Specialty Wood Products
Research Partnership

FOREST GROWERS RESEARCH

The Specialty Woods Products Research Partnership

FINAL REPORT
2015 – 2023



SWP Report SWP-T170

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FOREWORD

New Zealand needs resilient forests – forests that can sustainably deliver all the benefits trees can bring in the face of climate change and new pest and disease threats. Specialty species provide insurance against risks and give options in terms of silvicultural systems, rotation lengths, carbon settings, markets, and products.

The Specialty Wood Products Research Programme (SWP) has successfully demonstrated that specialty species can produce a range of products with significant economic value. These products can substitute our substantial imports and complement radiata pine. They include some exciting engineered wood products. The SWP has helped fine-tune ways to identify the wood properties we are seeking – for example durability and good processing properties – and developed innovative ways to test for these properties. And the breeding work done as part of the SWP will greatly improve the resource for future growers and processors.

The recent Forestry and Wood Processing Industry Transformation Plan emphasised that the forest industry needs to diversify, setting a target that 20% of all new planting should be non-radiata alternatives. We need to build on the research momentum created by the SWP over the past seven-plus years – we have top scientists in at least three leading research centres now, with substantial knowledge and experience in specialty species. The time is right to make the most of this research capability. We must take up the challenge and incorporate alternatives to radiata pine as a genuine component of our plantation forests and wood processing industries. The SWP has made a good start.

Peter Berg – Chair of the Specialty Wood Products Research Programme

SWP TECHNICAL REPORTS

The main reporting mechanism for the Specialty Wood Products Research Programme (SWP) has been Technical Reports. Almost all of the over 170 Technical Reports produced are freely available on the Forest Growers Research website: https://fgr.nz

File Notes, which report interim SWP outputs, are available on request from the SWP Programme Manager, Marco Lausberg marco.lausberg@fgr.nz

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INTRODUCTION

The Specialty Wood Products Research Partnership (SWP) began in 2015, when the New Zealand forest industry partnered with the Ministry for Business, Innovation and Employment (MBIE) to fund a seven-year programme which aimed to kick-start a high-value specialty wood products industry based on alternatives to radiata pine. The programme ended in June 2023.

This report summarises the technical content and outputs of the SWP. The programme should be considered as initiating the research and development needed to develop a specialty wood products industry. Longer-term outcomes which could result from the outputs of the SWP will depend on a range of factors. Continued investment in research and development is essential, leading to greater industry confidence in specialty species.

Transforming New Zealand's forest industry and the role of specialty species

The New Zealand forest industry is characterised by its almost total reliance on radiata pine – a remarkably successful species, and one which has had 50 years' and many millions of dollars of research and development investment by government and the forest industry.

Radiata pine comprises over 90% of the total New Zealand plantation area, and the way the forest industry has evolved around radiata pine leaves it very vulnerable to external risks. These include changing climate, changing overseas markets, and potentially devastating disease outbreaks.

The Ministry for Primary Industry's 2022 Forestry and Wood Industry Transformation Plan – Te Ara Whakahou – Ahumai Ngahere (ITP) is a strategy to de-risk and grow the forest industry. The ITP has five transformational goals, summarised below:

- reducing carbon emissions by providing bio-alternatives
- increasing domestic wood processing
- increasing export earnings from value-added wood products
- increasing use of wood in mid-rise or commercial construction
- planting of alternative species increases to 20% of all planting by 2030.

The risks associated with the dominance of radiata pine have been recognised for some time. The SWP was launched in 2015 as an early initiative to begin the long-term process of adding diversity to the forest industry. Its aim was to generate a broader range of relatively high-value, high-performing timber products from alternative species.

At the outset, key global market trends identified included the demand for high-stiffness timbers, naturally durable timbers, dark and rich-coloured timbers, and a strong sustainability brand. It was recognised that specialty species have the potential to supply these markets: also to directly complement the radiata pine industry through improving the performance of engineered wood products.

Developing improved breeding stock to overcome known wood quality and forest health issues of selected species was a key part of the SWP. A further aim was to support development of a new naturally durable eucalypt resource. Finally, regional investment in specialty species was to be encouraged through producing four regional business investment strategies.

By the end of the SWP in 2023, new pressures on the forest industry, including climate change, changing international conditions, and social licence challenges, have come to the fore. These new pressures make the work of the SWP still more relevant. The outcomes of the SWP increased confidence that specialty species can contribute to all the ITP goals, while adding many other benefits associated with a diversified plantation forest resource.

Diversifying the forest estate to meet ITP goals requires activity across multiple species. SWP activity was spread across four species/species groups, and involved at least 13 different species. Of necessity, much of the work was exploratory, but key gains have been made – for example in site/species matching, breeding for disease resistance, breeding for desirable wood properties, developing a naturally durable eucalypt resource, understanding and testing for durability, developing and testing engineered wood products and applications, modelling specialty species wood flows and processing options, and developing a new AI-based specialty species mapping technique. The programme provides a launching pad for further research and development, while several of the products and applications are ready for industry uptake.

Barriers to progress

Various barriers to progress in getting more specialty species planted, developing new technologies, and accessing markets for specialty species, came to light during the SWP. None of these barriers are insurmountable: while some progress was made during the SWP, further long-term support will be needed from government and industry to achieve a sustainable specialty wood products industry. An increase in strategically located, regionally focussed, specialty species planting at scale is a critical precursor to industry development. Problems to overcome include:

- **existing growers lack confidence in specialty species:** National Exotic Forest Description (NEFD) data shows that, over the seven years of the SWP, the large-scale plantation area of three SWP species/species groups declined slightly (Table 1). In 2015, the combined area of these species was over 137,000ha, around 8% of the total NZ plantation resource. By 2022, the combined area had declined slightly to 131,197ha, around 7.5% of the total plantation area. Perceived reasons for this decline are suggested in Table 1. Breeding work done by the SWP should, in the medium term, help to reduce the risk of Swiss Needle Cast and cypress canker.

Table 1: Change is areas of three specialty species/species groups, 2015-2022 (NEFD data).

Species/species group	Plantation area ha 2015	Plantation area ha 2022	Perceived factors causing decline in area
Douglas-fir	104,174	100,105	Risks associated with wildings (South Island) and Swiss Needle cast in warmer areas.
Non-durable eucalypts	23,181	22,035	No new markets emerging.
Cypresses	10,140	9,057	Loss of confidence due to canker risk; lack of markets of sufficient scale.
	137,495	131,197	

- **few new growers of specialty species:** the lack of economic models demonstrating the business cases of growing specialty species was cited many times as deterring growers (in stark contrast to radiata pine). Until more market data for specialty species are available, this problem will remain, but better theoretical models will help provide more investor information and confidence in the meantime. Work on site/species suitability and the growth modelling work done by the SWP will contribute to grower knowledge of potential productivity of specialty species on different site types.
- **developing new technologies:** the dominance of the radiata pine industry in New Zealand continues to constrain investment in new technologies related to any other species; however, the new technologies and products developed and tested by the SWP are a good start in demonstrating the potential of these species in a range of applications.
- **accessing markets:** current New Zealand building standards result in it being difficult or impossible to use specialty species in many applications, and despite on-going efforts to include specialty species in the various standards, this barrier is proving difficult to overcome. SWP work on strength and stiffness of some timbers and engineered wood products, and on durability, will contribute to evidence about the suitability of these species in different applications.

Main SWP research and development themes

The four species/species groups chosen for the SWP were Douglas-fir, durable and non-durable eucalypts, and cypresses.

1. Existing main specialty species

Three of the species groups selected for the SWP – Douglas-fir (*Pseudotsuga menziesii*), non-durable eucalypts (*Eucalyptus fastigata*, *E. nitens*, and *E. regnans*) and cypresses (*Cupressus macrocarpa*, *C. lusitanica*, and some hybrids) – comprise the main specialty species resource already growing in New Zealand.

In the case of these species, the SWP had two main objectives:

i. improving returns from existing crops, through research into processing, durability, and new product development and testing
ii. targeted breeding to enhance future wood supply, with a focus on wood quality and forest health.

2. Durable eucalypts – an emerging species group

The fourth species group chosen was durable eucalypts – eucalypts which produce naturally durable hardwood timber, suitable for in-ground and other exterior applications without needing chemical treatment. Durable eucalypts are an emerging forest resource in New Zealand. The SWP objective was to extend the breeding and wood quality research and development work being carried out by the New Zealand Dryland Forests Initiative (now New Zealand Dryland Forests Innovation, NZDFI).

3. Regional/business investment case studies

The third key research theme of the SWP was to produce a series of regional business investment strategies. These were intended to lay the foundations for later business development associated with specialty species. Four strategies were produced.

Allocation of SWP funds

Some 95% of SWP research funds went to species-specific work, with the remaining 5% allocated to generic work such as the regional business investment case studies. The allocation of species-specific SWP funds was determined by several factors including the contributions of SWP industry partners. Durable eucalypts were allocated the largest proportion of the funds because the resource and durable hardwood industry are in their infancy.

Table 2: Final allocation of SWP funding between species 2015-2023.

	Total expenditure by species/species group	% of total species-specific funding
Douglas-fir	$1,850,073	21%
E. nitens	$1,402,106	16%
Non-durable eucalypts excluding *Eucalyptus nitens*	$698,354	8%
Cypresses	$993,652	11%
Durable eucalypts	$3,768,921	43%

Mid-Programme Expert Advisory Panel Review, 2017

In 2017, an expert advisory panel (EAP) undertook a mid-programme review of the SWP.

The review panel recommended that the SWP should focus on a smaller number of key projects and encompass the whole forest system – i.e. the full chain from the forest resource, through processing, to products and markets.

The key projects identified were:

- Douglas-fir for current markets, optimised engineered lumber (OEL™), and other engineered products, for example laminated veneer lumber (LVL) cross-laminated timber (CLT) etc.
- Non-durable eucalypts for current markets, OEL™, and other engineered products (e.g., LVL, CLT etc.)
- Durable eucalyptus for vineyard posts, LVL and sawn timber (structural and appearance).

The recommendations of the EAP were followed from 2017 onwards.

SUMMARY: KEY ACTIVITIES AND ACHIEVEMENTS OF THE SPECIALTY WOOD PRODUCTS RESEARCH PARTNERSHIP

1. Existing main specialty species

Douglas-fir

The Douglas-fir resource is important in the southern South Island and colder parts of the central North Island. At the start of the SWP, Douglas-fir growers identified that they wanted to increase productivity and wood quality, reduce disease risk, and diversify the product range of the species. Key achievements over the seven years of the SWP include:

- developing a new GIS-based growth model for Douglas-fir and incorporating this into the industry's Forecaster calculator tool
- testing new engineered wood products – cross-laminated timber (CLT) and optimised engineered lumber (OEL™) – as a precursor to them attaining approval under the industry standards
- developing CLT fasteners and connection systems, and proving these to be resilient to seismic shocks and simple to repair after damage
- confirming that thermally modifying Douglas-fir sapwood and heartwood significantly improves durability
- establishing new breeding targets: new selections focusing on form and productivity; trials evaluated and high-performing families identified.

While Douglas-fir is recognised as an excellent species for colder, wetter parts of New Zealand, the Douglas-fir industry is constrained at present by the wildings risk, which has resulted in restrictions on planting. A solution to this problem exists, but relies on genetic modification, currently banned in New Zealand. In the meantime, the SWP has made a number of gains for growers and processors. The CLT fasteners and connection systems developed by the programme have already been taken up by industry.

Non-durable eucalypts

Non-durable eucalypts (*Eucalyptus fastigata*, *E. nitens* and *E. regnans*) are grown at scale in the central North Island and the southern South Island, and chipped for pulp. SWP research was dominated by work on *Eucalyptus nitens* as SWP partner Southwood Exports Ltd. is a major grower in Southland. One objective was to improve the solid wood properties of *E. nitens* by breeding gains, so as to open up higher-value markets: the new seed orchards established will contribute to accomplishing this.

Key achievements included:

- establishing two new *E. nitens* seed orchards based on enhanced solid-wood properties; making new *E. fastigata* selections incorporating wood stiffness
- testing *E. nitens* optimised engineered lumber (OEL™) – a product which is now industry ready
- testing *E. fastigata* veneer for stiffness with positive results; successfully testing glues for LVL production. LVL producers can now move towards incorporating *E. fastigata* into standard radiata products with confidence
- testing novel *E. nitens* and densified *E. nitens* flooring products with good results – these products have been taken up by industry
- successfully using near-infra-red spectroscopy (NIR) models to predict *E. nitens* wood shrinkage and cellulose content. The technique was used to incorporate these wood qulaity parameters into the breeding programme
- completing pre-release work and releasing a new biological control agent for *Paropsis charybdis* (eucalypt tortoise beetle) – an economically damaging eucalypt pest. The biological control agent was released in 2022, so it will take some time to know how effective it is.

Cypresses

Cypresses (especially *Cupressus macrocarpa*) have long been a New Zealand favourite for a range of uses, but the resource established in the early 20th century is dwindling fast. *C. macrocarpa* is badly affected by canker in some parts of New Zealand, so canker-tolerance is a key breeding priority to restore grower confidence. New cypress hybrids have the potential to deliver increased vigour, canker tolerance, and good solid wood properties.

Key research achievements included:

- industry survey and workshop leading to a new cypress strategy – 'Whakamahere Cypress – 2022-2042' which identifies research and market development priorities
- making new canker-tolerant selections of *C. macrocarpa* and *C. lusitanica*: establishing three new *C. macrocarpa* trials to test canker tolerant genotypes
- confirming that thermally modifying *C. lusitanica* sapwood and heartwood significantly improves durability
- testing bending strength and stiffness of young Ovens cypress (a canker-tolerant *C. lusitanica* hybrid now being deployed but with a lack of information about its timber properties)
- producing and deploying new cypress hybrids in trials on numerous farm forestry properties.

2. Durable eucalypts – developing a new forest resource

Durable eucalypts are an emerging species, considered to have excellent potential especially in New Zealand's north-eastern dryland environments. Their strong, stiff, and in some cases richly coloured durable timber has many potential applications.

Key achievements include:

- developing and testing durable eucalypt products and associated technologies, including posts, poles, veneer and LVL
- developing a near-infrared (NIR) spectroscopy technique for assessing heartwood extractives and durability
- establishing eight new site/species demonstration trials, setting up a network of 130 permanent sample plots (PSPs), trial measurement and analysis
- developing growth, taper and heartwood volume models for *E. globoidea*
- establishing a seed orchard; producing clonal material and establishing a clonal trial
- advancing knowledge of tolerance to *Paropsine* browsing; using LiDAR to assess insect defoliation
- assessing the potential to produce essential oils from *E. bosistoana*
- deploying the first generation of improved *E. bosistoana* and *E. globoidea* planting material under an aligned Tu Uru Rākau One Billion Trees project
- reporting in full in 2023 on early survival and growth results from the NZDFI demonstration trials network.

The NZ Dryland Forests Initiative (NZDFI), which began working on durable eucalypt breeding, research and development in 2008, managed all SWP durable eucalypt research and development.

3. Regional business investment strategies

Four regional business investment strategies were produced by the SWP:

1. Durable eucalypts: a multi-regional opportunity for New Zealand's drylands 2020-2030
2. New Zealand Cypress Strategy – Whakamahere Cypress 2022-2042
3. Douglas-fir processing options strategy
4. Portable sawmilling of locally grown alternative timber species - strategy for a sustainable small-scale regional industry in Hawke's Bay Region.

Other important outputs included a series of 'WoodScape' resource and processing analyses, and a new AI-based mapping methodology for alternative species.

Future direction

As the SWP draws to a close, work is underway to secure research and development funding for another multi-year government/industry strategic programme focusing on specialty species. Future research and development must be informed by anticipated industry needs, both in the medium and long-term. To this end, two workshops involving industry representatives have been held to identify and evaluate the specialty species considered to have most promise. A research and development gap analysis for these species has also been undertaken.

To maintain some momentum, a series of small-scale and short-duration research and development projects focusing on specialty species is being undertaken in the meantime. These are part-funded by the Forestry and Wood Processing Industry Transformation Plan.

Reporting the SWP programme

Some 174 SWP Technical Reports have been produced and are freely available on Forest Growers Research website (fgr.nz). Around 60 peer-reviewed journal papers, and 30 popular articles, have been produced. Scientists contributed to conferences, workshops, field events, and the SWP had a display at the November 2022 Fieldays at Mystery Creek.

"No one person or organisation can consistently have all the best ideas, information and opportunities to say nothing of the resources to achieve desired outcomes. Consequently the SWP partnership approach has been a great one for Ernslaw One, assisting us to achieve company goals long before we could have by working independently. In addition the synergies achieved when several bright minds are engaged on the same problem have resulted in some unexpected research outcomes for us as well. Lastly the impact of being exposed to examples of new technologies, plantings (both successful and not) of new species gives us tangible evidence to support business cases for new investment."

Mark Dean, Forest Planner, Ernslaw One Ltd

Original research aims and mid-programme review

The Specialty Wood Products Research Partnership (SWP) was a partnership between government and industry whose remit was to work towards developing a high-value specialty wood products industry based on alternatives to radiata pine, namely Douglas-fir, durable and non-eucalypts, and cypresses.

Original research aims

At the outset, the research programme had three distinct aims:

1. improving returns from the current value chain until new germplasm is delivered (current resource)
2. creating a superior, more readily processed and consistent wood supply for the future (future resource)
3. delivering higher-value products to export markets through embedding regional strategies (with strong support in-kind from co-investors).

More details of the original research programme can be found in Appendix 4.

How the Partnership operated

Forestry companies with a vested interest in one or more of the selected species became partners in the SWP. These companies, together with MBIE and the Forest Growers Levy Trust, committed funds and were closely involved in deciding research priorities and evaluating outcomes. A programme manager was appointed in 2015; a Programme Steering Group (PSG) and a Technical Steering Team (TST) – both comprising funding partners and research providers – oversaw programme governance and technical content of research over the seven years of the partnership.

Key research providers were the University of Canterbury, Scion, and the Marlborough Research Centre. Several other organisations, including the NZ Farm Forestry Association, had some research input. Research funds were allocated based on a regular cycle of proposals, evaluation by the TST, approval by the PSG, contract establishment and reporting. SWP funds were often used by research providers to leverage additional funds and in-kind contributions from other sources.

Mid-programme Expert Advisory Panel review, 2017

In 2017, an expert advisory panel (EAP) undertook a mid-programme review of the SWP.

The review identified the main strengths of the programme as including active industry/research collaborations, strong science, and having a large team with diverse expertise. The panel recommended that the SWP should focus on a smaller number of key projects and encompass the whole forest system – i.e. the full chain from the forest resource, through processing, to products and markets. Also that effort should go into achieving much greater long-term, project-wide integration and collaboration on species/site matching.

The key projects identified were as follows:

- Douglas-fir for current markets, optimised engineered lumber (OEL™), and other engineered products, for example laminated veneer lumber (LVL) cross-laminated timber (CLT) etc.
- Non-durable eucalypts for current markets, OEL™, and other engineered products (e.g., LVL, CLT etc.)
- Durable eucalyptus for vineyard posts, LVL and sawn timber (structural and appearance).

The panel also stressed that key projects are those that will increase the confidence of growers and processers to expand the use of specialty species. The importance of being able to communicate facts about the species involved in the SWP to potential growers was highlighted:

- where species and genotypes can be successfully grown
- what the characteristics of the resulting plantations will be
- what products can be successfully marketed internationally
- how the resource will be processed for these products
- what are the markets, wood properties required for those markets, and financial returns?

Expert Advisory Panel species-specific recommendations

The EAP made the following species-specific recommendations which were addressed during the second half of the SWP programme:

Species	Focus area
Douglas-fir	i. refining breeding and deployment zones - species/genotype site matching ii. improving stem form and growth (with and without Swiss Needle Cast pressure) iii. making new selections – speeding the measurement and analysis of genetic test plantations iv. implementing genomic selection v. developing business cases for promising products, starting with OEL™.
Non-durable eucalypts	For tree breeding and new plantings, focus on: i. species/genotype site matching ii. simplifying breeding by focusing on a fewer number of key traits. For existing forests, focus on: i. completing the drying research ii. evaluating the potential for high-stiffness products, such as LVL iii. evaluating the potential and economics of OEL™.
Durable eucalypts	i. species/genotype site matching ii. directly evaluating the durability of young plantation materials (e.g., is within-species improvement of durability even needed?) iii. simplifying breeding programmes, including focusing on a fewer number of key traits.
Cypresses	No specific recommendations.

SUMMARY OF SWP ACTIVITIES AND ACHIEVEMENTS BY SPECIES

DOUGLAS-FIR

Douglas-fir is New Zealand's second most popular plantation species by area after radiata pine. The national resource is currently 100,105 ha, about 6% of the total plantation area (NEFD 2022). It has an international reputation as an excellent producer of structural timber, and is the species of choice for higher elevations, especially those with winter snowfall.

The SWP Douglas-fir programme predominantly involved tree breeding and timber products research. It received 21% of the total SWP research budget. A separate research programme – the MBIE Endeavour-funded project 'Winning with Wildings' – has worked on overcoming the problem of wildings.

Key achievements: Douglas-fir

Theme	Activity
Products and technologies	Oriented Engineered Lumber (OEL™) tested Cross Laminated Timber (CLT) tested CLT fasteners and connection systems developed and tested, and seismic resilience confirmed Ease of repairs following seismic shocks confirmed.
Durability	Thermal modification shown to increase both sapwood and heartwood durability; longer-term durability testing is on-going.
Breeding	New breeding targets established; recent family selections focusing on stem form and productivity made from existing trials based on these targets.
Other	A regional strategy focusing on Otago, Southland and the central North Island modelled wood flows and provided options for future marketing and investment in sawmilling. A new spatial productivity surface (i.e. a GIS-based growth model) was produced and the industry's Forecaster Douglas-fir calculator was updated.

Breeding advances

A Douglas-fir industry workshop held at the start of the SWP defined breeding objectives for producing high quality wood products and for increased wood production. Industry direction resulted in updated breeding targets for growth and form, wood quality and resistance to Swiss Needle Cast (SNC):

- **growth** – targets are a 35-year rotation length; yield of 600 m^3 total recoverable volume (TRV) per hectare; average 20 m^3 per hectare mean annual increment (MAI)
- **form** should be maintained at the current level
- **wood stiffness** to be maintained at a minimum level of 8 GPa
- **needle retention** (indicating tolerance to SNC) – target set at needle retention of three years.

In 2017, the Douglas-fir breeding plan was updated based on the targets identified above. New selections were made from breeding populations which included selections for tree form, a trait that had not been assessed earlier as the trials were too young. Stiffness breeding values were determined for Douglas-fir progeny and stiffness was found to be moderately heritable, indicating there is good potential for incorporating this trait into the breeding programme. All Douglas-fir seedstock is now sourced from within New Zealand because of disease risk associated with importing seed. Further new selections were made from existing trials in 2018 targeting growth, wood quality and resistance to Swiss Needle Cast, and were established on three sites.

Progeny tests established in 2011 at two sites (one in the North Island, one in the South Island) were assessed for survival, growth and stem form. Genetic gain trials established in 2012 and 2013 across New Zealand were also assessed for productivity and stem form. In these early assessments, differences between the performance of various families in the North Island trials and between families in northern and southern South Island trials were identified.

New product development and testing

Optimised engineered lumber

Douglas-fir thinnings and low-quality logs were used to produce a new engineered wood product, optimised engineered lumber (OEL™). The optimised engineered lumber technology produces laminated, finger-jointed structural products with known, uniform and reliable properties. OEL™ provides the opportunity to add value to small diameter, tapered or swept logs which otherwise would go for pulp. Mechanical testing showed that Douglas-fir OEL™ achieved the strength and stiffness properties of the New Zealand structural grade SG8 – this was considered a very positive outcome given the low quality of the raw material. (Structural grade SG8 is the radiata pine framing timber standard.) OEL™ technology has now been commercialised for radiata pine in New Zealand, but has yet to be commercialised for Douglas-fir. For now, the company that owns the rights to the OEL™ technology is focusing on using radiata pine.

Figure 1: Douglas-fir OEL™ – a product with potential.

Cross-laminated timber

The demand for engineered wood products for high-rise construction is a global growth area, and Douglas-fir cross-laminated timber (CLT) is suitable for this application. A comprehensive database of the mechanical properties and connection behaviour of Douglas-fir CLT is needed to meet Building Code requirements. Work to contribute to this was undertaken as part of the SWP.

Douglas-fir CLT panels were constructed in Nelson and transported to Christchurch for testing at the University of Canterbury's Department of Engineering. Initial tests confirmed comparable strength properties to radiata pine CLT. A second batch of New Zealand-grown Douglas-fir CLT was made in Albury, Australia, by the company Xlam, and tested in New Zealand.

The focus then moved to developing efficient lateral-load resisting systems for CLT buildings to test the product's ability to withstand earthquakes. Work on fasteners and connection systems for the panels was also undertaken. Results showed that CLT core walls provide efficient lateral load-resisting systems for mid-rise and high-rise timber buildings, and that the long, self-tapping screws used for connecting panels are strong, rigid and fit for purpose. Experiments demonstrated generally excellent connection behaviour in Douglas-fir CLT: research outcomes will provide valuable technical information for engineers who wish to specify Douglas-fir CLT in building design. The hold-down connections that were tested can also be repaired after an earthquake to deliver the same strength as the original connections. This will make building remediation after an earthquake much faster and cheaper. The CLT fastening system is being used in a building being designed for construction in Nelson.

Figure 6: New medium-rise buildings being constructed using radiata pine CLT, Otago Polytechnic.

Figure 2: CLT and the screws used to connect the CLT panels.

Figure 3: Testing Dougals-fir CLT connections.

Figure 4: The Douglas-fir CLT structure being tested for seismic resilience in the University of Canterbury engineering lab.

Figure 5: Strength testing Dougals-fir CLT.

Thermal modification to increase Douglas-fir durability

Thermal modification involves heating wood to temperatures above 180°C (and to as high as 230°C) in the absence of oxygen to alter the chemistry of the wood and consequently alter wood properties. The aim is to increase durability and dimensional stability.

In trials carried out by Scion, thermal modification resulted in increased durability in both Douglas-fir sapwood and heartwood (Figure 9). Fungal cellular tests (treating wood with fungal agents that cause rot) showed that the thermally modified Douglas-fir performed significantly better than unmodified Douglas-fir, indicating improved durability. Samples of the thermally modified timber are now being tested in long-term durability trials at Scion.

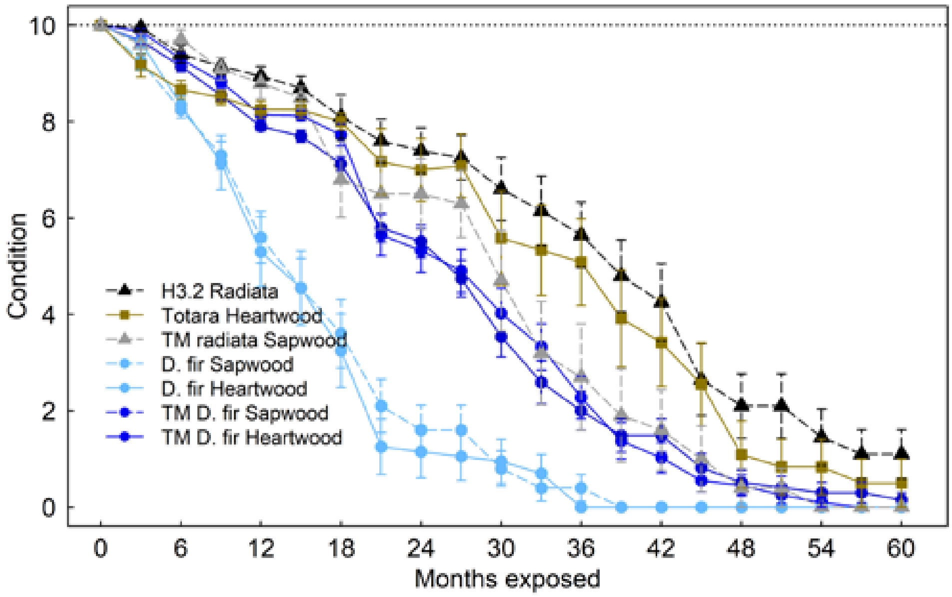


Figure 7: Results from durability trials, showing the gains made from thermal modification (Dark blue lines – thermally modified Douglas-fir vs. light blue lines – untreated Douglas-fir).

Associated research 2015-2023

- A new spatial productivity surface for Douglas-fir was produced in 2017. This is a GIS-based high-resolution model of Douglas-fir productivity, which can be imported into other mapping tools. The model marks a big step forward in understanding the interactions between Douglas-fir productivity and site conditions. It has been incorporated into the industry's Forecaster calculator.
- Work on Douglas-fir genomics began at Scion in 2018, utilising the aligned Strategic Science Investment Fund (SSIF). Over one thousand superior trees were selected from each of two large Douglas-fir plantations, one each in the North and South Islands. These trees had their genotype described as a precursor to an accelerated breeding programme. The study confirmed that knowing the exact origin of Douglas-fir populations, which can be described by genetic markers, is all-important when building an implementation strategy for genomics.

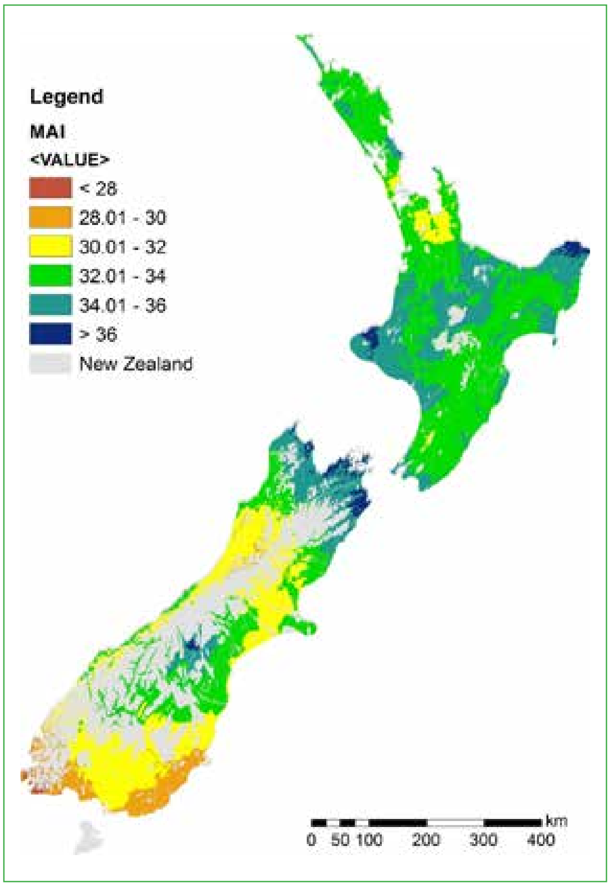


Figure 8: Modelling Douglas-fir productivity across New Zealand at 5 km resolution.

- New Douglas-fir planting is constrained by controls around wilding risk, especially in the South Island. Developing sterile Douglas-fir was considered high priority by industry partners at the start of the programme. As part of an aligned research portfolio, Winning with Wildings, scientists successfully produced sterile/low fertility genotypes. A law change is required before this material can be field-tested so the research is now on hold.
- Port Blakeley – a forest owner and SWP partner with a significant Douglas-fir resource in Otago and Southland, has recently diversified into the production of high-value essential oils from purpose-grown Douglas-fir foliage.

"The assessment of and calculation of breeding values for new Douglas-fir progeny has given seed orchard managers confidence to make selections and splice about 30 new parents into the existing seed orchard which have already produced sub-commercial quantities of seed. As this seed comes on-stream and is deployed into the forest it is expected that improvements in crop value of at least 5% are possible."

Mark Dean, Forest Planner, Ernslaw One Ltd

NON-DURABLE EUCALYPTS

Over 22,000 ha of eucalypts are recorded in the NEFD 2022. Three non-durable species make up the bulk of the total eucalypt area, *Eucalyptus nitens*, *E. fastigata* and *E. regnans*. These species were all part of the SWP programme. Non-durable eucalypts accounted for 24% of SWP expenditure, with *E. nitens* receiving 16% and other species 8% of the total.

The majority of New Zealand's *E. nitens* area comprises short-rotation biomass crops in Southland. The product is destined for export as chip into pulp markets. There is a particular interest in extending the solid wood product range for *E. nitens* through breeding gains. Thanks to contributions from a major *E. nitens* grower and SWP partner from 2015-2020, more work has been done on *E. nitens* than either *E. fastigata* or *E. regnans*. SWP research aims to also extend the product range of *E. fastigata* and *E. regnans*.

Key achievements: non-durable eucalypts

Theme	Activity/Achievement
Products and technologies	*E. nitens* optimised engineered lumber (OEL™) tested Novel *E. nitens* flooring products tested with good results Densification shows promise for increasing *E. nitens* flooring hardness *E. fastigata* tested for peeling veneer tested for stiffness with positive results; glues for laminate production successfully tested.
Breeding	Two new *E. nitens* seed orchards established New *E. fastigata* selections made incorporating wood stiffness NIR successfully used to predict wood shrinkage and cellulose content of *E. nitens.*
Other	Biological control agent for *Paropsis* released End splitting of *E. fastigata* logs assessed.

Improving drying quality of *Eucalyptus nitens*

A review of *Eucalyptus* processing issues highlighted the problems associated with cell collapse and checking in *E. nitens*. Several projects worked to better understand and overcome these challenges, including trials to review the potential of NIR technology for screening breeding populations to predict sawn timber quality and wood shrinkage. The NIR-based models developed from testing young timber samples add another option for screening and selecting the next generation of *E.nitens* beyond traditional methods based on phenotypic sampling for growth and form traits.

Breeding advances

The focus of the SWP *E. nitens* breeding work has been to improve sawn timber properties including wood density, growth strain, stiffness, shrinkage/collapse and internal checking. Two new fourth-generation seed orchards were established that will produce improved germplasm specifically for solid wood products while simultaneously maintaining high-quality production for pulp. Genomic selection focusing on solid wood properties to further boost genetic improvement of *E. nitens* breeding populations has begun. Using near-infra-red (NIR) techniques to screen young timber samples for wood quality properties can accelerate and enhance breeding selections.

Progeny trials for *E. fastigata*, already in their third cycle, were assessed for growth, form and adaptability to different site types. Results indicated potential for genetic improvement of productivity and tree form. Wood stiffness was measured for the first time in this breeding population, with an average modulus of elasticity (MOE) of ~12 GPa and a moderate estimate of heritability. Future breeding efforts can therefore include selection for stiffness, which could be an important benefit given the species' potential as a component of engineered wood products. A log-splitting trial suggested some selection for high growth and with low splitting index values should be possible.

New product development and testing

Eucalyptus nitens logs were used to produce OEL™ (optimised engineered lumber), using the same technique as with Douglas-fir. The results of the mechanical testing showed that the *E. nitens* OEL™ achieved the strength and stiffness properties of the New Zealand structural grade SG12.

Figure 9: A sample of *E. nitens* OEL™.

In 2020 Specialty Timber Solutions, a North Canterbury firm, produced three kinds of flooring from unpruned *E. nitens* – solid, cross-laminated, and birch plywood-backed. The performance of these products was compared to commercial engineered oak flooring. Overall, the differences between the engineered oak and the *E. nitens* boards were small, indicating that the *E. nitens* product should perform satisfactorily and can be marketed with confidence by Specialty Timber Solutions.

Figure 10: Samples of different *E. nitens* flooring products produced by Specialty Timber Solutions, North Canterbury.

Figure 11: John Fairweather of Specialty Timber Solutions with one of his *E. nitens* flooring products.

A peeling and sawing study of 24-year-old *E. fastigata* logs at Juken NZ Ltd divided logs into three stiffness classes. The veneer produced from these logs showed very promising Metriguard stiffness values compared to radiata pine LVL. This high stiffness will enable the manufacture of higher-value LVL products which cannot be made with radiata veneer.

Research into the potential to use *E. fastigata* as a component of laminated veneer lumber (LVL) was completed, and a veneer stiffness model developed. This model is intended to be used as a decision tool identifying the potential suitability of a wood resource to supply a range of LVL grades. The output of the model indicates possible LVL layup grades and options. This work was supported by Juken NZ Ltd, a SWP partner and producer of LVL from radiata pine.

In addition, a trial at Hexion examined the 'glue-ability' of the *E. fastigata* veneer and concluded that this species could be commercially bonded with standard phenolic formulations.

In summary, the research undertaken by the SWP has resulted in good progress towards manufacturers being ready to incorporate eucalypt veneer as a component of LVL.

Figure 12: *E. fastigata* veneer sheets being tested at Juken NZ Ltd.

Tasmanian firm Cusp Building Solutions, after launching the world's first certified plantation *E. nitens* CLT in 2021, have announced that they are planning to relocate to a larger site (Deep Creek in Tasmania). This will enable them to double their current production. The company is projecting that, by late 2024, manufacturing throughput will be four times the current monthly level. They are using *E. nitens* and this points to a real opportunity to produce higher value products from the *E. nitens* resource in New Zealand.

Thermal modification to increase durability and stability

Samples of *E. nitens* were thermally modified to examine impacts on timber characteristics. Results showed that durability and stability increased slightly, but not enough to enable *E. nitens* to be used in outdoor applications. The colour of the wood darkened, but this darker colour faded on exposure to sunlight. Stiffness was unchanged and strength was significantly reduced. Overall these outcomes therefore mean thermal modification can be ruled out as a way of increasing the versatility of *E. nitens* timber.

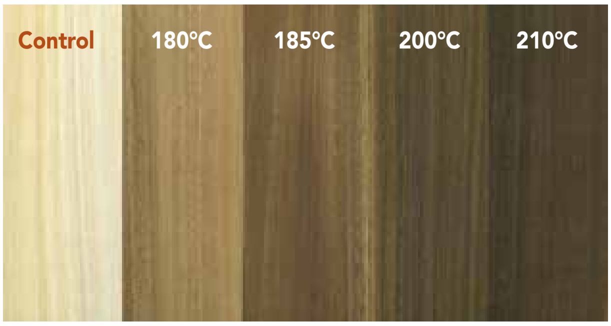


Figure 13: Thermally modified *E. nitens*, showing different outcomes from treatment at different temperatures.

Durability

The durability of the three non-durable eucalypt species continues to be tested under a number of conditions. Some durability tests are long-term by their nature, and the results will not be known for several more years. Tests which are still running include an accelerated test of framing timbers treated with boron as a preservative.

Timber densification

Wood densification is a process of heating wood and compressing it to flatten the wood cells and increase the density and hardness of the material. The objective of this work was to increase the surface density and surface hardness of *E. nitens* and *E. fastigata*. One important finding was that the densification process generally resulted in a peak density at or within 1 mm of the board surface, where most pressure is applied *in situ*. Overall *E. nitens* was more amenable to densification than *E. fastigata*. As it can be compressed to a greater degree without damage, larger increases in surface density and surface hardness were achieved. The bulk densified *E. nitens* swelled very little after contact with water or humid air, another positive result.

Eucalypt health

A 2018 study of the economic cost of *Paropsis* estimated potential losses of $400-$500 million to the existing *E. nitens* crop and concluded that in most situations biological control would be more cost-effective than chemical control. Pre-Environment Protection Authority (EPA)-application work to introduce a new biological control agent to control Eucalyptus tortoise beetle, *Paropsis charybdis* was completed. The Australian native parasitoid *Eadya daenerys* targets the feeding larval life stage of *P. charybdis*. Scion conducted laboratory-based tests with female parasitoids each summer for four years to confirm that risks associated with the release were minimal. The EPA application was approved in 2019, and an initial release of the parasitoid took place at three sites in Southland and the central North Island at the end of 2022.

Other eucalypt health research is described in the Durable Eucalypts section of this report.

Associated non-durable eucalypts research 2015-2023

The landowner of two breeding trials at Kaingaroa Forest (comprising *E. regnans* and *E. fastigata*) has production-thinned these trials. This provided an opportunity to convert the trials to a seed stand, by planning the thinning so the best trees per family were retained in case there is a need to make new selections in future. It also allowed an investigation into the economics of production thinning (File Note 145).

"The work we did on peeling and testing veneers for LVL showed us that the potential is there to produce a high-stiffness veneer with E. fastigata. *It was a stepping stone along the way - there's still a lot of challenges around yield recovery to be overcome from a forest management point of view. The progeny testing done by Scion as part of the SWP will help here. So we've started the journey but there's still a long way to go."*

Sean McBride, National Forest Manager, Juken NZ Ltd

CYPRESSES

The total area of cypresses growing in New Zealand is estimated at 9,057 ha (NEFD 2022). The three main species of interest to the SWP programme were:

- *Cupressus macrocarpa*, a favourite New Zealand timber species but now seriously compromised by cypress canker, especially in the North Island
- *Cupressus lusitanica* (Mexican cypress) – a fast-growing species which is less canker-prone than macrocarpa
- hybrids of *Chamaecyparis nootkatensis* (Yellow cedar) with both *C. macrocarpa* and *C. lusitanica*, which are showing good potential in terms of growth, form and canker tolerance. Ovens cypress, an early *Chamaecyparis nootkatensis* x *C. lusitanica* hybrid, is already widely planted and proving very canker-tolerant.

Key achievements 2015-2023

Theme	Activity/Achievement
Products and technologies	Tests on bending strength and stiffness of young Ovens cypress completed.
Durability	Thermal modification shown to increase cypress sapwood and heartwood durability, enabling exterior use of sapwood; longer-term durability tests are on-going.
Breeding	New canker-tolerant *C. lusitanica* selections made. Canker-tolerant *C. macrocarpa* genotypes identified and three new trials established New hybrids produced and deployed in trials Research results from older trials show there is good potential to select for heartwood, a highly desirable trait.
Strategy	A Cypress Strategy – Whakamahere Cypress 2022-2042 – produced in 2021-22 which identifies research and market development priorities and provides a roadmap for future activities.

Breeding work

The breeding programme funded by the SWP was a continuation of work done over several decades by Scion (previously known as the NZ Forest Research Institute).

Cupressus lusitanica progeny trials were evaluated for growth and health (canker) indicating good selection possibilities. New selections were then included in seed orchards, and new seed should be delivered to industry in 5-7 years.

A third generation of *C. lusitanica* trials were established by Scion in 2017, aiming to improve knowledge of genotype x environment interaction in this species. Genotype selection for these trials focused on selections showing maximum canker tolerance.

Two further sets of cypress trials featuring new genetic material were established in 2019:

1. three large-scale trials to test new *C. macrocarpa* genotypes identified by Scion's tree breeders as canker tolerant
2. a series of small-scale trials to test 12 *Ch. nootkatensis* hybrids. These trials are being managed by the NZ Farm Forestry Association's Cypress Development Group (CDG). First trials were planted in 2019 across a wide range of farm forestry properties, and more have followed.

Figure 14: Cypress Development Group member Vaughan Kearns with a 3.5 year old cypress hybrid.

Thermal modification to increase durability and stability

Cupressus lusitanica has been included as part of the thermal modification programme at Scion. The main question is whether thermal modification increases cypress durability, especially of non-durable sapwood. Early results have been encouraging, with both the non-durable sapwood and relatively durable heartwood showing increased durability.

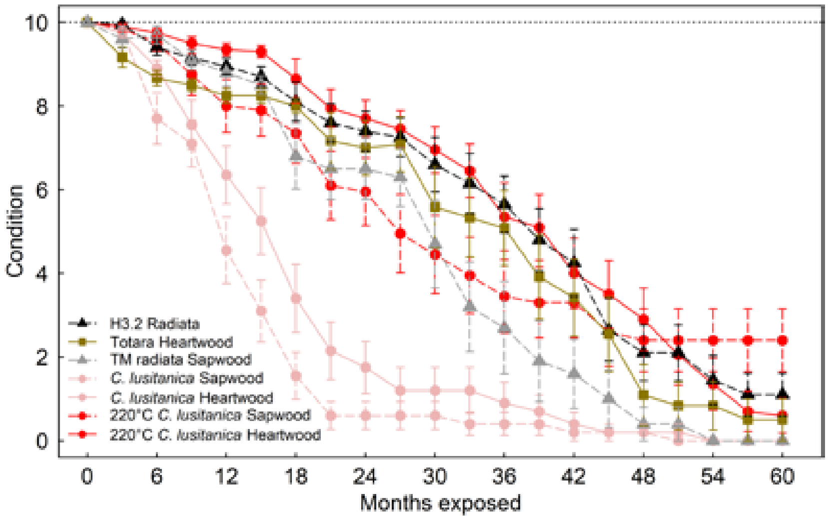


Figure 15: Results from durability trials showing the durability gains made from thermally modifying *C. lusitanica*. (Dark red lines - thermally modified *C. lusitanica* vs. light red lines - *untreated C. lusitanica*)

Longer-term durability testing is required to confirm the ultimate durability of these treatments.

New product development and testing

Researchers investigated whether young unpruned and unthinned cypress can be cost-effectively sawn into products suitable for high-value joinery. *Cupressus lusitanica* and Ovens cypress were included. Wood from 20-year-old trees was sawn, air-dried, and then grade recoveries assessed. The Ovens cypress was then also tested for strength and stiffness. In terms of bending stiffness, the Ovens cypress achieved the SG6 structural grade, and in terms of bending strength, it achieved the SG10 structural grade resulting in an overall grade of SG6.

Figure 16: Boards sawn from young unpruned cypress, ready to be resawn, air-dried and then graded.

The hope is that sapwood from young trees – for example from production thinning operations – can be thermally modified and then utilised in a range of internal and external applications.

➔ Figure 17: Edging young cypress boards, Ruapehu Sawmill.

Cypress Strategy

Following industry consultation, the *Cypress Strategy – Whakamahere Cypress 2022-2042* was produced. This work was led by the NZFFA Cypress Development Group. The Strategy identifies priority themes for research and development: work that will be led by the CDG (see Investment Case 2).

"I support all the work on cypresses undertaken by the SWP – it is all important because cypress is such a versatile species. We need the different themes - if people are going to plant more cypresses, they need confidence, both that they are going to grow a disease-free crop, and that there will be markets for their wood.

Breeding for canker-tolerance is a must-do, and the work on strength and stiffness is essential. I'm also pleased to see the thermal modification work. The lack of data describing how cypresses perform in situ is a real barrier - we need the evidence-base to get these species across the line and accepted into the NZ Standards.

The strategy work is crucial – having a coordinated strategy means we can work through different development stages in a considered way. We need to keep moving forward on several different fronts to create long-term confidence in cypresses. Having government support based on a realistic understanding of the risks involved in developing and maintaining a viable specialty species industry is going to be critical too."

Richard Thompson, MacBlack Timber

DURABLE EUCALYPTS

Durable eucalypts are an emerging species group in New Zealand, considered to have excellent potential due to their ability to thrive in dryland environments and produce naturally durable timber requiring no chemical preservative treatment. Over the seven years of the SWP, almost three million durable eucalypt seedlings were planted, up from only a few hundreds of seedlings per year beforehand.

SWP work on durable eucalypts was managed by the New Zealand Dryland Forests Initiative (NZDFI). Main contributing partners were Proseed NZ, the University of Canterbury's School of Forestry and the Marlborough Research Centre Trust. Juken NZ Ltd, Timberlands Ltd and Lake Taupo Forest Trust were major industry contributors and established NZDFI durable eucalypt trials. The durable eucalypt programme received 43% of SWP species funding. In 2023, the NZDFI changed its name to New Zealand Dryland Forests Innovation.

Collaboration between Marlborough Research Centre and the University of Canterbury's School of Forestry

NZDFI's SWP-funded research and development programme was delivered by the NZDFI Science Team – a collaboration between the Marlborough Research Centre (MRC) and the University of Canterbury's School of Forestry (SoF). The School of Forestry's Associate Professor Clemens Altaner continues to lead this team, which includes several other SoF academic staff members working closely with MRC consultants. The team's role includes recruiting and supervising post-graduate students. A total of 13 PhDs (Appendix 3) and 4 MScs related to durable eucalypt research have been completed or are in the final stages of completion, many of which have been partly or fully funded by the SWP. Numerous undergraduate students have undertaken NZDFI field work and/or have selected a related topic for their Honours thesis.

Details of NZDFI research activities since 2010, including SWP-funded research between 2017 and 2023, are available in six-monthly Project Update newsletters: https://nzdfi.org.nz/news-and-events/resources/project-updates/

Key achievements: durable eucalypts

Theme	Activity/Achievement
Products and technologies	Durable eucalypt vineyard posts proven to be working well after 10 years *in situ* *E. bosistoana, E. globoidea* and *E. quadrangulata* successfully tested for peeling and drying to produce veneer for LVL Small-scale post-peeling technology tested Potential markets for agricultural/horticultural posts and poles assessed *E. globoidea* machinability tests show the species machines as well as, if not better than, radiata pine.
Durability	New NIR technique for testing heartwood extractives/durability developed.
Breeding	First generation breeding assessments completed in six progeny trials of *E. bosistoana* and in three progeny trials of *E. globoidea* to determine growth, form and heartwood properties (including drying collapse) Elite families of both species identified and plus-trees selected for seed orchard deployment and commercial seed collection Taxonomic and genomics research on *E. bosistoana* and closely related species.
Site/species matching	*E. bosistoana* and *E. globoidea* site and productivity requirements evaluated Eight new demonstration trials planted in 2018 to add to NZDFI's trial network with 130 new PSPs subsequently established within these trials Clonal material established in trials An analysis of NZDFI's demonstration trials: 'Variation in adaptability and productivity between durable eucalypt species in different New Zealand environments' produced in 2023.
Other	Regional strategy 2020-2030 produced *Eucalyptus globoidea* growth, taper and heartwood model developed Advances in assessments of *Paropsine* impact on durable eucalypts Assessment of NZ-grown *E. bosistoana* essential oils Good progress in early attempts at in-vitro tissue culture.

Breeding advances

In 2018 SWP funded the establishment of eight new demonstration trials extending the geographical area of NZDFI's trial network.

In addition, test plantings of clonal stock were established at two Marlborough locations in 2018, following pioneering work on clonal propagation by Proseed NZ.

NZDFI's trial network has provided the foundation for the Science Team to conduct assessments of key genetic traits to identify elite families and select plus-trees for seed orchard deployment and commercial seed collection.

Using scion wood collected from plus-trees, Proseed NZ have successfully grafted and deployed these selections in seed orchards at their Amberley, North Canterbury, site. These seed orchards started producing the first generation of XyloGene-branded genetically improved seed deployed to produce *E. bosistoana*, and *E. globoidea* planting stock in 2021 under a separately funded but aligned Te Uru Rākau One Billion Trees (1BT) project (Project No. 0495).

➔ Figure 18: (a) First generation seed orchard tree of improved *E. bosistoana* at Proseed NZ, Amberley. (b) First generation *E. globoidea* seed being separated from seed capsules at Proseed NZ.

Site/species matching

The eight SWP-funded trials established in 2018 were planted in collaboration with a mix of forest growers and farm foresters. Sites were selected to extend testing durable eucalypts into new regions that included Northland and Taranaki with new trials also in Bay of Plenty, Waikato, Horizons, Hawkes Bay and Marlborough. Their purpose is to quantify how successfully eucalypts can grow following best practice establishment and demonstrate the direct benefits of matching eucalypt species to sites. Species planted were *E. bosistoana*, *E. cladocalyx*, *E. globoidea*, *E. macrorhnycha*, *E quadrangulata* and *E. tricarpa*.

Collaboration with these landowners continued in 2020 and 2021 and included their assistance to undertake the first measurement of all the 2018 trials and establish 130 permanent sample plots (PSPs). These PSPs increased NZDFI's total PSP database to over 600. Some older PSPs were also re-measured in 2020-22.

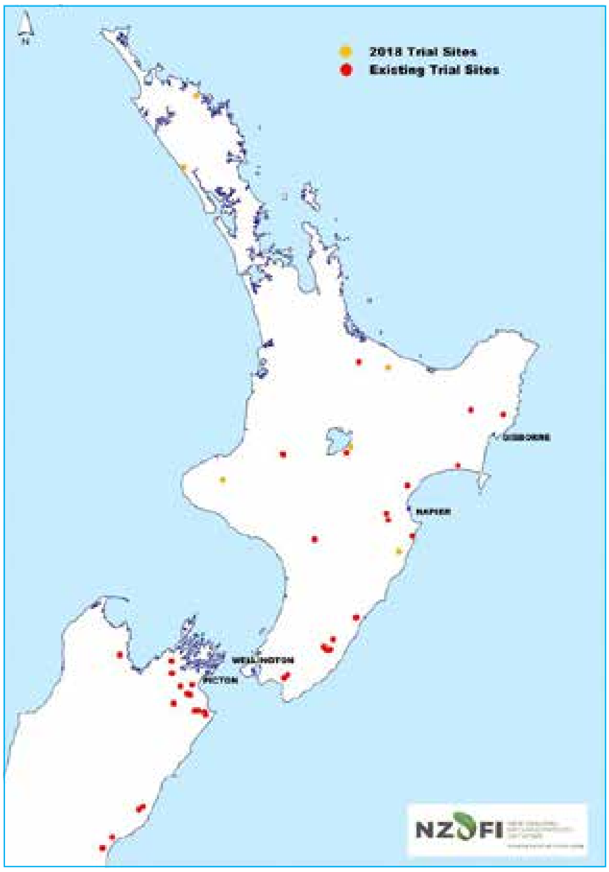


Figure 19: NZDFI trial sites following the addition of the eight 2018 trials.

Repeat measurement of PSPs over the long term captures unique data which can be used to assess comparative performance and phenotypic variability in survival, growth and form between species and individual genotypes across the different environments of NZDFI's trial sites. PSP data also allow the development, testing and validation of growth models that will assist growers to select sites and predict productivity. A report 'Variation in adaptability and productivity between durable eucalypt species in different New Zealand environments', which summarises analyses from the demonstration trial network, was produced in 2023 (SWP Technical Report 174). Results clearly demonstrate the significant opportunity to select adaptable species that can be very productive in some New Zealand regions. There are also species that have been less productive or have failed at some sites, and variability in performance seen for all species across sites. Forest growers can use this information to optimally match species to sites and maximise the productivity and value of the tree crop.

Figure 20: Fifteen new PSPs were measured in this two-year-old NZDFI demonstration trial planted in Northland in 2018.

Wood properties

Durability

In 2007-08, a number of Marlborough vineyards installed *E. bosistoana* and *E. globoidea* posts. In 2018 an assessment of the posts was undertaken at six of these vineyards. The feedback from vineyard owners/managers and the results of the decay assessments demonstrated that most of the durable eucalypt vineyard posts of both species are continuing in service after more than 10 years with a very low percentage of broken posts.

Durability tests of heartwood from young trees showed large variability. This highlighted the importance to select well-performing genotypes if class 1 durable timber is to be an objective for growers of short-rotation plantations.

Heartwood quantity and quality

Researchers from Callaghan Innovation worked with the School of Forestry to develop a coring tool which enables the rapid extraction of cores from the stems of young trees. The amount of heartwood in the cores can then be assessed. Thousands of cores were taken from throughout the progeny trials. These were assessed by SoF PhD students and a strong genetic component to heartwood quantity was identified, with some families having no heartwood and others having over 70 mm in six-year-old trees. These findings have been applied in making early selections of elite families for the second-generation breeding programme and seed orchard deployment for commercial production of improved seed.

Figure 21: PhD student Ebenezer Iyiola extracting cores from E. globoidea at a NZDFI trial site.

Figure 22: Examples of cores from which heartwood thickness can be measured.

Near-infrared imaging has been successfully used to assess heartwood quality in *E. bosistoana* and *E. globoidea* cores taken from NZDFI trial trees. The technique enables the cost-effective assessment of heartwood extractives content, a necessity for phenotyping breeding populations. It has also been shown that heartwood extractive content is correlated to mass loss and can act as a proxy measurement of durability. Lastly, in a proof-of-concept study it was shown that extractive content can be assessed contactless with an NIR camera, and that the resulting hyper-images show how this varies across the stem. The technology could be developed to test for durability, for example during the timber grading process.

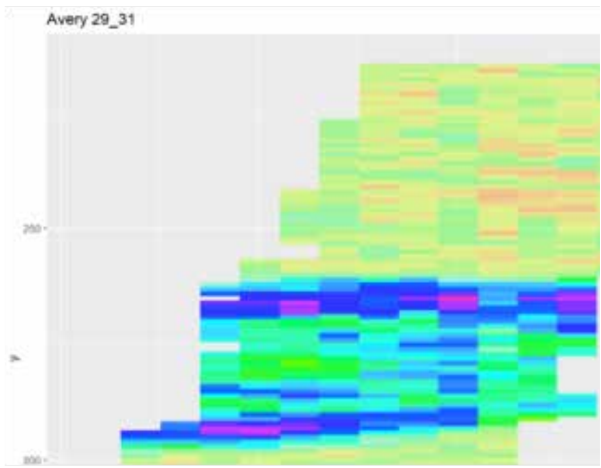


Figure 23: Spatial variation in predicted extractive content in heartwood (saturated colours) and sapwood (less saturated colours) in an *E. bosistoana* stem core.

Measuring heartwood content in standing trees using electrical resistance

Researchers at the University of Canterbury's Department of Electrical Engineering lab-tested a prototype tool which measures electrical resistance within the tree stem. The tool has the potential to rapidly assess of the amount of heartwood in standing trees based of differences in electric conductivity between heartwood and sapwood. Further work is needed before this tool is ready for in-forest use.

Modelling stem properties

Models of *E. globoidea* stem taper and heartwood volume have been developed, so that it is now possible to predict heartwood development of *E. globoidea*. Results from taper and volume modelling were combined and used to create an interactive tool that can graph tree shapes and calculate the volume of the three components of the main stem i.e. heartwood, wood inside bark and wood including bark. A similar model for *E. bosistoana* is under development.

Figure 24: Heartwood is clearly visible in the disc being cut from the tree stem.

Figure 25: PhD student Daniel Boczniewicz assesses heartwood in 29-year-old *E. globoidea*.

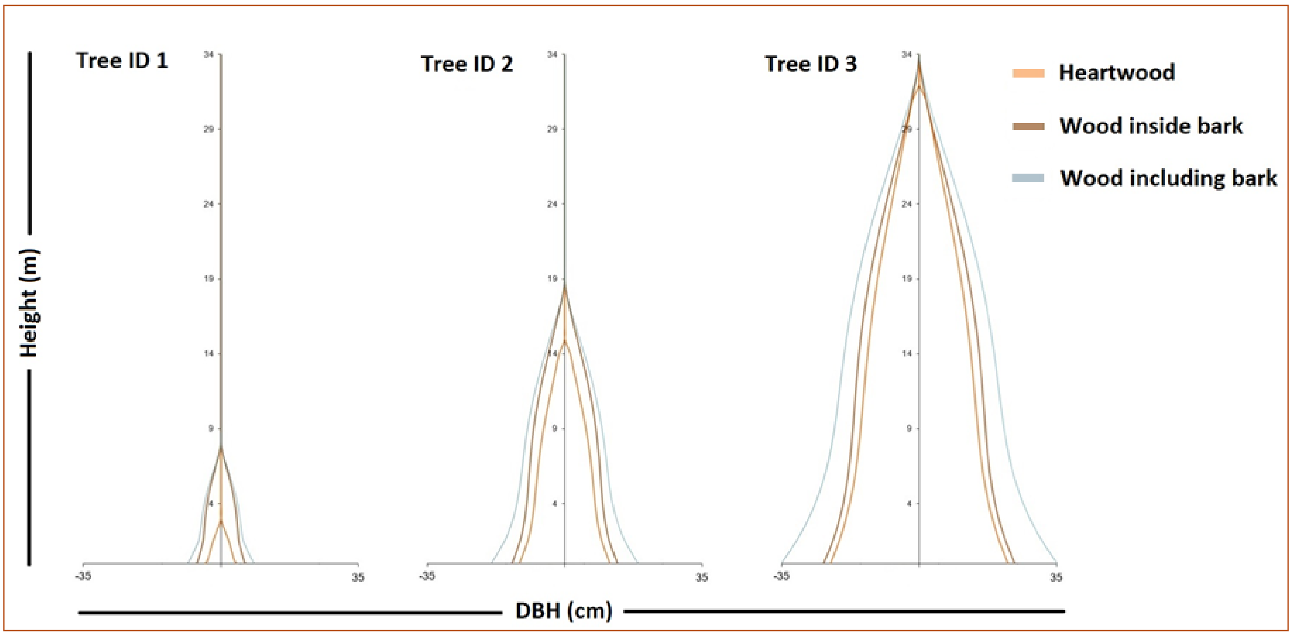


Figure 26: Results from simulations show that as the size of *E. globoidea* trees increase, the proportion of heartwood also increases.

Cell collapse during drying

Cell collapse is a major cause of drying degrade in plantation-grown eucalypt timber. PhD research at the School of Forestry investigated the genetic control of collapse in *E. globoidea* and concluded that it is a heritable trait. Therefore genetic selection for collapse (and other wood properties including extractive content and heartwood volume) is possible. In contrast to *E. globoidea*, no incidence of collapse was observed in thousands of *E. bosistoana* samples.

New product development and testing

Testing, peeling and drying of veneer for LVL

A key potential market identified for durable eucalypts is in engineered products such as laminated veneer lumber (LVL). This is because of the high stiffness of eucalypts, even at a young age. Work on assessing the suitability of *E. bosistoana*, *E. globoidea*, and *E. quadrangulata* as an LVL component was completed with the assistance of Nelson Pine Industries Ltd who successfully peeled and dried veneer using logs cut from 12-to-15-year-old trees. LVL was produced from these veneers and tested for bonding performance. Results indicated that the adhesive used with radiata pine needs to be modified to bond eucalypt veneers to meet the requirements set by the NZ standard. Further work, not funded by SWP, indicated that satisfactory bonding performance can be achieved.

Figure 27: Durable eucalypt logs being delivered to Nelson Pine Industries for peeling to make veneer.

Figure 28: Representative veneers of *E. bosistoana* (left) and *E. quadrangulata* (right).

Posts and poles: substitution of CCA treated timber

Replacing CCA-treated radiata with naturally durable eucalypt posts is considered an excellent regional opportunity to develop a durable eucalypt industry in Marlborough and Hawke's Bay, where many thousands of posts and poles are needed annually in vineyards and orchards.

Trials were conducted to assess the suitability of a conventional post peeler used for pine and a new imported portable tractor-mounted post-peeler to process eucalypt posts. This work included a review of New Zealand agricultural and horticultural treated wood markets and estimated that the domestic post and pole market alone is worth $210-$240 million/year. Countries such as Australia and China use relatively low-cost spindleless lathes to produce veneer and poles from small-diameter logs, another option considered to have good potential in New Zealand – for example as a way of utilising production thinnings. At present New Zealand only has a limited resource of durable eucalypts to supply these markets, but tractor-mounted post peelers and spindleless lathes both offer low-cost entry options into processing which could be expanded over time as the forest resource increases.

Figure 29: Associate Professor Clemens Altaner assesses durable eucalypt posts peeled by a tractor-mounted machine.

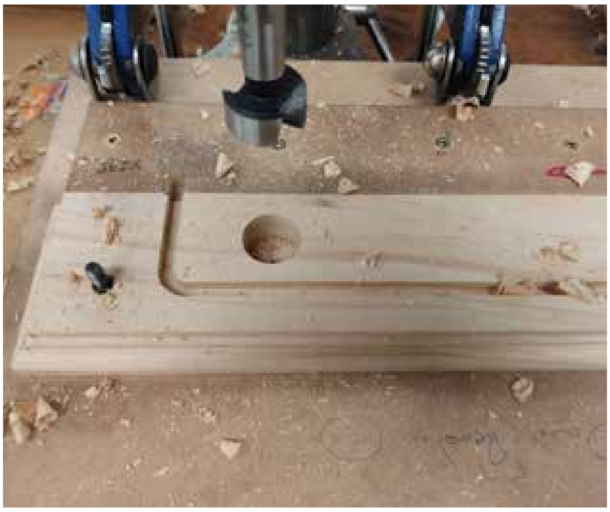


Figure 30: Testing the machinability of *E. globoidea.*

Machinability of *Eucalyptus globoidea*

A comparative machinability study has shown that 28-year-old *E. globoidea* machines equally well or even better than radiata pine, which is known for its good solid-wood processing characteristics. Using an industry standard, six tests were completed: planing, sanding, shaping (edging and grooving), boring, mortising and turning. The radiata pine had an air-dry density of 460 kg/m^3, compared to the *E. globoidea's* 723 kg/m^3, meaning the *E.globoidea* was much denser and heavier than the radiata pine.

Conclusions from the study include that solid-wood processors set up to work with radiata pine can work with *E. globoidea* without the need to invest in new machinery.

Essential oils in *Eucalyptus bosistoana* foliage

Essential oils from eucalypts are a commercial reality in many countries but not, as yet, in New Zealand. Research indicated that *E. bosistoana* contains essential oil in similar quality and quantity to *E. globulus*, the main international source of eucalyptus oils. Oil yield and quality was shown to vary seasonally and between families. Overall, production of essential oils from *E. bosistoana* has commercial potential – for example, as a by-product from production thinning operations to produce posts. As the forest resource expands, this could become a realistic proposition.

Durable eucalypt health

Early SWP eucalypt health research established that some durable eucalypt species (e.g. *E. cladocalyx, E. macrorhnycha* and *E. globoidea*), and some families within species, exhibit greater tolerance than others to defoliation by insects. Depending on heritability and the development of a cost-effective assessment, pest tolerance could be incorporated into future breeding programmes.

More recently, UAV-based LiDAR has been used to identify and measure insect defoliation. Until now, defoliation has been measured by manual techniques, and LiDAR could greatly increase the capacity for monitoring insect defoliation. More testing is needed to determine whether LiDAR can differentiate between insect defoliation and other stresses which may cause a tree to defoliate.

Another eucalypt health project is working on the phenology and natural enemies of two major eucalypt defoliators, *Parospsterna cloelia* and *Paropsis chayrbdis*, assessing the timing of different life stages of the two species and the abundance and impact of predators during these life stages.

Figure 31: PhD student Leslie Mann monitoring trees for insect damage.

Figure 32: 'This sucks!'. A Schellenberg's soldier bug *(Oechalia schellenbergii)* nymph feeding on larvae of the paropsine beetle *Paropsisterna cloelia.* (Award-winning photo by School of Forestry PhD candidate Carolin Weser.)

Other work

The NZDFI team produced a strategy document looking out to 2030: 'Durable eucalypts: a multi-regional opportunity for New Zealand's drylands.' (see Investment Case 1), and since then have worked with regional partners to introduce the concept of regional wood supply catchments based around future regional centres for processing.

NZDFI has developed resources for growers and others interested in durable eucalypts. A virtual workshop '*Developing a sustainable hardwood industry in Marlborough*' was produced and presented in November 2021. Participants were from New Zealand and overseas, and feedback was very positive. Workshop proceedings and various associated NZDFI videos are available on the NZDFI website. The NZDFI website contains comprehensive information and resources, all freely available https://nzdfi.org.nz

In March 2023, the SWP hosted a three-day visit by the Durable Eucalypt Forum – a group of durable eucalypt growers and processors from south-eastern Australia. The group visited the School of Forestry in Christchurch, and then travelled north to Blenheim, stopping at several NZDFI trial sites in North Canterbury and Marlborough before finishing at the Marlborough Research Centre, where a workshop was held.

Figure 33: Shaf van Ballekom, Managing Director of Proseed NZ, describes to the group how *Eucalyptus bosistoana* seed production is stimulated in the seed orchard.

Figure 34: Associate Professor Clemens Altaner, University of Canterbury School of Forestry and head of NZDFI's Science Team, discusses assessment of *Eucalyptus globoidea* wood properties at the Avery trial site, Marlborough.

"For several years now, we have been hearing about the extensive durable eucalypt breeding work that is being undertaken by NZDFI across New Zealand. To see the trials and laboratory work first hand, and to hear from those passionate people who are leading the charge on the ground, was both humbling and inspiring.

The work that NZDFI are doing will be the foundation of a successful durable hardwood plantation industry in New Zealand. We can only wish for the same level of foresight and support from the Australian Government, for our own plantation development activities across The Ditch."

Kaara Shaw, south Queensland forester and member of the Durable Eucalypt Forum.

REGIONAL BUSINESS INVESTMENT CASES

The SWP was tasked with developing four regional business investment cases as part of its overall programme. These are summarised below.

Investment case 1: NZDFI Strategy 2020-2030

The NZDFI team produced a regional strategy document in 2019 looking out to 2030: 'Durable eucalypts: a multi-regional opportunity for New Zealand's drylands.'

Focus areas identified in the strategy are:

- identifying markets for durable eucalypts
- modelling forest productivity and economic feasibility
- working regionally to encourage the planting of new forests
- breeding, propagation and trial management
- educating growers on durable eucalypt forest establishment and management
- industry partnerships to build support and capability.

Beyond the NZDFI Strategy document

Following production of its Strategy, the NZDFI went on to develop ideas for a multi-regional hardwood industry based on regional wood supply catchments with a centralised processing facility. This concept was initially evaluated in Woodscape modelling work by Scion (see section below on Woodscape models). One conclusion from the Woodscape work was that an area of 3,000-5,000 ha planted over thirty years will be enough to justify investment in a central wood processing facility.

NZDFI goals identified in 2021 were:

- twelve wood supply catchments planted by 2050 in NZDFI target regions
- wood-supply catchments centred on a suitably zoned 5 ha industrial site for a future small-to-medium sized hardwood processing business
- indicative catchment boundary – forests planted within 40 km radius of the planned processing site
- good road/rail/port connections for log supply and to transport hardwood products.

Maps of wood supply catchments have been developed showing the 40km radius catchment boundary around the proposed site of a processing facility; road, rail and port networks; and the areas of land most likely to become available for durable eucalypt planting (land in LUCs 5, 6 and 7). In all cases, the proposed area of new planting (3,000-5,000 hectares in total over 30 years) is less than 5% of the land identified as being suitable.

Each catchment is anticipated to generate over 200 direct full-time equivalent jobs plus additional indirect employment, contribute an estimated annual amount of $82.5 m to GDP once fully up and running, and generate a return on capital employed for the investor in the processing facility of around 25%.

NZDFI intends to continue working with regional partners to promote this concept.

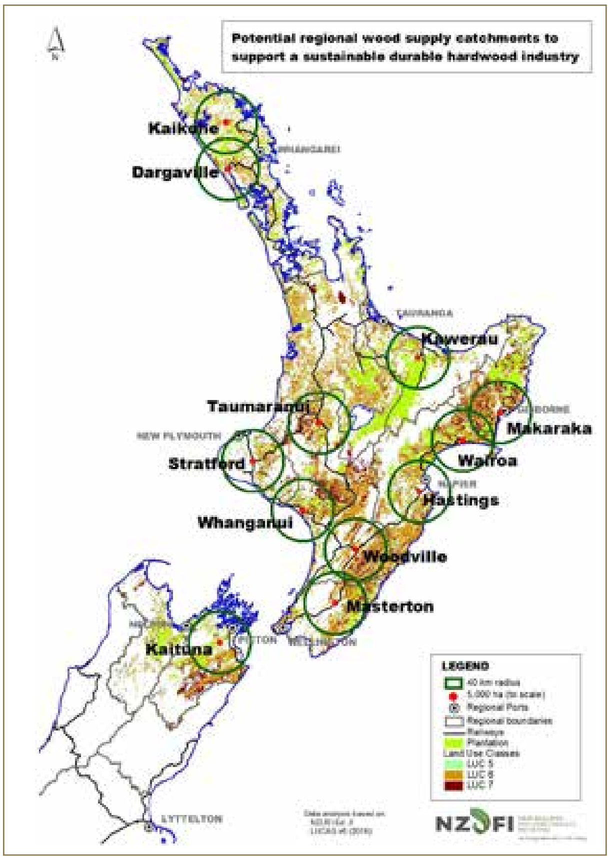


Figure 35: Potential regional wood supply catchments to support a sustainable durable hardwood industry - as envisaged by the NZDFI.

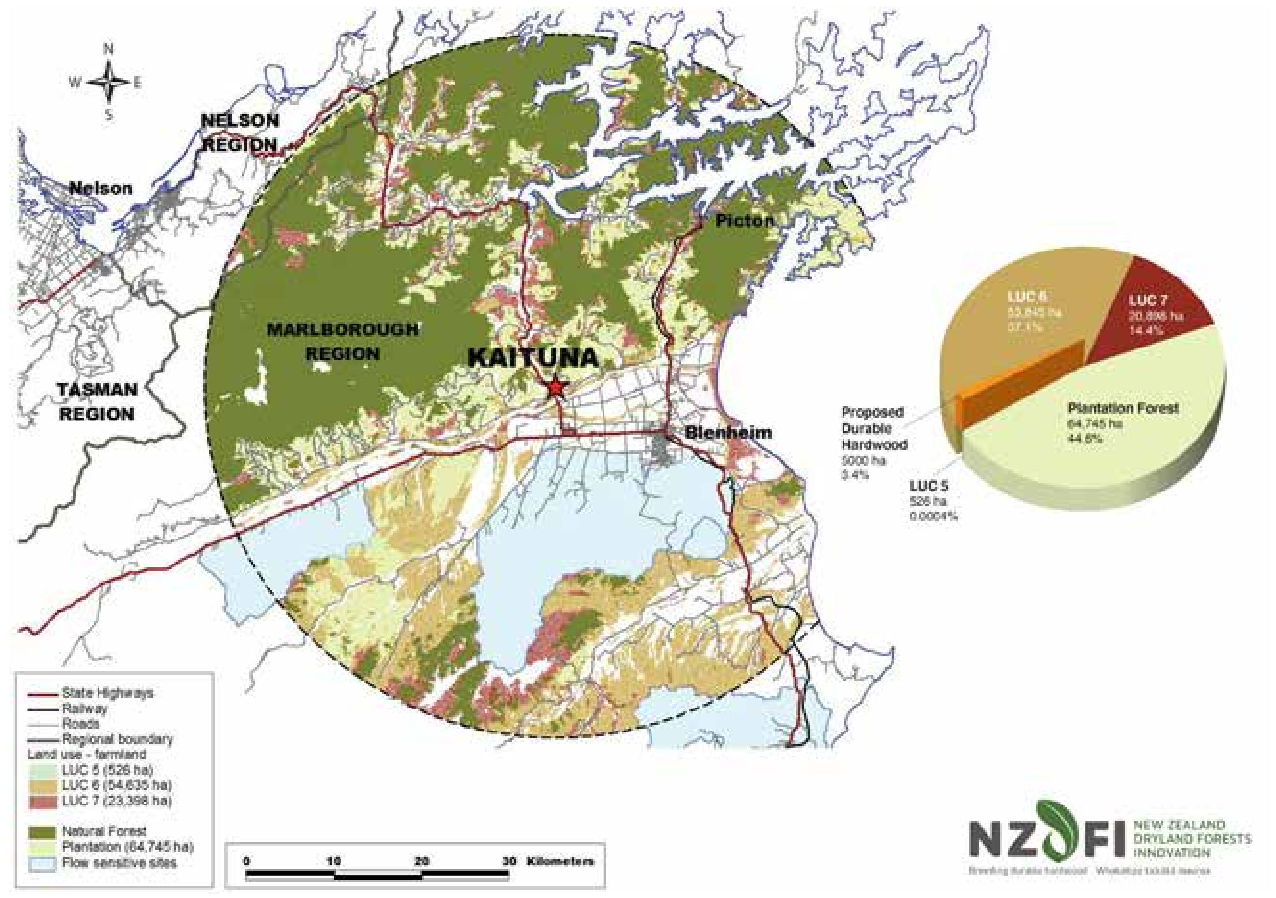


Figure 36: An example of a wood supply catchment based on a central processing plant in Kaituna, Marlborough.

Investment case 2: Cypresses: a strategy for the New Zealand cypress industry

A New Zealand Cypress Strategy: Whakamahere Cypress 2022-2042 was produced in 2022, led by the NZFFA Cypress Development Group (CDG). This followed consultation with industry sectors, and a workshop involving a range of industry stakeholders in October 2020.

The industry's mission is: 'Working regionally to ensure a sustainable cypress industry'. The Strategy identifies short, medium and long-term priority activities for research and development: work that will be led by the CDG. Main research and development themes are:

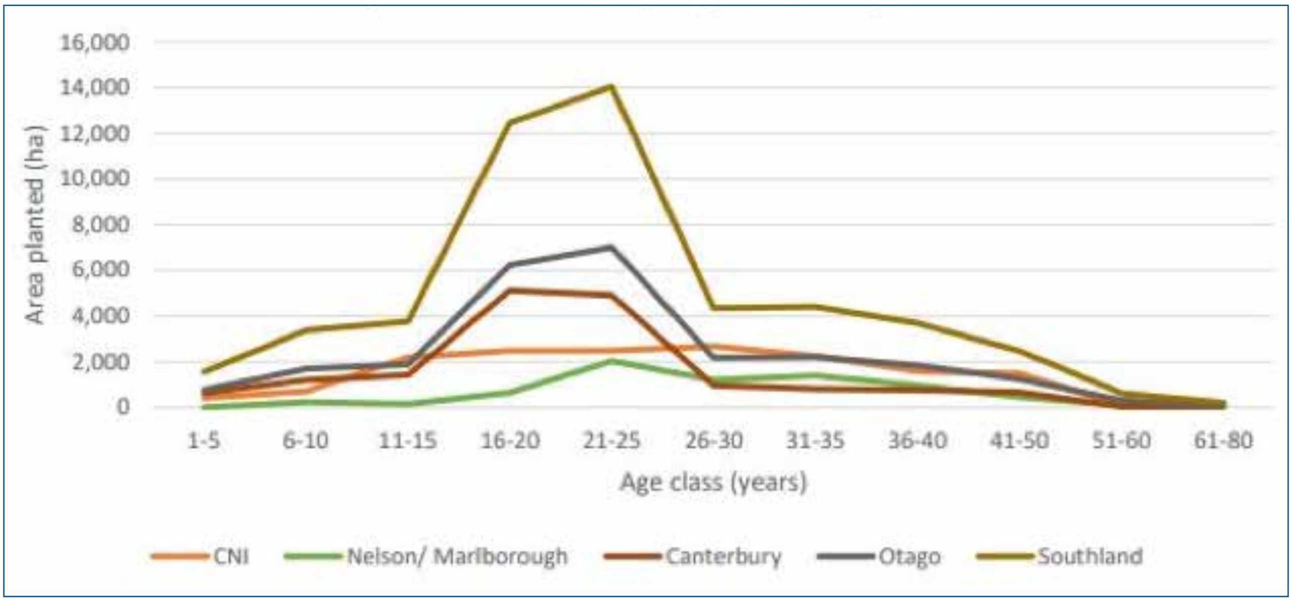
- cypress breeding, including clonal evaluation and selection
- site productivity and growth models
- silvicultural practices
- erosion mitigation
- carbon sequestration
- market access
- wood quality.

The focus will be on developing the future supply of timber, with sights firmly set on testing and scaling up production of elite hybrids and new genotypes. In addition, innovative products and markets for timber, especially from younger trees, are recognised as being needed. Developing a 'NZ Cypress' brand is also an important objective.

Investment case 3: Douglas-fir processing strategy

A review of Douglas-fir wood flows and regional processing opportunities concluded that four growing regions – Southland, Otago, Canterbury, and Central North Island – have sufficient volume to encourage investment in processing capacity.

Figure 37: Area planted in Douglas-fir by region and age class.



All four regions have a rapid increase in available volume in about 10 years from now: the fact that this increase is not sustained after 15 years presents some challenges that need to be overcome. Options identified include any or all of the following:

- allowing harvest age to increase to spread the spike in supply and provide a longer-term supply to those prepared to invest in processing capacity
- co-processing with radiata in existing and/or new mills
- exporting excess logs to global markets.

Other recommendations include that more focus is put onto Douglas-fir's superior qualities (when compared to radiata pine) to help increase market opportunities – these qualities include high stiffness, better stability, natural durability, and low variation in wood quality from bark to pith. In addition, the potential for value-adding processes needs to developed – for example, the production of glue laminated (GLT) beams, posts and lintels and specialty laminations, and cross laminated timber (CLT) panels. These products should extract extra value from Douglas-fir by making good use of its stiffness characteristics and stability.

Since the Douglas-fir strategy work was completed, two mills in Otago/Southland have indicated interest in Douglas-fir. Logs being produced in the region are predominantly small-diameter thinnings at present, and the mills are waiting for mature wood to become available. They will then consider investing in technology suitable for processing large diameter Douglas-fir.

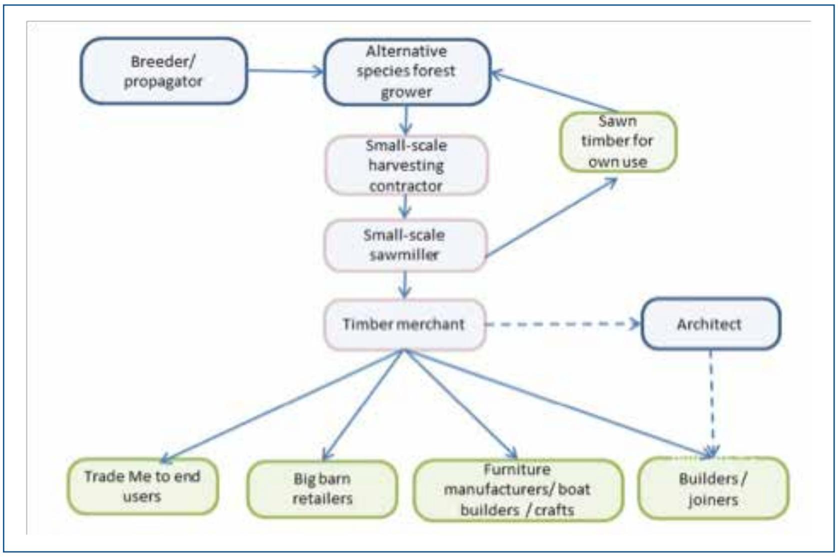
Investment case 4: Regional development of specialty (alternative) timbers and small-scale sawmilling industries

Following work on the alternative species resource and the potential for small-scale sawmilling in Hawke's Bay Region, SWP supported two associated projects: (i) a nation-wide survey of small-scale sawmillers to investigate the potential to develop an industry group for the sector, and (ii) a pilot study towards developing a new mapping methodology to capture New Zealand's alternative species resource more accurately than is currently the case with the National Exotic Forest Description (NEFD).

A graphic of the regional supply chain for alternative species timbers was developed, showing the various participants. Future work to strengthen this supply chain in different regions is urgently required.

The pilot mapping project was successful in developing a combined remote sensing/machine learning technique which has the capacity to identify and map different non-radiata species. Pilot studies were completed in Hawke's Bay and Gisborne/East Coast. In Hawke's Bay, the project revealed that the NEFD area data generally under-reported areas of non-radiata species. The mapping technique can be applied to any region, and work is underway to map the Wairarapa alternative species resource.

Figure 38: The specialty timbers regional supply chain.



Woodscape models

A series of 'Woodscape' reports have been completed by Scion and these form foundational work relevant to the regional investment business cases. The models projected regional supply of specialty species and analysed the economic feasibility of regional processing based on log supply, the costs of different processing options, and product prices. Work done for Hawkes Bay Regional Council/Hawkes Bay Regional Investment Company on future wood processing opportunities in the Wairoa District has been a fundamental component of the emerging thinking on regional wood supply catchments.

ADDITIONAL OUTCOMES

Site/species optimisation

A site/species mapping exercise reviewed the productivity potential of alternative species across a range of NZ sites. Species assessed were *E. fastigata*, *E. nitens*, *E. regnans*, *Sequoia sempervirens* (coastal redwood), *Pseudotsuga menziesii* (Douglas-fir), *Cupressus lusitanica*, and *C. macrocarpa*. The recommendations made provided a discussion base for the SWP workshop held in 2017 to decide priorities for research in this area. Participants came up with the following recommendations:

Establish commercial-scale demonstration trials of specialty timber species throughout New Zealand	Underway - new demonstration plantings have been established across New Zealand by NZDFI, Scion and NZFFA to encourage further planting of specialty species. The following species have been established: *C. macrocarpa, C. leylandii, C. ovensii, E. fastigata, E. bosistoana, E. cladocalyx, E. globoidea, E. macrorhyncha, E. quadrangulata* and *E. tricarpa*.
Continue the monitoring of existing PSPs of specialty timber species throughout New Zealand, and establish additional permanent sample plots (PSPs) for specialty timber species	Underway (2023) – funded by the ITP and coordinated by the NZFFA.
Elicit site-species mapping knowledge from existing experts and papers and incorporate into decision support systems.	Not yet undertaken.

Annual nursery survey

An annual survey of nurseries producing specialty species planting stock has been undertaken as part of the SWP since 2015, providing valuable information on levels of seedling sales of different species.

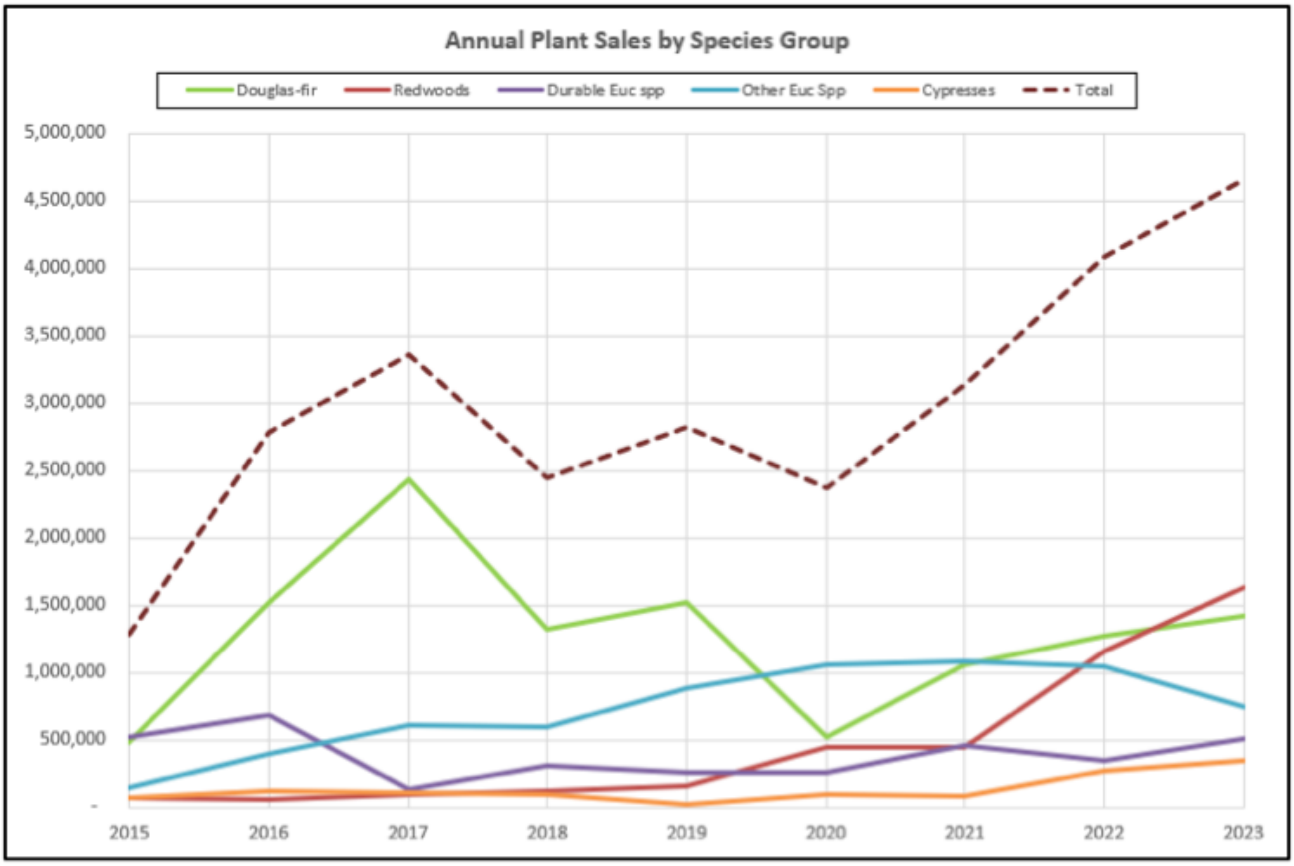


Figure 39: Annual plant sales by species/species group. Data for 2023 and 2024 are predictions. Note that redwoods are included, although they were not part of the SWP.

The data indicate an almost 400% increase in seedlings sold since 2015; levels in 2010, when the annual survey was in fact first conducted, were similar to those in 2015. The type of land being planted (i.e. cut-over or new planting land) is unknown.

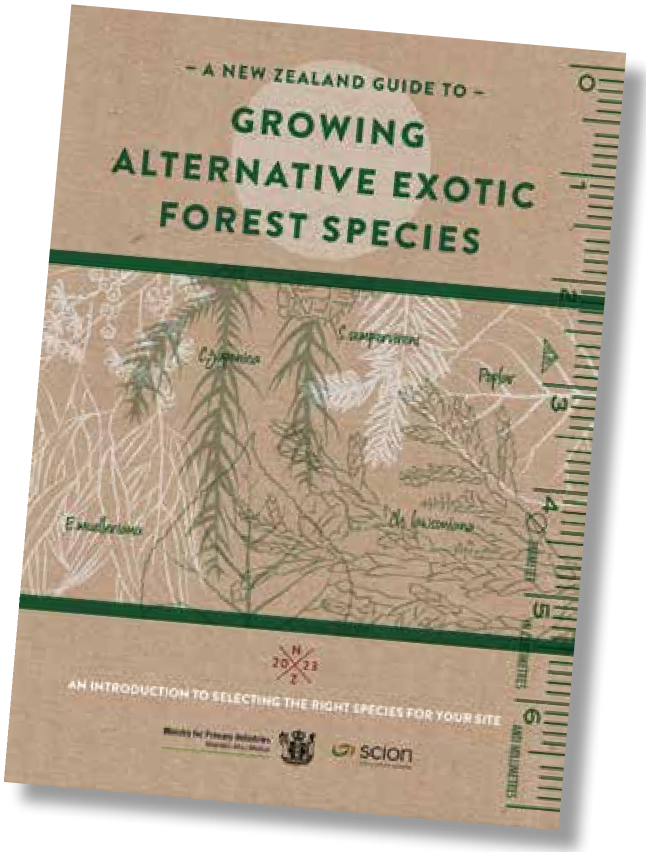
SWP/ Strategic Science Investment Fund strategy work on species other than radiata pine

As part of the process for determining future strategic research and development investment, the Forest Growers Levy Trust wanted to identify and evaluate species that could potentially act as contingency species if radiata pine was to fail. Two workshops were held with industry participation to identify and evaluate contingency species (species that could replace radiata pine) and alternative species. Other work looked at the general health and biosecurity risks to a number of alternative species.

All the above work will inform the design of future specialty species research and development programmes.

Booklet: A New Zealand Guide to Growing Alternative Exotic Forest Species

In 2023, a collaboration between SWP, Scion, NZFFA, the Ministry for Primary Industries and Te Uru Rākau resulted in the production of a booklet – A New Zealand Guide to Growing Alternative Exotic Forest Species. The booklet has been made widely available, free of charge, to landowners and their advisers, in the hope that it will encourage more people to consider growing alternatives to radiata pine.



STRENGTHS AND CHALLENGES OF THE SWP PROGRAMME

The 2017 Expert Advisory Panel (EAP) commented that the programme had many strengths, including the industry/ research collaborations, strong science, and the large programme team with diverse expertise.

Those involved with management and governance of the SWP also believe the programme had some real strengths, summarised below, which have helped to maintain the consistent momentum of research and development work for seven years.

Strengths of the SWP

- **investors and collaborators included growers, processors and research providers.** This has resulted in a diverse approach to solving research and technical problems, as well as strengthened links and understanding between sectors
- **industry priority setting has ensured relevance and uptake of results.** Workshops and reviews have ensured that industry has been able to set and fine-tune the research and development direction of the programme
- **the SWP's funding structure has meant good cost-effectiveness.** Contributions from SWP partners (both cash and in-kind) have enabled us to leverage significant funds from other sources. We have also had freedom to invest in the best research and development providers for any given work
- **the SWP's funding structure has also enabled flexibility** to change the direction of research as required, stop projects completely and fund some new ideas that came up as a result of project outcomes
- **a range of technology transfer mechanisms have been used** by partners and research providers to communicate outputs, including regular team meetings, reports and on-line material, workshops and conferences (both in person and on-line), field events, videos, and technology demonstrations
- **both undergraduate and graduate students have been closely involved** with the SWP (including 13 PhD students), thanks to the University of Canterbury's School of Forestry being a research provider.

Management challenges encountered over the seven years of the SWP programme

Several challenges were encountered during the SWP, especially towards the end of the programme. The current hiatus in funding for work on specialty species is accentuating these challenges, identified as follows:

- **a seven-year programme is relatively short** in relation to forestry cycles, and although good progress has been made in many areas, a longer-term funding commitment is needed to maximise early gains
- **postgraduate research** (PhDs) requires three-year rather than one-year contracts
- **sustaining core research and development capacity is challenging** now and will be in future: the current hiatus in programme funding is forcing skilled research and development providers to move into new work areas
- **quarterly meetings meant significant time commitments** for both technical and steering teams, and input from these governance teams may need to be reviewed for any future programme.

FUTURE SPECIALTY SPECIES RESEARCH AND DEVELOPMENT

The development of a case for a new multi-year research programme that can help transform the New Zealand forest industry is underway.

The first stage is to develop a 'case for change' that articulates the risks and the need for change and secures wider industry support for transformation. This will encompass a new vision for the industry, evolving from one which relies on a single species feeding a limited number of product streams into a more diversified, resilient, profitable, and valued growing and processing industry that continues to make a significant contribution to the economic, environmental and social fabric of New Zealand.

The forests of 2050 are expected to exhibit greater species diversity, a reduced reliance on large coupe clear-felling, more site-specific silviculture and a more diverse range of products feeding into more diversified markets and products.

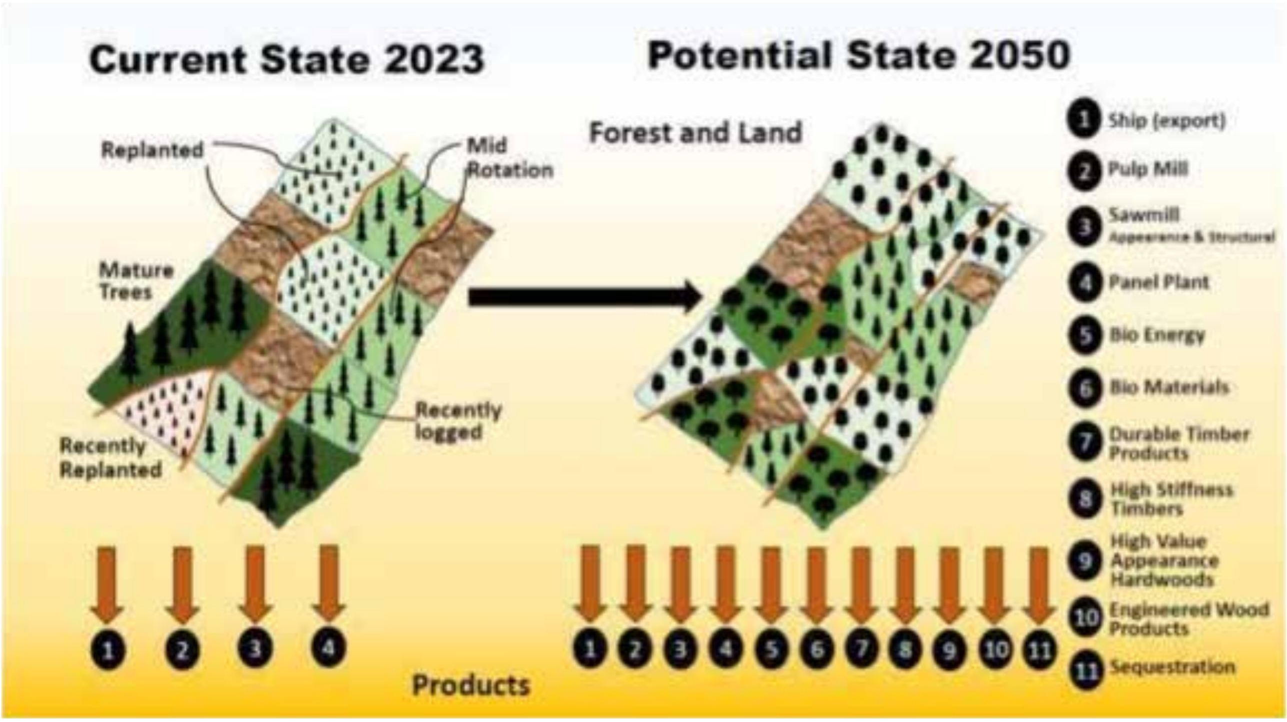


Figure 40: The vision for a diversified forest industry.

In the interim, a series of small-scale and short-duration research and development projects are underway using funds from the Forestry and Wood Processing Industry Transformation Plan as follows:

- Identifying coast redwood plus-trees
- Evaluation of elite cypress clones
- Economic evaluation of the bio-forest products economy
- Assessment of Specialty Wood Products durability trials
- Research for growing, managing, harvesting and marketing poplar
- Potential for *Abies grandis* and other *Abies* species
- Assessment of *Eucalyptus machrorhnycha* trial plantings
- Assessment of trial plantings of Class 1 durable eucalypts
- NZDFI seed collection and banking/archiving
- Eucalypt seed collection for improved genetics
- Expansion of the redwood seed collection programme
- Assessment of canker-resistant cypress hybrids
- Measuring Permanent Sample Plots
- Import substitution study – Scion
- Import substitution study – cypress cabin
- Alternative species mapping for the Wairarapa.

APPENDICES

APPENDIX 1: SWP TECHNICAL REPORTS

A1.1 Technical Reports specific to Douglas-fir

SWP-T003	2016	Breeding plan for the development of Douglas-fir	Breeding
SWP-T007	2016	Douglas-fir optimised engineered lumber (OEL™) trial	Products
SWP-T032	2017	Phenotypic assessment and quantitative genetic analysis of two Douglas-fir progeny tests	Breeding
SWP-T033	2017	Economic comparison of traditional and genomics breeding for Douglas-fir	Breeding
SWP-T034	2017	Initiation of genomic selection research, collection of cambium and extraction of DNA from a Douglas-fir breeding programme	Breeding
SWP-T035	2017	Expert Advisory Panel review of the SWP programme - 2017	Summary
SWP-T038	2017	Development of the Douglas-fir productivity spatial surface using the process-based model 3-PG	Growing
SWP-T047	2018	Thermal modification of Douglas fir for improved durability	Durability
SWP-T049	2018	Evaluation of the Ernslaw One Douglas-fir progeny tests	Breeding
SWP-T053	2018	Experimental studies on rolling shear strength properties of Douglas-fir CLT and monotonic behaviour of dowelled connections	Processing
SWP-T058	2018	Douglas-fir breeding and genomics	Breeding
SWP-T075	2019	Evaluation of wood stiffness in Douglas-fir progeny test FR280_2 and FR280_3	Breeding
SWP-T082	2019	Experimental studies on Douglas-fir CLT connections and core-walls	Products
SWP-T084	2019	Implementation of genomic selection in provenance/progeny test of Douglas-fir	Breeding
SWP-T098	2020	Experimental testing of high-capacity screwed connections in Douglas-fir CLT	Products
SWP-T113	2020	Douglas fir Strategy Part 2: Processing Opportunities	Processing
SWP-T117	2020	Douglas-fir Strategy Part 3: Regional Processing	Strategy
SWP-T119	2021	Experimental testing of high-capacity screwed connections in Douglas-fir CLT	Products
SWP-T128	2021	Experimental and parametric studies on Douglas-fir CLT shear walls with high-capacity connections	Products
SWP-T161	2023	Evaluation of D-fir progeny test FR 508/1 and FR 508/2	Breeding
SWP-T162	2023	Evaluation of genetic gain trials in Douglas-fir	Breeding
SWP-T171	2023	The condition of thermally modified cypress and Douglas-fir flat panels after one year's field exposure	Products
SWP-T172	2023	The condition of thermally modified cypress and Douglas-fir decking after one year's field exposure	Products
SWP-T173	2023	The condition of thermally modified cypress and Douglas-fir L-joints after one year's field exposure.	Products

A1.2 Technical Reports specific to non-durable eucalypts

SWP-T005	2016	Selection for solid wood properties in *Eucalyptus nitens*	Processing
SWP-T006	2016	Initial evaluation of genomic selection to improve wood properties in *Eucalyptus nitens* breeding population	Breeding
SWP-T008	2016	Improving drying quality of *Eucalyptus nitens* timber: results to date	Processing
SWP-T010	2016	Economic comparison of traditional and genomic breeding programmes for *Eucalyptus nitens*	Breeding
SWP-T011	2016	Scion's core funded experiments on thermal modification of *Eucalyptus nitens* – interim results	Durability
SWP-T014	2016	*E nitens* optimised engineered lumber (OEL™) trial	Processing
SWP-T015	2016	Identification of issues and opportunities for LVL from NZ eucalypts	Processing
SWP-T016	2016	Review of eucalypt wood processing Issues	Processing
SWP-T018	2016	*Eucalyptus nitens* breeding plan	Breeding
SWP-T021	2017	Thermal modification of *Eucalyptus nitens* - Core Funded_G2	Processing
SWP-T022	2017	Drying *Eucalyptus nitens*: screening for checking and collapse	Processing
SWP-T023	2017	100 years of the Eucalyptus tortoise beetle	Pests and disease
SWP-T027	2017	Modelling growth of *Eucalyptus spp*. on New Zealand dryland micro-sites	Growing
SWP-T030	2017	Review of methods and recommendation for assessing defoliation *Eucalyptus nitens* from *Paropsis charybdis* for breeding purposes	Pests and disease
SWP-T042	2018	LVL Trial: Pre-harvest stand assessment	Processing
SWP-T048	2018	*E. fastigata* veneer stiffness	Products
SWP-T050	2018	Genetic analysis of *Eucalyptus fastigata* progeny trials and implications to selection	Breeding
SWP-T055	2018	Improved drying of *Eucalyptus nitens*: Screening standing trees and drying thin boards	Processing
SWP-T056	2018	Eucalyptus variegated beetle creates concern for eucalypt growers	Pests and disease
SWP-T057	2018	Pre application consultation has begun for a new potential biological control introduction to control Eucalyptus tortoise beetle, *Paropsis charybdis*	Pests and disease
SWP-T062	2018	Supercritical CO2 dewatering of *E. nitens*. Results of Scion's core funded experiments	Processing
SWP-T066	2018	The decay resistance of six *Eucalyptus* species in stake and stakelet trials after two years exposure	Durability
SWP-T067	2018	Economic impact of eucalyptus tortoise beetle *(Paropsis charybdis)* in New Zealand	Pests and disease
SWP-T083	2019	Assessed defoliation of *Eucalyptus nitens* breeding population to quantify genetic basis of palatability to *Paropsis charybdis*	Pests and disease
SWP-T093	2020	Peeling pruned *E. fastigata* for high-stiffness veneers: Part 1. Green grade recoveries	Processing
SWP-T097	2020	Assessing properties of *E. nitens* laminated flooring	Processing

SWP-T103	2020	Bonding of *Eucalyptus fastigata* veneer	Processing
SWP-T104	2020	*Eucalyptus nitens* breeding plan update 2020	Breeding
SWP-T105	2020	Densification of *E. fastigata* and *E. nitens* for improved surface hardness	Processing
SWP-T109	2020	Peeling and sawing pruned *E. fastigata* for high-stiffness veneers: Part 2. Dry grade recovery and downstream testing	Processing
SWP-T118	2020	Eucalyptus resistance to paropsine beetles	Pests and disease
SWP-T125	2021	Spatial distribution of cell collapse in *Eucalyptus nitens* wood due to drying treatment	Processing
SWP-T135	2021	Producing high-stiffness LVL from *Eucalyptus fastigata*: Part 3. LVL production and mechanical properties	Products
SWP-T136	2021	Multi-environment single-step genomic evaluation of *Eucalyptus nitens* progeny test	Breeding
SWP-T145	2022	Using NIR to predict sawn timber quality in *E. nitens*	Processing
SWP-T146	2022	Using NIR to predict wood shrinkage and cellulose content in *E. nitens*	Processing
SWP-T148	2022	Densification of *E. nitens* and *E. fastigata*	Processing
SWP-T163	2023	Evaluation of multi-site progeny test in *Eucalyptus fastigata*	Breeding
SWP-T166	2023	Framing tests for cypress and H1.2 treated *E. nitens* and *E. fastigata.*	Durability

A1.3 Technical Reports specific to cypresses

SWP-T099	2020	NZ Cypress Forestry Strategy Stage One 2019-2020	Strategy
SWP-T112	2020	A strategy for the NZ Cypress Industry Workshop report and draft action plan	Strategy
SWP-T115	2020	Economic modelling of a *Ch. ovensii* clonal regimes for a range of growth rates	Growing
SWP-T116	2020	Grade recoveries from sawing 20-year-old unpruned cypress clones	Processing
SWP-T129	2021	Cupressus x ovensii bending strength and stiffness	Processing
SWP-T138	2021	NZ Cypress Strategy - Whakamahere Cypress, 2022-2042	Strategy
SWP-T147	2022	Decay rates of cypress stakes after one year's exposure at the Whakarewarewa test site	Durability
SWP-T154	2022	Recalculation of *Ch. Ovensii* bending strength and stiffness	Processing
SWP-T165	Placeholder	Thermal modification of young cypress timber	Durability
SWP-T166	Placeholder	Framing tests for cypress and H1.2 treated *E. nitens* and *E. fastigata*	Durability
SWP-T167	2023	Decay rate of cypress stakes after two years' exposure at the Whakarewarewa test site	Durability
SWP-T171	2023	The condition of thermally modified cypress and Douglas-fir flat panels after one year's field exposure	Products
SWP-T172	2023	The condition of thermally modified cypress and Douglas-fir decking after one year's field exposure	Products
SWP-T173	2023	The condition of thermally modified cypress and Douglas-fir L-joints after one year's field exposure.	Products

A1.4 Technical reports specific to durable eucalypts

SWP-T002	2015	Literature review: measuring growth-strain by IR-spectroscopy	Breeding
SWP-T009	2016	Screening *Eucalyptus bosistoana* for heartwood	Breeding
SWP-T012	2016	Heartwood formation in young *Eucalyptus bosistoana*	Breeding
SWP-T017	2016	Calibrating NIR spectroscopy for extractive content of *E. bosistoana* stem cores	Breeding
SWP-T019	2017	A regional approach to matching specialty timber species to sites	Growing
SWP-T020	2017	Predicting strain levels in air-dried wood using near infrared spectroscopy	Breeding
SWP-T023	2017	100 years of the Eucalyptus tortoise beetle	Pests and disease
SWP-T024	2017	Early heartwood screening by wounding	Breeding
SWP-T025	2017	Improving heartwood of durable eucalypts	Breeding
SWP-T026	2017	Measuring strain in wet eucalyptus wood by NIR	Breeding
SWP-T027	2017	Modelling growth of *Eucalyptus spp.* on New Zealand dryland micro-sites	Growing

SWP-T028	2017	Heartwood in *Eucalyptus bosistoana* (2010 plantings)	Growing
SWP-T029	2017	Pest management for durable eucalypts	Pests and disease
SWP-T036	2017	Potential for growing and processing durable eucalypts	Processing
SWP-T037	2017	Quantifying compounds in heartwood extractives of durable eucalypts	Durability
SWP-T039	2017	Performance of naturally durable eucalypt posts in Marlborough vineyards.	Durability
SWP-T040	2017	Prediction of extractive content of *E. globoidea* heartwood using NIR spectroscopy	Breeding
SWP-T041	2018	NZDFI Regional Strategic Plan consultation document	Strategy
SWP-T044	2018	Durable eucalypt forests - a multi-regional opportunity for investment in New Zealand drylands (NZ Journal of Forestry article)	Strategy
SWP-T045	2018	Natural durability: Correlation between extractive content and fungal assay	Durability
SWP-T046	2018	Heartwood in *Eucalyptus bosistoana* (2010 plantings)	Growing
SWP-T051	2018	NZDFI biosecurity risk management plan	Pests and disease
SWP-T052	2018	Developing GC methods for analysing the foliar chemistry of durable eucalypts: a potential pest-tolerance screening tool	Pests and disease
SWP-T054	2018	Sapwood depth tool – proof of principle	Growing
SWP-T056	2018	Eucalyptus variegated beetle creates concern for eucalypt growers	Pests and disease
SWP-T057	2018	Pre application consultation has begun for a new potential biological control introduction to control Eucalyptus tortoise beetle, *Paropsis charybdis*	Pests and disease
SWP-T060	2018	Bioactivity of heartwood compounds	Durability
SWP-T067	2018	Economic impact of eucalyptus tortoise beetle *(Paropsis charybdis)* in New Zealand	Pests and disease
SWP-T069	2018	Extending durable eucalypt species research by establishing new demonstration trials in 2018	Growing
SWP-T070	2019	Hybrid growth models for *Eucalyptus globoidea* and *E. bosistoana*	Growing
SWP-T071	2019	Molecular deformation of wood and cellulose studied by near infrared and Raman spectroscopy	Breeding
SWP-T072	2019	Heartwood in *Eucalyptus bosistoana* (2009 plantings)	Growing
SWP-T076	2019	NZDFI Regional Strategy: Durable eucalypt forests - a multi-regional opportunity for investment in New Zealand drylands	Strategy
SWP-T077	2019	Sapwood depth tool – proof of concept field prototype	Breeding
SWP-T078	2019	Susceptibility of *Eucalyptus bosistoana* families to EVB defoliation	Pests and disease
SWP-T079	2019	Rotary peeling of 15-year-old *E. bosistoana* and *E. quadrangulata*	Processing
SWP-T080	2019	Assessing the bending and density properties of six eucalypt species	Processing
SWP-T085	2019	The decay resistance of six *Eucalyptus* species after three years exposure	Durability

SWP-T087	2019	Minimising growth-strain in eucalypts to transform processing	Processing
SWP-T088	2019	Non-destructive detection of the heartwood-sapwood barrier	Breeding
SWP-T089	2019	A population-genomic and taxonomic study of *Eucalyptus argophloia* and *E. bosistoana*.	Breeding
SWP-T091	2019	Bonding of *E. bosistoana* and *E. quadrangulata* veneer	Processing
SWP-T092	2020	Assessment of *E. globoidea* wood properties at Atkinson	Growing
SWP-T094	2020	Preliminary juvenile height yield models for three durable *Eucalyptus* species by integrating site-specific factors	Growing
SWP-T095	2020	Wooden posts – A review	Products
SWP-T101	2020	Value of veneer, wood fibre and posts from improved *Eucalyptus bosistoana* trees	Processing
SWP-T108	2020	Heartwood in *Eucalyptus bosistoana* (JNL Ngaumu 2012 trial)	Growing
SWP-T111	2020	The decay resistance of six *Eucalyptus* species after four years exposure	Durability
SWP-T114	2020	Analysis of the treated wood market for agricultural and horticultural uses in New Zealand	Strategy
SWP-T118	2020	Eucalyptus resistance to paropsine beetles.	Pests and disease
SWP-T120	2021	Assessment of NZDFI *Eucalyptus quadrangulata* breeding populations	Breeding
SWP-T121	2021	Recommended sampling intensity for phenotyping durable eucalypt heartwood quality	Breeding
SWP-T123	2021	Feasibility trials - peeling posts of durable eucalypts	Processing
SWP-T124	2021	Assessing heartwood in *E. bosistoana* cores from NIR hyperimages	Breeding
SWP-T126	2021	Techno-economic analysis of veneers and posts from specialty wood species (durable eucalypts)	Processing
SWP-T127	2021	Techno-economic analysis of posts from specialty wood species and radiata pine	Processing
SWP-T131	2021	Assessment of *Eucalyptus globoidea* heartwood at Avery	Growing
SWP-T132	2021	The decay resistance of six *Eucalyptus* species after four years exposure	Durability
SWP-T134	2021	Developing fully compatible taper and volume equations for all stem components of *E globoidea* Blakely trees in NZ	Growing
SWP-T140	2022	*Eucalyptus* resistance to paropsine beetles	Pests and diseases
SWP-T142	2021	Assessment of *E. globoidea* heartwood at Ngaumu	Growing
SWP-T144	2022	Assessment of *E quadrangulata* breeding populations	Breeding
SWP-PW10	2022	Genetic variation in wood properties of mid-rotation *E globoidea*	Breeding
SWP-PW11	2022	Developing fully compatible taper and volume equations for all stem components of *E. globoidea* in NZ	Growing
SWP-T152	2022	Genetic variation in collapse and other wood properties of *E. quadrangulata* at mid-rotation age	Breeding/ processing

SWP-T153	2022	Assessing paropsine damage on *Eucalyptus* trees with remote sensing	Pests and diseases
SWP-T155	2023	Machinability of 28-year-old *E. globoidea* wood	Processing
SWP-T156	2023	Assessment of NZDFI's 2016 *E. quadrangulata* breeding population at NZRC Paparoa	Breeding
SWP-T157	2023	Assessment of *E. globoidea* heartwood at Avery	Growing
SWP-T168	2023	Genetic structure and diversity in the NZDFI *Eucalyptus bosistoana* **and** *E. argophloia* breeding populations	Breeding
SWP-T174	2023	Variation in adaptability and productivity between durable eucalypt species in different New Zealand environments.	Growing

A1.5 Non-species-specific Technical Reports

SWP-T004	2016	Alternative species site mapping review and analysis	Growing
SWP-T013	2016	Super critical CO2 chemical extraction - core funding	Processing
SWP-T031	2017	Preliminary DSS stakeholder analysis – towards the Scion SFF proposal for site-species matching	Growing
SWP-T059	2018	LVL stiffness calculator user guide	Processing
SWP-T061	2018	Core funded aligned research on insects and fungi on species other than radiata 2017/2018	Pests and disease
SWP-T063	2018	Thermal modification of specialty species: Results of Scion's core-funded experiments	Durability
SWP-T064	2018	The decay resistance of three wood species used as framing	Durability
SWP-T065	2018	Optimising new PSP locations	Growing
SWP-T068	2018	Identifying processing opportunities for key specialty tree species – resource analysis	Growing
SWP-T073	2019	Identifying processing opportunities for key specialty tree species; – processing options analysis using the WoodScape model	Growing
SWP-T074	2019	Dimensional stability of specialty species	Processing
SWP-T081	2019	Forest Protection SSIF research on species other than radiata pine 2018/19	Pests and diseases
SWP-086	2019	Thermal modification of specialty species: results of Scion's SSIF-funded experiments	Durability
SWP-T090	2019	Dimensional stability of specialty species	Processing
SWP-T096	2020	The decay resistance of some wood species used as framing. Final report.	Durability
SWP-T100	2020	Portable sawmilling of locally grown alternative timber species.	Strategy
SWP-T102	2020	Forest Protection SSIF research on species other than radiata pine 2019/20	Pests and diseases
SWP-T106	2020	Survey of small-scale sawmillers	Strategy
SWP-T107	2020	SWP five-year progress report (2015-2020)	Summary

SWP-T110	2020	National forest owner survey and resource inventory of alternative species: Stage One of Hawke's Bay Region pilot project	Strategy
SWP-T114	2020	Analysis of the treated wood market for agricultural and horticultural uses in New Zealand	Strategy
SWP-T122	2020	The current and future potential of contingency species to mitigate biosecurity risk for the New Zealand forest sector	Strategy
SWP-T130	2021	Forest Protection SSIF research on species other than radiata pine 2020/21	Pests and diseases
SWP-T133	2021	National forest owner survey and resource inventory of alternative species Stage 2a: Survey of small-scale woodlot owners	Strategy
SWP-T137	2021	Developing the potential of New Zealand's small-scale sawmilling and alternative timber sector	Strategy
SWP-T139	2021	Specialty species review	Strategy
SWP -T141	2022	Techno-economic analysis of producing engineered and thermally modified products from specialty wood species	Strategy
SWP -T143	2022	National forest owner survey and resource inventory of alternative species. Stage 2b: Mapping alternative species using remote sensing	Strategy
SWP-T151	2022	Forest protection SSIF research on species other than radiata pine	Pests and diseases
SWP-T159	2023	National forest owner survey and resource inventory of alternative species. Stage 3: Mapping alternative species in the East Coast region	Strategy
SWP-T160	2023	The decay resistance of alternative species in an accelerated framing test: Assessment of decay after one year's exposure	Durability
SWP-T170	2023	The Specialty Wood Products Research Partnership: Final report (2015-2023)	Summary
SWP-T171		The condition of thermally modified cypress and Douglas-fir flat panels after one year's field exposure	Durability
SWP-T172	2023	The condition of thermally modified cypress and Douglas-fir decking after one year's field exposure	Durability
SWP-T173	2023	May 2023 The condition of thermally modified cypress and Douglas-fir L-joints after one year's field exposure.	Durability

Note: Almost all these reports are freely available on the FGR website https://fgr.nz/

If you cannot find a report you are looking for on the website, please contact SWP Programme Manager Marco Lausberg.

APPENDIX 2: OTHER PUBLICATIONS

A 2.1 Journal articles.

Research provider: Scion

Ismael, A., Klápště, J., Stovold, G., et al (2021) "Genetic Variation for Economically Important Traits in *Cupressus lusitanica* in New Zealand." Frontiers Plant Science Sec. Plant Breeding Volume 12 - 2021 | https://doi.org/10.3389/fpls.2021.651729

Klápště, J., Dungey, H.S. Telfer, E. et al. (2020) "Marker Selection in Multivariate Genomic Prediction Improves Accuracy of Low Heritability Traits." Frontiers in Genetics Sec. Evolutionary and Population Genetics Volume 11 - 2020 | https://doi.org/10.3389/fgene.2020.499094

Klápště, J., Suontama, M., Dungey, H.S. et al. (2019) "Modelling of population structure through contemporary groups in genetic evaluation". BMC Genet 20, 81 https://doi.org/10.1186/s12863-019-0778-0

Klápště, J., Suontama, M., Dungey, H., et al. (2018) "Effect of hidden relatedness on single-step genetic evaluation in an advanced open-pollinated breeding program." (2018) Journal of Heredity, 109 (7), pp. 802-810. doi: 10.1093/jhered/esy051.

Klápště, J., Suontama, M., Telfer, E., Graham, N., Low, C., et al. (2017) "Exploration of genetic architecture through sib-ship reconstruction in advanced breeding population of *Eucalyptus nitens*." PLOS ONE 12(9): e0185137. https://doi.org/10.1371/journal.pone.0185137

Klápště, J., Graham, N., Dungey, H., Suontama, M., and Howe, G. "Tracing genealogy in the early stage of forest tree domestication using genomics." In preparation. Suggested journal for submission is New Forests.

Peixoto, L., Allen, G. R., Ridenbaugh, R. D., Quarrell, S. R., Withers, T. M. and Sharanowski, B. J. (2018). "When taxonomy and biological control researchers unite: species delimitation of *Eadya* parasitoids (Braconidae) and consequences for classical biological control of invasive paropsine pests of *Eucalyptus*." PLoS One 13 (8): e0201276.

Pugh, A. R., Wardhaugh, C., Scott, M. B. and Withers, T. M. (2022). "Notes on the endemic leaf beetle *Chalcolampra* nr. tarsalis (Chrysomelidae: Chrysomelinae) from Kahurangi National Park, Nelson". The Weta 2022 Vol. 56 Pages 43-50.

Pugh, A.R., Withers, T. M., Peters, E. M., Allen, G. R. and Phillips, C. "Why introducing a parasitoid of *Paropsis charybdis* Stål, 1860 (Coleoptera: Chrysomelidae) larvae is expected to enhance biological control of this *Eucalyptus* pest in New Zealand." Austral Entomology 2020 Vol. 59 Issue 4 Pages 829-837. DOI: 10.1111/aen.12492.

Smart, R., Quarrell, S., Corkrey, R., Withers, T. M., Pugh, A., Satchell, D., and Allen, G. R. (2023). "Circadian and seasonal flight activity differences between the sexes of the biocontrol agent Eadya daenerys (Hymenoptera: Braconidae) and the impact of host size on adult emergence." Austral Entomology Vol. online DOI: http://doi.org/10.1111/aen.12647

Suontama, M., Klápště, J., Telfer, E. et al. (2019) „Efficiency of genomic prediction across two Eucalyptus nitens seed orchards with different selection histories". Heredity 122, 370–379 (2019). https://doi.org/10.1038/s41437-018-0119-5.

Suontama, M. and Dungey,H. (2018) "Breeding Douglas-fir for high-value wood products in the genomic selection era." New Zealand Journal of Forestry 63(1): 24–28.

Weser, C., T. M. Withers and S. M. Pawson. In prep. "Potential pest impacts of *Paropsisterna cloelia* (Stål) (Coleoptera: Chysomelidae): a comparison of its biology and ecology to Paropsis charybdis". New Zealand Journal of Forestry Science submitted.

Withers, T. M., G. R. Allen, C. Todoroki, A. R. Pugh and B. A. Gresham. (2021) Observations of parasitoid behaviour in both no-choice and choice tests are consistent with proposed ecological host range Entomologia Experimentalis et Applicata Vol. 169 Issue 1 Pages 97-110 DOI: 10.1111/12956.

Withers, T. M., C. Todoroki, G. R. Allen, A. R. Pugh and B. A. Gresham. (2020) "Host testing of *Eadya daenerys*, a potential biological control agent for the invasive chrysomelid pest *Paropsis charybdis*, predicts host specificity to eucalypt-leaf feeding Paropsina". BioControl Vol. 65 Issue 1 Pages 25-36 DOI: 10.1007/s10526-019-09978-6.

Withers, T. M. and E. Peters (2017). "100 years of the eucalyptus tortoise beetle in New Zealand." New Zealand Journal of Forestry 62(3): 16-20.

Withers, T. M., G. R. Allen, S. R. Quarrell and A. R. Pugh. (2017). Larval parasitoids for biocontrol of invasive Paropsine defoliatiors. Proceedings of the 5th International Symposium on Biological Control of Arthropods. P. G. Mason, D. R. Gillespie and C. Vincent. Langkawi, Malaysia. September 11-15, 2017, CAB International: 58-92.

Withers, T. M., G. R. Allen and C. A. M. Reid (2015). "Selecting potential non-target species for host range testing of *Eadya paropsidis*." New Zealand Plant Protection 68: 179-186.

Withers, T. M., et al. (2012). "Investigating the potential of *Eadya paropsidis* (Braconidae) from Tasmania as a biocontrol agent for Paropsis charybdis in New Zealand." New Zealand Plant Protection 65: 292-292.

Research provider: University of Canterbury School of Forestry and Marlborough Research Centre

Altaner, C.M. (2015). "Developing a quality eucalypt resource at seedling stage." Australian Forest Grower **37**(4): 33/35.

Davies, N. T., Apiolaza, L. A. and Sharma, M. (2017). "Heritability of growth strain in Eucalyptus bosistoana: a Bayesian approach with left-censored data." New Zealand Journal of Forestry Science **47**.

Ghildiyal, V., Herel, R van., Heffernan, B., Altaner, C.M. (2022) "The effect of Joule heating on collapse and water absorption of wood." Wood material science and engineering, 09/2022.

Ghildiyal, V., Iyiola, E., Sharma, M., Apiolaza, L. A., Altaner, C.M (2023) "Genetic variation in drying collapse and heartwood properties at mid-rotation age of *Eucalyptus globoidea*." Industrial crops and products, 10/2023, Volume 201.

Guo, F. and Altaner, C. M. (2018). "Properties of rotary peeled veneer and laminated veneer lumber (LVL) from New Zealand grown *Eucalyptus globoidea*." New Zealand Journal of Forestry Science **48**(1): 3.

Guo, F. and Altaner, C. M. (2019). "Measuring Molecular Strain in Rewetted and Never-Dried Eucalypt Wood with Raman Spectroscopy." Biomacromolecules **20**(8): 3191-3199.

Guo, F. and Altaner, C.M. (2019). "Effects of mechanical stretching, desorption and isotope exchange on deuterated eucalypt wood studied by near infrared spectroscopy." Spectrochimica acta. Part A, Molecular and biomolecular spectroscopy, 03/2019, Volume 211.

Guo, F., Cramer, M., Altaner, C.M. (2019). "Evaluation of near infrared spectroscopy to non-destructively measure growth strain in trees." Cellulose (London), 09/2019, Volume 26, Issue 13-14.

Iyiola, E.A., Altaner, C. M., and Apiolaza, L.A. (2022). "Genetic variation in wood properties of mid-rotation *Eucalyptus globoidea*." NZ Journal of Forest Science Vol 52 (2022).

Li, Y. and Altaner C.M. (2018). "Predicting extractives content of *Eucalyptus bosistoana* F. Muell. Heartwood from stem cores by near infrared spectroscopy." Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy **198**: 78-87.

Li, Y., Apiolaza. L. A. and Altaner, C.M. (2018). "Genetic variation in heartwood properties and growth traits of *Eucalyptus bosistoana*." European Journal of Forest Research **137**(4): 565-572.

Li, Y. and Altaner, C.M. (2019). "Calibration of near infrared spectroscopy (NIRS) data of three Eucalyptus species with extractive contents determined by ASE extraction for rapid identification of species and high extractive contents." Holzforschung. **73**: 537.

Li, Y. and Altaner, C. M. (2019). "Effects of variable selection and processing of NIR and ATR-IR spectra on the prediction of extractive content in *Eucalyptus bosistoana* heartwood." Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy **213**: 111-117.

Li, Y., Sharma, M., Altaner, C.M. and Cookson L. J. (2020). "An approach to quantify natural durability of Eucalyptus bosistoana by near infrared spectroscopy for genetic selection." Industrial Crops and Products **154**: 112676.

Lin, H., Murray, T.J. and Mason, E.G. (2017). "Incidence of and defoliation by a newly introduced pest, *Paropsisterna variicollis* (Coleoptera: Chrysomelidae), on eleven durable Eucalyptus species in Hawke's Bay, New Zealand." New Zealand Plant Protection 70, 45-51 (2017). http://journal.nzpps.org/index.php/nzpp/article/view/26.

Mason, E.G., Salekin, S. and Morgenroth, J. (2017) "Comparison between meteorological data from the New Zealand National Institute of Water and Atmospheric Research (NIWA) and data from independent meteorological stations." New Zealand Journal of Forestry Science. **47** (1).

Millen, P. (2009). "NZ Dryland Forests Initiative: a market focused durable eucalypt R&D project." Pages 57-74 in L. A. Apiolaza, S. V. S. Chauhan, and J. C. F. Walker, editors. Revisiting eucalypts. Wood Technology Research Centre, University of Canterbury, Christchurch, N.Z.

Millen, P., van Ballekom, S., Altaner, C.M., Apiolaza, L.A, Mason, E., McConnochie, R., Morgenroth, J. and Murray, T. (2018). "Durable eucalypt forests – a multi-regional opportunity for investment in New Zealand drylands." New Zealand Journal of Forestry **63**: 11-23.

Mishra, G., Collings, D. A. and Altaner, C. M. (2018). "Cell organelles and fluorescence of parenchyma cells in *Eucalyptus bosistoana* sapwood and heartwood investigated by microscopy." New Zealand Journal of Forestry Science **48**(1): 13.

Mishra, G., Collings, D. A. and Altaner, C. M. (2018). "Physiological changes during heartwood formation in young *Eucalyptus bosistoana* trees." IAWA Journal **39**(4): 382-394.

Mishra, G., Garrill, A. and Altaner C.M. (2019). "Bioactivity of ethanol extracts from Eucalyptus bosistoana F. Muell. heartwood." Forest – Biogeosciences and Forestry **12**(5): 467-473.

Rajapaksha, C., Apiolaza, L.A., Squire, M.A., and Altaner, C.M. (2023) "Seasonal variation of yield and composition in extracts from immature and mature *Eucalyptus bosistoana* leaves." Flavour and Fragrance journal, 04/2023.

Salekin, S., Burgess, J. H., Morgenroth, J., Mason, E. G., and Meason, D. F. (2018). "A comparative study of three non-geostatistical methods for optimising digital elevation model interpolation." ISPRS international journal of geo-information, 7(8), 300.

Salekin, S. (2019) "Hybrid growth models for *Eucalyptus globoidea* and *E. bosistoana*: explaining within and between site variability." PhD thesis, University of Canterbury.

Salekin, S., Mason, E. G., Morgenroth, J., Bloomberg, M., and Meason, D. F. (2019). "Modelling the Effect of Microsite Influences on the Growth and Survival of Juvenile *Eucalyptus globoidea* (Blakely) and *Eucalyptus bosistoana* (F. Muell) in New Zealand." Forests, 10 (10), 857.

Salekin, S., Mason, E. G., Morgenroth, J., and Meason, D. F. (2020). "A preliminary growth and yield model for *Eucalyptus globoidea* Blakely plantations in New Zealand." New Zealand Journal of Forestry Science, (50) 2.

Salekin, S., Bloomberg, M., Morgenroth, J., Meason, D. F., and Mason, E. G. (2021). "Within-site drivers for soil nutrient variability in plantation forests: A case study from dry sub-humid New Zealand." CATENA, 200, 105149.

Salekin, S., Catalan, C.H., Boczniewicz, D., Phiri, D., Morgenroth, J., et al (2021). "Global tree taper modelling: a review of applications, methods, functions, and their parameters." Forests 12 (7).

Research provider: University of Canterbury Department of Engineering

Brown, J., Li, M., Karalus, B., and Stanton, S. (2020). "Withdrawal behavior of self-tapping screws in New Zealand Douglas-fir CLT." New Zealand Timber Design Journal. 28(2): 25-32.

Brown, J. and Li, M. (2021). "Structural performance of dowelled Cross-Laminated Timber hold-down connections with increased row spacing and end distance." Construction and Building Materials. 271: 121595.

Brown, J., Li, M., Palermo, A, Sarti, F., and Pampanin, S. (2021). "Experimental testing of a low-damage post-tensioned C-shaped CLT core-wall." ASCE Journal of Structural Engineering. 147(3): 04020357.

Brown, J., Li, M., and Sarti, F. (2021). "Structural Performance of CLT shear connections with castellations and angle brackets." Engineering Structures 240: 112346.

Brown, J., Li, M., Tannert T. and Moroder, D. (2021). "Experimental study on orthogonal joints in Cross-Laminated Timber with self-tapping screws installed with mixed angles." Engineering Structures. 228: 111560.

Brown, J., Li, M., Palermo, A., Pampanin, S., Sarti, F., and Nokes, R. (2022). "Experimental testing and analytical modelling of single and double post-tensioned CLT shear walls." Engineering Structures 256:114065.

Brown, J., Li, M., Palermo, A., Pampanin, S., and Sarti, F. (2023). "Analytical modelling of post-tensioned C-shaped CLT core-walls." ASCE Journal of Structural Engineering. 149(3):04023009.

Moerman, B., Li, M., Cao, Y., and Lim, H. (2021). "Compressive behaviour of hardwood dowel reinforced CLT loaded perpendicular-to-grain." Construction and Building Materials 302: 124137.

Moerman B., Li M., Palermo A. and Liu A. (2022). "Moment-resisting self-drilling dowel connections between steel link beams and CLT for coupled walls." Structures 41: 365-374.

Moerman, B., Li, M., Smith, T. and Lim, H. (2022). "Design and cyclic testing of bolted end plate connections between steel link beams and CLT for coupled shear walls." Construction and Building Materials 353:129060.

Moerman, B., Li, M., Smith, T., and Liu, A. (2023). "Cyclic testing of high-capacity CLT shear walls." ASCE Journal of Structural Engineering. (accepted).

Wright, T., Li, M., Lim, H., Moroder, D., and Carradine, D. (2023). "Repair and reinstatement of Douglas-fir CLT hold-down connections using mixed angle self-tapping screws." New Zealand Timber Design Journal. 56(1):29-37.

Wright, T., Li, M., Moroder, D., Lim, H. and Carradine, D. (2023). "Cyclic behaviour of CLT shear wall hold-down connections using mixed angle self-tapping screws." Engineering Structures. 286:116123.

A2.2. New Zealand Tree Grower articles

Altaner, Clemens and Palmer, Harriet (2021). Producing posts and veneer from durable eucalypt timber. NZ Tree Grower November 2021. Pages 33-37.

Berg, Peter (2016). Special Purpose Timbers research project: an introduction to the SWP. NZ Tree Grower. May 2016. Pages 12-13.

Boczniewicz, Daniel and Mason, Euan (2022). Predicting the shape and volume of *Eucalyptus globoidea* heartwood. NZ Tree Grower August 2022. Pages 42-44.

Kearns, Vaughan (2023). Encouraging investment in the New Zealand cypress industry. NZ Tree Grower February 2023. Pages 31-33.

Lausberg, Marco and Palmer, Harriet (2020). Developing a strategy for the cypress forest industry. NZ Tree Grower August 2020. Pages 24-26.

Lausberg, Marco, and Palmer, Harriet (2021). The Specialty Wood Products research programme. NZ Tree Grower August 2021. Pages 40-44.

Lausberg, Marco and Palmer, Harriet (2022). Research on non-durable eucalypts by the Specialty Wood Products Research Partnership. NZ Tree Grower February 2022. Pages 16-21.

Lausberg, Marco and Palmer, Harriet (2022). Research on Douglas-fir by the Specialty wood Products Research Partnership. NZ Tree Grower May 2022. Pages 28-31.

Lausberg, Marco and Palmer, Harriet (2022). Advances in cypress research by the Specialty Wood Products Research Partnership. NZ Tree Grower August 2022. Pages 30-33.

Lausberg, Marco and Palmer, Harriet (2023). A visit by Australian durable eucalypt growers and processors. NZ Tree Grower May 2023. Pages 41-42.

Millen, Paul (2017). Naturally durable strainer posts producing an income. NZ Tree Grower (February 2017). Page 41.

Millen, Paul, Altaner, Clemens and Palmer, Harriet (2018). Naturally durable timber posts performing well. NZ Tree Grower February 2018. Pages 24-26.

Millen, Paul and Palmer, Harriet (2019). The Dryland Forests Initiative enters a new phase. NZ Tree Grower November 2019. Pages 42-44.

Millen, Paul, Altaner, Clemens and Palmer, Harriet (2020). Growing a new hardwood industry is not just about planting trees. NZ Tree Grower February 2020. Pages 19-25.

Millen, Paul, Altaner, Clemens and Palmer, Harriet (2020). Durable hardwood peeler pole plantations: a new growing regime for eucalypts. NZ Tree Grower May 2020. Pages 8-13.

Millen, Paul and Palmer, Harriet (2020). The current value and future potential of the small-scale sawmilling sector. NZ Tree Grower November 2020. Pages 38-41.

Millen, Paul and Palmer, Harriet (2021). Establishing an industry group for New Zealand's small-scale sawmilling sector. NZ Tree Grower February 2021. Pages 39-42.

Palmer, Harriet and Millen, Paul (2016). A new era for the NZ Dryland Forests Initiative. NZ Tree Grower. August 2016. Pages 40-43.

Palmer, Harriet and Li, Minghao (2018). Testing the strength of Douglas-fir cross-laminated timber. NZ Tree Grower, November 2018. Pages 24-26.

Palmer, Harriet and Berg, Peter (2019). Major Specialty Wood Products partners lead the way. NZ Tree Grower, May 2019. Pages 30-33.

Rajapaksha, Chamira, Altaner, Clemens and Squire, Marie (2022). Evaluating the potential of *Eucalyptus bosistoana* essential oil. NZ Tree Grower November 2022. Pages 39-41.

Satchell, Dean (2021). This cypress shows promise after only 22 years. NZ Tree Grower August 2021. Pages 11-12.

Schroeder, Paul and Altaner, Clemens (2016). Propagation – a bottleneck in tree breeding programmes? NZ Tree Grower August 2016. Pages 34-36.

Weser, Carolin, Pawson, Steve and Withers, Toni (2022). Have you seen this beetle? Tracking the spread of the Eucalyptus variegated beetle. NZ Tree Grower November 2022. Pages 34-35.

Withers, Toni, McDougal, Rebecca, Harnett, Michelle and Murray, Tara (2018). Eucalyptus variegated beetle creates concern for growers. NZ Tree Grower May 2018. Pages 18-20.

Withers, Toni and Harnett, Michelle (2019). Good news for eucalypt growers: the approved release of *Paropsis charybdis* bio-control agent. NZ Tree Grower May 2019. Pages 34-35.

Withers, Toni and Cridge, Andrew (2021). Watch out I, Eadya is coming for you. NZ Tree Grower August 2021. Pages 38-39.

Wright, Mark, Lambert, Jon and Palmer, Harriet (2020). Growing, processing and marketing smaller durable hardwoods logs Australian style. NZ Tree Grower August 2020. Pages 39-41.

APPENDIX 3: DURABLE EUCALYPTS – SCHOOL OF FORESTRY PHD RESEARCH

School of Forestry post-graduate research team members funded by SWP were complemented by others who received funding from different sources. A full list of all School of Forestry PhDs associated with durable eucalypt research is provided below.

Project area	Student	Funding	Date completed	First employer
Risk and impact of insect herbivores on the development of dryland eucalyptus forestry in New Zealand http://hdl.handle.net/10092/15646 http://dx.doi.org/10.26021/3283	Huimin Lin PhD	SWP, New Zealand Plant Protection Society, Owen Browning Scholarship	2017	MPI
Heartwood formation and the chemical basis of natural durability in Eucalyptus bosistoana http://hdl.handle.net/10092/16403 http://dx.doi.org/10.26021/2444	Gayatri Mishra PhD	SWP	2018	PostDoc University of Bordeaux
Use of near infrared spectroscopy to predict wood traits in Eucalyptus species http://hdl.handle.net/10092/16040 http://dx.doi.org/10.26021/3059	Yanjie Li PhD	SWP	2018	AgResearch
Hybrid growth models for Eucalyptus globoidea and E. bosistoana: explaining within and between site variability http://hdl.handle.net/10092/16889 http://dx.doi.org/10.26021/2385	Serajis Salekin PhD	Agricultural and Marketing Research and Development Trust (2015-20117), Speciality Wood Product programme (2017-2018), T W Adams postgraduate scholarship (2018), the McKelvey Prize (2017).	2019	Scion
High throughput breeding for wood quality improvement http://hdl.handle.net/10092/17469 http://dx.doi.org/10.26021/2240	Nick Davies PhD	MPI Sustainable Farming Fund, T W Adams postgraduate scholarship	2019	AgResearch
Molecular deformation of wood and cellulose studied by near infrared and Raman spectroscopy http://hdl.handle.net/10092/16781 http://dx.doi.org/10.26021/8003	Fei Guo PhD	Chinese Scholarship Council (CSC), Sustainable Farming Fund, Specialty Wood Products Partnership, Future Forest Scholarship (NZIFF)	2019	Acedemic Fujian Agricultural University

Wood quality of durable eucalypts https://hdl.handle.net/10092/103482 http://dx.doi.org/10.26021/12583	Ebenezer Iyiola PhD	University of Canterbury PhD Scholarship, SWP	2021	PostDoc Université Laval
Seasonal, genetic and economic analysis of *Eucalyptus bosistoana* essential oil https://hdl.handle.net/10092/104452 http://dx.doi.org/10.26021/13549	Chamira Rajapaksha PhD	Sri Lanka PhD Scholarship	2022	Scion
Developing fully compatible taper and volume equations for all stem components of *Eucalyptus globoidea* Blakely trees in New Zealand https://hdl.handle.net/10092/105183 http://dx.doi.org/10.26021/14278	Daniel Boczniewicz PhD	SWP, Future Forest Scholarship (NZIFF)	2023	MfE
Eucalypt health – pest damage	Leslie Mann PhD	SWP, Future Forest Scholarship (NZIFF)	Submitted 2023	MPI
Taxonomic study of *Eucalyptus* species – genetic relatedness of *E. bosistoana*	Seol-Jong Kim	South Korean PhD Scholarship, SWP	Submission scheduled 2023	
Drying collapse of eucalypts	Vikash Ghildiyal	SWP, NZIF PhD Scholarship	Submission scheduled 2023	
Eucalypt health – phenology and ecology of the Eucalyptus variegated beetle (EVB)	Carolin Weser	SWP, Scion	Submission scheduled 2024	

APPENDIX 4: ORIGINAL STRUCTURE OF THE SWP

Research aims and timing

To optimise the delivery of value to the specialty wood products industry and the New Zealand economy, the research programme has three distinct aims:

1. **Research Aim 1** (RA1): Improving returns from the current value chain until new germplasm is delivered (current resource)
2. **Research Aim 2** (RA2): Creating a superior, more readily processed and consistent wood supply for the future (future resource)
3. **Research Aim 3** (RA3): Delivering higher-value products to export markets through embedding regional strategies (with strong support in-kind from co-investors).

These research areas identified to achieve these three research aims over the seven years of the SWP programme are illustrated below:

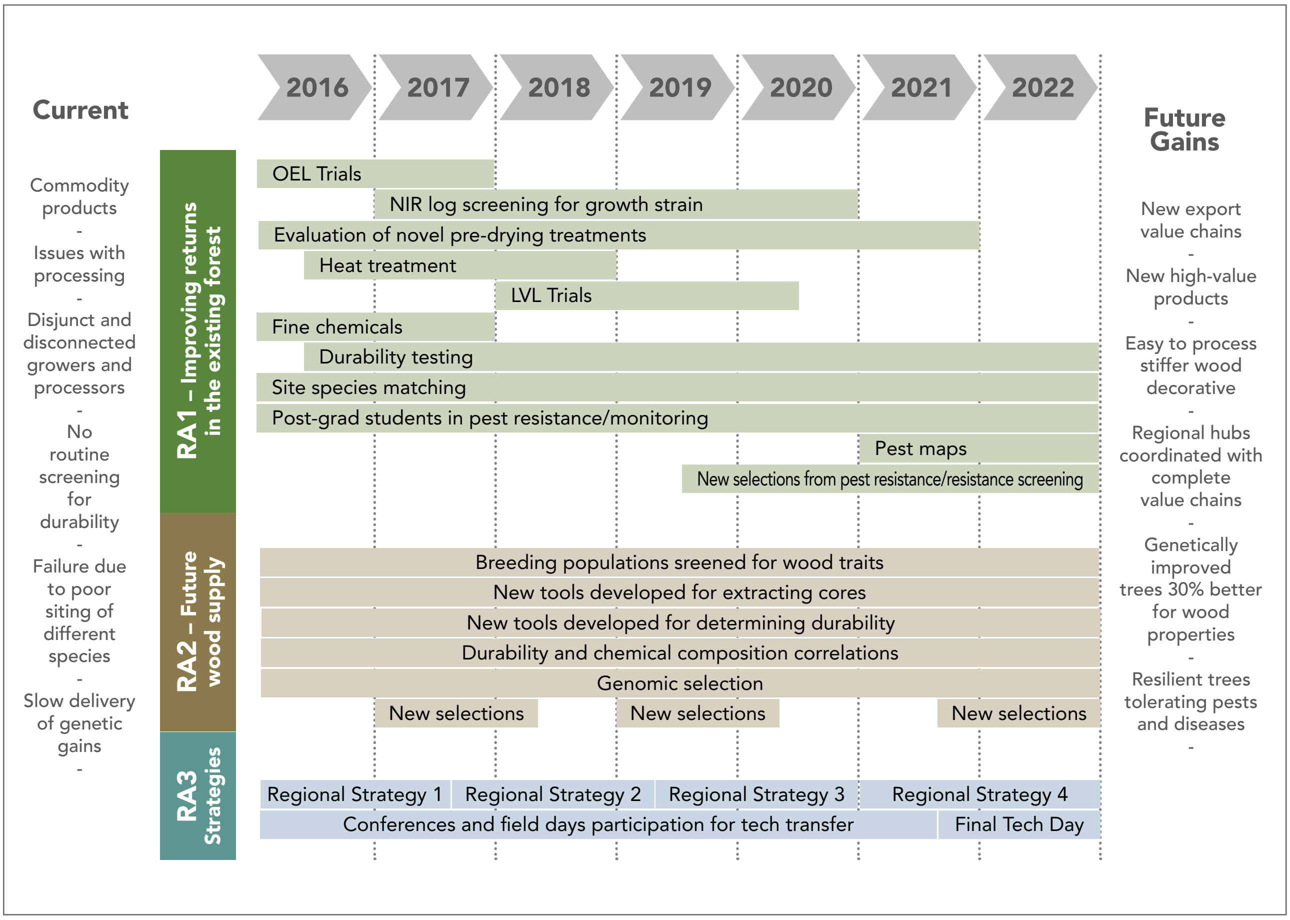


Figure 38: SWP's original seven-year high-level research plan.

Full details of the original programme are covered in detail in the Specialty Wood Products Research Partnership Programme Description.

APPENDIX 5: CONTRIBUTORS TO SWP

SWP Programme Manager

Marco Lausberg, Forest Growers Research

Project Steering Group members

Individual	Company	Role in company
Peter Berg	Berg Forests Ltd	Chairman
Graeme Manley	Southwood Exports Ltd	General Manager
Sean McBride	Juken New Zealand Ltd	National Forest Manager
Bruce Manley	University of Canterbury	Head of School of Forestry
Phil Delamare	Ernslaw One	South Island General Manager
Doug Gaunt	Scion	General Manager
Angus Gordon	NZ Farm Forestry Association	Executive Member
Paul Adams	Forest Growers Research /FOA	R&D Director
Shaf van Ballekom	Proseed NZ	Managing Director
Alison Slade	MBIE	Principal Investment Manager

Technical Steering Team members

Individual	Company	Role in company
John Moore	Timberlands Limited	Inventory and Trials Manager
Brendan Smith	Juken New Zealand Ltd	Mill Manager
Clemens Altaner	University of Canterbury	Associate Professor
Mark Dean	Ernslaw One Ltd	Forestry Planner
Vaughan Kearns	NZ Farm Forestry Association	NZFFA Executive/Research Manager
John Filmer	Southwood Exports Ltd	Forest Manager
Shawn Foster	Southwood Exports Ltd	Forest Manager
Paul Millen	Millen Associates Limited	Research Manager
Toby Stovold	Scion	Scientist
Andrea Stocchero	Scion	Portfolio Leader
Jack Burgess	Port Blakely	Silviculture Forester
Rosie Sargent	Scion	Scientist
Marco Lausberg	Specialty Wood Products	Programme Manager

SWP members

Ministry for Business, Innovation and Employment,
Forest Growers Levy Trust, City Forests Ltd.,
Ernslaw One Ltd., Juken New Zealand Ltd.,
Lake Taupo and Rotoaira Forest Trusts,
Marlborough Lines, Marlborough Timbers Ltd.,
New Zealand Farm Forestry Association,
Port Blakely Ltd., Southwood Export and Southland
Plantation Forest Company,
Te Tumu Paeroa, Timberlands Ltd.

Key research providers

University of Canterbury

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Minghao Li, Thomas Lim, Bruce Manley, Euan Mason,
Tara Murray, Justin Morgenroth, Steve Pawson,
Pieter Pelser, Monika Sharma, Vega Xu

Marlborough Research Centre

Kevan Buck, Susan Foster, Gerald Hope, Roger May,
Ruth McConnochie, Paul Millen, Harriet Palmer

Proseed NZ

Paul Schroeder, Shaf van Ballekom

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Tripti Singh, Andrea Stocchero, Toby Stovold,
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