors are properly acknowledged as primary co-authors of this document in full.

Strategic research trials: aims, methods, results and discussions

This research project involved literature review and writing, collaborative research design with interstate research teams, and scientific experimentation. Three major research trials were established, each with its own subset of trials which included field work, systematic experimentation with preservative treatments, and development of new evaluative methods for testing durability, with hundreds of samples being tested across the project.

The field work, laboratory analysis and preservative treatment approaches trialled in this project were evaluated against Australian Standard criteria as much as possible. International standards or theoretical measures were employed where the research dealt with novel methods with no Australian benchmark.

The following sections and subsections of this document provide a summary of each of the major research trials and sub-trial components that were conducted under the auspices of the NT047/NIF108 project. Each summary outlines the primary concept, aims, methods, and results, and provides a brief discussion of the potential benefits for industry with some suggestions for further research and development to improve the likelihood of implementation.

Trial 1 Accelerated and Mid to Long-term Field Trials

As noted in the introduction, field trials are one of the most reliable methods for testing the durability of both treated and untreated timber and wood products. Despite the often lengthy times required to produce results, field trials remain an important industry evaluation tool and benchmark against which novel, accelerated durability assessment techniques must be compared. Field trials can also be accelerated by putting the field trial site in a relatively high-risk environment (e.g. tropical, sub-tropical, and marine) and by creating high-risk micro-climates and water-trapping joints in the arrangement of samples.

For this trial, two long-term field trial sites were established in two different climatic zones with different hazards. A new site was established at Upper Castra in northern Tasmania (wet, temperate); and the other was an existing site owned by the Queensland Department of Agriculture and Fisheries (DAF) at Nambour in north Queensland (wet, sub-tropical, termites). Due to the focus of the affiliated NIFPI project (NT014/NIF078) on wall claddings, a marine field trial site was not needed for this research. A memorandum of understanding was negotiated with Sustainable Timber Tasmania (STT) for ongoing use of, and access to the northern Tasmanian site for up to thirty years (from 2019). The site is securely located in one of STT's shining gum seed orchards, about a one-and-a-half-hour drive from the University of Tasmania's Launceston campus. The value of orchard means that it is a high priority site in the event of a bushfire, and is only accessible via a locked gate, making it suitably secure in the long-term.

An agreement was also established with the National Centre for Timber Durability and Design Life (NCTDDL), for ongoing monitoring and data collection to be done by the NCTDDL at the DAF operated Maroochy Research Facility in Nambour, and for that data to be shared with and owned by the University of Tasmania researchers as it becomes available.

Both sites currently include in-ground stake tests (H4 exposure) and ground proximity arrays (H3 exposure). The ground proximity arrays are a standard test method for H3 exposures, that create an aggressive, 'worst-case-scenario' microclimate for the above ground samples, that might not be truly representative of a wall cladding application. In light of this a third accelerated above ground test method was included in the trial at the Nambour site, namely the sandwich test, in which three boards of a given treatment are clipped together and exposed on racks that are elevated off the ground. This configuration still creates a water trapping joint between three boards but represents a less severe leaching/decay environment than would occur between a board and a wet concrete block.

The research for Trial 1 was undertaken by researchers at the University of Tasmania's Centre for Sustainable Architecture with Wood and the University of the Sunshine Coast's National Centre for Timber Durability and Design Life. Materials were either provided in-kind by industry partners or purchased from local suppliers.

Trial 1.1 Stake (graveyard) and ground proximity arrays: natural durability

Concept: The natural durability ratings for many timber species are provided in the Australian Standard AS 5604:2005(2016), but there are limited actual data on the natural durability of some *Eucalyptus* species. For example, field trials which began in the late 1960s (Thornton et al., 1983), and which subsequently provided the long-term data on the natural durability of 77 of the species now classified in AS 5604, did not include shining gum (*E. nitens*) or alpine ash (*E. delegatensis*), two significant hardwood species for the Australian timber industry. Species that were included in those trials mostly originated from eastern Australian forests,

while trees with southern (Tasmanian) provenance were not included. In addition, it is probable that material used in those early field trials was from trees that were much older at the time of harvest than the plantation or regrowth material which forms the focus of this NIFPI project. Younger trees tend to contain a greater ratio of juvenile wood, which may affect durability. Knowing the natural durability characteristics of various Tasmanian grown plantation and regrowth trees is important for designers and engineers planning to specify the material for built environment applications. It is also a critical benchmark from which to understand and evaluate the effectiveness of any novel preservative treatment strategies.

Table 3. Trials evaluating untreated Tasmanian plantation and regrowth forest hardwoods and untreated plantation forest softwood control in-ground and above ground exposures, TAS and QLD

Species (untreated)	Test/Exposure	Current natural durability rating in AS5604**	Sample dimensions in mm (WxHxL)	No. of samples* /location	Date installed	Next inspection due
E. globulus	In-ground	D3 (5-15yrs)	90 x 35 x 450	25 (TAS)	06/2020	07/2023*
			90 x 35 x 450	25 (QLD)	07/2020	10/2022**
	Above ground	D2 (15-40yrs)	90 x 35 x 125	25 (TAS)	06/2020	05/2023***
			90 x 35 x 125	25 (QLD)	07/2020	10/2022**
E. nitens	In-ground	D4 (0-5yrs)	90 x 35 x 450	25 (TAS)	06/2020	07/2023*
			90 x 35 x 450	25 (QLD)	07/2020	10/2022**
	Above ground	D3 (7-15yrs)	90 x 35 x 125	25 (TAS)	06/2020	05/2023***
			90 x 35 x 125	25 (QLD)	07/2020	10/2022**
E. obliqua	In-ground	D3 (5-15yrs)	90 x 35 x 450	25 (TAS)	06/2020	07/2023*
			90 x 35 x 450	25 (QLD)	07/2020	10/2022**
	Above ground	D3 (7-15yrs)	90 x 35 x 125	25 (TAS)	06/2020	05/2023***
			90 x 35 x 125	25 (QLD)	07/2020	10/2022**
P. radiata (controls)	In-ground	D4 (0-5yrs)	90 x 35 x 450	25 (TAS)	06/2020	07/2023*
			90 x 35 x 450	25 (QLD)	07/2020	10/2022**
	Above ground	D4 (0-7yrs)	90 x 35 x 125	25 (TAS)	06/2020	05/2023***
			90 x 35 x 125	25 (QLD)	07/2020	10/2022**
E. delegatensis	In-ground	D4 (0-5yrs)	90 x 35 x 450	25 (TAS)	05/2022	05/2023
			90 x 35 x 450	25 (QLD)	03/2022	03/2023
	Above ground	D3 (7-15yrs)	90 x 35 x 125	25 (TAS)	05/2022	05/2023
			90 x 35 x 125	25 (QLD)	03/2022	03/2023
E. regnans	In-ground	D4 (0-5yrs)	90 x 35 x 450	25 (TAS)	05/2022	05/2023
			90 x 35 x 125	25 (QLD)	03/2022	03/2023
	Above ground	D3 (7-15yrs)	90 x 35 x 450	25 (TAS)	05/2022	05/2023
			90 x 35 x 125	25 (QLD)	03/2022	03/2023
P. radiata (controls)	In-ground	D4 (0-5yrs)	90 x 35 x 450	25 (TAS)	05/2022	05/2023
			90 x 35 x 125	25 (QLD)	03/2022	03/2023
	Above ground	D4 (0-7yrs)	90 x 35 x 450	25 (TAS)	05/2022	05/2023
			90 x 35 x 125	25 (QLD)	03/2022	03/2023
TOTAL SAMPLES				**700**		

*First evaluation of in-ground stakes in Tasmania was conducted in 08/2021; **First evaluation of in-ground stakes and above ground blocks in Queensland was conducted in 07/2021***First evaluation of above ground blocks was conducted in 05/2022, two years after installation as no decay detectable in first year inspection.

Aims: To establish a field trial site that can provide long-term data on the natural durability characteristics of certain Tasmanian hardwood species for comparison with treated timber

Figure 1. University of Tasmania field trial site at Upper Castra, Tasmania. Photo: Stuart Meldrum.

undergoing accelerated durability tests; and to assess the performance of untreated Tasmanian plantation and younger regrowth hardwoods in soil, Hazard Class 4 (H4) and above ground Hazard Class 3 (H3) exposures (AS 1604.1:2021), using 'graveyard'/stake tests and ground proximity arrays.

Materials and methods: The species used in this test were: fibre-managed plantation Tasmanian blue gum, thinned and pruned plantation Tasmanian shining gum, and native regrowth Tasmanian oak (mixed species) with plantation Tasmanian radiata pine as a control. Test samples were cut into stakes measuring 90 mm x 35 mm x 450 mm (W x H x L) or blocks measuring 90 mm x 35 mm x 125 mm.

Labels were affixed with Monel or brass silicon coated ship building nails to avoid a potential negative interaction between the tannins in the wood and the metal fastener over time. Details of the samples and installation are outlined in Table 3.

For the stake test, samples were buried 250-300 mm deep, directly into the soil following the methods outlined in both the Australian protocols for assessment of wood preservatives (AWPC Field Decay and Termites, Hazard Class H4 and H5) and the American Wood Protection Association standard test methods (AWPA E7-15 Standard field test for evaluation of wood preservatives to be used in ground contact [UC4A, UC4B, UC4C]; stake test). For the ground proximity array, concrete blocks were placed on the ground, with test samples placed directly onto the concrete and the entire assembly covered with a frame containing a shade cloth that allowed rainfall to strike the samples but limited ultra-violet light. The ground proximity array set up also followed methods outlined in the Australian and American

standards (AWPC Field Decay, Hazard Class H3: ground proximity test; and AWPA E18-15 Standard field test for evaluation of wood preservatives to be used above ground [UC3B]; ground proximity decay test).

Evaluation of sample condition is ongoing and being assessed at least annually using visual evaluation and pick/splinter tests according to the American Wood Preservers Association Standards E7-15 and E18-15 for evaluation of wood preservatives (Table 4). Stakes are pulled from the soil and a screw-driver or blunt knife is used to scrape any soil from the wood, tap the surface to detect areas of decay, and/or it is driven into the surface of the board to determine the degree of decay (Figure 2). Each board is rated on a scale from 0 (complete failure e.g. a broken board) to 10 (sound). The same method is used to evaluate the degree of decay in samples in the ground proximity array. This data collection process will continue until the material is completely decayed or for at least five years.

Figure 2. Pick/splinter test showing screwdriver buried in *P. radiata* stake after one year in the ground at Upper Castra. Photo: Kyra Wood.

Results: This research is ongoing and will likely continue for at least another five years, but results so far have shown lots of mycological activity complete failure in some of our control stakes (*P. radiata*) at the Tasmanian site within one year (Figures 3 and 4), which means that fungi at the site are aggressive. This means that the Tasmanian field trial site has potential national value as an accelerated test site.

Figure 3. Mycelial growth on an in-ground stake at Upper Castra, Tasmania. Photo: Kyra Wood.

The sub-tropical field trial site at Nambour in Queensland has produced some interesting results so far, with the ground proximity arrays being overwhelmed by an unknown white rotter (Figure 5) that has quite aggressively attacked blue gum and shining gum samples, whereas a similar level of decay has only been noted in one or two of the inground stakes. Normally the inground stake test would be far more aggressive than the ground proximity array. Research is underway at the University of the Sunshine Coast to try to identify the species of fungus.

Decay ratings appear to be lower at the Tasmanian field trial site (Tables 5 and 6).

This reflects the qualitative nature of the research, and is an important consideration for ongoing data collection. Different individuals who rate the level of decay are likely to have slightly different perceptions. This variability can be accounted for in the final data analysis; however, it is recommended that where possible, the same individuals are responsible for decay rating for the duration of the trial, or that they hand-over/supervise their replacement so as to minimise the variability.

Another interesting result was the relatively low decay ratings at both sites for some of the *Eucalyptus* species at such an early stage in the test, particularly regarding the blue gum in-ground ratings at both sites (Tables 7 and 8), the above ground ratings at the Nambour site, and also the Tasmanian oak (*E. obliqua*) above ground ratings at the Nambour site. The levels of decay at this stage indicate that those samples are not likely to match the expected decay resistance timeframes outlined in AS 5604 (Table 1). For example, according to the standard, blue gum is supposed to resist decay for fifteen to forty years above ground and five to fifteen years in-ground. Although data collection are ongoing, it is likely that the blue gum samples will fail sooner than the standard recommends. There are several possible explanations for these premature failures. There is emerging evidence that heartwood durability tends to be lower in regrowth timber vs old-growth and this may also be occurring in the durability characteristics of the plantation blue gum. The extensive decay on the Tasmanian oak at the Nambour site was unexpected, and likely due to the presence of the as yet unidentified highly aggressive white rotter that has been discovered there. However, the extent of decay remains a concern since Tasmanian oak is extremely difficult to treat with preservatives using conventional methods.

Figure 4. Example of complete failure of a *P. radiata* stake after one year in the ground at Upper Castra. Photo: Kyra Wood.

Figure 5. Example of two blocks from the ground proximity array at Nambour, Queensland, with the aggressive fungus showing white rot attack. Photo: Jeffrey Morrell.

Table 4. AWPA Decay Rating Scheme (E7-15 stake test; E18-15 ground proximity test)	
Rating	Description
10	No sign or evidence of decay, wood softening or discoloration caused by microorganism attack.
9.5	Some areas of discoloration and/or softening associated with superficial microorganism attack.
9	Decay and wood softening is present. Up to 3% of the cross-sectional area is affected.
8	Similar to "9", but more extensive attack with 3-10% of cross sectional area affected.
7	Sample has between 10-30% of cross-sectional area decayed.
6	Sample has between 30-50% of cross-sectional area decayed.
4	Sample has between 50-75% of cross-sectional area decayed.
0	Sample has functionally failed. It can either be broken by hand due to decay, or the evaluation probe can penetrate through the sample

Benefits for industry?

The collection of natural durability data on Tasmanian hardwood species and the characterisation of plantation and regrowth trees is important for anyone producing timber for exterior applications. The establishment of a field trial site in Tasmania, and ongoing collaboration with researchers monitoring the sister site (Figure 6) in Queensland were key objectives of this research project, and will be vital for comparing any new preservative treatments that industry partners may want to trial. The sites offer industry partners access to a reliable and high decay risk site, where they can expose treated or untreated material they need to have tested, with monitoring and data collection capacity at UTAS and an ongoing relationship with the NCTDDL in QLD for a comparative evaluation in a sub-tropical field trial site. The data being collected on the natural durability of key Tasmanian hardwood species are also of great importance, particularly with regard to plantation timber that appears to be less durable than its current ratings in the AS 5604.

What still needs to be done?

Ongoing data collection, monitoring and maintenance of the field trial site is required. This may incur some costs (e.g. paying for fencing and weed maintenance, paying for personnel to collect and evaluate the data, etc.) *The Regional Research Collaboration grant received by UTAS will allow Dr Kyra Wood to continue monitoring the results of this trial until end of 2024.*

Figure 6. DAF Maroochy field trial site at Nambour. Photo: Kyra Wood.

Table 5. Condition of 450mm stakes of selected species exposed for one year in-ground, TAS										
Species	Average Decay Rating[a]	Reps	Decay Rating Distribution							
			10	9.5	9	8	7	6	4	0
E. nitens	7.36 (1.29)	25	-	-	3	11	7	2	2	-
E. obliqua	8.84 (0.75)	25	5	-	11	9	-	-	-	-
E globulus	7.35 (0.89)	26	-	-	-	15	6	4	1	-
P. radiata	3.28 (2.39)	25	-	-	2	-	-	1	7	15
[a]Values represent means while figures in parentheses represent one standard deviation.										

Table 6. Condition of 125mm blocks of selected species exposed for two years in a ground proximity arrays, TAS (Note: results after one year are not included as no decay was noted)										
Species	Average Decay Rating[a]	Reps	Decay Rating Distribution							
			10	9.5	9	8	7	6	4	0
E. nitens	9.76 (0.59)	25	19	-	4	1	1	-	-	-
E. obliqua	10 (0)	25	25	-	-	-	-	-	-	-
E globulus	9.62 (0.81)	25	16	-	5	1	3	-	-	-
P. radiata	9.72 (0.54)	25	17	-	6	2	-	-	-	-
[a]Values represent means while figures in parentheses represent one standard deviation.										

Table 7. Condition of 125mm blocks of selected species exposed for one year in a ground proximity arrays, QLD								
Species	Average Decay Rating[a]	Reps	Decay Rating Distribution					
			10	9.5	9	7	4	0
E. nitens	8.12 (1.75)	26	6	-	9	9	2	-
E. obliqua	8.68 (1.25)	30	7	11	8	1	3	-
E globulus	8.10 (1.84)	25	8	-	9	7	-	-
P. radiata	8.79 (1.02)	24	5	-	14	5	-	-
[a]Values represent means while figures in parentheses represent one standard deviation.								

Table 8. Condition of 450mm stakes of selected species exposed for one year in-ground, QLD								
Species	Average Decay Rating[a]	Reps	Decay Rating Distribution					
			10	9.5	9	7	4	0
E. nitens	8.80 (1.26)	25	5	2	15	2	1	-
E. obliqua	9.06 (1.14)	25	11	1	8	5	-	-
E globulus	9.27 (0.83)	26	11	-	13	2	-	-
P. radiata	7.42 (2.69)	25	4	1	7	10	1	2
[a]Values represent means while figures in parentheses represent one standard deviation.								

Trial 1.2 Ground proximity arrays: treated materials

Concept: To evaluate the effectiveness of the supercritical carbon fluids (SCF) + azole treatment (see Trial 2.3 below for more detail on the treatment), the boron-based dip diffusion treatment (see Trial 2.5 below), the Nex-Gen water repellent coating treatment (see Trial 2.4 below) and the vacuum pressure impregnation (VPI) + alkaline copper quaternary (ACQ) treatment (see Trial 2.2 below) in refractory Tasmanian hardwood materials of varying thickness, treated samples need to be exposed to a reasonable decay risk for a H3 application (outside, above ground). A ground proximity array provides suitable H3 exposure, that is somewhat accelerated due to the hazardous microclimate (i.e. exaggerated time of wetness inside the array) and the hostile macroclimate (i.e. wet/sub-tropical/termites at Nambour, and wet/temperate at Upper Castra). The length of time it takes for the treated samples to decay in this exposure will be compared with the length of time it takes untreated material from Trial 1.1 (above) to decay.

Aims: To expose SCF + azole treated shining gum samples of varying thicknesses, VPI + ACQ treated shining gum and Tasmanian oak samples of varying thicknesses, NexGEN water repellent coated shining gum, Tasmanian blue gum and Tasmanian oak, and boron-based dip diffusion treated Queensland maple to H3 conditions over time and compare their performance with untreated controls of the same material.

Material and methods: Ninety SCF treated plantation thinned and pruned shining gum samples (see Trial 2.3 for detail on the treatment), fifty ACQ treated plantation thinned and pruned shining gum and fifty ACQ treated native regrowth Tasmanian oak samples (see Trial 2.2 for detail on the treatment) of varying thicknesses were weighed, measure and labelled (Table x). Twelve boron dip-treated samples and twelve boron dipped with an overcoating of copper naphthenate treated samples of Queensland maple were prepared for installation (see Trial 2.5 for detail on treatment). Finally, eight plantation shining gum, eight plantation Tasmanian blue gum, and eight Tasmanian oak samples immersed in Nex-Gen, a ready-to-use water repellent solution, were also prepared for installation. SCF samples were installed in two field trial sites which experience high rainfall throughout the year, at Upper Castra, Tasmania, and at a sister site in Nambour, Queensland (Figure 7). ACQ treated material was included in the Tasmanian field

Figure 7. SCF (and some other) treated material in ground proximity array at Nambour, Queensland. Photo: Kyra Wood.

Figure 8. Boron and copper naphthenate treated material in ground proximity array at Nambour, Queensland. Photo: Kyra Wood.

trial site, while a matching set were used for separate accelerated laboratory decay tests (see Trials 3.1 and 3.4 for more detail). Boron-treated (Figure 8) and water repellent treated material were only included in the Queensland field trial site, with a separate trial using boron-treated Tasmanian hardwood species to be installed as part of a PhD project in the affiliated NIFPI project (NT014/NIF078). Details of the samples and installation are outlined below (Table 9). Samples will be evaluated at least annually using the AWPA decay rating scale and pick/splinter methods described in Trial 1.1 (above).

Figure 9. ACQ treated material of varying thicknesses in ground proximity array at Upper Castra, Tasmania. Photo: Kyra Wood.

Results: At this stage there are no results from this sub-trial, due to the length of time it takes for the treated wood to deteriorate sufficiently to make comparisons with untreated material of the same species. It is possible that none of these treatment options will perform particularly well, at least not in the thicker dimensioned samples, as none of the treatments consistently meet the target preservative retentions and penetrations required by the Australian Standard (1604.1:2021) for an H3 exposure (the reasons for this are discussed in detail in the relevant Trial descriptions below). Some of the thinner dimensioned ACQ treated samples did meet the penetration requirements for an H3 exposure, but theoretical retention (based on uptakes, solution strengths and sample density) was not calculated; observing how they perform in comparison to thicker samples is of interest. It will also be of interest to observe how treated material performs in comparison to untreated material and for how long samples remain sound according the AWPA decay rating assessment outlined in Table 4, Trial 1.1 above.

Benefits for industry?

Although the treatments being evaluated in this trial did not meet the Australian Standard requirements for H3 exposures, this decay test will help to establish the effectiveness of the current SCF + azole, NexGEN water repellent coating, VPI + ACQ and boron-based treatments in materials of varying thickness, and in the Australian context. Although it is unlikely that they will perform as well as similar samples meeting the Standard, the results could show that they might still be fit for purpose under less severe exterior exposures.

What still needs to be done?

Ongoing data collection, monitoring and maintenance of the field trial site are required. This may incur some costs (e.g. paying for fencing and weed maintenance, paying for personnel to collect and evaluate the data, etc.) *At this stage, the Regional Research Collaboration grant received by UTAS should allow Dr Kyra Wood to continue monitoring the results of this trial until the end of 2024. The Nambour samples will be monitored by the National Centre for Timber Durability and Design Life.*

Table 9. SCF treated, boron-based dip diffusion treated, NexGEN dip-coated, and ACQ treated Tasmanian hardwoods of varying thicknesses in ground proximity arrays, QLD and TAS						
Species/Treatment type	Test/Exposure	Current natural durability rating in AS5604**	Sample dimensions in mm (WxHxL)	No. of samples/ location	Date installed	Inspection due*
E. nitens / tebuconazole : propiconazole : IPBC (2:2:1 ratio) treated via SCF	Above ground H3, ground proximity array	Above ground: D3 (7-15yrs)	90x19x125	15 (TAS)	05/2022	05/2023
				15 (QLD)	03/2022	03/2023
			90x25x125	15 (TAS)	05/2022	05/2023
				15 (QLD)	03/2022	03/2023
			90x35x125	15 (TAS)	05/2022	05/2023
				15 (QLD)	03/2022	03/2023
F. brayleyana / DOT (5% or 10% BAE solution) treated via dip diffusion		Above ground: (no information available in AS5604:2005, but is classed as D4 in ground contact [0-5yrs])	90x35x125	12 (QLD)	08/2021	10/2022
F. brayleyana / DOT (5% or 10% BAE solution) treated via dip diffusion plus 3min. dip in 2% copper naphthenate			90x35x125	12 (QLD)	08/2021	10/2022
E. nitens / NexGEN (water repellent) treated via immersion		Above ground: D3 (7-15yrs)	90x35x120	12 (QLD)	7/2020	10/2022
E. globulus / NexGEN (water repellent) treated via immersion		Above ground: D2 (15-40yrs)	90x35x120	12 (QLD)	7/2020	10/2022
E. obliqua / NexGEN (water repellent) treated via immersion		Above ground: D3 (7-15yrs	90x35x120	12 (QLD)	7/2020	10/2022
E. nitens, ACQ treated via VPI		Above ground: D3 (7-15yrs)	100x5x125	5 (TAS)	08/2022	08/2023
			100x12x125	5 (TAS)	08/2022	08/2023
			100x16x125	5 (TAS)	08/2022	08/2023
			100x19x125	5 (TAS)	08/2022	08/2023
			100x25x125	5 (TAS)	08/2022	08/2023
E. obliqua, ACQ treated via VPI		Above ground: D3 (7-15yrs)	100x5x125	5 (TAS)	08/2022	08/2023
			100x12x125	5 (TAS)	08/2022	08/2023
			100x16x125	5 (TAS)	08/2022	08/2023
			100x19x125	5 (TAS)	08/2022	08/2023
			100x25x125	5 (TAS)	08/2022	08/2023
TOTAL SAMPLES**				**250**		
*Inspections will not necessarily result in ratings in first few years, depending on level of decay present **Matching untreated controls not included in tally						

Trial 1.3 Ground proximity arrays: treated and modified material from the affiliated NIFPI project (NT014/NIF078)

Concept: Although ACQ, MCA, and LOSP are already known to be effective H3 preservative treatments in easy-to-treat timber (like the sapwood of radiata pine), the capacity of these preservatives to protect refractory Tasmanian hardwoods has not been successfully demonstrated. Trials using these chemicals to treat a representative refractory Tasmanian hardwood (shining gum) via vacuum pressure impregnation (VPI) in the affiliated NIFPI project (NT014/NIF078), failed to consistently achieve the penetration or retention amounts requirements described in the Australian Standard (AS/NZ 1604), even with the addition of penetration enhancing adjuvants. Copper-based treatments, tended to preferentially treat earlywood bands more easily than latewood bands (see Trials 2.1 and 2.2 below), leaving a striped pattern of untreated timber through each board cross section. LOSP treatment was extremely shallow around the surface of each board, (i.e. >1 mm in most cases), leaving the majority of the core of each board completely untreated.

Similarly, Kop-Coat treatments which have received Codemark certification[3] for H3 and H4 exposures in some refractory Australian hardwoods did not achieve the AS/NZS 1604 required retentions in most of the shining gum samples that were treated in the affiliated trial (note: penetration and theoretical retention were unable to be properly calculated). However, seasoned timber from the species under investigation in this research were also very resistant to water uptake (see Trial 2.4 below), leading to some speculation that even a small amount of treatment in the boards may still be sufficient to protect the timber from decay fungi, or at least increase the longevity of treated samples somewhat beyond their current natural durability ratings especially in lower decay risk exposures such as cladding.

Thermo-mechanically densified material for the affiliated NIFPI project was also included in this trial.

The effectiveness of the MCA and ACQ + adjuvants, LOSP and Kop-Coat treatments and the densified material needs to be assessed under conditions that pose a reasonable decay risk for H3 application (outside, above ground). Ground proximity arrays provide a suitable H3 exposure, that is somewhat accelerated due to the hazardous microclimate (i.e. exaggerated time of wetness inside the array) and the hostile macroclimate (i.e. wet/subtropical/termites at Nambour, and wet/temperate at Upper Castra). The time required for the treated samples to decay in the H3 exposure, will be compared with the time it takes untreated material of the same species and thickness to decay under the same exposure conditions. These results will be used to determine if the treatments provided any increased decay resistance despite not meeting the Australian Standards in terms of penetration or retention requirements.

Aims: To accelerate decay in densified and MCA and ACQ + adjuvant, LOSP and Kop-Coat treated Tasmanian hardwoods from the affiliated NIFPI project (NT014/NIF078) by exposing the timber in high-risk macro and micro-environments, and to evaluate the effectiveness of the non-complying treatments for H3 exposure.

[3] To know more about Codemark certification you can read about it here: https://www.abcb.gov.au/about-codemark; or here: https://saiassurance.com.au/codemark-certification-scheme.

Materials and methods: This trial used MCA and ACQ + adjuvants, LOSP and Kop-Coat treated, and thermo-mechanically densified material from the affiliated NIFPI project (NT014/NIF078). The treatment materials and methods are described in that report (sections 2.1, 2.2, 2.3 and 4.1). Sixty samples of MCA + adjuvant (from three different charges), sixty samples of ACQ + adjuvant (from three different charges), five samples of LOSP, five samples of Kop-Coat treated shining gum material, as well as fifteen samples of densified (compression ratio: 25%) shining gum and fifteen samples of densified Tasmanian oak were weighed, measure and labelled. Details of the samples and installation (Figure 10) are outlined below (Table 10). Samples will be evaluated using the AWPA decay rating scale and pick/splinter methods described in Trial 1.1 (above).

Results: At this stage there are no results from this sub-trial due to the length of time it takes for the wood to deteriorate sufficiently to make comparisons with untreated material of the same species.

Benefits for industry?
This trial will ultimately reveal the effectiveness of the treatments trialled in the affiliated NIFPI project in an H3 exposure and will eventually enable comparison with the accelerated decay testing methods that have been trialled or that are still ongoing (i.e. in the PhD research project) to determine the effectiveness and reliability of the novel accelerated testing methods.

Figure 10. (Top and Bottom) Densified material, and MCA, ACQ, LOSP, and Kop-Coat treated material in ground proximity arrays at Upper Castra, Tasmania. Photo: Kyra Wood.

What still needs to be done?
Additional treated and densified material from the affiliated NIFPI project (NT014/NIF078) are yet to be received from DAF and the University of Melbourne. Once received, the materials will be prepared for installation and included at both trial sites. This includes: pre-treated and VPI treated material (i.e. compression, incision, microwave pre-treated material from the comparison trial) and densified material from the upscaled trial at UM.

Ongoing data collection, monitoring and maintenance of the field trial site is required. This may incur some costs (e.g. paying for fencing and weed maintenance, paying for personnel to collect and evaluate the data, etc.) *The Regional Research Collaboration grant received by UTAS will allow Dr Kyra Wood to continue monitoring the results of this trial until end of 2024. The Nambour samples will be monitored by the National Centre for Timber Durability and Design Life.*

Table 10. MCA + adjuvant (3 x charges), ACQ + adjuvant (3 x charges), LOSP and Kop-Coat treated plantation shining gum in ground proximity arrays, TAS and QLD

Species/Treatment type	Test/Exposure	Current natural durability rating in AS5604**	Sample dimensions in mm (WxHxL)	No. of samples* /location	Date installed	Inspection due*
E. nitens / MCA + adjuvant treated via VPI charge 1	Above ground H3, ground proximity	Above ground: D3 (7-15yrs)	100x19x125	20 (TAS)	08/2022	08/2023
E. nitens / MCA + adjuvant treated via VPI charge 2				20 (TAS)	08/2022	08/2023
E. nitens / MCA + adjuvant treated via VPI charge 3				20 (TAS)	08/2022	08/2023
E. nitens, ACQ + adjuvant treated via VPI charge 1				20 (TAS)	08/2022	08/2023
E. nitens, ACQ + adjuvant treated via VPI charge 2				20 (TAS)	08/2022	08/2023
E. nitens, ACQ + adjuvant treated via VPI charge 3				20 (TAS)	08/2022	08/2023
E. nitens, LOSP treated via VPI				5 (TAS)	9/2022	09/2023
E. nitens, Kop-Coat treated via VPI				5 (TAS)	9/2022	09/2023
E. nitens, TM densified			50x10x125	15 (QLD)	06/2021	10/2022
E. obliqua, TM densified				15 (QLD)	06/2021	10/2022
TOTAL SAMPLES**				**160**		

*Inspections will not necessarily result in ratings in first few years, depending on level of decay present

**Matching untreated controls not included in tally

Trial 1.4 Sandwich arrays: treated and modified material from the affiliated NIFPI project (NT014/NIF078)

Concept: Sandwiching two or three boards together and tying them tightly before exposing them with the joints upwards facing promotes water-trapping between the surfaces and increases the likelihood of fungal growth. A sandwich array mimics a real-life wall cladding decay scenario more closely than a ground proximity array where the samples are constantly in contact with concrete. Most cladding does not touch concrete and the water can be shed from the surface. Sandwich tests are slightly less aggressive than ground proximity arrays, but still have an elevated risk of decay due to the water-trapping that occurs between the surfaces of the boards that are tightly bound together.

Aims: To accelerate decay in densified and MCA and ACQ + adjuvants, LOSP and Kop-Coat treated Tasmanian hardwoods by mimicking an application where the timber might trap moisture (like in a window or door frame) but is not constantly touching a moist substrate.

Table 11. TM densified plantation shining gum and native regrowth Tasmanian oak, and MCA + adjuvant (3 x charges), ACQ + adjuvant (3 x charges), LOSP and Kop-Coat treated plantation shining gum in sandwich arrays, QLD

Species/Treatment type	Test/Exposure	Current natural durability rating in AS5604**	Sample dimensions in mm (WxHxL)	No. of samples* /location	Date installed	Inspection due*
E. nitens / MCA + adjuvant treated via VPI charge 1	Above ground H3, sandwich	Above ground: D3 (7-15yrs)	100x19x125	40 x 3 (QLD)	07/2021	10/2022
E. nitens / MCA + adjuvant treated via VPI charge 2					07/2021	10/2022
E. nitens / MCA + adjuvant treated via VPI charge 3					07/2021	10/2022
E. nitens, ACQ + adjuvant treated via VPI charge 1					07/2021	10/2022
E. nitens, ACQ + adjuvant treated via VPI charge 2					07/2021	10/2022
E. nitens, ACQ + adjuvant treated via VPI charge 3					07/2021	10/2022
E. nitens, LOSP treated via VPI				2 x 3 (QLD)	07/2021	10/2022
E. nitens, Kop-Coat treated via VPI				2 x 3 (QLD)	07/2021	10/2022
E. nitens, TM densified			50x10x125	10 x 3 (QLD)	07/2021	10/2022
E. obliqua, TM densified			50x10x125	10 x 3 (QLD)	07/2021	10/2022
TOTAL SAMPLES**				**192**		

*Inspections will not necessarily result in ratings in first few years, depending on level of decay present
**Matched untreated controls not included in tally

Materials and methods: This trial exposed thermo-mechanically densified shining gum and Tasmanian oak material, as well as shining gum samples treated with MCA and ACQ + adjuvants, LOSP and Kop-Coat treatments from trials in the affiliated NIFPI project (NT014/NIF078). The treatment materials and methods are described in that report (sections 2.1, 2.2, 2.3 and 4.1). Treated or modified samples were weighed, measured and labelled, then attached together in sets of three samples of the same treatment using zip ties. The degree of preservative penetration on the MCA, ACQ, and Kop-Coat treated samples was estimated visually and the exposed end-grain on the cut surface was supplementally treated with a 2 % solution of ACQ. The thermally modified samples received no end-coating.

Sandwich samples were then exposed on specialised stands in the field at Nambour, with the joints facing upward to trap moisture. Sandwiches will be visually evaluated at least annually by cutting the zip tie to expose the faces that are touching each other, and visually evaluated and tested using the AWPA decay rating scale and pick/splinter tests described in Trial 1.1 (above).

Results: At this stage there are no results from this sub-trial, due to the length of time it takes for the wood to degrade sufficiently to allow comparisons with untreated material of the same species.

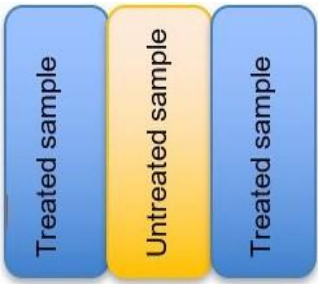

Figure 11. Schematic showing usual layout of boards in a sandwich array. In this trial most sets of three had no untreated boards in the middle.

Figure 12. Thermo-mechanical densified material in sandwich arrays at Nambour, Queensland. Photo: Jeffrey Morrell.

Benefits for industry?

Sandwich tests potentially provide a more realistic decay scenario than a ground proximity array to test the durability of wall cladding. Ground proximity arrays exaggerate the decay hazard to a certain degree (which is necessary for accelerating the time it takes to decay). The sandwich test may take slightly longer but will provide a clear understanding of the material's durability in the proposed cladding exposure.

What still needs to be done?

Ongoing data collection, monitoring and maintenance of the field trial site is required. This may incur some costs (e.g. paying for fencing and weed maintenance, paying for personnel to collect and evaluate the data, etc.) *The Regional Research Collaboration grant received by UTAS should allow Dr Kyra Wood will be able to continue monitoring the results of this trial until end of 2024. The Nambour samples will be monitored by the National Centre for Timber Durability and Design Life.*

Figure 13. Densified material, and MCA, ACQ, LOSP, and Kop-Coat treated material in sandwich arrays at Nambour, Queensland. Photo: Kyra Wood.

Trial 2 Initial preservative treatments

The evaluation of accelerated durability test methods required the availability of treated Tasmanian hardwoods, and this was clearly articulated in the original proposal. It was also an attempt to build upon the NIFPI supported treatment work, maximise effort and increase the coordination between the projects. Unfortunately there were numerous delays and challenges that prompted the establishment of several alternative treatment trials in this project to provide material for evaluation. The aim was to treat several species of Tasmanian hardwoods including plantation Tasmanian blue gum and shining gum, and native regrowth Tasmanian oak (3 *spp.*) to be suitable for use in H3 (exterior, above ground) exposures, specifically wall cladding, according to the requirements of the Australian Standard (AS/NZS 1604.1:2021).

The Tasmanian hardwood species of interest have high proportions of extremely refractory heartwood in each board that resist conventional preservative treatments. Thus, conventional treatment methods that work well in non-refractory species like radiata pine are unlikely to achieve good penetration or uptake results. Nevertheless, it was important to establish a benchmark, and two of the trials used conventional methods and chemicals which aimed to replicate what would happen in commercial preservative treatment processes in Australia for softwoods. These trials primarily used vacuum pressure impregnation via the Bethell (full cell) method (Findlay, 1985) with a 0.7% solution of alkaline copper quaternary (ACQ) a standard copper-based waterborne chemical preservative. A third trial used a commercially available water repellent coating, while the two further treatment trials used more experimental methods including supercritical carbon fluids (SCF) and a non-pressure dip-diffusion treatment using a boron-based solution, which is directly linked to the research of a University of Tasmania PhD candidate.

Preservative treatment in Trials 2.1 and 2.2 were largely performed in laboratory scale vacuum pressure treatment cylinders at the Queensland Department of Agriculture and Fisheries Salisbury Road facility. The SCF treatment in Trial 2.3 was a collaboration between the University of Tasmania (material provision and sample preparation), the Danish Technological Institute (arrangement of SCF treatment process) and Oregon State University (retention analysis) with the treatment being conducted at Superwood (Denmark), the world's only commercial SCF treatment facility in Denmark. Finally, the water repellent coating trial and the boron-based dip-diffusion treatments in Trials 2.4 and 2.5 were undertaken at the University of the Sunshine Coast.

Timber materials used in this research were either supplied as in-kind by collaborators or purchased from suppliers. Alkaline copper quaternary (ACQ) preservatives were supplied as in-kind contributions to the project by Koppers Performance Chemicals (KPC). SC200 preservative treatment was provided in-kind by Superwood. NexGEN was supplied by the producer. Chemical reagents (e.g. PAN, chrome azurol S, Azomethine H) were purchased. Disodium octaborate tetrahydrate (DOT) was provided by Rio Tinto.

Trial 2.1 Vacuum pressure impregnation (VPI) pilot

Concept: Little was known about the treatability of plantation shining gum and other Tasmanian hardwoods at the start of this project. A pilot trial using conventional, commercially available treatment methods and chemicals was a prudent starting point from which to establish the large scale, iterative, replicated treatment trials that were subsequently undertaken in the affiliated NIFPI project (NT014/NIF078). This project also provided some material for durability studies. Given what is known about the refractory nature of these species, good results were not expected, but it was important to establish a benchmark for plantation and regrowth material, and understand the effectiveness of the most widely used treatment method on the currently available Tasmanian timber resource.

Aims: To establish a baseline for treatment quality using vacuum pressure impregnation (VPI) and a common preservative chemical, alkaline copper quaternary (ACQ), on representative, refractory Tasmanian hardwood species and analyse the degree of preservative penetration possible using this method.

Materials and methods: Plantation Tasmanian blue gum, shining gum and a representative native Tasmanian oak species (*E. obliqua*), were prepared for this trial. A total of twenty 90 mm x 35 mm x 450 mm samples and twenty 90 mm x 35 mm x 125 mm long samples were prepared from each species for each of the nine treatment schedules. All samples for each species were numbered, weighed and measured to determine the air-dry density. The moisture content for one sample from each species was determined by weighing the sample then drying overnight at 100 ^{o}C. The moisture contents 9.2%, 10% and 9.9% for the Tasmanian oak, shining gum Tasmanian blue gum respectively.

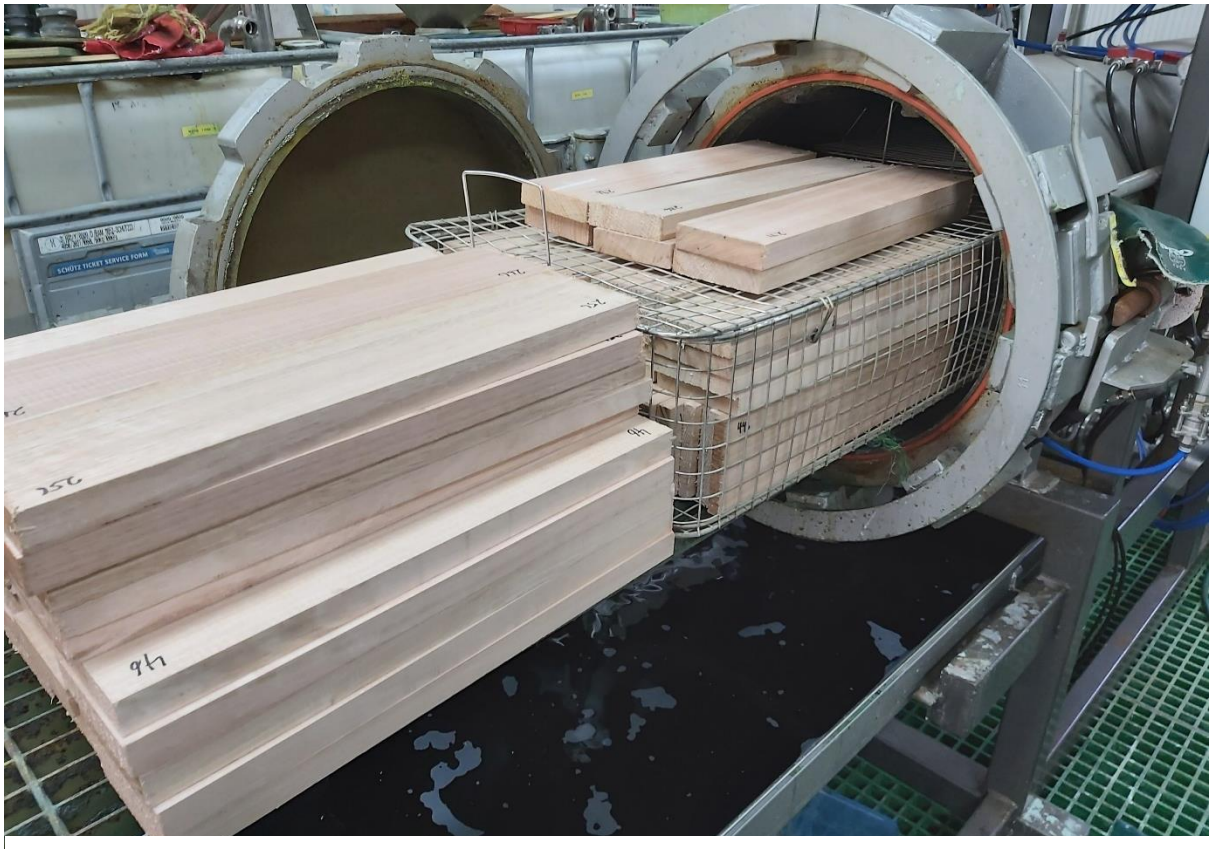

Figure 14. Untreated boards in preparation for VPI treatment in cylinder at DAF. Photo: Stuart Meldrum.

All samples were sprayed with a 0.1% methyl orange solution to determine the presence of heartwood and sapwood according to AS/NZS 1604.3:2021. However, there are some hardwood species where the 0.1% methyl orange does not assist in differentiating the heartwood and sapwood.

Seven treatment schedules were devised (Table 12) either using the pilot timber vacuum pressure impregnation treatment cylinder (Figure 14), or bathing samples in hot water followed by dipping into a room temperature chemical solution. The hot-cold bath was explored because it is simple and has been shown to improve solution uptakes with pine in as-yet unpublished research undertaken at DAF. Following the completion of the seven schedules the potential for excess end penetration to affect uptakes was examined by repeating the same schedules with a 0.7% ACQ solution on 450mm long samples with and without an end-seal.

Once the samples were treated, they were again weighed and measured to determine the solution uptake expressed as litres per cubic metre (l/m^3). The treated samples were partially air dried before being cut in half. One half of each sample was placed in a vacuum oven overnight set at 50 ^oC. 10 mm wide biscuits were cut from each dried sample and sprayed with chrome azurol S to indicate the presence of copper as per AS/NZS 1604.3:2021. However, the copper presence was not clear within the biscuits sprayed with chrome azurol S, so all samples were re-cut and sprayed with PAN (1-(2-pyridylazo)-2-napthol) indicator as per AS/NZS 1604.3:2021. It is important to note that PAN can be more reactive to copper at lower levels than chrome azurol S and some hardwood species react more clearly to PAN than chrome azurol S.

Table 12. Vacuum pressure and non-pressure schedules used to assess the treatability of Tasmanian hardwood species

Treatment Schedule	Initial Vac	Time	Hold Vac	Time	Pressure	Time	Final Vac	Time
1	-85kPa	30			+1350kPa	30	-85kPa	10
2	-85kPa	60			+1350kPa	60	-85kPa	10
3	-85kPa	30	-70kPa	30	+1350kPa	30	-85kPa	10
4	-85kPa	60	-70kPa	60	+1350kPa	60	-85kPa	10
8	-85kPa	120	-70kPa	60	+1350kPa	120	-85kPa	10
	Hot water	Time	ACQ dip	Time				
5	90^{O}C	2 hours	room temp	2 hours				
6	90^{O}C	2 hours	room temp	4 hours				
7			room temp	24 hours				
9	90^{O}C	5 hours	room temp	18 hours				

Results: Cross section biscuits revealed the presence of copper in most samples when sprayed with an indicator spray; however only a few achieved penetration passes. Back sawn Tasmanian blue gum (*E. globulus*) boards appeared to be better treated, and record higher uptakes than other boards which were mostly quarter sawn (Figure 15). Copper penetration tended to be much better in the earlywood portion of the quartersawn boards and there was relatively little penetration in the latewood. Average uptakes for the varying treatment cycles are indicated in Table 13. Preservative flow tends to be better in the vessels than the fibres and the improved treatment in earlywood vessels likely reflects the slightly more open pathways in these elements.

The PAN indicator (which turns pink) was also more sensitive to the presence of copper than the chrome azurol S (Figures 15 and 16) leading to differing interpretations of the amount of copper penetration. The AWPA Standards (A69 and A76 for chrome azurol S and PAN, respectively) also note that PAN is ~2.5 times more sensitive. In the current case, it is unclear whether the indicators are more sensitive or if PAN is less affected by other compounds in the wood that might reduce sensitivity.

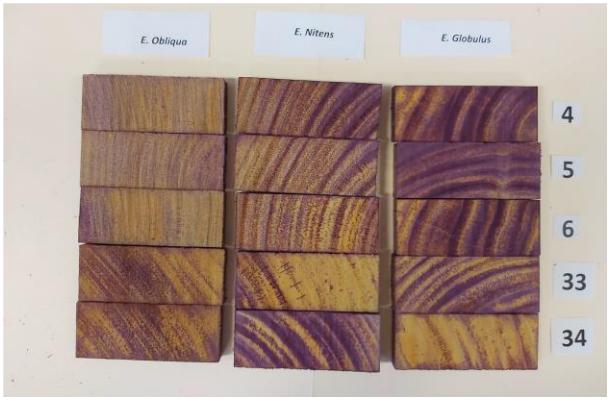

Figure 15. *E. obliqua, E. nitens, E. globulus* (left to right) Charge 2 board cross sections treated with ACQ and sprayed with PAN indicator showing reasonable penetration, particularly in back sawn *E. globulus*. Photo: Stuart Meldrum.

Figure 16. *E. obliqua, E. globulus, E. nitens,* (left to right) Charge 2 (matching boards in Figure 15 above) board cross sections treated with ACQ and sprayed with chrome azurol S, showing less penetration than with PAN indicator spray. Photo: Stuart Meldrum.

These conflicting results warranted further analysis, which led to an x-ray fluorescence trial that was conducted by researchers at DAF, but was outside the scope of this project. (DAF report on x-ray fluorescence trial can be made available on request).

There have been other instances when the presence of copper in some hardwoods with some preservatives was not detectable using chrome azurol S. However, PAN and rubeanic acid indicators were found to be better options for these species. PAN was mores sensitive to the presence of copper for these three eucalypt species.

Samples treated via the hot/cold process typically showed minimal penetration (Figure 17) with no samples passing the AS/NZS 1604 penetration requirements. These results indicated that this process would not be suitable for these wood species.

Benefits for industry?

This work was a vital first step intended to inform further research in both durability projects. It also enabled us to determine the most appropriate pressure cycles for each species. This work effectively showed that some improvements were possible with increased pressure treatment times and helped to eliminate other methods that were demonstrably ineffective, like the hot/cold process.

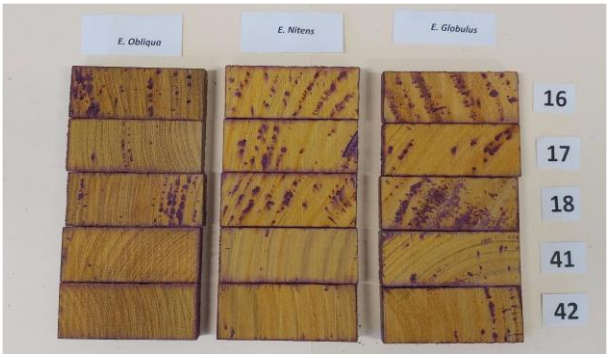

Figure 17. *E. obliqua, E. nitens, E. globulus* (left to right) Charge 6 board cross sections treated with ACQ showing extremely minimal penetration, even using the more sensitive PAN indicator spray. Photo: Stuart Meldrum.

What still needs to be done?

Further research is needed into methods for overcoming the inability of pressure treatment to impregnate the latewood. In later trials (Trial 2.2 in this project, and Trial 2.1 in the affiliated NIFPI project NT014/NIF078), this effect was equally pronounced, and when assessed against the standard it significantly reduced the number of boards that met the penetration requirement, despite over 80% of the heartwood being penetrated in most instances.

Table 13. Effect of variations in preservative treatment cycles on solution uptake of three Tasmanian hardwoods

Samples and treatment			Average Uptake L/m3			Average Density kg/m3		
Treatment Charge	Sample dimensions (WxHXL)	Reps	*E. nitens*	*E. globulus*	*E. obliqua*	*E. nitens*	*E. globulus*	*E. obliqua*
1	90x35x125	9*	214	232	177	576	545	729
	90x35x450	6**						
2	90x35x125	9*	329	298	241	564	591	709
	90x35x450	6**						
3	90x35x125	9*	138	191	141	578	547	717
	90x35x450	6**						
4	90x35x125	9*	169	284	182	601	522	714
	90x35x450	6**						
5	90x35x125	9*	60	76	57	582	559	713
	90x35x450	6**						
6	90x35x125	9*	68	76	64	611	548	752
	90x35x450	6**						
7	90x35x125	6**	65	68	53	571	544	752
	90x35x450	-						
8	90x35x125	-	164	224	163	619	621	730
	90x35x450	18***						
9	90x35x125	-	73	85	86	647	566	694
	90x35x450	6**						
TOTAL SAMPLES		**120**						

*Three of each species; **two of each species; ***six of each species.
Blue highlighted cells indicate highest uptakes for each species; green highlighted cells indicate highest densities for each species.

Trial 2.2 Varying thicknesses

Concept: Tasmanian hardwoods are used for various products (e.g. cladding, decking, veneer-based products) which vary in thickness. Thickness has a number of potential effects on performance. Thinner samples are more likely to have a higher proportion of the cross section treated (assuming that the depth of treatment will be constant for a given species). This would result in a more complete shell with less untreated, decay susceptible wood at the core. Conversely, thinner samples are likely to wet more quickly (as a percentage of the total cross section). Repeated wetting and drying creates the potential for stress developments that lead to checking and splitting. While some 35 mm thick samples passed the penetration requirements for AS/NZS 1604.1 when treated with ACQ in Trial 2.1 (above), reducing sample thickness may represent one method for ensuring that a majority of the cross-section of a given piece is well-treated, even though it might fail to meet the Standard.

Aims: To investigate the effect of material thickness on degree of preservative penetration in Tasmanian hardwood species.

Methods: 100 mm wide shining gum (*E. nitens*) and Tasmanian oak (*E. obliqua*) matched boards and 87 mm wide southern pine boards (controls) were machined to five thicknesses prior to treatment: 5 mm, 12 mm, 16 mm, 19 mm and 25 mm. Samples were end sealed with two coats of PVA glue, weighed and their dimensions were measured to determine the air-dry density. The samples were treated in the DAF pilot treatment plant with a 1% ACQ solution with five pre-determined treatment charges based on the best results from Trial 2.1 (Table 14). A total of 125 samples were treated in each treatment charge. The samples were weighed after treatment to determine net solution uptake before being air dried for two weeks. The dried samples were cut in half and a 20 mm biscuit was cut from each sample to evaluate the copper penetration using PAN indicator spray and a grid overlaid to measure percentages in each board. (Theoretical and actual retention were not evaluated in this trial.)

Table 14. Vacuum pressure processes used to evaluate the effect of varying thicknesses on ACQ retention and penetration

Treatment Charge	Initial Vac	Time	Hold Vac	Time	Pressure	Time	Final Vac	Time
1	-85kPa	15			+1350kPa	30	-85kPa	10
2	-85kPa	30			+1350kPa	30	-85kPa	10
3	-85kPa	60			+1350kPa	60	-85kPa	10
4	-85kPa	60	-70kPa	60	+1350kPa	60	-85kPa	10
5*	-85kPa	10			+1350kPa	10	-85kPa	10

Results: Shining gum sample density averaged 552kg/m^3, while the average density of all Tasmanian oak samples treated was 632kg/m^3. There was obvious evidence of preservative penetration for all the shining gum samples for the various VPI charges, although there was less preservative penetration in the latewood bands (Figure 18). Preservative penetration was detected in both earlywood and latewood bands for most Tasmanian oak samples (Figure 19). Tasmanian oak had slightly better penetration than shining gum across all thicknesses. Southern pine control samples provided a clear impression of penetration targets (Figure 20).

For shining gum, the treatment process that added a second sixty-minute vacuum period (charge 4) was associated with the highest solution uptake (Table 15) and improved penetration with 36/50 showing more than 75% of the surface area of the biscuit would pass the preservative penetration requirements. However, this schedule took over three hours,

making it unlikely that this schedule would be practical in a commercial setting. Charge 3, which used the sixty-minute initial vacuum but did not include the second one-hour vacuum also produced good penetration results with 39/50 showing more than 75% of the surface area of the biscuit would pass the requirements, but charge 3 had a slightly lower uptake than charge 4. Nevertheless, this schedule took an hour less than charge 4 making it more likely to be commercially used.

The best penetration and solution uptake results for the 5 mm thick shining gum samples were found with charge 3. These samples could be used to produce plywood or LVL that would meet the AS/NZS 1604 requirements. This is an important result as plywood constructed of treated shining gum veneers would have several uses in exterior applications.

In general, the penetration results for Tasmanian oak were similar regardless of sample thickness. The highest solution uptake was found with charge 4 (Table 15), with 42/50 Tasmanian oak samples showing more than 75% of the surface area of the biscuit would pass the preservative penetration requirements. The total process for this charge was over three hours, therefore it is unlikely that this schedule would be practical in a commercial setting. Charges 3 and 5 also gave good penetration results with 41/50 samples showing more than 75% of the surface area of the biscuit would pass the preservative penetration requirements for both charges. These charges required less time than charge 4 and therefore they are more likely to be used in a commercial setting. Oscillating treatments were once used for CCA treatment in New Zealand, but they require some additional equipment and can be harder to control. They also tend to produce more post-treatment drippage as the residual pressure in the timber carries preservative solution to the surface.

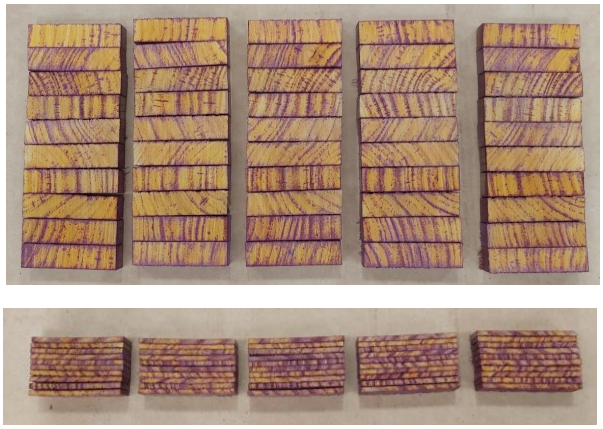

Figure 18. Shining gum cross sections from boards VPI treated with ACQ, and sprayed with PAN indicator spray, charges 1 – 5 from left to right. 25 mm thick boards (top) and 5 mm thick boards (bottom). Photos: Stuart Meldrum.

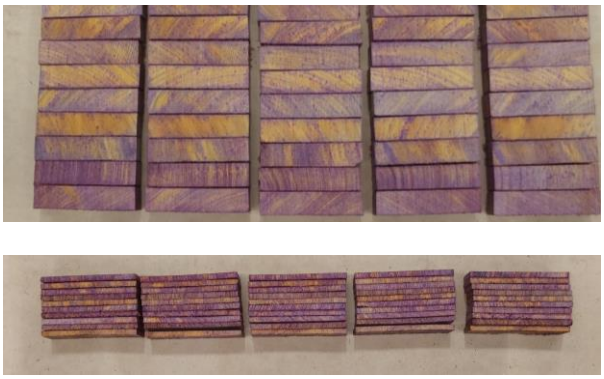

Figure 19. Tasmanian oak cross sections from boards VPI treated with ACQ, and sprayed with PAN indicator spray, charges 1 – 5 from left to right. 25 mm thick boards (top) and 5 mm thick boards (bottom). Photos: Stuart Meldrum.

Figure 20. Southern pine cross sections from boards VPI treated with ACQ, and sprayed with PAN indicator spray, charges 1 – 5 from left to right. Thicknesses ranging from 25 mm thick boards (top) to 5 mm thick boards (bottom). Photos: Stuart Meldrum.

Table 15. Effect of variations in preservative treatment cycles on solution uptake of three Tasmanian hardwoods							
			Uptake L/m3				
Species	Dimensions	No. of samples	Charge 1	Charge 2	Charge 3	Charge 4	Charge 5
Tas oak	500x100x25 mm	50	192	186	242	249	225
Tas oak	500x100x19 mm	50	185	186	246	251	229
Tas oak	500x100x16 mm	50	218	224	279	269	240
Tas oak	500x100x12 mm	50	184	175	216	219	199
Tas oak	500x100x5 mm	50	206	218	264	280	252
			Avg 197	Avg 198	Avg 249	Avg 254	Avg 229
Shining gum	500x100x25 mm	50	95	90	123	135	118
Shining gum	500x100x19 mm	50	146	150	184	213	156
Shining gum	500x100x16 mm	50	125	132	153	151	151
Shining gum	500x100x12 mm	50	98	103	141	141	120
Shining gum	500x100x5 mm	50	131	144	198	180	177
			Avg 119	Avg 124	Avg 160	Avg 165	Avg 144
Sth Pine	500x87x25 mm	25	664	644	646	651	652
Sth Pine	500x87x19 mm	25	611	614	638	623	620
Sth Pine	500x87x16 mm	25	541	577	557	561	546
Sth Pine	500x87x12 mm	25	588	584	593	593	582
Sth Pine	500x87x5 mm	25	600	598	588	587	550
			Avg 601	Avg 603	Avg 604	Avg 603	Avg 590
	TOTAL SAMPLES	**625**					
Highlighted cells indicate highest uptakes per species per thickness.							

Benefits for industry?

This research was a vital step towards refining the treatment methods for the subsequent VPI and veneer-based trials in NT014/NIF078. However, it also provided some key findings of its own, which can point interested parties in a useful direction for further R&D. In general, penetration results for shining gum, improved as the dimension sizes decreased. For example, most of the 19 mm samples would pass the preservative penetration requirements which was an important finding, given that exterior wall claddings and decking are likely to be of similar thickness. Prolonged vacuum and pressure periods (>3 hours) also produced better results, but may not be practical in industrial settings.

Another interesting finding that was also observed in several of the affiliated NIFPI projects (NT014/NIF078) as well as the VPI pilot trial described above (Trial 2.1), was that the average density of both shining gum (*E. nitens*) and Tasmanian oak (in this case, *E. obliqua*) is generally lower than previously reported (e.g. Table 16). Lower densities have also been observed with second growth timbers of other species such as spotted gum and Gympie messmate. These density differences likely reflect more aggressive management strategies that emphasise rapid growth.

What still needs to be done?

Treated thinner dimensioned boards could potentially be used to manufacture various glue laminated beams for exterior applications. However, the thinner sections (<19 mm) would require more processing and adhesives, that may make the process uneconomical.

Table 16. Reported density for two *Eucalyptus* species	
Species	Density (kg/m3)
E. obliqua	770
E. nitens	680
Source: www.WoodSolutions.com.au (as at: 6/05/2022)	

Trial 2.3 Supercritical carbon fluid (SCF) pilot

(Article reference: Wood, K.C., Konkler, M., Morrell, J.J., Kjellow, A., and Presley, G. (2022) 'Preservative treatment of Tasmanian plantation *Eucalyptus nitens* using supercritical carbon fluids'. DRAFT submitted to *Wood and Fiber Science* - awaiting review.)

Concept: Preservative treatment is driven by several factors including the size of the smallest pores in the wood, the level of pressure applied to the wood and the characteristics of the treatment solution. It is difficult to modify the wood and there are limits to the pressures that can be used in conventional processes without inducing physical/mechanical damage. However, it is possible to modify the treatment solution by reducing viscosity. This can involve the use of heat or the inclusion of surfactants. However, these changes only produce minor improvements. One option for treating refractory heartwoods that hasn't been widely explored in Tasmanian hardwoods previously is supercritical fluid treatment. Supercritical fluids (SCFs) are defined as materials that are at a temperature and pressure where distinct gas and liquid phases do not exist. SCFs can behave like a liquid in terms of the ability to solubilize biocides but move through materials like a gas (Kayihan, 1992; Krukonis, 1988; Kjellow et al., 2010; Sahle Demessie et al., 1995a, b). SCF density and viscosity are easily adjustable by varying pressure or temperature. While a variety of solvents can be used for supercritical fluid treatments, carbon dioxide is more commonly used because of its low cost, minimal toxicity and low critical temperature/pressure. It can also be captured and recycled in a closed-loop treatment system. SCFs treatment might be an attractive alternative for properly impregnating the heartwood of Tasmanian plantation shining gum with biocides for H3 or H4 exposures.

Aims: To investigate the effectiveness of supercritical carbon dioxide fluids (SCFs) for preservative treatment of refractory Tasmanian hardwoods and to establish whether the method would cause crushing or undue collapse due to high-pressure gradients.

Materials and methods: Tasmanian thinned and pruned plantation shining gum 90 mm x 35 mm x 900 mm with an average oven dry density of 547kg/m^3 was air-seasoned for approximately six to nine months then reconditioned and kiln dried to a target moisture content (MC) of 12 % (wt % oven dry basis) prior to final dressing and cutting. Fifteen samples each were planed to 19, 25 or 35 mm thickness. The material was sent to a commercial treatment facility (Superwood in Hampen, Denmark) where it was reconditioned to 19 % MC and included in one of their commercial spruce charges, and treated using a registered biocide SC200 containing tebuconazole, propiconazole and 3-iodo-2-propynyl butylcarbamate (IPBC; ratio 2:2:1). As the timber was treated in Denmark, the treatment followed European standard requirements for outdoor above ground exposures (EN113, UC3). The target concentration for the spruce boards was 120 g/m^3 of total active ingredient. This is lower than what is required by the Australian Standards for preservative treatment using azoles but the azole treatment in Australia does not include IPBC. AS/NZS 1604.1 (Standards Australia, 2021) requires a minimum retention of 0.03% tebuconazole and 0.03% propiconazole mass/mass for H3 exposures based on the oven dry weight in each piece; a total of 0.06% m/m combined azoles. For clarity, analysed retention % m/m may be converted to g/m^3 using the following formula:

$$Retention\ (g/m3) = \frac{retention\ (\%\ m/m)\ x\ oven\ dry\ timber\ density\ (g/m3)}{0.1}$$

The ability of the SCFs method to achieve core penetration of a solid board with a given biocide in shining gum was determined through subsequent retention analysis of different

assay zones to determine the amount and gradient of biocide in each zone from the outer surfaces to the core of each board.

Results: There was no visible evidence of excessive crushing, splitting or collapse in the samples following treatment; however, some minor collapse was observed in the samples after several months stored indoors indicating that there may have been excess moisture in the timber (Figure 21). This was particularly evident on the surface of the 35 mm thick samples and was also apparent when samples were cut into assay zones for retention analysis. The long lag between treating and collapse makes it unlikely that the collapse was due to pressure differentials during SCF treatment, but rather due to the reconditioning of the timber to 19 % MC prior to the treatment. The higher moisture content was used to facilitate heat transfer through the wood and make it slightly more plastic to mitigate potential cracking. Rewetting the wood to as much as 19 % MC prior to treatment may not be necessary, and warrants further exploration in future research.

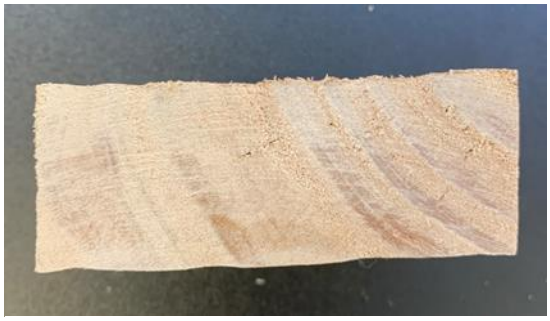

Figure 21. Example of internal collapse in 35 mm thick shining gum boards, several months after SCF impregnation. Photo: Kyra Wood.

Treatment of Tasmanian plantation shining gum via SCFs resulted in a detectable presence of both tebuconazole and propiconazole in the outer, middle and inner assay zones in every treated sample (Figure 22). IPBC was not analysed in this trial. While retentions in the middle and inner zones of the three thicknesses of wood were much lower than those near the surface, both azoles were detected in every treated sample analysed, indicating supercritical carbon dioxide was capable of carrying the biocides well into the heartwood. Although the average retention amounts achieved were less than what is required to meet the Australian Standard for H3 applications, they exceeded the targeted amount for spruce in g/m^3 (Table 17). Achieving the higher retention to meet the Australian retention target in each board would require modifying the treatment temperature or pressure to increase solubility, or simply by adding more fungicide to the treatment.

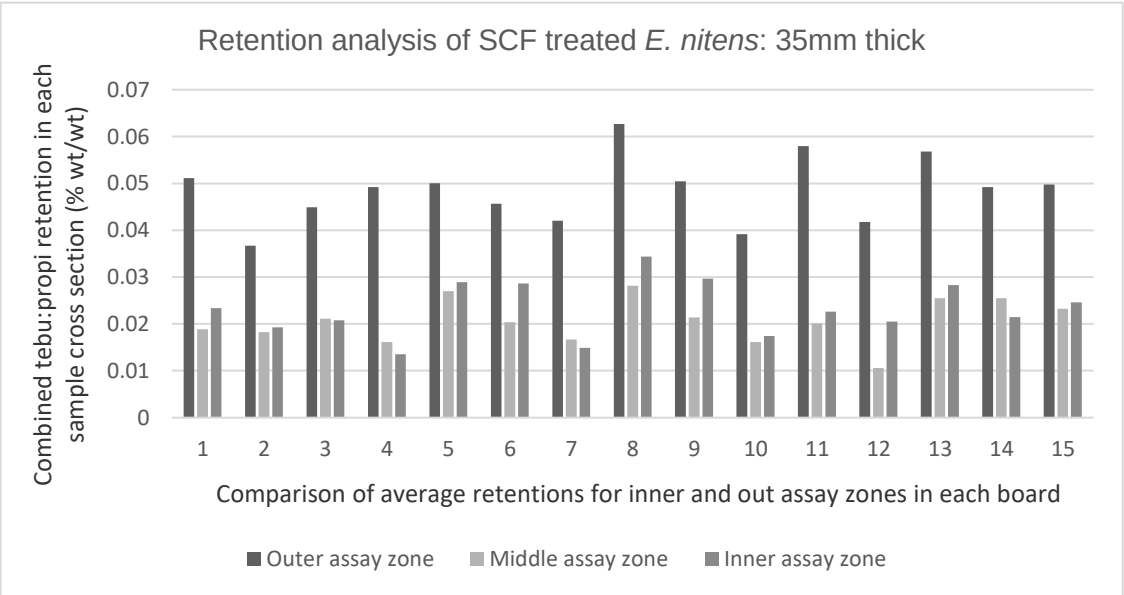

Figure 22. Retention of tebuconazole/propiconazole at selected depths in 35mm thick shining gum boards treated using supercritical carbon dioxide.

Table 17. Average g/m^3 of propiconazole/tebuconazole in shining gum treated using supercritical carbon dioxide[a]				
Sample thickness (mm)	Assay Zone	Average g/m^3 by assay zone	Total g/m^3 in cross section	Target g/m^3 for spruce (*Picea albies*)
19	Outer 0-5 mm	277 (68)	191	120
	Inner 6-14 mm	104 (26)		
25	Outer 0-5 mm	226 (77)	165	120
	Inner 6-19 mm	103 (28)		
35	Outer 0-5 mm	265 (52)	161	120
	Middle 6-11 mm	103 (32)		
	Inner 12-24 mm	116 (35)		

[a]Samples were treated to the spruce target retention of 120 g/m^3 of the azole/IPBC mixture.

[b]g/m^3 is a less precise treatment measure as SCF treatments can solubilize wood extractives during the process while simultaneously depositing the biocides, potentially resulting in net weight losses. Values represent analyses of 30 replicates per assay zone for three board thicknesses, and 60 or 90 analyses for the combined cross sections for the 19/25 mm and 35 mm thick samples, respectively. Values in parentheses represent one standard deviation.

Benefits for industry?

The advantages of being able to treat the inner cross-section of a refractory plantation *Eucalyptus* timber board, particularly in an Australian timber industry context, warrants further investigation as it presents a unique market opportunity. The process did not cause undue collapse or crushing, and the appearance of the treated timber was completely unchanged which is extremely unusual for any form of wood preservative treatment.

What still needs to be done?

There is only one commercial treatment facility using this technique and it is located in Denmark. Setting up a commercial treatment facility in Australia would likely be expensive without some kind of government or other sponsorship. However, the upfront capital costs would likely be solvent savings since the carbon dioxide and treatment chemicals are easily recycled for reuse.

This research project was a pilot trial and while the results are extremely promising, upscaled and broader research investigation is needed. Laboratory decay tests and field trial durability analysis (ground proximity and cladding trials) are currently underway to establish the effectiveness of the current treatment, however further trials are recommended to refine and optimise the SCFs process for plantation shining gum and other Tasmanian hardwood species. There is potential to do some pilot plant exploratory evaluations at a plant located at Oregon State University.

Trial 2.4 Water uptake and NexGEN coating

(Published article reference: Hassan, B., Morrell, J.J. and Wood, K.C. (2021) 'Effect of a water repellent treatment on moisture behaviour of three Australian hardwoods: a preliminary report'. *Proceedings IRG Annual Meeting*, IRG/WP 21-40921, 16pp.)

Concept: Wood preservatives have long been used to minimize the risk of fungal attack, but general concerns about all chemicals have encouraged exploration of alternative protection strategies, including water repellent coatings that help keep moisture conditions below those required for fungal attack (i.e. below fibre saturation point or approximately 25-30% MC). Water repellents have been shown to provide some wood protection without supplemental preservatives (Brischke and Melcher 2014; Chen and Wang 2018; Cheumani et al 2020; Donath et al 2006; Lesar and Humar 2011; Lesar et al 2009a; Matsuoka et al 2002; Scholtz et al 2010; Žlahtič and Humar 2020). However, they appear to be more useful for improving the performance of preservative treated timber, especially with regard to enhancing dimensional stability and limiting the physical damage that can occur with repeated wetting and drying (Evans et al 2009; Humar et al. 2017, 2020; Lesar et al 2009b, 2011). It is important to note that water repellents do not completely exclude water, but instead delay water sorption. The hope is that this delay allows excess water to either run off the wood or evaporate, thereby maintaining moisture levels below those considered essential for fungal growth, generally ~30 % moisture content, oven-dry basis (Zabel and Morrell, 2020). Water repellents alone have been explored on a number of species, but generally on more permeable softwoods with inherently low durability. There are relatively few studies on water repellent performance on hardwoods (Scholtz et al 2010). It is unclear how well they would function on timbers that are inherently more resistant to water uptake. For example, many lower durability *Eucalyptus* species are inherently resistant to fluid ingress, making them difficult to treat with preservatives for use in exterior above ground applications. Inherent resistance to water ingress could also be beneficial, especially if it could be enhanced by supplemental water repellent treatments to slow further moisture uptake, thereby limiting the development of conditions conducive to fungal development.

Aims: To measure the amount of water uptake in seasoned Tasmanian hardwood species after prolonged water immersion, and to evaluate the effectiveness of a commercially available water repellent coating in reducing water uptakes.

Materials and methods: 90 mm × 35 mm timber of varying lengths of plantation Tasmanian blue gum (*E. globulus*), shining gum (*E. nitens*), and native regrowth Tasmanian oak (*E. obliqua*) were obtained from mills in Tasmania. The samples were a mixture of sapwood and heartwood, but primarily heartwood and were cut into a series of 120 mm long sections that were weighed (nearest 0.01 g). A total of twenty-four samples were cut from each species. Twelve samples were allocated as untreated controls, while the remainder were allocated for water repellent treatment.

Samples were fully immersed in a ready-to-use solution of a water repellent (NexGEN, Vancouver, B.C. Canada) at room temperature. Per the supplier's directions, the samples were placed in plastic bags for twenty-four hours, then allowed to air-dry for seven days. The samples were then oven-dried at 60 °C before being weighed again. The difference between initial and final weight was used to determine net solution uptakes. Four treated and four untreated samples were used for moisture uptake tests while the rest were included in the QLD based ground proximity arrays as part of the field trial.

Materials and methods (water repellence): The relative water repellence of the samples was assessed on three treated and three untreated samples of each species that were destined to be placed in the E18-15 Ground Proximity test. Water repellence was assessed by adding five 20 ul droplets of water to different locations on the tangential surfaces of each sample (Beck, 2014). Droplet shape was observed one, five, and twenty-five minutes after application and visually assessed on a scale from 1 (droplet contact angle >90º) to 5 (contact angle <5º) (Figure 23). The values for the five drops on each of three samples per treatment were averaged.

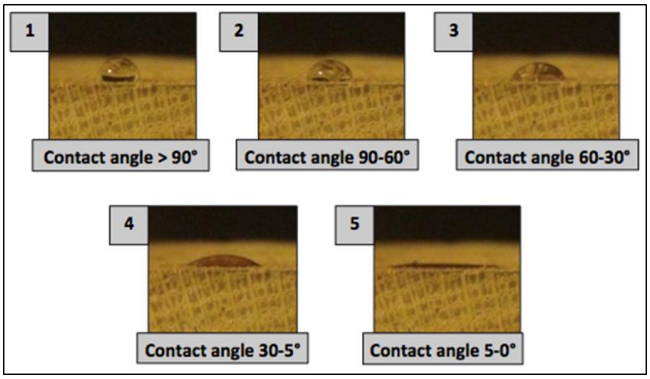

Figure 23. Examples of water droplet shapes on timber that were used to quantify water repellence of the treated and untreated *Eucalyptus* timbers (Photo: Greeley Beck, Oregon State University).

Materials and methods (moisture uptake): The dimensions of the treated and untreated samples were measured using a digital vernier calliper at six points for the 35 mm direction (thickness) and two locations in the 90 mm direction (width). These locations were marked so that they could be remeasured at later time points.

Four treated and four non-treated samples of each species were then completely immersed in cold tap water in separate tanks to avoid cross-contamination. The samples were removed from the water after two, twenty-four, forty-eight, ninety-six, 168, 240, 336 and 504 hours of immersion. The samples were weighed, and the dimensions were remeasured at the original locations at each time point. The samples were then immersed in fresh tap water until the next measurement time. The resulting data were used to calculate the net weight gain as well as the degree of swelling (%) in each direction.

Materials and methods (final moisture content gradient): At the end of the immersion period, one treated and one untreated sample of each species that had experienced the greatest increase in moisture content was blotted dry. A 10 mm thick cross-cut section was cut from the middle of each sample and this section was further cut to segregate the outer 0-7 mm and the inner 10 mm core. The wood from each zone was immediately weighed and then oven-dried at 103 ºC to constant weight before being weighed again. The difference between initial and final weight was used to calculate moisture content.

Materials and methods (radiata pine moisture uptake): While pine sapwood was not included in the original tests, a sub-test was established using 50 mm × 19 mm × 125 mm radiata pine (*P. radiata*) sapwood samples. These blocks were oven-dried and weighed. Four samples were immersed for twenty-four hours in water repellent, then weighed to determine uptake before being stored in a plastic bag for twenty-four hours. The samples were then air-dried for seven days before being oven-dried at 60 ºC and weighed. Four untreated samples were similarly oven-dried and weighed. The sample dimensions were measured as described above; then, the treated and untreated samples were immersed in water in separate tanks to avoid cross-contamination. The samples were weighed and measured after two, twenty-four, and ninety-six hours of immersion. Shorter times were used because this was a supplementary test.

Table 18. Weight gain of three *Eucalyptus* species immersed in a water repellent solution for three minutes		
Species	Average uptake (%)[a]	Range (%)
E. nitens	1.64 (0.52)	0.99 to 2.38
E. globulus	1.48 (0.22)	1.13 to 2.03
E. obliqua	1.27 (0.66)	0.93 to 3.35
[a]Values represent means of four samples per species, while figures in parentheses represent one standard deviation.		

Results (water repellent uptakes): The three-minute dips produced relatively low uptakes for the three species with average uptakes of 1.64 %, 1.48 %, and 1.27 % for shining gum, blue gum and Tasmanian oak, respectively (Table 18). Uptakes also varied widely within each species, illustrating the inherent variability of timber in terms of treatments. While the uptakes were low, the manufacturer's instructions recommend dipping or brushing. As discussed further below, the prolonged immersion of radiata pine did result in much higher solution absorptions; however, this species is far more permeable, and the twenty-four-hour soaking period exceeds what would be used commercially.

Results (moisture uptakes): The samples were initially dried at 60 °C and weighed. Thus, the initial moisture content was slightly above the oven-dry (103 °C) value. Moisture contents of untreated samples of the three species rose 4.2 to 6.7 % in the first two hours of soaking then steadily increased with time (Table 19). At the end of the 336-hour soak, average moisture contents ranged from 33.7 to 39.2 % for untreated samples. Moisture levels tended to be slightly lower in Tasmanian oak samples, but the differences were negligible. While these levels would be over a presumed 30 % moisture content for fibre saturation, water uptake was fairly slow compared to that observed for pine sapwood samples and illustrated the inherent resistance to moisture uptake of these timber species. While resistance to fluid ingress is often considered a negative trait because it hinders effective preservative treatment, slow water

Figure 24. Cross-sections cut from the middle of 90 x 35 mm samples after 504 hours of water immersion. The permanent marker delineates the area of visibly wet wood. Samples correspond to *E. globulus* (13 untreated/14 treated), *E. nitens* (35 untreated/36 treated) and *E. obliqua* (55 untreated/56 treated). Photo: Jeffrey Morrell.

Table 19. Effect of water repellent treatment on water sorption and swelling of three *Euc.* species[a]										
Soak Time (hr)	Treat	Weight Gain (%)			Thickness Swell (%)			Width Swell (%)		
		E. globulus	*E. nitens*	*E. obliqua*	*E. globulus*	*E. nitens*	*E. obliqua*	*E. globulus*	*E. nitens*	*E. obliqua*
2	No	6.70 (1.65)	5.25 (1.92)	4.15 (0.38)	0.79 (0.47)	1.26 (0.27)	-0.17 (0.87)	0.45 (0.17)	0.44 (0.30)	0.79 (0.37)
24		13.06 (2.75)	11.03 (3.02)	9.24 (2.43)	2.00 (0.68)	2.24 (0.46)	0.97 (0.46)	0.89 (0.22)	0.93 (0.44)	1.43 (0.22)
48		17.29 (3.06)	15.14 (3.57)	13.55 (0.71)	3.19 (0.54)	3.27 (0.31)	2.14 (0.44)	0.94 (0.11)	1.45 (0.81)	3.05 (0.62)
96		23.09 (3.79)	18.73 (6.74)	18.81 (0.87)	4.13 (0.67)	4.33 (0.19)	3.43 (0.80)	1.43 (0.13)	1.95 (1.04)	2.64 (0.28)
168		29.16 (4.54)	26.23 (5.41)	24.02 (0.73)	4.06 (2.33)	5.43 (0.51)	4.71 (0.28)	2.02 (0.21)	2.73 (1.29)	3.32 (0.31)
240		33.67 (5.46)	30.32 (6.25)	28.07 (0.95)	6.20 (0.69)	5.96 (0.43)	5.51 (0.48)	2.19 (0.30)	3.33 (1.30)	3.73 (0.46)
336		39.20 (6.27)	35.77 (6.97)	33.66 (1.09)	6.56 (0.89)	6.26 (0.93)	4.93 (2.45)	2.39 (0.15)	3.53 (1.56)	4.14 (0.47)
504		51.02 (3.74)	42.89 (7.50)	40.61 (1.38)	7.66 (0.78)	6.76 (1.78)	6.80 (0.50)	2.56 (0.37)	4.01 (1.81)	4.45 (0.54)
2	Yes	6.46 (2.19)	7.11 (2.67)	4.58 (0.26)	0.81 (0.27)	0.76 (0.14)	0.49 (0.64)	0.41 (0.05)	0.44 (0.50)	0.31 (0.29)
24		12.93 (3.24)	13.71 (4.51)	9.49 (0.96)	2.00 (0.52)	1.86 (0.33)	1.51 (0.71)	0.59 (0.15)	0.97 (0.69)	1.22 (052)
48		16.88 (3.96)	17.47 (5.35)	12.70 (1.27)	3.21 (0.65)	2.80 (0.22)	2.43 (0.58)	0.91 (0.08)	1.48 (0.97)	1.53 (0.48)
96		22.50 (4.51)	22.82 (6.08)	17.07 (1.58)	4.14 (0.23)	3.14 (0.47)	3.68 (0.59)	1.31 (0.14)	2.11 (1.24)	2.32 (0.33)
168		28.58 (5.50)	28.64 (7.00)	21.15 (1.15)	5.49 (0.40)	4.44 (0.73)	5.10 (0.57)	1.83 (0.43)	2.90 (1.57)	3.14 (0.14)
240		33.38 (6.29)	33.26 (7.77)	25.74 (1.39)	6.44 (0.31)	4.75 (0.85)	5.78 (0.46)	2.17 (0.26)	3.50 (1.91)	3.90 (0.35)
336		39.40 (6.81)	38.71 (8.42)	30.85 (1.79)	7.03 (0.43)	4.96 (1.27)	6.35 (0.61)	2.72 (0.50)	3.90 (2.22)	4.22 (0.44)
504		47.23 (8.14)	46.09 (9.66)	37.32 (2.09)	7.66 (0.97)	5.81 (1.75)	7.74 (0.88)	2.85 (0.27)	4.50 (2.12)	4.98 (0.70)

[a]Values represent means of four replicates per species per time, while figures in parentheses represent one standard deviation.

Table 20. Reported tangential shrinkage and radial shrinkage for three *Eucalyptus* species		
Species	Shrinkage (%)	
	Tangential	Radial
E. obliqua	11.3	5.1
E. globulus	14.4	6.9
E. nitens	9.4	4.9
Source: www.WoodSolutions.com.au (as at: 6/06/2022)		

Table 21. Average degree of water repellency of three untreated and three water repellent treated Tasmanian hardwoods measured by water droplet behavior on the wood surface				
Species	Treatment	Water repellency[a]		
		1 minute	5 minutes	25 minutes
E. globulus	+	3.07 (0.15)	4.47 (0.57)	4.93 (0.15)
	-	2.60 (0.33)	3.13 (0.33)	4.27 (0.45)
E nitens	+	4.67 (0.37)	4.67 (0.37)	5.00
	-	1.93 (0.64)	2.00 (0.61)	4.13 (0.30)
E. obliqua	+	3.60 (0.15)	4.07 (0.15)	4.60 (0.15)
	-	1.60 (0.43)	2.13 (0.71)	2.20 (0.76)

[a]Values represent the averages of five water drop assessments on each of three samples per treatment per species where 1 represents high water repellency and 5 represents little or no repellency. Values in parentheses represent one standard deviation.

absorption can be a positive attribute where wood was only subjected to periodic wetting with regular drying intervals. Moisture uptake of the water repellent treated samples ranged from 4.6 to 7.1 % after two hours, then gradually increased to 30.9 to 39.4 % at the end of the 336-hour soak. Moisture uptake was again lowest with Tasmanian oak but there were no major differences in uptake between treated and untreated samples of the same species. The uptake results suggest that water repellent treatment had no noticeable effect on moisture uptake for any of the three species. It is important to note that these samples contained a high proportion of exposed cross-section, which should have been more receptive to fluid uptake. The exposed cross sections could also make it more difficult to limit moisture uptake using water repellents.

Results (thickness and width swelling): The samples were not cut to a specific orientation although many tended towards vertical grain (quarter sawn) which should have been more stable. However, the thickness and width were not oriented to be tangentially or radially aligned, and the data were combined for discussion.

Thickness increases ranged from 4.9 to 6.0 % at the end of 336 hours for the untreated samples, and 5.0 to 7.0 % for the water repellent treated samples (Table 19). Blue gum samples tended to have the highest degree of swelling, but the differences were small. The higher degree of swelling is consistent with the previous reports for shrinkage of this species (Table 20).

Water repellent treated samples followed trends that were similar to those observed for the untreated samples. Thickness increased by 0.5 to 0.8 % in the first two hours of soaking, then reached 5.0 to 7.0 % at the end of the 336-hour soaking period. Thickness swell was once again highest with blue gum samples. There were few consistent differences in swelling between treated and untreated samples of the three species.

Increases in the width of the specimens followed trends that were similar to those for thickness. Width increased by 0.4 to 0.8 % for untreated samples after two hours of immersion while they increased by 0.3 to 0.4 % for treated samples. Width increases were similar for untreated and treated samples at the end of the 336-hour immersion. Interestingly, increases tended to be lowest with blue gum samples and highest with Tasmanian. The overall results indicate that the water repellent treatment had no noticeable effect on dimensional changes for any of the three species over either a short or prolonged immersion period.

Results (final moisture gradients): Cross cuts taken from the end and middle of one treated and one untreated sample of each species suggested that most of the moisture uptake had occurred near the wood surface and towards the exposed cross-sections (Figure 24).

The moisture contents of samples representing the end 10 mm of two Tasmanian oak samples averaged 80.3 %, while those cut from the next 10 mm inward averaged 32.5 %, illustrating the dramatic effect of end-grain water uptake on average block moisture content. Similarly, moisture contents of the cross-sections cut from the outer/inner zones of blue gum, shining gum Tasmanian oak were 39.7/23.1 %, 46.1/25.6 %, and 35.9/23.6 %, respectively. As with the moisture contents of the end cuts, these data indicate that moisture was still largely confined to the outer surface of each species. While this illustrates the difficulty in delivering effective levels of preservatives into the core of these species, it also suggests that adding a small amount of water repellent to the surfaces of these species coupled with diffusion of low

levels of a preservative such as boron into the core might represent a simple method for enhancing above ground performance in exterior applications.

Results (Eucalyptus water repellence): Water droplets on untreated *Eucalyptus* initially formed droplets with contact angles between 30 and 60 degrees (ratings of one to three) then were gradually absorbed (Figure 25). The most water-resistant species was Tasmanian oak, which is consistent with the water uptake values obtained in the soaking test. Droplets on water repellent treated samples rapidly spread over the surface and had ratings of three to over four out of five within one minute (Table 21). The results are difficult to explain because most water repellents result in water droplets with steep contact angles, while this treatment resulted in much greater spread of the droplet, suggesting that the system contained surfactants that reduced surface tension. Although this was not the primary purpose of the test, similar behaviour was observed on the radiata pine samples, which were treated to much higher levels. The absence of any measurable difference in water uptake between treated and untreated samples suggests that the differences in water droplet behaviour are less important in terms of performance.

Figure 25. Examples of water droplet behaviour on the surfaces of two *E. globulus* samples. The sample on the left is untreated, while the one on the right was dipped in water repellent for 3 minutes. Droplets on the untreated sample were rated a 1 while those on the treated sample were rated 3 and 4. Photo: Jeffrey Morrell.

Benefits for industry?

The relatively slow droplet absorption in the untreated Tasmanian hardwood species is promising since it creates an opportunity for effective water-shedding design in a vertical application such as cladding. Although the water repellent used in this trial did not improve the timber's resistance to uptake, adding an effective water repellent to these materials could further slow moisture absorption thereby reducing the risk that moisture conditions would become conducive to fungal attack.

What still needs to be done?

Treated material from NIF078 will be used to construct a large-scale comparative trial of a wall assemblies combining water shedding design with a selection of water repellent coated and uncoated samples is being installed at UTAS soon. Although this will not be accelerated through artificial means, it will provide useful long-term performance data. Further research combining water repellents with a standard chemical treatment like ACQ in a VPI treatment would be of interest.

Trial 2.5 Boron and copper naphthenate dual treatment

(See corresponding trials 1.1 and 1.2 in the final report of NIF078 for further detail and discussion of this approach.)

Concept: One alternative to using only conventional pressure treatment is to combine that treatment with a boron pre-treatment. Boron is an excellent fungicide and insecticide with a low toxicity profile. It also has the advantage of being able to diffuse inward from the surface when the wood is wet. At the same time, boron can also diffuse out of the wood when wetted. As a result, boron use is typically restricted to interior applications for protection against either beetles or termites. However, an alternative approach with boron is to dip or pressure treat the freshly cut timber with boron, allow it to air-season and then over treat this dry material with a conventional preservative. The boron diffuses inward as the timber seasons. The over-treatment helps to retain the boron on the interior, potentially completely protecting the cross section. Long term field trials of railway sleepers that were boron dipped, air-seasoned and then pressure-treated with creosote showed that the dual treatment markedly extended the service life of the sleepers, even under high decay hazard conditions in the United States (Amburgey and Sanders, 2007; 2009). As a result, most major U.S. railroads now use some form of boron pre-treatment. This approach might also work with Tasmanian hardwoods since they are air-seasoned for some time after cutting and prior to final drying and dressing. While creosote is not the preservative of choice, the goal would be to develop some form of protective barrier on the wood surface. Toward this goal, a PhD student at the University of Tasmania is evaluating the ability of various barriers to slow boron diffusion (see report on affiliated NIFPI project, NT014/NIF078) and a similar study using Queensland maple was undertaken as part of this project to provide treated material for testing.

Aims: To treat Queensland maple using dip-diffusion in a boron-based preservative treatment (some with a copper napthenate overcoat) to compare with similarly treated Tasmanian oak and shining gum material from the affiliated NIFPI project (NT014/NIF078) and to provide treated material for durability analysis.

Materials and methods: Freshly sawn Queensland maple (*Flindersia brayleyana*) was cut into forty-four 90 mm x 35 mm x 700 mm long sections. Small sections cut from these boards were weighed, oven dried at 103 ^{o}C and weighed again to determine initial moisture content which averaged 101 %. The 700 mm long sections were allocated to be dipped in water alone or in solutions containing 5 or 10 % boric acid equivalent of disodium octaborate tetrahydrate (DOT). Boards were dipped for either three or six minutes in the 10 % DOT solution and six or fifteen minutes in the 5 % DOT solution. The boards were allowed to drip dry before being wrapped in plastic and stored for seventy-two hours at room temperature (23-25 °C). The boards were removed from the plastic and solid piled (Figure 26) under plastic to retard drying. The boards were sub-sampled one, two, and four weeks after

Figure 26. Solid piled boron treated *F. brayleyana* with substantial moisture still evident in the core of the boards after a twelve week diffusion period. Photo: Jeffrey Morrell.

treatment by cutting a 100 mm section from one sealed end of each board. A surface coating was applied to the freshly exposed surface on the parent board to retard end-grain drying. The 100 mm long section was weighed before being air-dried for several days, oven dried at 60 °C for two days and finally dried at 103 °C before being weighed again. The wet and dry weights were used to calculate moisture content (oven dry basis) at the time of sampling. The staged drying was used to reduce the potential for boron to diffuse to the surface as the wood dried. Two 20 mm thick slices were cut from the middle of the sample and retained for boron analysis. The samples were stored for four weeks under plastic, then the plastic was removed, and the samples were stickered to allow for air-drying to stable weight. At the end of eight weeks, a final 100 mm long sample was cut, then the remaining 300 mm of each board was cut into two 125 mm long samples as well as a 50 mm thick piece for boron analysis. The 125 mm long samples were allocated to be either left as they were, or dipped for three minutes in a 2 % solution of copper naphthenate. The samples were weighed before and after immersion to determine net solution uptake then the allowed to dry before being tagged and placed in a ground proximity test at the Nambour test site.

Results: The analyses of boron in Queensland maple are nearly complete and the ground proximity samples were first inspected in October, with no evidence of decay. The results should provide a measure of the ability of boron to diffuse inward as well as the ability of the dual treatment to provide enhanced protection compared to the copper naphthenate dip treatment alone. Boron solution uptakes were similar regardless of DOT concentration or dip time suggesting that dipping time was less important than solution strength since the purpose of dipping is to deliver a sufficient quantity of chemical on the wood surface to allow uniform diffusion to an effective level (Table 22). Moisture contents varied little over the four-week diffusion period. The elevated moisture regime (>85 % moisture content) should have created ideal conditions for boron diffusion. Samples dried relatively rapidly when the plastic sheeting was removed and the boards were stickered to encourage air-flow. No evidence of mould was observed over the test even though no co-biocide was added to limit growth of these fungi. The boron analysis will be completed over the next two months.

Table 22. Moisture contents and net boron uptake as % boric acid equivalent (BAE) of Queensland maple samples dipped for varying times in DOT at two concentrations

Boron Conc (% BAE)	Dip Time (min)	Reps	Net Boron Uptake (% BAE)	Wood Moisture Content (%)[a]			
				Week 1	Week 2	Week 4	Week 8 (post-drying
5	6	12	0.53 (0.14)	87.8 (7.2)	94.4 (6.1)	95.3 (6.3)	26.2 (3.2)
5	15	5	0.63 (0.21)	96.0 (12.1)	101.8 (11.7)	99.6 (9.7)	27.2 (3.3)
10	3	11	0.59 (0.79)	93.8 (13.4)	97.7 (9.7)	94.1 (9.0)	19.5 (4.2)
10	6	13	0.67 (0.19)	91.7 (9.0)	96.2 (8.0)	96.1 (6.2)	21.5 (4.3)

[a]Values represent means while figures in parentheses represent one standard deviation. Moisture content at time of dipping was 101.7 % (SD=9.0). Net uptake of the water controls was 1.03 (SD=0.17) % BAE.

Benefits for industry?

If a boron-based preservative treatment solution can be reliably prevented from leaching using an overcoat or envelope barrier treatment, it could provide one of the most effective, simple, environmentally responsible, and economically feasible preservative treatments for refractory Tasmanian hardwoods. This trial will provide early data (i.e. in relation to the material that was treated in the affiliated NIFPI project) on the potential effectiveness of the tested dual treatment system.

What still needs to be done?

As noted, this project relates to an ongoing PhD research investigation at the University of Tasmania, and as such this trial should be read in conjunction with the final report of the affiliated NIFPI project (NT014/NIF078). The project requires further research and development before the proposed dual treatment system would be considered appropriate for commercialisation or industry-uptake. It is also unlikely that the proposed system would meet the Australian requirements for preservative treatment without changes to the current Australian Standards, and would require an alternative form of certification to be deemed fit for purpose, for example using Codemark[4] certification.

[4] To know more about Codemark certification you can read about it here: https://www.abcb.gov.au/about-codemark; or here: https://saiassurance.com.au/codemark-certification-scheme;

Trial 3 Accelerated laboratory trials

An early hypothesis in this research trial was that fluid preservative treatment in the refractory species under investigation would result in a shallow preservative barrier with a largely untreated core beneath. This hypothesis stemmed from a basic understanding of the capillary structure of wood and how chemicals penetrate the surface of wood in most full and empty cell pressure treatment processes (Morrell, 2018). It is also a requirement of the Australian Standard (AS 1604.1), that the minimum penetration for a board less than 35mm thick is 5 mm from all surfaces for hardwoods with low natural durability. Without having access to treated material to evaluate and test until later in the research trial period, this hypothesis led to the formation of several accelerated tests and test methods, including the moisture cycling test (Trial 3.1) that aimed to induce check development beyond a shallow preservative barrier, and the subsequent specialised vermiculite decay chamber (Trial 3.4).

However, when treated material became available to test, this hypothesis proved to be mostly irrelevant in relation to the fluid preservative treatment of Tasmanian hardwoods, particularly shining gum. The research in two of the preservative treatment trials in this project (Trials 2.1 and 2.2 above) and in the affiliated NIFPI project (NT014/NIF078) showed that preservative penetration patterns were extremely inconsistent across the surfaces and through the cross-sections of most treated samples. Treatment appeared to penetrate more easily into the earlywood growth rings, but not into latewood growth rings. As discussed in Trials 2.1 and 2.2, given that most of the hardwood timber in this research was quartersawn which resulted in a candy-stripe penetration pattern through the cross section of each board (Figure 27). There was a negligible barrier or envelope (i.e. often less than 1mm) in many of the latewood bands. This lack of a consistent barrier treatment across the surface potentially provides easy pathways for fungal intrusion into untreated sections in the core of each board. This effect was most pronounced in shining gum and blue gum boards, while the Tasmanian oak appeared to have a slightly more uniform treatment although still mostly insufficient to pass the penetration requirements of the AS/NZS 1604.1.

Achieving reasonable treatment in the earlywood growth rings, but not in the latewood, is the opposite of what happens in most refractory softwoods, where the latewood is more easily penetrated than the earlywood (MacLean, 1952; Siau and Shaw, 1971). Siau and Shaw

Figure 27. Example of 'candy-striping' effect in ACQ treated shining gum sprayed with a PAN indicator spray. Photo: Stuart Meldrum.

suggest that this phenomenon is due to more extensive pit aspiration that occurs in earlywood during drying, and that latewood resists the aspiration due to a more rigid structure and smaller sized pits. An interesting observation from this trial is that there is evidence of internal checks that appeared to form largely in the earlywood bands which was also where the copper treatment appeared to be concentrated. Further investigation of these phenomena is needed, but was outside the scope of the current research project.

In summary, achieving a consistent 5 mm or even a 3 mm envelope treatment is very unlikely in the Tasmanian hardwood species. In response to this finding, one of the aims of the current PhD candidate (Trial 3.3) is to investigate what is the absolute shallowest preservative barrier that is needed to prevents fungal intrusion into a Tasmanian hardwood board with untreated sections through the core. Due to the very slow water uptake observed in these species Trial 2.4, it is hypothesised that even a very shallow barrier may provide sufficient protection, especially if the treatment includes an effective water repellent and if there is some level of chemical mobility retained within the board following treatment, so that some preservative could migrate into cracks or checks as they open. If 1 mm or less envelope treatment is sufficient protection when combined with some chemical mobility, then some of the treatments trialled in this research may yet be viable options for H3 exposures.

Although it is now outside the timeframe for this project, further research using the treated material from Trials 2.1 and 2.2 and from the affiliated research project (NT014/NIF078) is planned and will help to extend the original aims of this project, i.e., to accelerate testing timeframes for preservative treated refractory Tasmanian hardwoods.

The laboratory decay tests in this trial were performed in the National Centre for Timber Durability and Design Life at the Ecosciences precinct, University of the Sunshine Coast, with some sample preparation undertaken at the University of Queensland and the University of Tasmania. The cone calorimeter testing in Trial 3.2 was done at the University of Queensland.

Timber materials used in this research were either supplied as in-kind by collaborators or purchased from suppliers. Treated materials used in Trials 3.1, 3.3 and 3.4 were supplied from projects undertaken in Trial 2 (above), for which treatments were largely performed at the Queensland Department of Agriculture and Fisheries. Densified material for Trial 3.2 was provided from the affiliated NIFPI project (NT014/NIF078) from the University of Melbourne.

Trial 3.1 Repetitive moisture cycling: ACQ treated material of varying thicknesses

Concept: One approach to overcoming the treatment issues in Tasmanian hardwoods that was trialled in this project (Trial 2.2, above), was to target products that use thinner cross sections. While the depth of heartwood penetration may fail to achieve the level required in the AS/NZS 1604, the proportion of treated cross section may still be sufficient to maintain the treatment barrier if the wood can withstand repeated wetting and drying. Previous tests (Trial 2.4, above) suggest that shining gum displays some resistance to moisture uptake, which is also why it is so difficult to treat. But this negative treatment attribute may be advantageous in terms of reducing the extent of swelling and shrinkage that creates stresses leading to cracking beyond the depth of preservative treatment.

Aims: To assess the effects of repeated wet/dry cycles on water uptake and crack development in ACQ treated shining gum samples of different thicknesses.

Materials and methods: 100 mm x 500 mm shining gum samples of varying thickness were end-sealed to retard longitudinal penetration and pressure treated with ACQ (see Trial 2.2 above for details on the treatment). Following treatment, the samples were cut in half and preservative penetration was visually assessed (Figure 28). The boards were dried and retained. Selected pieces from the 12 mm, 19 mm and 25 mm thick samples were then oven dried at 60 °C and weighed before being immersed in water and subjected to a double vacuum where a vacuum was drawn for at least twenty minutes, released and then reapplied for up to two hours. The samples were treated in a desiccator that limited replication to three 25 mm thick samples, four 19 mm thick samples and five 12 mm thick samples. The samples were removed, wiped clean of residual water and weighed before being dried overnight at 60 °C. This process was repeated ten times. The samples were

Figure 28. Examples of cross sections of ACQ treated *E. nitens* and *E. obliqua* samples of varying thicknesses showing the differences in degree of preservative penetration for 12 mm (bottom) and 25 mm (top) thick samples. Photo: Jeffrey Morrell.

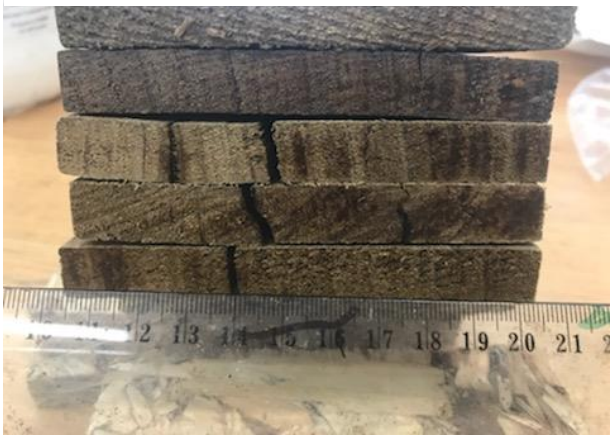

Figure 29. Cross sections of three oven-dried 12 mm thick shining gum samples after 10 wet/dry cycles showing major splits in three of the five samples evaluated. Photo: Jeffrey Morrell.

subjected to an eleventh wetting cycle and weighed before they were cut into a series of six ~35 mm long cross sections beginning from the unsealed end and leaving an approximately 70 mm long section. All the pieces were weighed and then oven dried before being weighed again. The data were used to calculate moisture content. The presence of checks or splits was observed after each wet/dry cycle. The number of checks as well as the width, length and depth of each were noted for each sample (Figure 29).

Results: Moisture uptake tended to slowly increase with repeated wetting and drying and moisture contents tended to be highest in the 25 mm thick samples (Table 23). While one end of each sample was end-sealed to minimize longitudinal penetration, there did appear to be some end-penetration from both sides. Moisture contents on the sequential 30 mm thick samples cut from each piece after the final vacuum treatment showed considerable variation among the samples, but a general trend to higher moisture levels at the non-end-sealed end, then a sharp decline in moisture content further inward (Table 24). These results suggest that the depth of water penetration remained minimal in most instances.

Samples began to develop splits after five to seven wet/dry cycles. The 25 mm thick samples developed small internal cracks, but none were detected near the surface. The 19 and 12 mm thick samples developed deep end checks that split through the cross section on the 12 mm samples (Figures 29-31, Table 25).

Initial discussions suggested that treating thinner sections would improve the prospects for meeting the AS 1604 penetration requirements. While this was true (see Trial 2.2 above), repeated wetting and drying resulted in much greater deformation on the thinner samples.

Figure 30. Cross section of a 19 mm thick ACQ treated shining gum sample after 10 wet/dry cycles showing small end splits. Photo: Babar

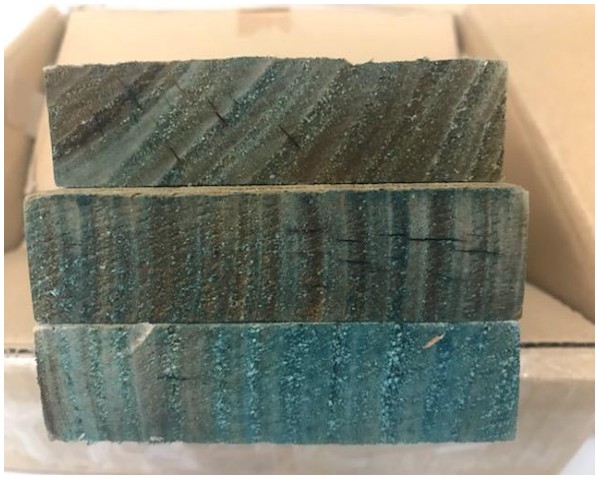

Figure 31. Cross sections of three oven-dried 25 mm thick shining gum samples after 10 wet/dry cycles showing minor internal splits. Photo: Jeffrey Morrell.

Table 23. Average water uptake values for 12, 19, and 25 mm thick ACQ treated shining gum samples subjected to repeated wetting and drying cycles										
Thickness (mm)	Moisture absorption average (%)[a]									
	Cycle 1	Cycle 2	Cycle 3	Cycle 4	Cycle 5	Cycle 6	Cycle 7	Cycle 8	Cycle 9	Cycle 10
12	17.16 (2.78)	8.85 (0.79)	7.77 (1.02)	9.06 (1.45)	7.94 (1.00)	8.72 (1.11)	12.18 (1.55)	10.89 (1.65)	9.70 (1.35)	12.99 (1.24)
19	16.54 (2.59)	10.24 (1.95)	12.25 (4.22)	11.47 (4.03)	13.87 (5.12)	17.86 (8.64)	17.97 (8.30)	18.84 (8.78)	20.54 (9.97)	20.93 (11.35)
25	15.57 (9.83)	17.10 (12.99)	18.51 (13.78)	24.68 (16.37)	23.26 (15.14)	23.01 (15.07)	21.11 (15.31)	27.73 (16.01)	26.66 (15.61)	28.11 (15.63)
[a]Values represent means of five, four and three samples for the 12, 19 and 25 mm thick samples, while figures in parentheses represent one standard deviation. All values are based upon oven drying at 60 °C.										

Examination of cross sections after the final soaking suggested that moisture penetration into the thicker samples remained minimal, while deeper penetration was noted on many of the thinner samples that experienced cracking or splitting (Figure 32).

The shallow moisture penetration in thicker samples would likely reduce the risk of internal drying stresses developing to the point where they exceeded the shear capacity of the samples. Deeper wetting in the thinner samples increases the risk of steep drying gradients that induce exterior shrinkage while the interior is still swollen, and this would lead to crack development. These results suggest that efforts to develop treatments that would allow use in H3 applications despite limited preservative penetration will depend on selecting appropriate dimensions, potentially coupled with the inclusion of a water repellent in any preservative system to further slow moisture absorption. It is important to note that these tests were performed on a limited number of samples and further evaluations are underway.

Figure 32. Examples of the sequential 20 mm thick cross cuts from 12 mm thick ACQ treated shining gum samples after the final wetting cycle showing minimal wetting on the upper sample and complete soaking on the lower one. Note the lower, wetted sample also experienced more deformation and cracking. Photo: Jeffrey Morrell.

Benefits for industry?

Although the findings from this trial are not unexpected, they show that simply reducing the sample thickness to improve the penetration performance of VPI preservative treatment does not necessarily result in a useable product, because reducing the thickness also increases the likelihood of deformation and cracking. This is particularly important if preservative efficacy relies on a

barrier or shell treatment with an untreated core beneath. In this scenario, the dimensional stability of the thicker boards is advantageous.

What still needs to be done?

This research could be extended by gluing thinner treated samples together, and evaluating the dimensional stability and formation of splits/checks in glued samples in comparison to non-glued boards.

Table 24. Moisture contents at 20 mm increments inward from the non-sealed cross sections of 12, 19, and 25 mm thick samples after 10 wetting and drying cycles

Sample #	Thickness (mm)	Moisture Content (%)[a]						
		0-20 mm	20-40 mm	40-60 mm	60-80 mm	80-100 mm	100-120 mm	Remaining ~75 mm
1	25	23.10	10.69	9.25	9.51	9.78	10.19	
36	25	19.01	7.85	7.03	7.25	7.17	7.32	11.32
50	25	20.20	10.00	9.18	9.05	9.42	10.06	14.58
55	19	27.18	11.00	10.14	10.05	10.43	10.30	17.18
80	19	29.07	12.72	11.52	11.57	12.05	12.88	20.47
319	19	48.38	41.95	42.32	42.21	41.30	41.24	44.62
334	19	42.75	34.34	30.41	27.82	26.55	25.79	31.63
405	12	38.70	25.50	21.55	19.96	19.36	19.58	28.24
415	12	40.52	27.39	23.24	22.01	21.46	23.03	33.29
416	12	36.92	18.93	15.79	15.31	15.34	15.39	18.06
445	12	40.86	29.47	26.26	25.52	24.85	25.16	31.09
450	12	64.22	63.83	63.89	60.80	58.67	60.54	64.58

[a]Values based on drying at 60 °C.

Table 25. Effect of repeated wetting and drying (ten cycles) on development of splits/checks on 12, 19, and 25 mm thick ACQ treated shining gum samples

Sample #	Thickness (mm)	Checks (#)	Width (mm)	Depth (mm)	Length (mm)
1	25	0	0	0	0
36	25	0	0	0	0
50	25	0	0	0	0
55	19	0	0	0	0
80	19	0	0	0	0
319	19	1	1	15	50
334	19	>15	1.5	10 to 16	20-100
405	12	3	5	12	100
415	12	2	<0.5	5	25
416	12	2	<1	6	50
445	12	2	5	12	100
450	12	1	4	12	125

Trial 3.2 Laboratory decay and fire performance test: thermo-mechanically densified boards

(Published article reference: Hassan, B., Morrell, J.J., Wiesner, F., Wenxuan, W., Belleville, B. and Wood, K.C. (2022) 'Effect of densification of *Eucalyptus nitens* and *E. obliqua* on moisture uptake, swelling, decay resistance, and fire performance'. Proceedings Annual Meeting Document No IRG/WP 22-40946, 11pp.)

Concept: Densification has been used since the early 1900s to make various species of wood harder and more resistant to surface abrasion, and thus more attractive as furniture or flooring material. In some cases, it has had the ancillary benefit of also making the wood more resistant to fungal attack (Welzbacher, 2008). It might also improve timber's fire performance (Gan, et al., 2019; Tran et al., 2022) as higher density species are associated with improved resistance (AS 3959). Laboratory decay tests help to build a picture of how well and how long treated material can withstand fungal and/or insect attack. Similarly, cone calorimeter tests are used to assess the fire performance of various materials.

Aims: To assess decay resistance, the extent of swelling in laboratory decay tests, and the fire performance (in cone calorimeter tests) of densified shining gum and Tasmanian oak from the affiliated NIFPI project (NT014/NIF078).

Materials and methods: Seasoned quarter-sawn thinned and pruned plantation shining gum and native regrowth grown Tasmanian oak (*E. obliqua* only) samples were densified according to procedures described in the affiliated NIFPI project (see final report for NT014/NIF078, Trial x).

Materials and methods (decay tests): The 50 mm long densified samples were used to prepare 35 mm x 35 mm x ~10 mm decay test samples of each species that were oven-dried at 60 °C and weighed (nearest 0.01 g). Sample thickness was then remeasured using digital callipers to the nearest 0.1 mm. The samples were allocated to be exposed to either *Fomitopsis ostreiformis*, a brown rotter, or *Pycnoporus coccineus*, a white rotter. The samples were then sterilized by autoclaving for twenty minutes at 100 °C.

Figure 32. Agar block test using densified material. Photo: Jeffrey Morrell.

Decay chambers were 1.5 litre autoclavable plastic boxes. Approximately 200 ml of 1% malt extract agar was added to each chamber and the boxes were autoclaved for twenty minutes at 121 °C before being allowed to cool so the agar could solidify. Sterilized perforated plastic plates were then placed on the agar surface along with multiple 3 mm diameter agar discs cut from the actively growing edge of cultures of one of the respective decay fungi. The plastic plates provided some separation between the wood and the agar, minimizing wicking that would result in higher moisture contents that could limit fungal growth. The boxes were incubated for approx. ten to fourteen days until the surface was completely covered by fungal growth, then the blocks were randomly allocated to each box. The chambers were incubated at 25 °C and 70 % relative humidity for ten or twenty weeks.

Half of the chambers were removed at the end of ten weeks. The blocks were removed and gently scraped clean of any adhering mycelium before being weighed to determine moisture uptake. Sample thickness was again measured and then the blocks were dried at 60 °C for forty-eight hours before being weighed. The results were used to calculate final moisture content (on the basis of the final oven-dry weight), % swelling, and fungal associated wood weight loss. The remaining samples were removed after twenty weeks of incubation and processed in the same manner except that the thickness measurement was omitted since the blocks had almost recovered their original thickness at the end of the first ten weeks.

Materials and methods (cone calorimeter tests): Samples of densified and non-densified shining gum and Tasmanian oak were subjected to a 50 kW/m^2 radiative heat flux exposure in a cone calorimeter conforming with specification in AS/NZS 3837, using piloted ignition. The heat release rate (HRR) was measured from the exhaust gases via oxygen consumption calorimetry. Two samples were evaluated for each condition.

Figure 33. Example of grid used to restrain the compressed samples during cone calorimeter testing. Photo: Wenxuan Wu.

The first densified sample expanded rapidly when subjected to heat; this caused fast ignition and a higher-than-expected HRR. The expansion also affected the appearance of the remaining char after the test (Figure 34). To ensure consistent conditions, the remaining samples were constrained using a metal grid as described in AS/NZS 3837 to prevent expansion and enable comparisons between densified and non-densified samples (Figure 33).

Figure 34. Example of the charring produced with an unrestrained densified shining gum sample. Photo: Wenxuan Wu.

Results (decay tests): The samples in both boxes were covered with mycelium at the end of the ten-week incubation period. Samples exposed to *F. ostrifomis* were covered by a thick mycelial mat and many were soft to the touch. Many of the samples exposed to *P. coccineus* showed evidence of white rot as well as the distinctive reddish colouring produced by this fungus.

Moisture contents of shining gum samples exposed to *F. ostriformis* were all over 40 % and approached 60 % at the end of the twenty-week exposure period. Moisture contents were similarly high for blocks exposed to *P. coccineus* except for the twenty-week densified samples. Non-fungal exposed shining gum samples averaged 31 to 43 % moisture content at the end of the test. Moisture contents for Tasmanian oak samples exposed to the same fungus tended to be similar for both fungi, while moisture contents for non-fungal exposed controls were slightly higher than those for shining gum. The results indicate that average moisture contents were suitable for fungal attack in all treatments and that there was little consistent difference in moisture contents for the control and densified materials of a given species.

Fungal associated weight losses tended to be much lower in blocks exposed to the white rot fungus although many blocks contained evidence of bleaching typical of white rot attack. Weight losses of blocks exposed to *P. coccineus* for ten weeks averaged 26.99 and 32.07 % for control and densified shining gum blocks, respectively (Table 26). Weight losses by the same fungus increased to 39.79 and 41.18 % for the same materials after 20 weeks. The results indicate that densification had no meaningful effect on resistance to attack by the white rot fungus.

Table 26. Effect of densification of *E. nitens* and *E. obliqua* on decay resistance, final moisture content and swelling following a 10-week or 20-week exposure to white and brown rot fungi in a modified agar block test[a]

Wood Species	Treatment	*F. ostreiformis*				
		10 Weeks		20 Weeks		10 Wk Swelling (%)
		MC (%)	Wt Loss (%)	MC (%)	Wt Loss (%)	
E. nitens	Control	43.15 (1.51)	26.99 (4.17)	55.98 (4.02)	39.79 (6.58)	6.06 (3.38)
E. nitens	Densified	46.10 (5.52)	32.07 (4.94)	58.62 (5.30)	41.18 (7.56)	33.95 (22.42)
E. obliqua	Control	40.94 (6.17)	15.76 (12.42)	46.32 (4.33)	18.07 (8.98)	5.89 (1.81)
E. obliqua	Densified	48.06 (16.66)	9.63 (7.77)	57.93 (10.44)	24.18 (11.08)	58.38 (6.26)
		P. coccineus				
E. nitens	Control	45.37 (22.11)	7.64 (2.51)	55.40 (22.11)	15.34 (3.36)	6.46 (1.44)
E. nitens	Densified	45.94 (8.16)	5.91 (2.50)	27.40 (10.28)	14.63 (5.74)	27.77 (5.03)
E. obliqua	Control	43.90 (10.64)	1.67 (0.76)	60.95 (22.50)	3.12 (5.09)	6.32 (1.42)
E. obliqua	Densified	61.86 (13.45)	1.60 (1.26)	57.33 (18.03)	3.43 (3.59)	56.65 (6.28)

[a]*Values represent means of 7 replicates per treatment while figures in parentheses represent one standard deviation. Non-fungal exposed weight losses were -0.12 (0.16), -0.45 (0.39), -0.08 (0.45), and -0.15 (0.30) for E. nitens control and densified and E. obliqua control and densified respectively.*

As noted, shining gum samples exposed to *P. coccineus* experienced much lower weight losses with the control blocks experiencing 7.64 and 15.34 % weight loss after ten and twenty weeks respectively. Densified shining gum samples experienced 5.91 and 14.63 % weight losses after ten and twenty weeks, respectively. The results, while lower than would typically be expected for a decay test, indicate that densification did not appreciably improve resistance to attack by this fungus.

Weight losses in Tasmanian oak blocks were consistently lower than those found with shining gum for both fungi, reflecting the slightly higher decay resistance of this species. Weight losses in control and densified blocks exposed to *P. coccineus* all averaged below 4 %. Weight losses of blocks exposed to *F. ostriformis* were much higher than those exposed to the white rot fungus. While weight losses in control blocks exposed for ten weeks were slightly higher than those for the densified material, there were considerable variation in individual values suggesting that the differences were not meaningful. Weight losses increased in both control and densified Tasmanian oak exposed for an additional ten weeks, but the differences were again dwarfed by the high standard deviations, suggesting that densification failed to improve decay resistance of this species.

Densified samples of either species experienced thickness changes ranging from 5.9 to 6.5 % which would be consistent with swelling associated with increased moisture content. Densified samples experienced much higher swelling with shining gum samples increasing by 34 and 27.8 % when exposed to the brown and white fungus, respectively. Densified Tasmanian oak samples experienced much larger increases in swelling averaging 58.4 and 56.7 % for the brown and white rot fungi, respectively. The larger swelling reflects, in part,

the higher density of Tasmanian oak which provides more material for water absorption and therefore swelling.

Results (cone calorimeter): The heat release rates (HRR) for two densified and two control samples are shown along with those for the unrestrained densified sample (Figure 35). Heat release rates for the non-constrained densified sample rose rapidly then declined to levels similar to those for the other samples. Rates for the two non-densified samples followed very similar trends, while those for the densified samples were more variable with one sample producing a second heat release peak suggesting that the restraint might have failed. No marked differences were observed between densified and control samples for the initial peak HRR. The results suggest that densification had the potential to produce more rapid initial heat release if the timber was not constrained, but densification did not improve fire performance. In building applications, the observed expansion of the densified material would not usually be restricted indicating that densified timber would contribute to faster fire growth, potentially earlier flashover and thus a reduced available safe egress time.

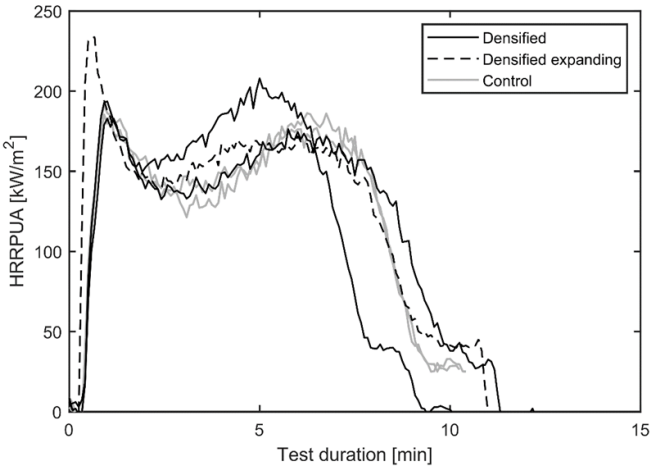

Figure 35. Heat release rates for densified and non-densified shining gum samples during cone-calorimeter testing.

Previous studies (Tran, et al., 2022) on compressed spruce observed slower mass losses for compressed samples (no mass loss was measured herein, as the specimen dimensions were too small). At the same time the authors' models predicted a higher heat release rate for the compressed timber, in alignment with the findings herein.

Benefits for industry?

This research helps to clarify that the use of thermo-mechanical densification does not appear to improve durability or fire-performance of Tasmanian hardwoods to make them suitable for use in an Australian context. However, further research using different densification processes (e.g thermo-hydro-mechanical modification) may be useful. This however remains a mostly theoretical project, as the densification process and full-scale densification equipment have not been commercialised and sample sizes were too small to be representative of real cladding boards.

What still needs to be done?

Densified material may still be desirable for other non-durability or non-fire performance-related purposes. Further durability testing using thermo-hydro-mechanical (THM) modified *Eucalyptus* (i.e. using pressurised vapour to heat the wood) or material from a combined thermo-mechanical and oil-heat-treatment approach, as well as a larger sample sizes for fire performance investigations are possible next steps.

Trial 3.3 Accelerated decay testing methods for Australian hardwoods (PhD project)

The research for Trial 3.3 was primarily undertaken by a PhD candidate and other researchers and technical staff at the University of the Sunshine Coast, using the laboratory equipment at the National Durability Centre's Eco-sciences precinct, and with support from and access to facilities within the University of Queensland. Note that the research for this trial is incomplete for two reasons: due to initial delays in recruiting a suitable PhD candidate, and due to the length of the PhD candidacy.

Concept: The research is focussed on methods for rapidly assessing the ability of barriers to inhibit fungal attack. The investigation draws on prior research done by Professor John Ruddick (1991; Ruddick and Doyle, 1990) and colleagues at the University of British Columbia in assessing the ability of shallow chromated copper arsenate (CCA) to limit fungal attack on spruce, a refractory softwood. Ruddick's work helped support changes to the Canadian Standards allowing for shallower penetration on spruce-pine-fir decking. The Ruddick method cuts plugs from timbers with varying levels of preservative penetration. These plugs are encapsulated on all surfaces using heat shrinkable plastic but the treated face. The samples are sterilized and then the treated face is placed downward on the surface of an actively growing culture of a test fungus. The plugs are incubated for varying lengths of time. The ability of the fungus to penetrate the preservative barrier is assessed by examining the wood underneath for evidence of fungal growth. This can be done using either microscopic examination or culturing of wood cut from beneath the barrier. While the Ruddick procedures are useful, they were only performed on refractory softwood and may not function as well on refractory Tasmanian hardwoods. This is especially true of shining gum given the 'candy-stripe' effect discussed in Trials 2.1 and 2.2 above.

Aims: Given the challenges with treating refractory Tasmanian hardwoods and the failure in both of the NIFPI durability projects to achieve a consistent 5 mm deep envelope in a timber board less than 35 mm thick using copper-based VPI treatments, the aims of this PhD project have evolved. It now includes: a test to determine the minimum effective penetration depth for a barrier or envelop treatment in various species of refractory Tasmanian hardwood (i.e. treatment less than 5 mm deep and as shallow as <1 mm); a test to determine the amount of chemical migration and redistribution possible on untreated surfaces (i.e. to protect holes or cracks that penetrate beyond a shallow treatment barrier; following findings from Choi [2004], on the chemical mobility of copper chromated arsenate); and a test to determine if the redistributed chemical prevents fungal colonisation (preliminary research is described further below).

Materials and methods: A preliminary experiment to assess the accelerated decay test process based on Ruddick's approach in shallow barrier treated softwoods has already been completed. Plugs (27 mm across, by 19 mm or 25 mm thick) were cut from 100 mm wide ACQ treated shining gum boards from the Varying Thicknesses trial (Trial 2.2). The amount of preservative penetration in each plug was assessed by spraying the surfaces with chrome azurol S (Figure 36). Plugs were then coated with a selection of potential barriers including:

- Control (no barrier)
- Heat shrinkable plastic
- Two coats of a 2-part epoxy plastic
- Three coats of a marine varnish
- Two-three coats of a shoe repair compound (butadiene styrene)
- Two coats of epoxy then heat shrinkable plastic

- Three coats of varnish then heat shrinkable plastic
- Two-three coats of the shoe compound plus heat shrinkable plastic

A total of twenty samples with varying degrees of ACQ penetration were tested for each barrier type. The materials were heat sterilized (100 ^{o}C for fifteen minutes) before being placed exposed, treated face downward on an actively growing culture of an aggressive brown rot fungus, *Fomitopsis ostreiformis* (Figure 37). The chambers were incubated at 25 ^{o}C for varying time periods and four samples with each coating were removed at selected time points for assessment, the plug surface was carefully cleaned and the surface sterilized. The presence of fungus inside the plug beneath the treated shell was assessed following exposure by cutting cross cutting the plugs into 3 mm thick slices just below the exposed surface and then cutting out the centre of each slice. This material was then placed on malt extract agar and observed for growth of the test fungus which served as a measure of barrier effectiveness (Figure 38).

Results: While the preliminary trials showed that two coats of an epoxy coating limited fungal attack, additional tests are underway. This is a PhD dissertation that will take another two years to complete.

Benefits for industry?
An effective and reliable accelerated decay test method for assessing the role of barrier treatments in refractory Tasmanian hardwoods remains a primary challenge for the timber industry if they want to sell treated products for exterior exposures here in Australia or overseas. This was and remains the primary underlying challenge for NT047/NIF108. Although this research project is still incomplete due to the PhD timeframe, the findings will be of great benefit to the timber industry.

What still needs to be done? This project requires further research and development before the proposed system may be considered appropriate for commercialisation or industry-uptake. PhD research is ongoing.

Figure 36. Plugs cut from ACQ treated *E .nitens* and sprayed with copper indicator showing extremely shallow and inconsistent barrier and core treatment. Photo: Juan Roberto Vargas.

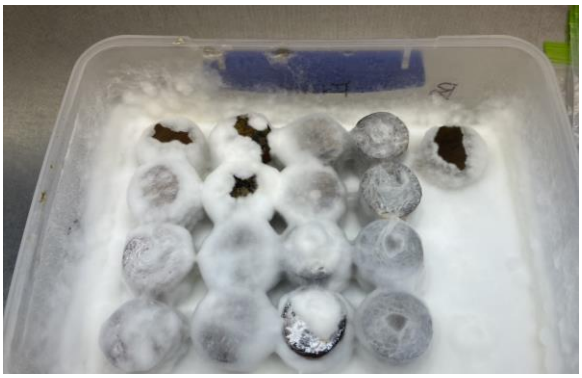

Figure 37. Barrier coated samples being exposed to *F. ostreiformis*. Photo: Juan Roberto Vargas.

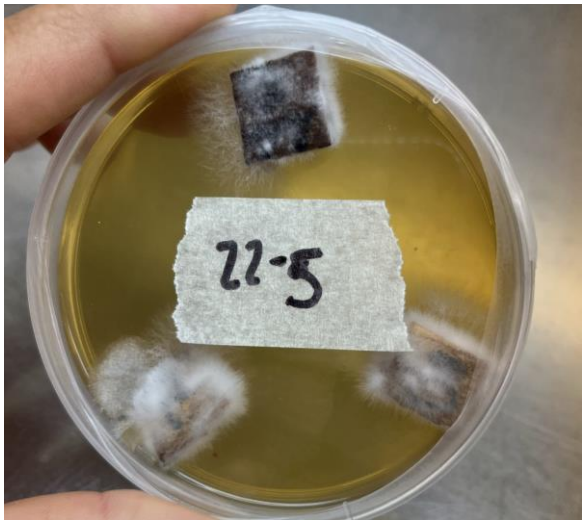

Figure 38. Slices taken from 3 mm below exposed surface to determine effectiveness of barrier. Photo: Juan Roberto Vargas.

Trial 3.4 Specialised six-month vermiculite decay chamber: ACQ treated material of varying thicknesses

Concept: Many of the accelerated laboratory-based decay tests described in the introduction and in the literature are for small scale samples that have been well treated. As noted, the problem with small samples is that they are likely to experience higher than normal leaching rates, and they also may be more thoroughly treated than a full size board (as demonstrated by the Varying Thicknesses Trial 2.2, above). This is a key consideration for refractory species like Tasmanian hardwoods which are unlikely to be thoroughly treated through the core in a full-size board. These distortions can skew results, so being able to replicate a highly aggressive fungal environment with larger sample sizes is a key consideration for accelerating the time frames for evaluating preservative treated Tasmanian hardwoods.

Aims: To assess the resistance of preservative treated material that has been subjected to repeated wetting and drying cycles to decay fungi in specialised decay chambers that enable exposure of larger sample sizes.

Materials and methods: This trial used ACQ treated shining gum and Tasmanian oak material of varying thicknesses (see Trial 2.2 above for more details on the treatment). Samples were 100 mm x 200 mm and had been subjected to repeated wetting and drying cycles (see Trial 3.1 above for more details on the wet/dry cycle test).

Figure 39. Plastic bags used to inoculate the samples in moist vermiculite for six months. Photo: Jeffrey Morrell.

Decay chambers consisted of 30 litre autoclavable plastic bags to which 1200 g of dry vermiculite was added. The blocks from a given thickness group were added to a bag and the vermiculite was distributed around the blocks. The vermiculite was wetted with 3.6 litres of a 0.5 % malt extract solution. The bags were loosely sealed and sterilized by autoclaving for thirty minutes at 121 °C. After cooling, the bags were inoculated with agar squares cut from an actively growing culture of *Fomitopsis ostreiformis*, an aggressive brown rot fungus. The bags were incubated at 25 °C for six months, by which time, the fungus had thoroughly colonized the vermiculite and produced mycelial mats on many of the timber samples (Figures 39 and 40).

Figure 40. Examples of samples covered in thick mycelial mat in a freshly opened bag. Photo: Jeffrey Morrell.

The effect of fungal exposure was assessed by removing each sample from the bag, gently scraping away any residual vermiculite and mycelium and weighing to determine moisture content at time of

harvest. The samples were then oven-dried at 60 °C to constant mass, which required seven to ten days, and weighed. The mass loss over the fungal exposure period was used to assess fungal decay resistance. The results were categorized by species and degree of penetration.

Results: Mass losses for the untreated controls ranged from 3 % to 70.1 % (Table 27). The fungus failed to grow in one bag with the very dry samples and these results were not included in the analysis. Mass losses for remaining untreated controls averaged 53.5 % (SD 11.7) indicating that conditions were suitable for aggressive fungal attack (Figures 39-41). Many untreated control samples crumbled upon drying. Moisture contents in the timber were generally between 30 and 50 % at the end of the test, indicating that conditions were also suitable for fungal growth and attack. The results with the untreated controls suggest that this test posed an extreme challenge to the treated timbers included in each decay chamber. Mass losses for the ACQ treated samples varied widely, but most were well below those found with the untreated controls. Mass losses with ACQ treated shining gum failed to follow a trend with regard to the degree of preservative penetration. Ideally, mass loss should decrease with degree of penetration but the variation between samples precluded any clear separations. The results were similar for the ACQ treated Tasmanian oak samples although the average weight losses for the 25 mm thick material tended to be low, regardless of depth of penetration.

Figure 41. Example of ACQ treated blocks covered with an extensive mycelial mat and showing evidence of darkening and surface cracking at the end of the incubation period. Photo: Jeffrey Morrell.

The presence of substantial mass losses in most of the test pieces regardless of degree of treatment is perplexing. Probing the ACQ dipped ends of some pieces suggested that some of this decay developed as a result of the failure of the end coating; however, there was also considerable evidence of decay directly on the wide faces of the samples. While the test fungus is an aggressive brown rotter, it is not known for being copper tolerant and the quaternary ammonium component in the system should have limited that risk. However, there was some evidence that copper on the surface was being mobilized. While circumstantial, samples were wiped down with a rag that inadvertently contained traces of chrome azurol S and the rag turned blue. Chrome azurol S is sensitive to 25 ppm of copper and would be expected to react with trace amounts of copper mobilized on the wood surface. We plan to explore the potential copper tolerance of this fungus in a separate study.

These trials were only completed recently, and the data are still being analysed. However, they do indicate the potential for using larger test pieces to expose barrier treated materials while creating conditions suitable for aggressive decay.

Benefits for industry?

This method was not a standard durability decay test method. It proved extremely aggressive and would most likely not be representative of a real-life cladding hazard risk. However, with some further refinement, this test may prove to be one of the few accelerated test measurements that could accurately represent the durability of treated refractory Tasmanian hardwoods.

Table 27. Weight losses of *E. nitens* and *E. obliqua* samples treated with ACQ to different degrees of preservative penetration and exposed to the brown rot fungus *Fomitopsis ostreiformis*

Species	Penetration %	Fungal Associated Weight Loss (%)[a]							
		12 mm		16 mm		19 mm		25 mm	
		n	Wt Loss	n	Wt Loss	n	Wt Loss	n	Wt Loss
E. nitens	<20	13	11.05 (9.16)	6	9.60 (4.91)	10	13.30 (9.34)	9	10.68 (7.30)
	20-50	4	11.18 (7.51)	7	13.75 (11.30)	5	6.68 (3.08)	5	8.23 (5.17)
	50-80	-	-	-	-	2	0.18 (0.25)	7	9.15 (6.75)
	>80	3	16.99 (13.15)	6	6.37 (4.41)	6	11.57 (16.84)	2	13.58 (1.54)
E. obliqua	<20	10	8.62 (4.52)	4	10.30 (3.61)	2	23.18 (5.66)	2	5.87 (8.06)
	20-50	2	11.31 (7.10)	3	8.95 (4.48)	3	8.47 (5.03)	4	6.73 (3.99)
	50-80	3	10.53 (0.74)	-	-	7	9.90 (6.75)	5	9.84 (5.91)
	>80	4	14.07 (4.06)	8	7.96 (5.21)	7	10.26 (5.23)	6	4.71 (4.78)

[a]Values represent means while figures in parentheses represent one standard deviation. A "-" denotes no samples in that group.

What still needs to be done?

This accelerated test method is a blunt but effective instrument. It showed that the material included in the trial was unable to withstand the fungal attack under such aggressive conditions. Although this doesn't necessarily reflect the real-life conditions that, for example, exterior cladding would be exposed to, it is still mostly likely an accurate representation of the durability of the material that was used in the test. A more sensitive and nuanced method has been proposed by a PhD candidate at USC (see trial 3.3. above). Per the original aims of this research project, the PhD research aims to identify the minimum treatment barrier thickness that can protect untreated wood beneath that layer. Nevertheless, the decay chambers in this trial show the potential for testing larger scale samples under aggressive decay conditions. Some further testing of this method using preservative treated material that achieved higher overall uptakes and theoretical retention would be of great interest and should be pursued using material from the 'best bet' trial in NT014/NIF078.

Communication

Industry Engagement Workshop

The results of the research trials were communicated to our industry partners, in an industry engagement workshop was developed and run for NIF108 and its affiliated research project, NIF078, at the Centre for Sustainable Architecture with Wood in Launceston, in May 2022. The one-day workshop had research partners travelling from interstate to present and discuss their work with interested timber industry collaborators (Figures 42 and 43). The workshop was held face-to-face, at the T40 workshop in Newnham, with the opportunity for people to handle treated material and directly interact with researchers throughout the day. A small handbook was provided to participants (Figure 42).

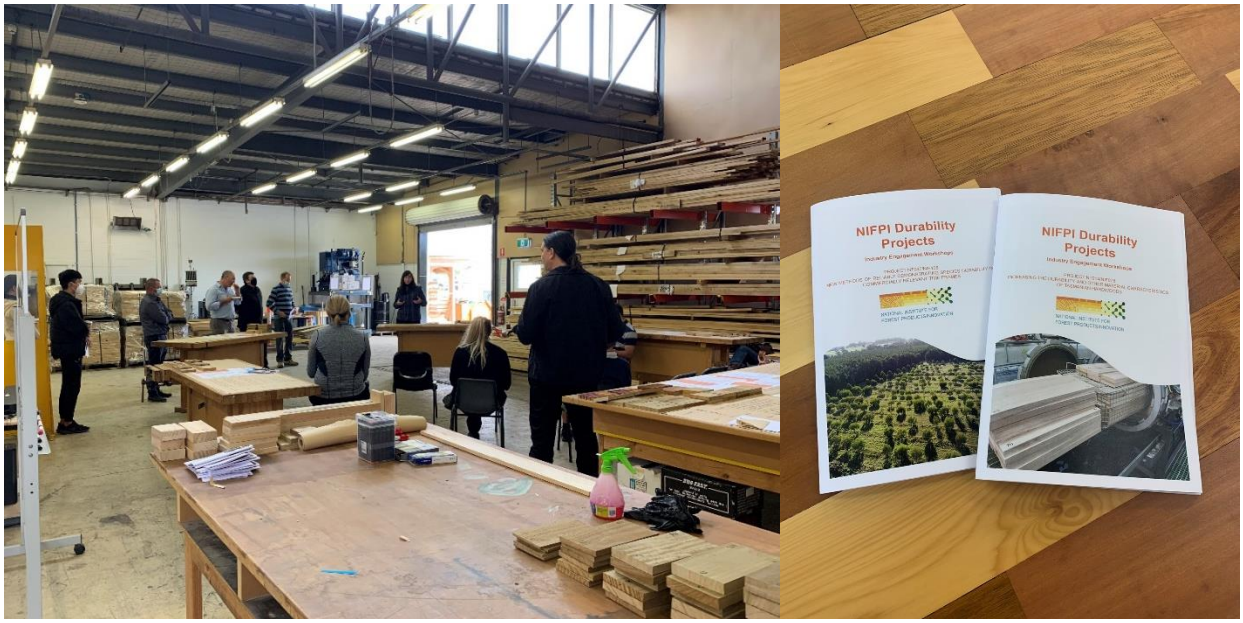

Figure 42. Launceston NIFPI durability projects Industry Engagement Workshop at CSAW in Newnham (left) and printed workshop booklets (right). Photos: Donna Jackman (left) and Kyra Wood (right).

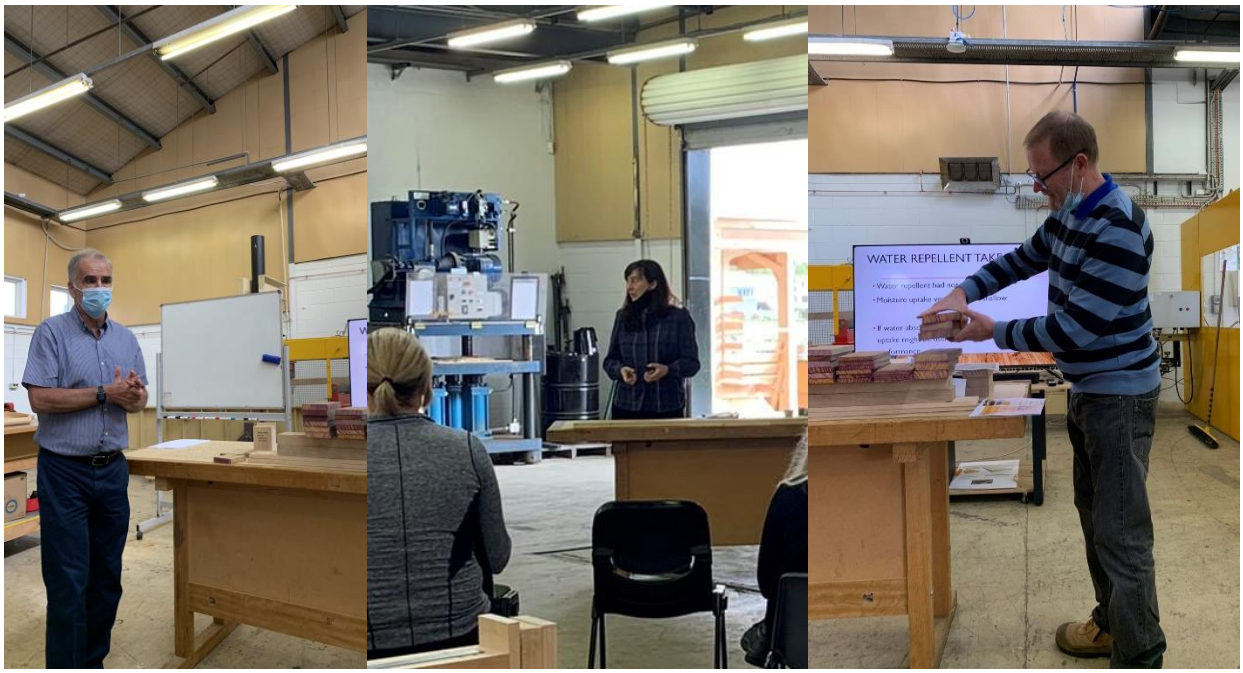

Figure 43. Lead researchers presenting during the Industry Engagement Workshop including: Jeffrey Morrell (left), Kyra Wood (middle) and Stuart Meldrum (right). Photos: Kyra Wood (left, right) and Donna Jackman (mid).

Conferences and presentations

Work from this project has already been presented at four conferences in Australia and overseas [IRG51 Online, 2020; IRG 52, Online, 2021; IRG 53, Bled Slovenia, 2022; Forestry Australia (formerly IFA AFG) Launceston, Australia, 2021 (Figure 44); and SWST 2022, Kingscliff, Australia], with further presentations planned next year (IRG54, Cairns, Australia).

Figure 44. Forestry Australia (previously IFA AFG) annual conference delegates attending a presentation at CSAW in 2021. Photo: Kvra Wood.

Written Publications

The results from this work have been published in several conference proceedings, and one paper has been submitted for peer review in an open access scientific journal. Other open access peer-reviewed publications are planned or in draft, and a copies will be provided to FWPA, the Launceston NIFPI steering committee, and interested industry partners upon publication.

In addition to journal publications, a series of graphic one-page briefing papers (following a similar format to that used in the industry engagement workshop booklet) are being prepared at the suggestion of the steering committee representative for the affiliated NIFPI project, Ms Suzette Weeding. These will be circulated to interested industry partners and individuals at their request.

Tabulated summaries of research trials

Table 28. Summary of Trial 1 Accelerated and mid to long-term field trials			
Test	Aims	Results	Recommendations
Trial 1.1 Stake (graveyard) and ground proximity arrays: natural durability	To set up a field trial site in Tasmania; provide long-term data on the natural durability characteristics of certain Tasmanian hardwood species for comparison with accelerated durability tests; and to assess the performance of untreated Tasmanian plantation and younger regrowth hardwoods in H4 and H3 exposures	Some of our control stakes at the Tasmanian site failed within one year, which means that the site has national value as an accelerated test site. Also interesting are the relatively low decay ratings at both sites for some species at such an early stage in the test, particularly regarding the blue gum (*E. globulus*) in-ground ratings at both sites and above ground ratings at the Nambour site, and also the Tasmanian oak (*E. obliqua)* above ground ratings at the Nambour site. Such low ratings at this stage indicate that those samples are not likely to match the expected decay resistance timeframes outlined in AS 5604.	Ongoing data collection, monitoring and maintenance of the field trial site is required. Salary costs are covered at least to the end of 2024, but the trial may incur some costs (e.g. paying for fencing and weed maintenance, paying for additional personnel to collect and evaluate the data, etc.) so ongoing cash and in-kind support for the field trial is recommended.
Trial 1.2 Ground proximity arrays: treated materials	To accelerate decay in SCF + azole treated, VPI + ACQ treated, NexGEN water repellent coated, and boron-based dip diffusion treated Tasmanian hardwoods and other materials of varying thicknesses by placing the timber in a ground proximity array, and to evaluate the effectiveness of the treatment for H3 exposure.	At this stage there are no results from this sub-trial, due to the length of time it takes for the wood to deteriorate enough to make comparisons with untreated material of the same species.	(As above)
Trial 1.3 Ground proximity arrays: treated and modified material from the affiliated NIFPI project (NT014/ NIF078)	To accelerate decay in densified and MCA and ACQ + adjuvant, LOSP and Kop-Coat treated Tasmanian hardwoods from the affiliated NIFPI project (NT014/NIF078) by placing the timber in a ground proximity array, and to evaluate the effectiveness of the treatment for H3 exposure.	(As above)	(As above)
Trial 1.4 Sandwich arrays: treated and modified material from the affiliated NIFPI project (NT014/ NIF078)	To accelerate decay in densified and MCA and ACQ + adjuvants, LOSP and Kop-Coat treated Tasmanian hardwoods by mimicking an application where the timber might trap moisture (like in a window or door frame) but was not constantly touching a moist substrate, and to evaluate the effectiveness of the treatment for H3 exposure.	(As above)	(As above)

Table 29. Summary of Trial 2 Initial preservative treatments			
Test	Aims	Results	Recommendations
Trial 2.1 Vacuum pressure impregnation (VPI) pilot	To use a conventional treatment method of treatment (VPI) and a common preservative chemical (ACQ), to treat representative, refractory Tasmanian hardwood species and analyse the amount of preservative penetration possible using this method.	This study enabled us to determine which pressure cycles and lengths of time work most effectively with the species in question. This work effectively showed that some improvements were possible with changes to the schedule lengths under pressure, and helped to eliminate other methods that were demonstrably ineffective, like hot/cold baths.	Further research to better understand the causes for concentration of preservative treatments along early-wood bands is recommended.
Trial 2.2 Varying thicknesses	To investigate the effect of material thickness on preservative penetration using VPI in Tasmanian hardwood species.	In general, the penetration results improved as the dimension sizes decreased. For example, most of the 19 mm samples would pass the preservative penetration requirements which was an important finding, given that exterior wall claddings and decking are likely to be of similar thickness. Longer, slower treatment cycles (i.e. 3 hours +) also produced better results, but may not be practical in industrial settings.	Treated thinner dimensioned boards could potentially be used in the making of glue laminated beams for exterior applications. As an end use for treated shining gum, with dimensions of 19mm or less, treated boards could be laminated to standard glue lam beam sizes. Further investigation into treatment of glue laminated products is recommended.
Trial 2.3 Supercritical carbon fluid (SCF) pilot	To investigate the effectiveness of supercritical carbon fluids (SCFs) as a method for preservative treatment of refractory Tasmanian hardwoods and to establish whether the method would cause crushing or undue collapse due to high-pressure gradients.	Azoles were retained in the core of each board in amounts higher than the targeted amount of 120kg/m^3. This was an extremely promising result.	An upscaled trial using a variety of Tasmanian hardwood species to refine the process and chemical retention amount to make them suitable for the Australia H3 requirements is highly recommended. An economic/market feasibility study of the cost benefits of establishing an SCF treatment facility in Australia is also recommended.
Trial 2.4 Water uptake and Next Gen coating	To measure the amount of water uptake in seasoned Tasmanian hardwood species after prolonged water immersion, and to evaluate the effectiveness of a commercially available water repellent coating in reducing uptakes.	The overall results indicated that the water repellent treatment trialled had no noticeable effect on dimensional changes for any of the three species over either a short or prolonged immersion period. The relatively slow droplet absorption in the untreated Tasmanian hardwood species was promising since it creates an opportunity for effective water-shedding design in a vertical application such as cladding.	Further research using this material with a preservative that combines a water repellent with a standard chemical treatment like ACQ in a VPI treatment would be of interest. Further research using different water repellent coatings is also recommended.

Trial 2.5 Boron and copper naphthenate dual treatment	To treat Queensland maple using dip-diffusion in a boron-based preservative treatment (some with a copper naphthenate overcoat) to compare with similarly treated Tasmanian oak and shining gum material from the affiliated NIFPI project (NT014/NIF078) and to provide treated material for durability analysis.	The analyses of boron in Queensland maple are still pending but the results should provide a measure of the ability of boron to diffuse inward as well as the ability of the dual treatment to provide enhanced protection compared to the boron dip treatment alone.	Future comparison of the results of this field trial with similarly treated material from NT014/NIF078 is recommended.

Table 30. Summary of Trial 3 Accelerated laboratory trials			
Test	Aims	Results	Recommendations
Trial 3.1 Repetitive moisture cycling: ACQ treated material of varying thicknesses	To assess the effects of repeated wet/dry cycles on water uptake and crack development in ACQ treated shining gum samples of different thicknesses.	Although the findings from this trial were not unexpected, they showed that simply reducing the sample thickness to improve the penetration performance of VPI preservative treatment did not necessarily result in a useable product, because it increased the likelihood of deformation and cracking.	This research could potentially be extended by gluing thinner dimensioned treated samples together, and evaluating the dimensional stability and formation of splits/checks in glued treated samples in comparison to non-glued boards.
Trial 3.2 Laboratory decay and fire performance test: thermo-mechanically densified boards	Using material that was thermo-mechanically densified in the affiliated NIFPI project (NT014/NIF078), the aim was to assess its decay resistance and the extent of swelling in laboratory decay tests, and the fire performance of densified shining gum and Tasmanian oak in cone calorimeter tests.	Thermo-mechanical densification did not improve the durability or fire-performance of Tasmanian hardwoods to make them suitable for use an Australian context.	Further durability testing using thermo-hydro-mechanical (THM) modified Eucalyptus (i.e. using pressurised vapour to heat the wood) or material from a combined thermo-mechanical and oil-heat-treatment approach, as well as a larger sample sizes for fire performance investigations are possible next steps.
Trial 3.3 Accelerated decay testing methods for Australian hardwoods (PhD project)	To determine the minimum effective penetration depth for a barrier or envelop treatment in various species of refractory Tasmanian hardwood; to determine amount of chemical migration and redistribution onto untreated surfaces; and to determine if the redistributed chemical prevents fungal colonisation.	Results are still pending as this is part of an ongoing PhD study, however results from the preliminary trial showed that the most effective barrier for this accelerated assessment method based on John Ruddick's method was two coats of a 2-part epoxy plastic as it forced the fungus to enter through the ACQ barrier.	The PhD research is ongoing.
Trial 3.4 Specialised six-month vermiculite decay chamber: ACQ treated material of varying thicknesses	To assess the resistance of preservative treated material that has been subjected to repeated wetting and drying cycles to decay fungi in specialised decay chambers that enable larger sample sizes.	Testing larger scale samples under aggressive decay conditions was possible using this accelerated method. Although the conditions were more aggressive than a real life H3 exposure, when results from longer-term field trials of the same material become available, comparison of the resulting timeframes can be used to develop a predictive model based on this test.	Some further testing of this method using preservative treated material that achieved higher overall uptakes and theoretical retention and penetration passes would be of great interest and should be pursued using material from the 'best bet' trial in NT014/NIF078.

Conclusion

Three major trials were undertaken as part of this NIFPI project: Trial 1: accelerated and mid to long-term field trials; Trial 2: initial preservative treatment trials; and Trial 3: accelerated laboratory trials.

The field trials are still in their infancy, but their establishment creates opportunities for more active assessment of new treatments in future. The initial results from the newly established field trial site at Upper Castra in Tasmania indicate that the site has strong mycological activity. This means Tasmania now has a field trial site for durability evaluation of national relevance. The early decay ratings of Tasmanian hardwood species exposed in ground proximity arrays at Nambour (QLD) indicate that some species are decaying at faster rates than would normally be expected according to their durability classification in AS 5604. The relatively rapid degradation rates compared with previous tests may reflect differences in tree age. The older tests used to develop the decay ratings in AS 5604 were from mature forest trees, while the material currently in test was obtained either from plantation or regrowth forests. This has important implications for design and use of these materials. This also highlights the need for further and ongoing research to build a clearer picture of the changing characteristics of younger plantation and native resources.

General results from the preservative treatment and accelerated laboratory trials revealed that Tasmanian hardwood species were extremely resistant to water or fluid uptake. This made conventional pressure treatment challenging, and also made it difficult to develop treatment-responsive accelerated decay procedures that could circumvent the long timeframes currently required to demonstrate treatment efficacy. Penetration indicator tests following VPI treatment showed that penetration was extremely inconsistent across the surfaces and through the cross-sections of most samples. Treatment appeared to penetrate more easily into the earlywood portion of growth rings, but not into the latewood. We also observed internal checks that appeared to form largely in the earlywood bands and which seemed to facilitate copper penetration. Developing methods for enhancing these checks might be one approach to improving overall treatment. Other NIFPI tests from the affiliated project (NT014/NIF078) showed that penetration could be somewhat improved with the use of additives, longer treatment cycles and pre-treatments that altered the physical characteristics of the wood (e.g. through incising or compression). Further work is still needed to determine whether achieving a barrier or shell treatment is possible in Tasmanian hardwood species, and if so, what is the minimum effective penetration depth for preservative treatment. Some of that work is already being undertaken by the PhD candidate at the University of the Sunshine Coast.

One of the more promising results from the preservative treatment trials showed that alternative treatment processes such as high-pressure supercritical carbon dioxide (SCF) treatment with azole-based preservative or non-pressure dip-diffusion boron-based treatment prior to conventional impregnation were more successful at achieving good penetration in Tasmanian hardwoods. The SCF process in particular achieved higher than targeted levels of preservative retention in the timber with little or no internal deformation. Field trials of SCF treated and boron diffusion/copper naphthenate treated timbers are underway in Nambour and a PhD candidate at the University of Tasmania is undertaking work to establish leach preventing overcoat treatments for boron treated material.

The overall results showed that conventional pressure treatment to meet the current AS/NZS1604 Standards is problematic, but alternative approaches that use dual treatments

with boron or modify the treatment fluid using supercritical fluid treatment have potential and merit further study.

Recommendations

- Continued research into the SCF treatment of refractory Tasmanian hardwoods is highly recommended. An economic/market/feasibility study would also help to establish possible routes to commercialisation in Australia.

- Ongoing industry and other support for the continued data collection, monitoring and maintenance of the field trial site is highly recommended.

- Investigation into the treatment and durability of glue laminated products of varying thicknesses is highly recommended.

- Further research into the concentration of preservative treatments along early-wood bands is recommended.

- Further research using a preservative that combines a water repellent with a standard chemical treatment like ACQ in a VPI treatment is recommended.

- Laboratory and field-trial durability analysis of additional types of non-chemical treatment (e.g. thermo-hydro-mechanical densified timber, and thermally modified timber) is recommended.

- Further tests using the vermiculite decay chambers with larger scale treated material from the ‘best bet’ trial in the affiliated NIFPI project (NT014/NIF078), to ascertain its comparative effectiveness as an accelerated method of analysis for properly treated material is recommended.

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