Tree Breeding & Genetic Improvement
Research Development & Extension Investment Plan
2019–2024

APPENDICES

FINAL REPORT– Forest and Wood Products Australia Limited

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PTM Solutions
Developing Pathways to Market

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Appendix Two: A framework for investment in tree breeding and genetic improvement within the Australian forest plantation industry

Tree improvement, or as it is often referred to as genetic improvement, is the process of improving the genetic quality of a tree species. Despite recent advances in genetic improvement, the key forest plantation taxa within Australia (*Eucalyptus sp., Pinus radiata* and Southern Pine) remain genetically close to their wild relatives. As such, considerable variation exits for economic traits between different populations within a species, and also between individual trees within populations. This presents both an opportunity and a challenge in the genetic improvement of forest plantations for productivity and quality.

The opportunity exists to improve the value of a species by identifying the best wild seed sources (i.e. genetic evaluation); and also, to select individuals within these to develop selections (i.e. genetic improvement) that are considerably better than the wild material or previous selections used for commercial production[1].

Since the introduction of the first plantations in Australia tree breeders have constantly strived for genetic improvement from one generation to the next through constant selection of material which demonstrated superior performance in key selection traits. As a result, current *Eucalyptus* sp., *Pinus radiata* and *Southern Pine* selections are yielding significantly higher than in previous decades.

For wood production, growth rate, whether in height, diameter, basal area or volume, is the trait most commonly considered for improvement. In the case of pulpwood, important additional components of wood quality include density, pulp yield as well as traits such as fibre length, cell width, cell-wall thickness and proportion of reaction wood.

The art of the breeder is to identify the element of genetic variation which is the target for genetic improvement that will be passed on from parent to progeny and isolate it from the more random effects of development and environment. Traditionally this has been a difficult and time-consuming process, involving a whole system of species, provenance and progeny trials, however the basis of tree improvement lies in the possibility of selecting trees which possess heritable, rather than non-heritable, superiority in desirable characteristics[2].

1.1 Why genetic evaluation and genetic improvement are necessary in the plantation forestry industry?

Banks (1997)[3] stated that the observed performance (P – Phenotype) of all living things results from the joint action of the genes (G) of that individual and the effects of the environment (E). This is simply expressed as in the formula: **P = G x E**.

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[1] www.forestryfocus.ie/growing-forests-3/establishing-forests/reproductive-material/tree-improvement
[2] R.L. Willan. (1988). Benefits from tree improvement, Danida Forest Seed Centre, Humlebæk, Denmark
[3] Banks, R. (1997) Investment in Genetic Evaluation and Improvement. (2nd Draft) Pers Comm.

Phenotypes vary between individuals within a population, because individuals vary in their genetic makeup and in the environments they exist. Phenotypic variation will therefore be a combination of:

- Developmental variation (e.g. a mature tree is bigger than a young seedling of the same species)
- Environmental variation (e.g. a tree on a good site is bigger and healthier than one of the same species and age on a poor site)
- Genetic variation (e.g. one tree may be bigger or straighter than another of the same species and age growing on an identical site).

This is usually expressed as: Variance (P) = Variance (G) + Variance (E)

Based on this equation choosing individuals with better genes to be parents will result in a better progeny (i.e. better P) than choosing parents at random. If this process can be repeated generation after generation, successive generations of progeny will show better and better P (or maintain P in the face of declining E (i.e. climate change).

Choosing individuals with better genes requires identifying their genetic merit, selections can be ranked from 'poor' to 'elite' – this is genetic evaluation. Using these 'elite' selections as parents in a breeding program and repeating the process – this is genetic improvement.

- ***Genetic evaluation*** will allow better progeny generations to be bred than would otherwise result from random mating.
- ***Genetic improvement*** will allow continuous increase in the average genetic merit of successive generations.

It is important to note that genetic improvement requires genetic evaluation, but not the reverse[4]. Genetic improvement can not only compensate for environmental variance due to abiotic and biotic stress (e.g. climate change, pest tolerance), genetic improvement can also compensate for changing market values in 15 – 30 years post planting for end use products (i.e. declining product prices or declining terms of trade).

1.2 Where is value generated from genetic evaluation and genetic improvement?[5]

The overall enterprise of genetic evaluation and improvement can be broken into three steps:

1. **Data collection**. This is typically undertaken by breeders acting individually, or more recently where some collective investment from organisations (e.g. Tree Breeding Australia)[6] on behalf of their members into reference populations, and also some

[4] Banks, R. (1997) Investment in Genetic Evaluation and Improvement. (2nd Draft) Pers Comm.
[5] Anon, (2015) Livestock Genetics Investment Priorities - Industry Discussion Paper 5. MLA.
[6] Tree Breeding Australia (Formerly Southern Tree Breeding Association) http://www.stba.com.au

collection of data from a range of points along the value chain (e.g. from the miller the proportions of different quality material cut from logs).

2. **Transforming data into information**. This depends on knowledge of how records of individual performance (phenotypes) relate to genotype (which means knowing genetic parameters), being able to make valid comparisons, and having software that can handle extremely heterogeneous data. The end result is estimates of relative genetic merit (i.e. Estimated Breeding Values; EBVs), all in the form of comparative values (i.e. compared to some base)[7].

3. **Harvesting this information to generate wealth**. Estimates of genetic merit are turned into wealth by choosing from which breeding program (Internal and/or external) to select a parent(s).

Each section or step can be defined in terms of what maximises value at that point, which can then form the basis of quality control.

Three different forms of value, or types of benefit, are generated:

1. **The ability to make informed choice.** This reduces the risk of a negative outcome which can include paying too much for a parent with a particular genetic merit or getting the wrong genetics for a particular job. This ability to make better choices increases as the number of parental lines with genetic information and the accuracy of that information increases[8].

2. **The ability to generate genetic improvement over time.** This enables enterprises throughout the value chain to combat the cost-price squeeze. (i.e. if a breeder can deliver a log to a miller which generates a greater proportion of high quality – high value wood there is the incentive to distribute some of this incremental value back to breeders so as to support further research into delivery of additional improvement). The value over a period of time is simply the sum of the annual increment in genetic merit as measured through economic value. This is wealth that the industry would not have if there was no genetic improvement (i.e. Opportunity Cost/ Benefit).

3. **The ability to make better management decisions assuming the genetic merit of the trait of importance is known.** The size of this benefit has not been estimated, but it could be generated in many ways. However, this benefit is not cumulative as it is a management decision– it does not grow over time in the way that genetic improvement does.

[7] Theo Meuwissen, Ben Hayes, Mike Goddard, Genomic selection: A paradigm shift in animal breeding, *Animal Frontiers*, Volume 6, Issue 1, January 2016, Pages 6–14, https://doi.org/10.2527/af.2016-0002

[8] Banks, R.G., "Who Benefits from Genetic Improvement?" Proc. WCGALP 10 (2014)

1.3 Investment in genetic evaluation and genetic improvement research and development (R & D)

Research into genetic evaluation and genetic improvement typically focusses on one of three aspects:

1. **Breeding program goals:** involves market and product research designed to allow optimal weighting of genetic gain across different traits. This goal will assist industry more profitably target or direct its genetic change, including the knowledge required to determine whether multiple targets will be optimal.
2. **Genetic evaluation:** involves partitioning observed variation (Variance in P) into its genetic (G) and environmental (E) components, and of increasing importance, determining the strength(s) of genetic relationships amongst different traits. The goal allows values to be produced for a set of traits and provides an input to 3).
3. **Breeding program design:** focuses on the effects of different strategies for measurement, selection, crossing/mating and multiplication. This goal produces the rules for designing breeding programs, drawing on 1) and 2) that allow breeders (or industry) to maintain high rates of well targeted, sustainable improvements.

Banks (1997) noted that 1) and 2) incur mainly investment into personnel costs (although formal market research for determining the value of different product attributes will require data collection) and computing time. Whereas, 3) is different in that it requires data for particular traits (usually not previously measured) be collected from a reference population, together with other traits of interest[9]. These principles are highly relevant to forest plantation improvement.

Historically, analysis of the data collected has been time consuming and expensive, however with the rapid advancements in IT technology and capacity, together with advancements in the science of bioinformatics has significantly reduced the time and cost of data analysis.

Advances in the fields of phenomics, genomics and bioinformatics has enabled the expansion in the scope of the analysis that can be undertaken on the data collected for both current traits and additional traits. To date the major cost of generating phenomic data is the collection and collation of the data, however with the rapid development of data collection technology (e.g. drones, automated glasshouses etc) the scope of the data collected for current and additional traits, together with the cost of collection is declining exponentially over time.

Banks (1997) went onto identify three additional core areas for research investment related to genetic improvement:

1. **Measurement, data handling and reporting** – costs associated with data collection, collation into databases which are readily accessible for data analysis, and the results reported to breeders.

[9] Banks, R. (1997) Investment in Genetic Evaluation and Improvement. (2nd Draft) Pers Comm.

2. **Advice** – the provision of support by an appropriately skilled advisor(s) to breeders and commercial producers to understand, adopt and translate the information generated into the generation of 'elite' planting material that delivers an incremental economic advantage over previous generations.
3. **Management** – for an industry driven approach to genetic improvement, an overall management system will be required to gather information relating to the impact of the performance of the 'elite' planting material. The information collected can be used to measure the rate and impact of genetic improvement as measured against historical base line criteria (e.g. market share, product value, exports, profitability etc).

1.4 Implications for the FWPA Investment Plan for genetic improvement in the Australian forest plantation industry.

Research and Development (R & D) is the term commonly used to describe the activities undertaken by firms and other entities such industry representative organisations (e.g. FWPA) in order to create new or improved products and processes. The broadest meaning of the term covers activities from basic scientific research performed in universities and laboratories all the way to testing and refining products before commercial sale or use.

Basic research is research undertaken primarily to acquire new knowledge without a view as to its application. Applied research is research directed towards a specific objective and development is work drawing on existing research results and directed specifically towards the creation of new and improved products and processes[10].

The Frascati Manual of the Organization for Economic Cooperation and Development (OECD), first published in 1963, defines R & D as *"…creative work undertaken on a systematic basis in order to increase the stock of knowledge, including knowledge of man, culture and society, and the use of this stock of knowledge to devise new applications*"[11].

Within the context of R & D that is directed towards genetic evaluation and genetic improvement within the Australian forest plantation industry the following more focused definition developed by Banks (1999)[12] applies:

- **Research (R)** means understanding genetic variation and how to manage or exploit it
- **Development (D)** means everything aimed at harvesting the value inherent in the described genetic variation. (Note: This includes **Extension (E)** related activities)
- Research is the only discretionary cost of an industry – everything else is essentially some form of cost of production. The amount of and return on Research effectively determines the long-term success of an industry.

[10] Hall, B.H. (2006) Contribution to the International Encyclopedia of the Social Sciences, second edition.
[11] Anon, (2019) www.oecd.org/sti/inno/frascati-manual.htm
[12] Banks, R. (1997) Investment in Genetic Evaluation and Improvement. (2nd Draft) Pers Comm.

Banks (1997) suggests that modern breeding technology has made improvement virtually automatic and able to be achieved at far higher rates than have been traditionally achieved. This means that high quality market research (i.e. what to breed for?) is critical, as is investment in understanding the genetic variation so that all (or at least as many as possible) effects of genetic change can be predicted before they occur.

The effectiveness of modern breeding technologies fundamentally changes how R & D is defined and the framework for investment. To this end the methodology adopted in preparing the FWPA 5 year R, D & E investment plan for genetic improvement in the Australian forest plantation industry (2019 – 2024) has focused on generating high quality market research generated by domestic and international industry participants from across the value chain, with a focus on identifying:

- What are the current and future traits (priorities) that industry want focused on to improve the value of the *Eucalyptus sp. and Pinus Radiata* plantation products?
- The current industry status with regard to its capabilities and capacity in genetic evaluation and improvement that will enable it to focus on the industry priorities
- What are the plantation industries current strengths and future opportunities that will contribute to genetic improvement and increasing value within the industry and what are its current weaknesses and potential threats (i.e. barriers) that will inhibit achieving these outcomes?
- What industry driven prioritised opportunities exist within the following categories for industry wide investment during the next 5 years and beyond to improve the value of the *Eucalyptus sp.* and *Pinus radiata* plantation industry:
    - Breeding Program Goals
    - Genetic Evaluation Technologies
    - Breeding Program Design
    - 'In-field' measurement of key traits of interest,
    - Data handling, storage, management, access, analysis and reporting technologies
    - Advice Management.

Appendix Three: The current status of tree breeding and genetic improvement research in Australia.

3.1 Australian tree breeding and genetic improvement research[13]

Australia has gained a substantial base of scientific understanding of the characteristics and functions of its unique forest ecosystems, based on more than 100 years of research in a broad range of forest areas. This knowledge is required to underpin sustainable forest management.

Australia's capacity to conduct and apply forest R&D at the national level has been coordinated and delivered through a number of organisations, including the:

- Australian Bureau of Agricultural and Resource Economics and Sciences
- Australian Centre for International Agricultural Research
- Commonwealth Scientific and Industrial Research Organisation
- Forest and Wood Products Australia
- Cooperative Research Centre for Forestry
- Bushfire and Natural Hazards Cooperative Research Centre
- Plant Biosecurity Cooperative Research Centre (No longer exists)
- Terrestrial Ecosystem Research Network.

The capacity of Australia's states and territories to conduct and apply forest R&D is led by the government agencies that are responsible for forest policy, management or conservation in each jurisdiction. Much of this state and territory forest research effort is conducted in collaboration with other organisations, including national organisations such as CSIRO and various CRCs as well as universities, and can involve state and territory government research units hosted by these institutions.

Much of our scientific understanding of Australia's forests is developed in universities, with the capacity for forest research present at a number of Australia's universities. Research is carried out both by university research staff and by students enrolled in Honours, Masters or Doctoral degrees. Universities produce high-quality, peer-reviewed research that adds to the development of assessment methodologies and the scientific understanding of Australia's forests, and which is needed to underpin sustainable forest management. Many academic institutions contribute to the range of forest research programs established under research agencies funded by the Australian Government, as well as research agencies funded by state and territory governments. In addition, research centres and facilities at universities provide

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[13] Montreal Process Implementation Group for Australia and National Forest Inventory Steering Committee, 2018, Australia's State of the Forests Report 2018, ABARES, Canberra, December. CC BY 4.0.

focal points for research training and collaboration, including with other universities, government agencies and the private sector.

In addition to public sector engagement in forestry related R,D & E there are a number of private sector companies engaged in R,D & E. The scope of private sector companies engaged in R, D & E range from large scale fully integrated multinational companies through to small companies which have a focus of providing specific services to the industry.

3.2 Australian Forestry R, D & E - Scope

In an industry survey undertaken as background research to the current project 30 industry participants representing a cross section of public (7) and private (21) sector organisations from Australia plus two (2) public sector organisations from New Zealand were asked to indicate which spheres of R,D & E they were engaged (**Figure 1**).

Of the fields nominated all 30 public and private sector participants were engaged in tree breeding and genetic improvement R,D & E followed by management and mensuration (21) (including growth modelling), pests and diseases (20), remote sensing/GIS (17), silviculture (22) and soils and nutrition (20).

By contrast in a study reported in the FWPA R,D & E Strategy for the forests and wood products sector (2010)[14] in which Turner et al., (2009)[15] looked at what fields of R,D & E people were engaged. The study indicated that the predominant field in which people were engaged was soils and productivity, followed by tree breeding and genetic improvement, ecology, wood science and technology. Turner (2009) went onto suggest that discussions with employing organisations indicated that since 1990 the major decline had occurred in research fields, such as forest health, silviculture and forest hydrology.

In terms of the scope of R,D & E field's public and private sector industry participants are currently engaged, the number of fields ranged from one to thirteen. With two private sector organisations indicating they were engaged in all R,D & E fields nominated. By contrast there were no public sector organisations engaged in all 13 fields nominated (**Figure 2**).

In relating to tree breeding and genetic improvement, of the 21 private sector respondents to the survey, 16 (76%) indicated that they only undertook internal focused research. Of the remaining private sector (5) and public sector organisations (9) they indicated that they were undertaking contract research for a mix of Australian and international private and public sector organisations (**Table 1**).

[14] Anon. (2010), R, D & E Strategy for the Forest and Wood Products Sector. FWPA. ISBN 978-1-920883-95-9
[15] Turner J and Lambert M (2009). Expenditure on Forestry Research and Forest Products Research in Australia 2007–2008, report prepared for Forest and Wood Products Australia, Melbourne.

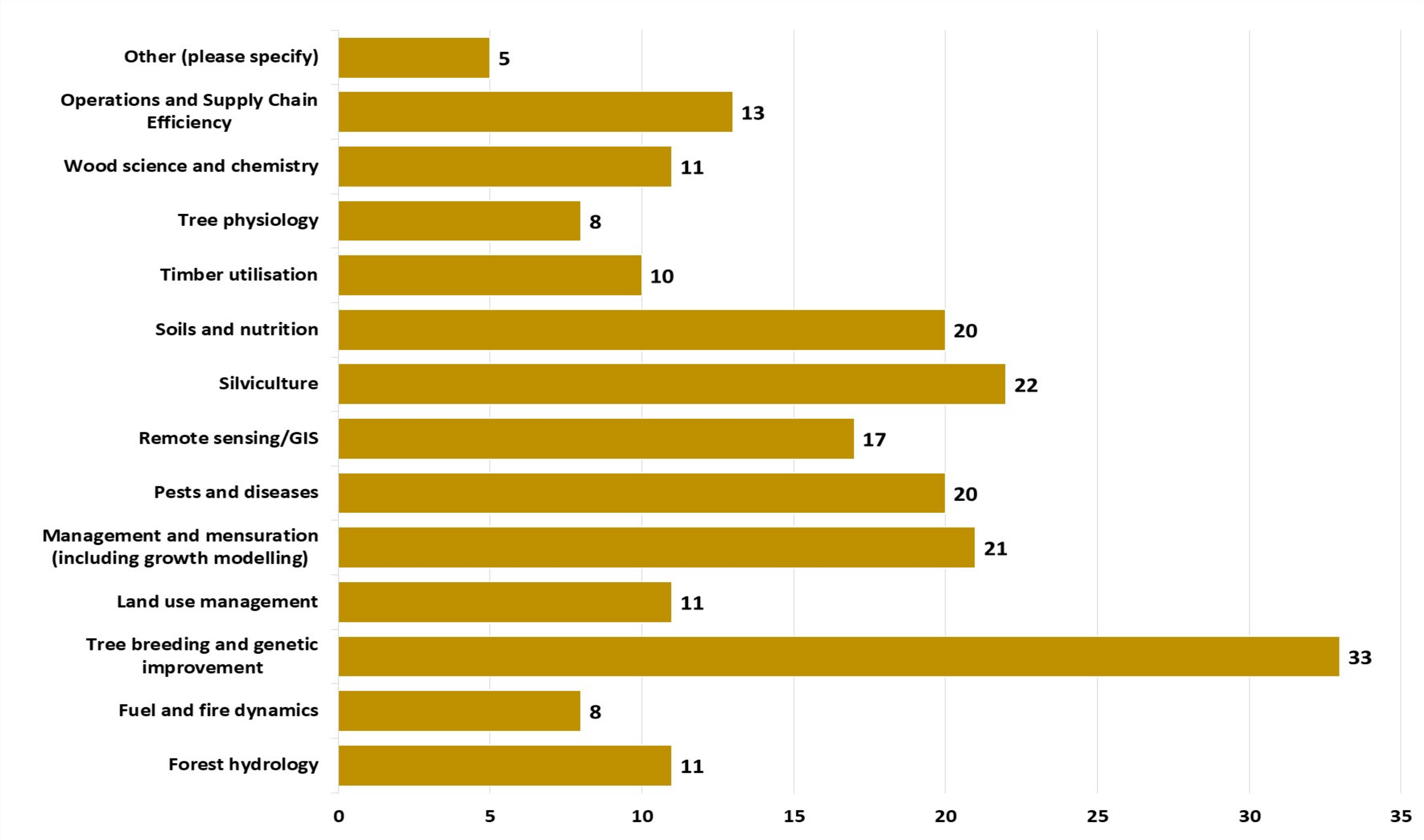

Figure 1. Current fields of forestry R,D & E that public and private sector organisations are engaged (2019).

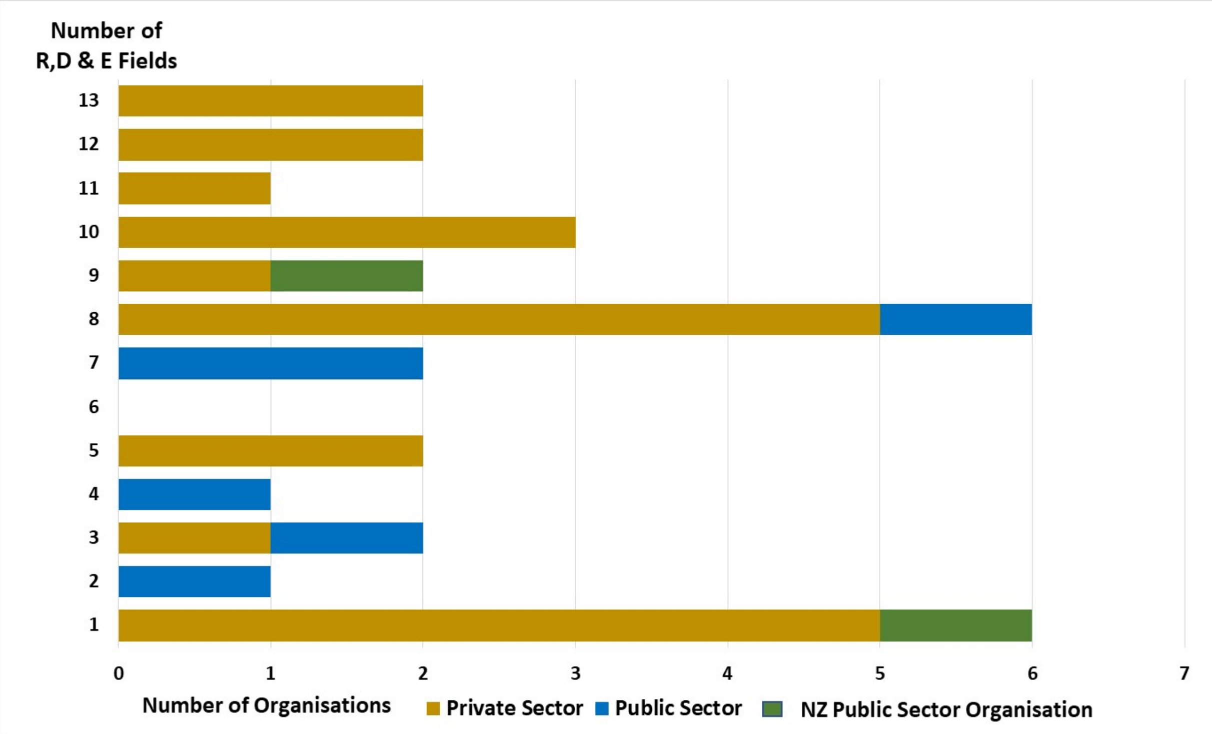

Figure 2. Scope of R,D & E across the public and private sector.

Table 1. Sectors undertaking research on tree breeding and genetic improvement

Research Client (Multiple responses accepted)	Responses
'In-House' Only (Private Sector Companies)	**16**
Forest Industry (Public Sector)	**12**
Individual industry participants (Private sector contracts)	**15**
Individual industry participants (Public sector contract)	**6**
International industry participants (Private sector contracts)	**9**
International industry participants (Public sector contract)	**3**
Other	**8**

3.3 Technical Capability

3.3.1 Universities[16]

The majority of Australia's research capability is located primarily within various universities, public sector research institutions and to a lesser extent within the private sector.

In the 2015 Excellence Research Australia survey eight Australian universities reported activities in the field of forestry sciences:

- Australian National University,
- Murdoch University,
- Southern Cross University,
- University of Melbourne,
- University of Queensland,
- University of Tasmania,
- University of the Sunshine Coast, and
- University of Western Sydney.

Research in forest products also occurs at Monash University (through the Australian Pulp and Paper Institute) and Queensland University of Technology (through the Biorefineries for Profit project). In Tasmania, the ARC Centre for Forest Value situated on the University of Tasmania's Hobart campus was established in early 2016. The research effort of the centre covers forest ecology and restoration, timber in service, and supply chain information management, and the Centre also trains forest scientists to work within the forest industry. In the north of the state the Architecture and Design School have produced and tested engineered timber products from plantation timbers.

In Queensland, the Forest Industries Research Centre (FIRC), located at the University of the Sunshine Coast, is focused on issues relating to complex forestry value chains, and thus the economic and environmental sustainability of forest industries. This approach covers research disciplines including genetics and genomics, silviculture and stand management, forest health and pest management, ecology and biodiversity management, timber and biomass harvest and haulage, fibre quality and value, timber processing and biorefinery, renewable energy and biofuels, and timber construction materials.

Also, in Queensland, the Centre for Future Timber Structures, University of Queensland, is a Centre of Excellence for the education of future timber industry professionals and innovation in the use of timber in the built environment. Areas of research include fibre-reinforced timber composites, fire safety of timber structures, and timber use in advanced manufacturing.

[16] Montreal Process Implementation Group for Australia and National Forest Inventory Steering Committee, 2018, Australia's State of the Forests Report 2018, ABARES, Canberra, December. CC BY 4.0.

In New South Wales, the Western Sydney University Hawkesbury Institute for the Environment operates the world's only 'free air carbon dioxide enrichment' (FACE) experiment in native forest (EucFACE), as well as a series of Whole-Tree Chambers in the Hawkesbury Forest. EucFACE is designed to predict the effects of rising atmospheric carbon dioxide (CO_2) levels on Australia's native forests, including trees, animals, soil and grasses. The Whole-Tree Chambers provide enclosed, controlled environments for trees up to nine metres tall, in which researchers manipulate air temperature, soil moisture, irrigation, CO_2 levels and humidity to determine the integrated effects of altered climates on tree physiology.

Also, in New South Wales, researchers at Southern Cross University's Forest Research Centre investigate the ecology of native forests both in Australia and overseas, as well as studying how native forests and plantations can sustainably produce wood products, environmental services and carbon. Particular areas of focus include tropical and subtropical forestry and agroforestry, computer modelling for forest management and decision-support systems, forest ecology and management, forest genetics, new products from trees, mixed-species plantations, and community engagement in land-use planning.

In the Australian Capital Territory, the Fenner School of Environment and Society at the Australian National University takes a multi-disciplinary approach to research, research training and policy in environment and sustainability, including issues relating to the management, conservation and sustainability of forest ecosystems. The School includes economists, hydrologists, historians, ecologists, foresters, geographers and climatologists, working both nationally and internationally.

In Western Australia, the State Centre of Excellence on Climate Change, Woodland and Forest Health at Murdoch University focuses on tree, woodland and forest decline under climate change, with the aim of restoring biodiversity values, and developing policies and action for the restoration of woodlands and forests.

In Victoria, the Integrated Forest Ecosystem Research (IFER) program is a research initiative between the School of Ecosystem and Forest Sciences at the University of Melbourne and DELWP. It aims to enhance the evidence base for managing the impacts of fire, climate and management regimes on multiple forest values in Victoria's forest ecosystems. The IFER program investigates forest ecosystems in Victoria under six main landscape-level themes: fire behaviour, carbon, biodiversity, water, vulnerability, and social and economic values.

3.3.2 Research Institutions

CSIRO

CSIRO is the major Australian public sector organisation engaged in forestry research where they are leading the way in forest processes research in Australia, specialising in forest growth, health and responses to environment, and understanding and managing risks to forests, such as bushfires, pests and diseases and climate change.

CSIRO's skills in physiological ecology, biogeochemistry, forest management and bushfire science are being applied to address questions such as:

- sustainable forest production, and the environmental controls over forest growth including impacts of extreme (drought, high temperature) events and rising atmospheric CO_2 concentrations
- water uptake by forests and implications for forest management to control catchment water supplies; management of riparian zones with forests for control of water quality
- carbon accounting and natural capital accounting in a range of planted and natural forests and management impacts; measurement of fire conditions on greenhouse gas emissions
- growing and managing forests in developing countries for poverty alleviation, including genetic selection, nutritional management, sustaining the soil resource and impacts of management
- predicting risk from bushfires, effectiveness of prescribed burning and suppression and emergency response; potential impacts of future climates and fire regimes on fuel loads and risk.

CSIRO undertakes research across a range of spatial and temporal scales, from tissue to leaf/wood, to tree, forest and landscape, both within-years and across decades.

CSIRO's knowledge of forest growth and carbon sequestration have been applied to develop models, specifically 3-PG2 and Cabala, which are widely used around the world to improve management of planted forests.

AgrBio - Centre for AgriBioscience

AgriBio, Centre for AgriBioscience is a joint initiative of the Government of Victoria, through the Department of Jobs, Precincts and Regions (DJPR), and La Trobe University (La Trobe).

AgriBio is one of Australia's premier biosciences facilities, with a key emphasis on supporting and protecting Victoria's A$11.6 billion agricultural sector by focussing on cutting-edge research to:

- improve productivity
- fight disease and
- reduce environmental impact.

The facility is located at La Trobe Universities campus in Bundoora and accommodates over 400 government and La Trobe University staff, including scientists, students, business and science-support staff.

AgriBio, Centre for AgriBioscience, is a major international facility for plant, animal and microbial biosciences and biosecurity research and diagnostics. Research at AgriBio spans the spectrum from strategic to applied science.

Joint scientific programs include:

- world-leading gene discovery and functional genomics in major plant and animal species of importance to Victoria and Australia
- molecular breeding for disease resistance, drought tolerance, bioenergy and health
- molecular diagnostics, biological control and other management strategies for weeds and plant and animal pests and diseases of importance to Victoria and Australia
- physiology and genetics related to plant and animal bioactives and health
- the development of sustainable systems for animal and plant production.

Collaborations include animal, plant, soil and microbial biosciences, ecology and biodiversity.

Potential collaborations may include forensic science, nanotechnology, electronic engineering / sensor technology, e-science, physics, and chemistry.

A multi-disciplinary and collaborative approach to research and development is increasingly seen as a more effective way to tackle complex problems, rather than in isolation, leading to better, and more innovative science outcomes.

Scion (NZ)

In New Zealand the leading public sector research capability resides with Scion[17]. Scion is a Crown Research Institute (CRI), which is a government-owned company that carries out scientific research for the benefit of New Zealand. Scions primary purpose is to focus on contributing to:

> "*To drive innovation and growth from New Zealand's forestry, wood product and wood-derived materials and other biomaterial sectors, to create economic value and contribute to beneficial environmental and social outcomes for New Zealand."*

Scion has industry defined three research impact areas to 2030 that it will focus its expertise to deliver maximum impact for New Zealand.

- **Forests and landscapes** - Development of healthy, resilient forests that are planted primarily for their standing- forest benefits.
- **High-value timber manufacturing and products** - Development of products, manufacturing, high-value trees and healthy, resilient forests that capture an increasing share of the global high-end market for timber.

[17] Anon. (2019) https://www.scionresearch.com

- **Bio-based manufacturing and products -** Development of products, processes, manufacturing, trees, other biomaterials and healthy, resilient forests to replace petrochemicals and non-sustainable materials

Each impact area spans the forest industry value chain. For each impact area, Scion will take a designed 'gene-to-product' value chain approach, reflecting both current and new or emerging opportunities to fast track New Zealand into increasing its standard of living while achieving its low-carbon future, government policy and industry targets. Research capabilities with Scion include the following:

- Automation and robotics specialists
- Bioenergy researchers
- Bioinformatics
- Biotechnologists
- Chemists
- Data scientists
- Environmental technologists
- Fermentation specialists
- Fire researchers
- IP specialists
- Material scientists and engineers
- Mechanical and structural engineers
- Microbiologists
- Molecular biologists
- Multi-scale modellers
- Product designers and developers
- Packaging technologists
- Pest and disease researchers
- Physicists
- Plant geneticists, breeders and physiologists
- Silviculturists
- Social scientists
- Soil scientists
- Value chain
- optimisation researchers

3.3.3 Private Sector

Within the private sector, a number of private consultants and companies such as Tree Breeding Australia (formerly Southern Tree Breeding Association) provide important contract research, development and extension (consulting / advice) services to the plantation industry in Australia and internationally in the field of tree breeding and genetic improvement.

Tree Breeding Australia (formerly Southern Tree Breeding Association)[18]

Tree Breeding Australia formerly the Southern Tree Breeding Association Inc. (STBA) is the national body which manages the Australian tree improvement programs for Radiata Pine (*Pinus radiata*) and Blue Gum (*Eucalyptus globulus*) and provides genetic evaluation services in forest trees. TBA is essentially a not for profit cooperative in which works is funded by industry members funded on the basis of production area.

TBA was formed in 1983 to develop improved genetics for plantation forestry. The business is based in Mount Gambier but has expanded to service member companies in Western

[18] Tree Breeding Australia (2019) http://www.stba.com.au

Australia, South Australia, Victoria, New South Wales, ACT, Tasmania and New Zealand. TBA has consolidated genetic resources developed over more than sixty years by private companies, State and Federal Governments in order to breed better genetics more cost effectively.

TBA uses natural breeding methods to breed new trees by mating (cross-pollinating) superior females (flowers) with elite male (pollen) parents to produce higher performance progeny (seed) with improved growth rates and superior wood quality. Progeny of elite crosses are rigorously tested in many genetics trials which are planted across temperate Australia in order to identify elite trees with potential for improved productivity.

Individual tree data is collected on growth rates, branching characteristics, stem straightness and form, wood quality and fibre properties, and resistances to pests and diseases. This information is analysed on a national basis and used to select the best trees for use in each region.

TBA uses the leading edge TREEPLAN® genetic evaluation system for ranking trees on genetic merit. The TREEPLAN® system is a world first in that it can use all performance data and pedigree information available to produce robust genetic values for all production regions in Australia. The TREEPLAN® system of genetic evaluation has dramatically changed the way TBA tests and identifies elite material for Industry use, ensuring Members have the opportunity to capture gain without delay. The systematic approach enables TBA to undertake breeding activities every year and update TREEPLAN® breeding values regularly to assist in identifying the best material for use in industry deployment programs.

The TBA provides scions for grafting by TBA member companies and SeedEnergy Pty Ltd into seed orchards to produce commercial quantities of genetically improved seed. Quality genetics is also available to non-members of the TBA, but subject to payment of royalties when purchasing plants.

TBA is also developing and testing Radiata Pine clones for commercial potential under Australian conditions. TBA is a not for profit Association. It is more cost effective for forestry growers to be a member of the cooperative programs and share the operational cost of breeding with other companies.

TBA has five member organisations that are internationally recognised as leading forestry and genetics research agencies: CRC for Forestry, Ensis (a joint venture between CSIRO-FFP and Scion NZ), the University of Melbourne and the University of New England (AGBU).

These partnerships in genetic research ensure the commercial breeding programs of TBA for Radiata Pine and Blue Gum are world class. Innovative research projects include the development of economic breeding objective functions for Pine and Blue Gum, the Juvenile Wood Initiative for Pine, and enhancements to the TREEPLAN® genetic evaluation system. Many research projects are also done in partnership with the Forest and Wood Products Research and Development Corporation.

With the introduction of TREEPLAN®, the TBA has been able to adopt progressive rolling front breeding and testing strategies for P. radiata and E. globulus. This means greater genetic gain is captured per unit time, but also more cost effectively for individual companies. TREEPLAN® allows industry to benchmark genetic material from different breeding programs, provided there are some related trees and data is made available for inclusion. TREEPLAN® is continually being enhanced to incorporate new innovation developed through research.

TBA is currently establishing a National Genetic Resource Centre at Mount Gambier for breeding and conservation purposes. This will further consolidate the Pine and Blue Gum genetic resource, but also provide operational efficiencies in breeding operations.

TBA members (industry), Forest and Wood Products Research and Development Corporation and South Australian Government are funding this strategic initiative. The centre will service the Australian forestry sector, but also enhance relationships with the New Zealand industry.

Gondwana Genomics[19]

Gondwana Genomics are providing contract services for the application of genetic marker-assisted selection (MAS) for the purpose of accelerating selection of 'elite' parents within plantation breeding programs.

Staffed by ex- CSIRO scientists, Gondwana Genomics is providing services to clients within Australia and internationally from their research facility which is located within the Australian National University campus in Canberra. Its primary focus is on applying its recently developed next-generation genotyping platform which allows for cost-effective implementation of a testing program, fast turnaround and high accuracy.

Gondwana Genomics is a global leader in molecular tree breeding services for eucalypt plantation companies. With over 10 years of experience in genomics research.

The markers developed by Gondwana Genomics assist clients in maximising yield, while maintaining genetic diversity in breeding populations. Through the application of marker-assisted selection (MAS) technology Gondwana Genomics is paving the way for tree breeders to achieve future improvements in commercial traits, to address disease threats, and to adapt to changing commercial priorities.

Gondwana Genomics next generation testing platform, including DNA finger printing is providing a wealth of information relating to clients breeding programs and seed orchards including pedigree reconstruction, identification of paternal parents, full sib and half sib families and estimation of inbreeding.

Additional tree improvement services provided by Gondwana Genomics include sourcing marker-identified elite families from the seed orchards of their partners, analysing genetic data from trials, and identifying markers of interest for clients.

[19] Anon (2019) http://www.gondwanagenomics.com.au/

3.4 Australian Forestry R, D & E - Human Resource Capacity

Since 2007, Australia's capacity to conduct and apply R,D & E to improve the scientific understanding of forests and delivery of forest products has progressively decreased. Significant changes in R,D & E capacity have occurred at the national, state and territory levels of government, and within the Commonwealth Scientific and Industrial Research Organisation (CSIRO) and academic institutions. Many of these changes reflect either general changes in overall government priorities or specific changes in government priorities for science-based R&D.

In the recently released Australia's State of the Forests Report 2018[20], ABARES reported that an estimated 276 researchers and technicians were involved in forestry and forest products R & D in Australia in 2013. This is a reduction from 455 estimated for 2011, and 733 estimated for 2008. The decline has occurred across the public and private sectors, including government agencies and universities.

An example is the Commonwealth Scientific and Industrial Research Organisation (CSIRO) which is Australia's national science research agency. In 2017 approximately 25 staff worked in forestry disciplines, down from 235 staff (including 85 scientists) that worked in CSIRO Forestry and Forest Products in 2000[21].

Ongoing changes in funding and delivery models by the Australian Government reduced forest R & D capacity across a number of national organisations, including some for which government funding or support ceased during the reporting period (e.g. Plant Biosecurity CRC).

Changes in the capacity of state and territory agencies to conduct and apply forest R & D have significantly been reduced during the 2011/12 – 2015/16 period, decreasing from 172 FTE in 2011/12 to 90 FTE in 2015/16. Of this the number of staff engaged in plantation R & D reduced from 85 to 34.

In the specific field of tree breeding and genetic improvement the number of people engaged by states and territory organisations declined from 4 to 2.

Despite the decline in the public sector, a number of new, university-based forestry and/or forest products research centres were established during the reporting period.

Turner and Lambert (2009)[22] estimated that there were 276 researchers and technicians involved in forestry and forest products R & D in 2012–13, together with additional support staff and external contractors. This represented a steady decline in research staff in the Commonwealth and state sectors since about 1990, not fully compensated by increases in research staff in the university and private sectors. The increases in university and private

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[20] Montreal Process Implementation Group for Australia and National Forest Inventory Steering Committee, 2018, Australia's State of the Forests Report 2018, ABARES, Canberra, December. CC BY 4.0.

[21] Kile GA, Nambiar EKS and Brown AG (2014). The rise and fall of research and development for the forest industry in Australia. Australian Forestry 77:142–152.

[22] Turner J and Lambert M (2009). Expenditure on Forestry Research and Forest Products Research in Australia 2007–2008, report prepared for Forest and Wood Products Australia, Melbourne.

sector research capacity to 2008 were due to more organisations reporting research, rather than an increase in actual numbers of any particular research group. Despite the decline in the public sector, a number of new, university-based forestry and/or forest products research centres were established during the reporting period.

In an industry survey undertaken as background research to the current project 26 industry participants representing a cross section of public (7) and private (17) sector organisations from Australia plus two (2) public sector organisations from New Zealand indicated the number of scientists, technical staff and support staff that were engaged in tree breeding and genetic improvement activities.

Within the 24 Australian public and private sector organisations responding to the survey a total of 105 employees were engaged in tree breeding and genetic improvement related activities. This compares to a total of 276 scientists, technical staff and support staff who were reported by Turner (2009) as being engaged in all R & D activities within the forest industry in 2013.

Within the 7 public sector organisation respondents there were a total of 43 people engaged in tree breeding and genetic improvement activities compared to 62 people from 17 organisations from the private sector and 14 people from the 2 NZ public sector organisations (**Figure 3**).

In terms of the number of scientists versus the number of technical staff and support staff the ratio for the Australian public sector organisations and that of the NZ organisations was similar with 56% and 50% respectively. However, within the private sector the ratio of scientists to technical staff and support staff was lower at 40%.

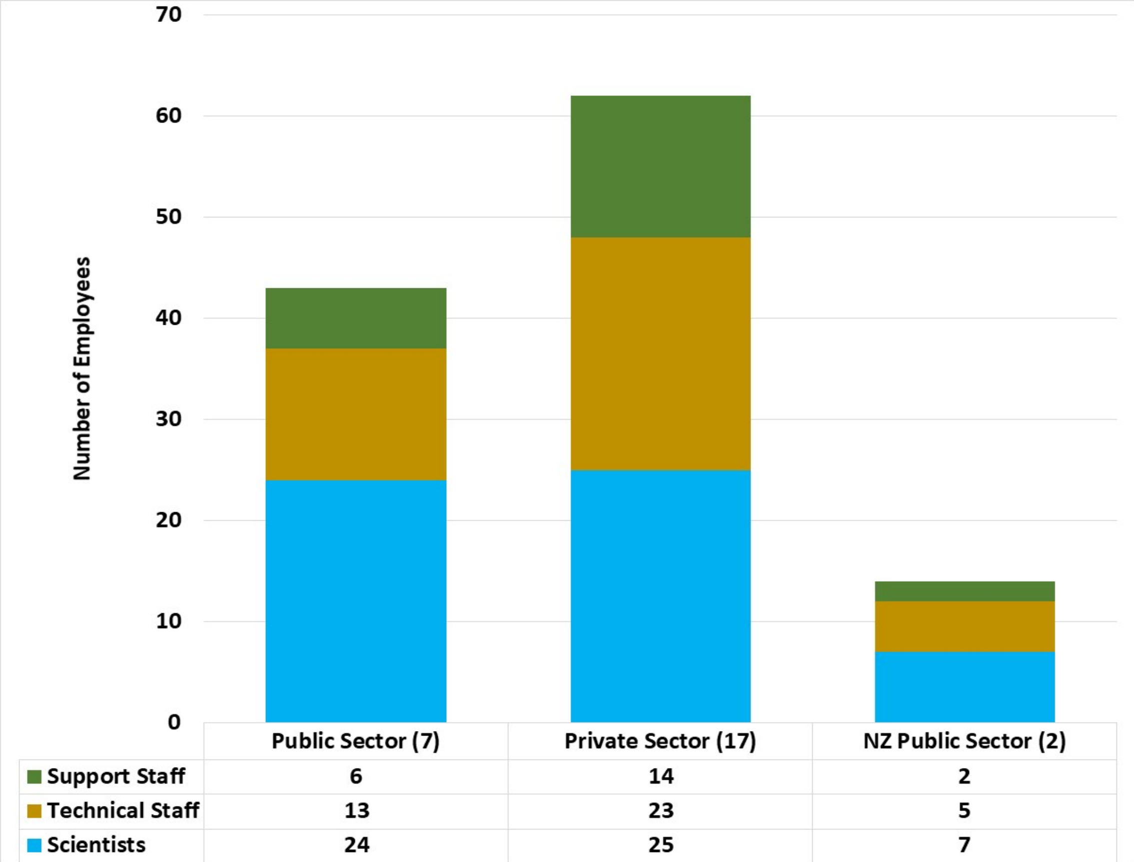


Figure 3. Number of people engaged in tree breeding and genetic improvement activities.

3.5 Plantation Forest Tree Breeding and Genetic Improvement – Investment

In the recently released Australian State of Forests Report 2018[23], ABARE reported that Australian Bureau of Statistics data showed that, from 2007–08 to 2013–14, total expenditure on research and development (R & D) reported by businesses in the forest and wood products sector declined from $144 million to $86 million.

This decline in forestry related research investment was confirmed by Turner and Lambert (2016)[24] in a separate series of surveys of the forest and forest products sector. The authors applied the following definitions when assessing the level and type of investment in forestry related R & D investment:

- **'Forestry R & D'** which was defined as research relating to the commercial management and protection of forests, including environmental and ecological considerations, but not research on areas managed specifically for conservation (e.g.

[23] Montreal Process Implementation Group for Australia and National Forest Inventory Steering Committee, 2018, Australia's State of the Forests Report 2018, ABARES, Canberra, December. CC BY 4.0.
[24] Turner J and Lambert M (2016). Changes in Australian forestry and forest products research for 1985–2013. Australian Forestry 79:53–58.

forest areas in public nature conservation areas such as national parks), or costs of monitoring growth, health, nutrition or biodiversity, and

- **'Forest Products R & D'** which was defined as including R & D on value-adding to timber, but not work on final product development (e.g. furniture production), production runs in mills, environmental monitoring or quality control assessment. For both 'Forestry R & D' and 'Forest products R & D'.

The estimates included contributions from both public and private sources, and not just expenditure by business alone.

The estimated total expenditure on Forestry and Forest Products R & D in 2007–08 was about $87.8 million, declining to $48.1 million in 2012–13. The report demonstrated that, although expenditure on forest R & D (unadjusted for inflation) increased in the period 1981–82 to 2007–08, when adjusted for inflation expenditure declined by 60.8% over the period 1981–82 to 2012–13. By 2012-13 investment into Forest Products R & D had declined to an estimated $10.2 million with investment into Forestry R & D declining to $38.1 million. (**Figure 4**)

The authors went onto to report that during the reporting period the major area of research decline was in native forest and pine plantation research.

In an industry survey undertaken as background research to the current project 29 industry participants representing a cross section of public (6) and private (21) sector organisations from Australia plus two (2) public sector organisations from New Zealand were asked to indicate the trend (i.e. decline, stay the same, increase) in investment within a range of forestry related research fields in which they participated during the previous five year period (2013 – 2018) and the forecast trend in investment for the forthcoming five year period (2019 – 2024).

Of the fields of research nominated by respondent's, tree breeding and genetic improvement was followed by Management and Mensuration, Pest and Diseases, Remote Sensing / GIS, Silviculture and Soils and Nutrition were most frequently identified fields of research.

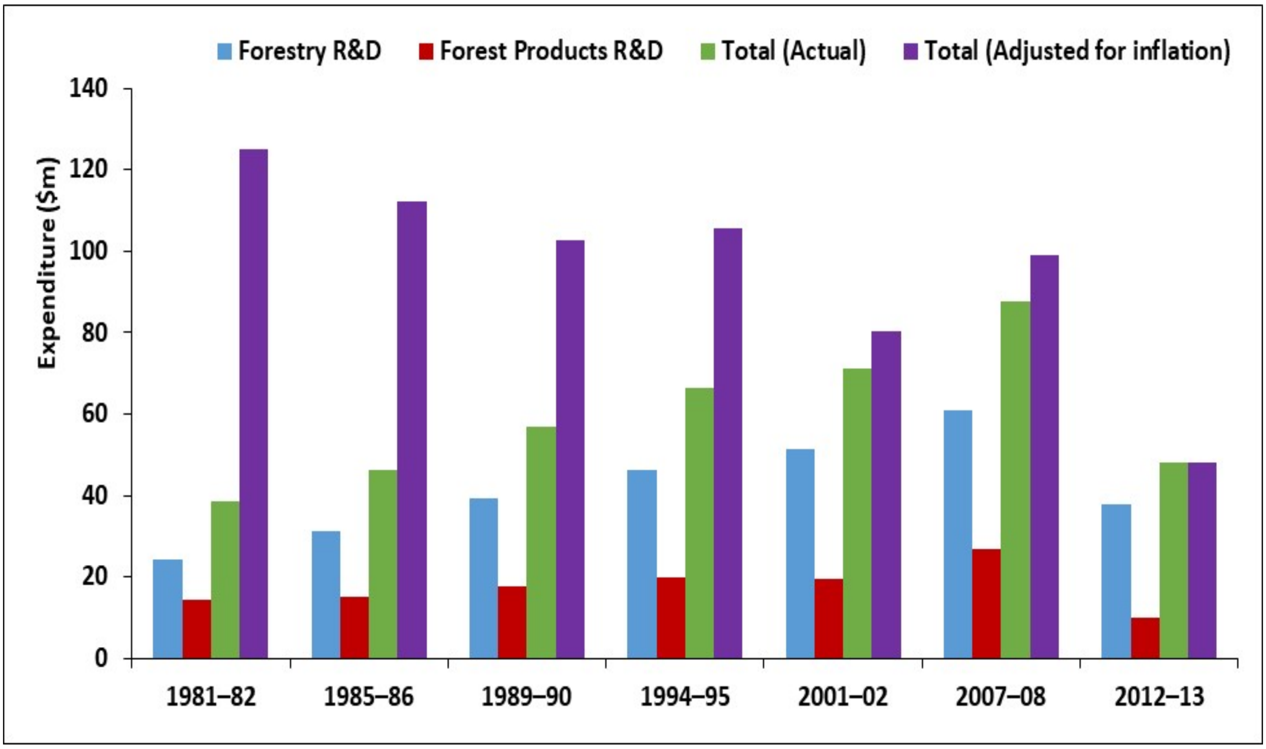


Figure 4. Expenditure on forestry and forest products R&D, 1981–82 to 2012–13 (*Source:* Turner and Lambert[25])

During the previous five year period respondents from the private sector indicated that investment into the majority of the research fields related to forestry research has stayed the same, although some individual respondents had recorded declines in all fields excluding remote sensing/ GIS which was the only field not to record a decline from the respondents (**Table 2**).

The key field of research which recorded an increase in investment was tree breeding and genetic improvement with 12 (63%) of the 19 respondents indicating they had received an increase in investment during the five-year period. Two additional fields of research which recorded an increase in investment were management and mensuration (including modelling) with 9 (64%) of the 14 respondents and remote sensing/GIS where 8 (57%) of the 14 respondents recorded an increase in investment.

Of the public sector organisations responding the survey the majority indicated that there had also not been a change to the level of investment in the majority of the research fields nominated. However, in contrast to the private sector of the 3 (50%) of public sector organisations indicated that they had received a declining level of investment in tree breeding and genetic improvement with only one organisation indicating that it had received an increase in funding. This trend was similar in New Zealand where one organisation recorded a decline

[25] Turner J and Lambert M (2016). Changes in Australian forestry and forest products research for 1985–2013. Australian Forestry 79:53–58.

in the level of investment in tree breeding and genetic improvement and one had recorded an increase in investment.

As with the private sector both public sector organisations in Australia and New Zealand had seen an increase in the level of investment being applied to remote sensing/GIS.

As to future trends in forestry related research investment, the majority of respondents from the private and public sector were of the view that in the majority of research field's investment would be retained at its current level or more optimistically it may be increased in key research fields (**Table 3**).

Table 2. Trends in the level of investment in forestry related research fields during the previous 5 years (2013 – 2018).

Field of Research Investment	Private Sector Companies				Public Sector - Universities & Research Institutions				NZ Public Sector - Research Institutions		
	Decreased	Stayed the Same	Increased		Decreased	Stayed the Same	Increased		Decreased	Stayed the Same	Increased
Forest hydrology	2	7	2		1	2					1
Fuel and fire dynamics	1	6	1			4			1		
Tree breeding & genetic improvement	1	8	12		3	2	1		1		1
Land use management	2	7	1			3				1	
Management and mensuration (including growth modelling)	1	4	9			4				1	
Pests and diseases	1	9	5		1	3					1
Remote sensing/GIS		6	8			2	2				2
Silviculture	2	9	3		1	3				1	
Soils and nutrition	2	7	4			3				1	
Timber utilisation		5	4			2				1	
Tree physiology	1	4	2			3				1	
Wood science and chemistry	1	4	3			3			1		
Operations and Supply Chain Efficiency	1	7	4			3					1

Table 3. Trends in the level of investment in forestry related research fields during the forthcoming 5 year period (2019 – 2024).

Field of Research Investment	Private Sector Companies			Public Sector - Universities & Research Institutions			NZ Public Sector - Research Institutions		
	Decrease	Stayed the Same	Increase	Decrease	Stayed the Same	Increase	Decrease	Stayed the Same	Increase
Forest hydrology		5	4	1	2	1		1	
Fuel and fire dynamics		3	1		2	1			1
Tree breeding & genetic improvement		12	8		2	3		1	1
Land use management		7			2	1			1
Management and mensuration (including growth modelling)		9	6		3	1		1	
Pests and diseases		9	6		3	1			1
Remote sensing/GIS		4	10		3	1			1
Silviculture	1	9	5		3	1		1	
Soils and nutrition	1	7	5		2	1			1
Timber utilisation		4	3		1	1			1
Tree physiology		4			2	1		1	
Wood science and chemistry		5	4		2	1		1	
Operations and Supply Chain Efficiency		9	1		3				1

Within the private sector the key field that was identified as attracting additional investment were remote sensing / GIS with 10 (72%) of 14 respondents nominating an increase investment. Respondents provided the following comments in relation to expected increase in investment in remote sensing/GIS:

> *"Remote sensing talks directly to efficiency - allowing scarce research dollars to be invested more effectively."*
>
> *"Increased capture and use of remote sensed data will lead to better understanding of forest dynamics."*
>
> *"Opportunities arising from LiDAR data will assist in inventory and research (field trial assessment)."*
>
> *"As we need to service more members there is a need for faster and more accurate data collection as we need to service more members."*

Another key field of research investment that is expected in increase is in tree breeding and genetic improvement with 8 (40%) of the 20 respondents forecasting an increase in investment. By contrast to the previous five-year period three of the public sector organisation respondents were expecting to see an increase in the level of investment being applied to tree breeding and genetic improvement. One respondent suggested the following as the key reason for the continued increase in investment in tree breeding and genetic improvement:

> "*There is likely to be increased activity around utilisation of genomic data in genetic evaluation and breeding program design."*

The forecast continued increase in research investment in both remote sensing / GIS and tree breeding and genetic improvement continues the trend of investment in these two fields from the previous five-year period.

Additional fields of research which private sector respondents indicated there would be an increase in investment were:

- Management and mensuration (including growth modelling)
- Pests and diseases
- Silviculture
- Soils and nutrition.

Additional comments provided by respondents as to forecast changes in research investment in forestry related research fields are as follows:

> *"The change in research investment in fuel and fire dynamics is due to a better understanding of the hazards and consequences in this area."*
>
> *"The change in research in timber utilisation is due to the increasing availability of hardwood plantation saw logs."*

"The change in research in fuel and fire dynamics is due to a better understanding of the hazards and consequences in this area."

"Shareholders are flagging disease as being of more concern in future."

"There is an increasing attention to wood quality."

"The industry needs refinements to site specific silviculture."

3.6 Adoption of modern breeding technologies within the Australian plantation forestry industry.

Plant breeding started with sedentary agriculture, particularly the domestication of the first agricultural plants, a practice which is estimated to date back 9,000 to 11,000 years. Initially, early human farmers selected food plants with particular desirable characteristics and used these as a seed source for subsequent generations, resulting in an accumulation of characteristics over time. In time however, experiments began with deliberate hybridisation, the science and understanding of which was greatly enhanced by the work of Gregor Mendel. Mendel's work ultimately led to the new science of genetics.

Modern plant breeding is a highly interdisciplinary science that requires the skills and teamwork of many scientists to be successful, these disciplines include but are not limited to fields such as applied genetics, but its scientific basis is broader, covering molecular biology, cytology, systematics, physiology, pathology, chemistry and statistics (biometrics).

Intensive research in molecular genetics has led to the development and advancement in techniques such as molecular markers for traits of interest, Genomic Wide Selection (GWS) and a range of new gene editing techniques. These advancements have opened many possibilities for breeding crops with a range of desirable traits of value to the grain grower (input traits) and the consumer (output traits).

The rate of adoption of the molecular marker and genome wide selection strategies into wheat and barley breeding programs within Australia and internationally has varied significantly. Adoption has been dependent on the available resources of breeding programs to invest in developing 'in-house' capability and capacity or to alternatively establish collaborations with research institutions that have developed the respective technology platforms for supporting adoption and use of the technologies.

In an industry survey undertaken as background research to the current project 28 industry participants representing a cross section of public (7) and private (19) sector organisations from Australia plus two (2) public sector organisations from New Zealand indicated the extent to which they had adopted and applied a nominated range of modern breeding technologies and disciplines to their tree breeding activities. The modern breeding technologies and disciplines nominated to survey participants were:

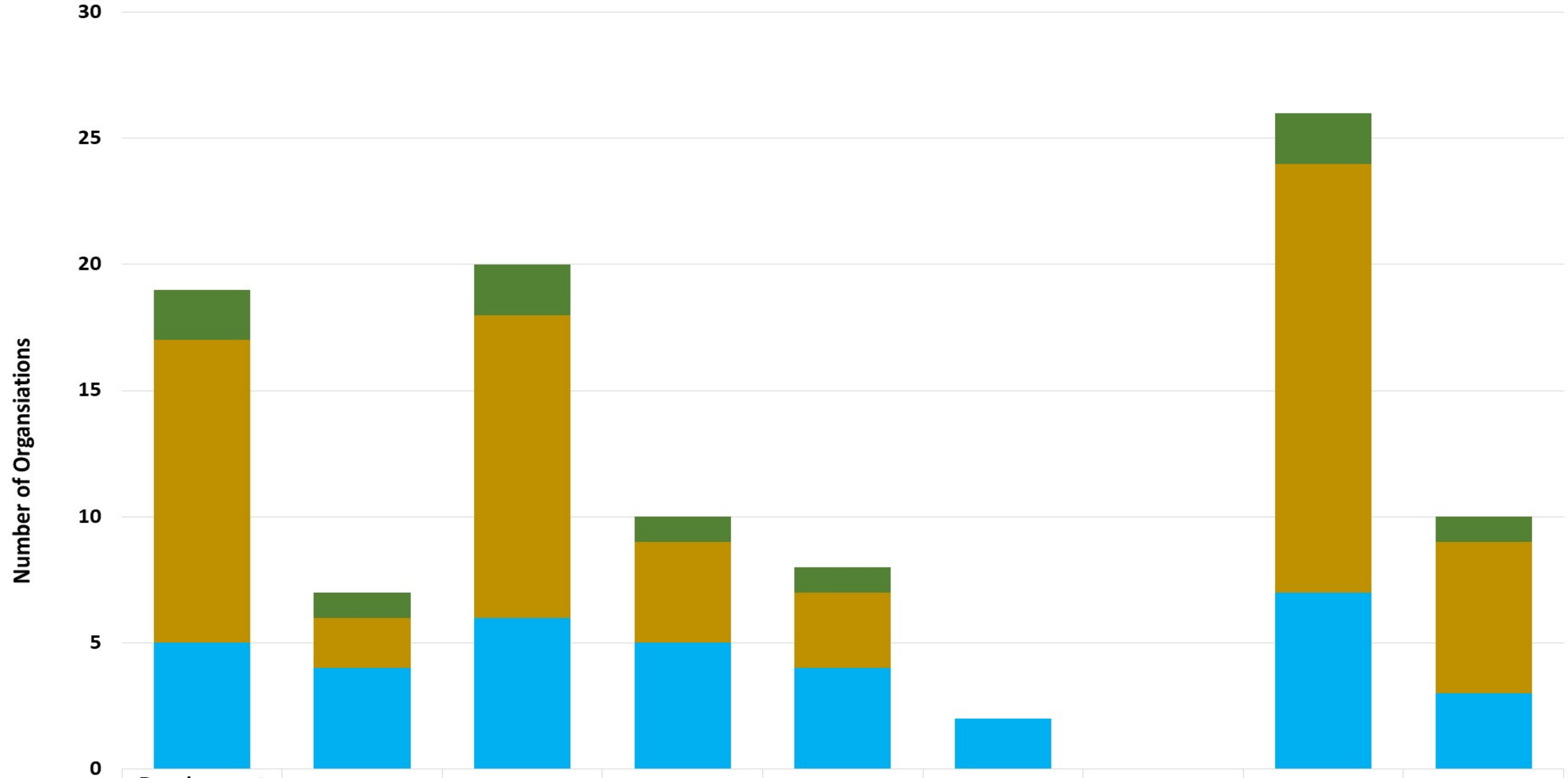
- Development and use of molecular markers
- Gene Sequencing
- Genomics
- Phenomics
- Bioinformatics
- Metabolomics
- Proteomics
- Breeding Values
- Genome Wide Selection

Of the modern breeding technologies and disciplines, 24 (86%) respondents confirmed that they had adopted the use of Breeding Values in their breeding programs. All 9 (100%) Australian and New Zealand Public sector respondents together 17 (90%) of Australian private sector respondents confirmed the adoption of Breeding Values in their breeding programs (**Figure 5**).

Twelve (63%) private sector respondents together with both New Zealand public sector respondents indicated they had adopted the use of genomics and molecular markers in their breeding programs. Of the Australian public sector respondents 5 indicated they had adopted the use of molecular markers and 6 had adopted the use of genomics in their breeding programs.

There were only two Australian public sector respondents who indicated they had adopted the use of metabolomics, all other respondents indicated they had not adopted the discipline within their breeding program.

Of the modern breeding technologies and disciplines nominated metabolomics was the only discipline which had not been adopted by any of the 28 public and private sector respondents to the survey.



	Development and use of molecular markers	Gene Sequencing	Genomics	Phenomics	Bioinformatics	Metabolomics	Proteomics	Breeding Values	Genome Wide Selection
NZ Public Sector	2	1	2	1	1			2	1
Private Sector	12	2	12	4	3			17	6
Public Sector	5	4	6	5	4	2		7	3

Figure 5. Modern breeding technologies and disciplines utilised by forest research sectors

3.7 What are the current and future traits (priorities) that industry want focused on to improve the value of the *Eucalyptus sp.* and *Pinus Radiata* plantation products?

3.7.1 Softwood Traits in Pinus radiata

Radiata pine is characterised as a species that has fairly good stem form and matures within 30 years producing wood of medium density, with a light colouring and quite wide growth rings. It competes on the international market with other medium density softwoods such as spruces, other pines, Douglas fir and cypresses. As the volume of radiata pine logs that are exported increases the focus on wood properties (i.e. traits) has increasingly become a priority for the industry in Australia and New Zealand.[26]

The objective of the national tree breeding program for *Pinus radiata* in Australia is to breed, select and deploy genetic material with improved biological characteristics for traits of commercial importance. Economic objectives for plantation growing for structural timber are fundamental to the breeding and deployment programs.

The radiata pine breeding program has undergone substantial change in the past decade with the development and adoption of economically defined breeding objectives, screening for new pest and disease traits, increased measurement of stiffness, development of DATAPLAN® software for comprehensive industry wide genetic evaluation with regionalised genetic values, a rolling front operational program, development of selection, breeding (TREEPLAN®) and deployment tools (SEEDPLAN®), gene conservation coordinated nationally, improved security of the national genetic resource (breeding population) and a focused research portfolio with rapid adoption of results and findings.[27]

During the same period there has been a significant increase in the use of modern breeding technologies such as genomics, phenomics and bioinformatics to manage and analyse the data being generated. From this has been the development and adoption of tools such as molecular markers for specific traits of interest which have been applied to breeding strategies, including selecting elite families from seed orchards.

Wu et al (2005) identified four primary traits to focus on within a soft wood breeding program:

1. Mean annual increment in volume - m^3/ha/year (MAI).
2. Stem sweep (SWE).
3. Modulus of elasticity (MoE); and
4. Branch Size (BIX).

[26] Bayne, K. (2015). Wood quality considerations for radiata pine in international markets. New Zealand Journal of Forestry. 59.
[27] McRae et al. (2013) Breeding of radiata pine in Australia. Forest Genetics Conference Presentation, Whistler, British Columbia, Canada. 22-25 July 2013

The authors also identified seven traits as early selection criterion as these were found to be heritable and also genetically correlated with later-age traits and were relatively easy and inexpensive to measure (except for MfA). These traits were:

- Growth rate (DBH)
- Wood density (DEN)
- Microfibril angle (MfA)
- Stem straightness (STS)
- Branch Size (BRS)
- Branch angle (BRA)
- Branch cluster frequency (BRC)

These breeding objective traits were then developed into a bio-economic model which linked these objectives with each component of the production system (value chain) and were used to estimate economic weights for the individual breeding objectives.[28]

In New Zealand there are seven traits which have been routinely assessed in *Pinus radiata.* They are stem diameter (dbh), straightness score, branch cluster frequency score, needle retention score, malformation score, acceptability for final crop and ranking families for wood density. A summary of the selection traits and the purpose for assessing them is given in **Table 4**[29]**.**

Table 4. Selection traits routinely assessed in NZ radiate pine trials.

Trait	Goal in assessing trait
Diameter	Log size
Straightness	Log quality
Branch Cluster Frequency	i) Clearwood yield from unpruned stems ii) reduce branch size
Malformation	Log quality
Acceptability	Log quality
Dothistroma Infection	Log size by reducing *Dothistroma* needle blight
Needle retention	Log size by reducing *Cyclaneusma* needle cast
Density	Stiffness, strength
Spiral Grain Angle	Stability of wood

[28] Wu et al (2005). Breeding radiata pine to maximise profit from solid wood production. Summary report. FWPA Project PN01.1904
[29] Jayawickrama, K. & Carson, M. (2000). A breeding strategy for the New Zealand Radiata Pine Breeding Cooperative. Silvae Genetica. 49. 82-90.

In a survey undertaken as part of the current project Australian softwood value chain participants were asked to nominate which criteria were required to be focused on within a breeding program.

The respondents identified a total of sixteen breeding criteria, of which ten were classed as traits that could be measured and phenotypically evaluated (**Table 5**).

Table 5. Breeding criteria identified by survey and workshop participants

Breeding Criteria (Traits)	Breeding Criteria (Other)
• Increased Stiffness • Volume / Yield • Abiotic/Biotic Stress Tolerance • Growth Rate • Wood Quality • Density • Smaller Branches • Reduced Sweep • Stem Form • Straightness	• $NPV / Profit • Resilience • Risk Mitigation • Root Soil Carbon • Site Matching • Deployment Tools / Decision Support

Respondents were provided the opportunity to nominate criteria (unaided awareness)[30] as being tier one, two, three or other. As to the priority that the respondents placed on the various breeding criteria identified, the priorities for Tier One were volume/ yield, growth rate and $NPV / Profit followed by wood quality and stress tolerance. In Tier Two the priorities were increased stiffness and density, and in Tier Three smaller branches and abiotic/biotic stress tolerance (**Table 6**).

With regard to the traits that breeders focus on a measure the survey participants identified volume /yield as the primary trait which is consistent with what that stated in previous industry studies in Australia and New Zealand. This is not surprising given that volume and growth rate ultimately drive the quantity of products marketed and the responding generation of revenues along the value chain. Hence, its close association with $NPV / Profit as a breeding objective. When the frequency of traits is collated across the four tiers available for nomination the most frequently nominated traits were increased stiffness, volume / yield, abiotic / biotic stress tolerance and growth rate (**Figure 6**).

[30] Unaided Awareness = A measure of the number of people who express knowledge of a trait without prompting.

Table 6. Softwood breeding criteria priority nomination by industry participants.

Breeding Objective	Tier One	Tier Two	Tier Three	Other
Growth Rate	6	1		
Volume / Yield	8			
$NPV / Profit	7	1	1	1
Wood Quality	3			2
Density		4	1	
Resilience		2		
Risk Mitigation		2		
Increased Stiffness		7	2	
Abiotic/Biotic Stress Tolerance	1	1	3	3
Root Soil Carbon			1	
Stem Form		2		
Smaller Branches			5	
Reduced Sweep		1		3
Straightness			1	1
Site Matching		2	1	
Deployment Tools / Decision Support			1	2

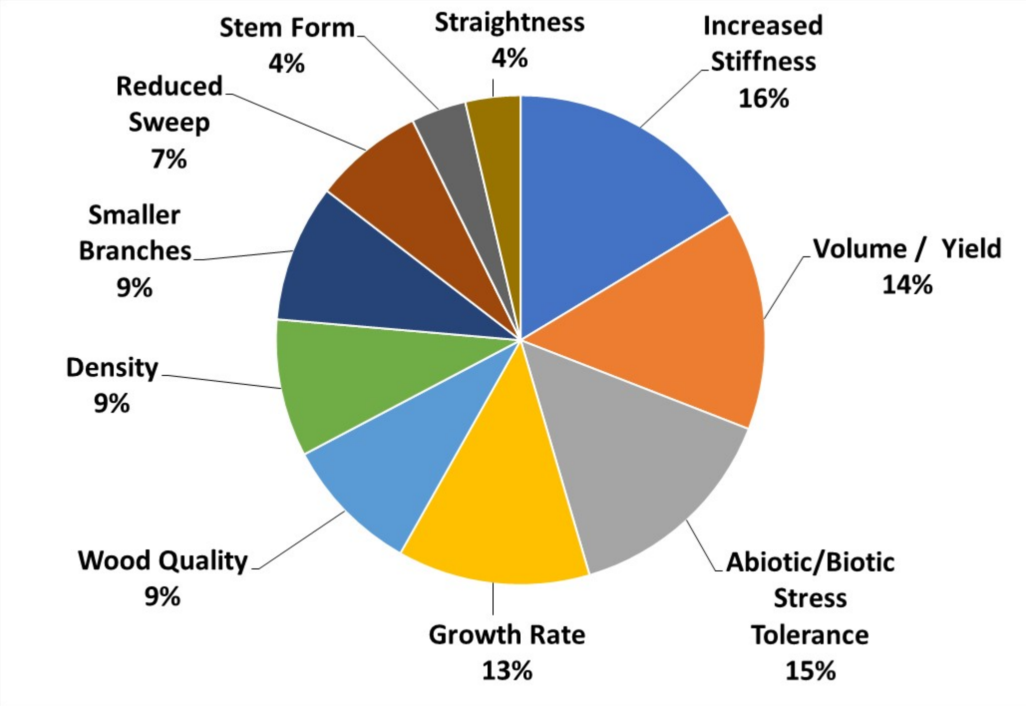


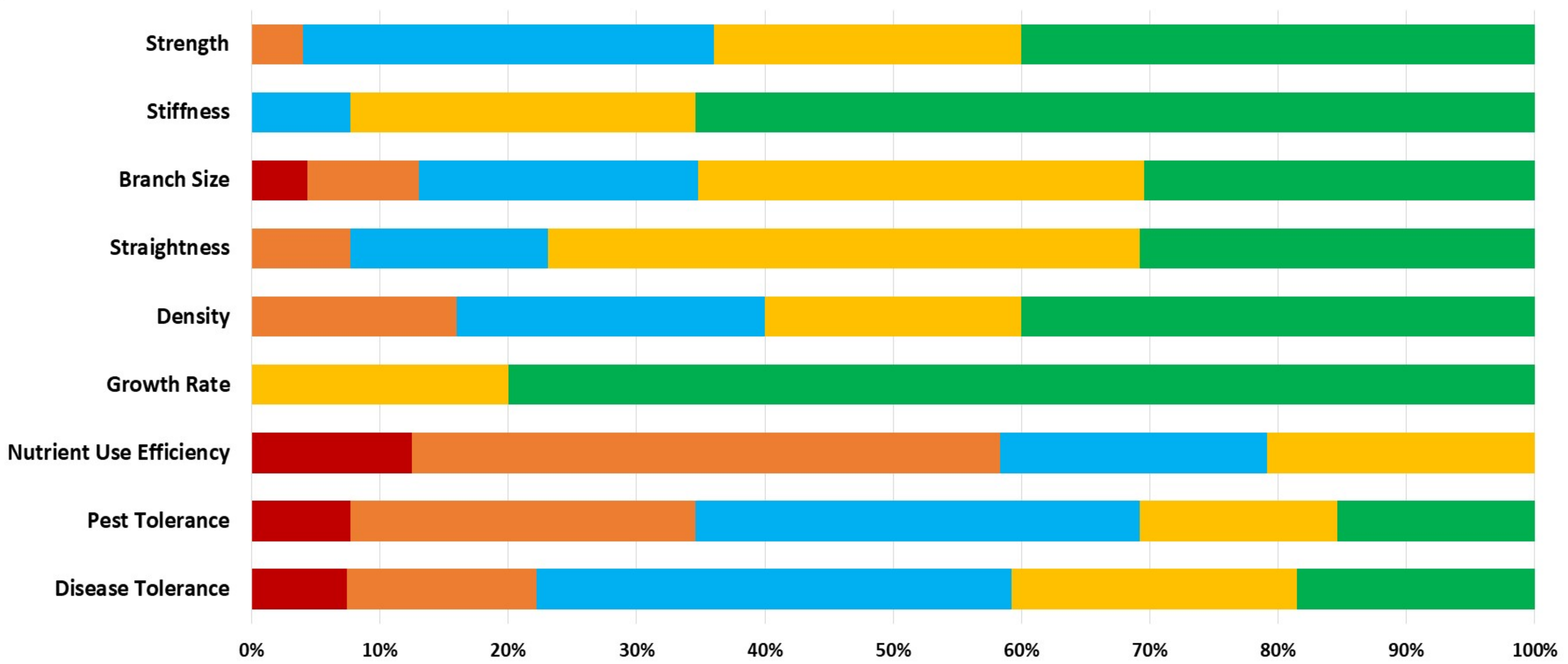
Figure 6. Softwood Traits of Interest - Frequency of Response (Unaided Awareness)

Industry participants were asked to rate in terms of the level of economic importance a nominated list of traits within a softwood breeding program (aided awareness[31]). The nominated traits were as follows:

- Disease Tolerance
- Pest Tolerance
- Nutrient Use Efficiency
- Growth Rate
- Density
- Straightness
- Branch Size
- Stiffness
- Strength

Of the nominated traits the most highly important economic trait was growth rate with 80% of respondents rating as highly important, followed by 65% of respondents rating stiffness as highly important. The traits of density and strength were rated as highly important by 40% of respondents respectively. (**Figure 7**) Traits such as nutrient use efficiency, disease and pest tolerance were significantly lower on the scale of importance.

[31] Aided awareness - A measure of the number of people who express knowledge of a trait when prompted



	Disease Tolerance	Pest Tolerance	Nutrient Use Efficiency	Growth Rate	Density	Straightness	Branch Size	Stiffness	Strength
2 = Low Importance	2	2	3	0	0	0	1	0	0
3	4	7	11	0	4	2	2	0	1
4	10	9	5	0	6	4	5	2	8
5	6	4	5	5	5	12	8	7	6
6 = Highly Important	5	4	0	20	10	8	7	17	10

Figure 7. Priority of genetic traits of economic importance within current softwood breeding programs (Aided awareness)

Within the survey respondents nominated a list of additional traits with lower importance that they considered worth including, these were:

- Wind – firmness
- Crown defects
- Flowering for seed orchards
- Propagation ability for cloned somatic varietals

These traits were consistent with a list of traits generated by industry participants at a softwood workshop held as part of the background research for the project. Workshop participants suggested that to be meaningful it was important that these traits be identified and started to be measured early in the life cycle of the tree. The additional traits nominated at the workshop were:

- Carbon capture,
- Environmental adaptation,
- Water use efficiency,
- Drought tolerances,
- Temperature extremes
- Wind firmness/resilience

In relation to additional traits that could be incorporated into a softwood breeding program Bayne (2015)[32] suggested for New Zealand the versatility of radiata pine has been its major advantage, but it has often been referred to as 'the second-best species for everything.' There are a number of areas where radiata pine could improve including:

- Uniformity
- Dimensional stability
- Softness
- Timber stiffness (NZ only issue versus Australia)
- The appearance of radiata pine
- Lack of natural durability

[32] Bayne, K. (2015). Wood quality considerations for radiata pine in international markets. New Zealand Journal of Forestry. 59.

3.7.2 Hardwood Traits in Eucalyptus sp.

Eucalyptus is the most widely planted hardwood genus for pulp production and currently provides around 50% of all short-fibre pulp traded in the international market. This share is expected to increase to at least 60% within the next few years[33].

The pulp and paper industry is by far the largest user of plantation grown eucalypt wood and the major client for intensive breeding technology, so its long term viability is of central concern. Today 50% of bleached hardwood kraft pulp is from eucalypt wood and in 10 years this share could increase to 75%[34]. However the long term demand for paper products is quite unclear as digital technology threatens paper as a communication and storage medium and profitability of pulp production is squeezed between rising wood price and price pressures on product.[35] There are moves to consider the tree more broadly as a natural product factory, with all components of wood having potential value, transforming the pulp mill into a biorefinery. Increased cellulose content and reduced cost of pulping will remain of value whatever the end products.

In Australia the major plantation eucalypts are *Eucalyptus globulus* and *E. nitens* and while initially established as a pulpwood resource there is now increasing interest in the use of these plantations for other purposes including bioenergy, timber and veneer production. [36]

In a survey undertaken as part of the current project Australian hardwood value chain participants were asked to nominate which criteria were required to be focused on within a breeding program. Respondents were provided the opportunity to nominate and prioritise criteria (unaided awareness)[37] as being tier one, two, three or other.

The respondents identified a total of nineteen breeding criteria, of which twelve were classed as traits that could be measured and phenotypically evaluated (**Table 7**).

With regard to the priority that the respondents placed on the various breeding criteria identified, the priorities for Tier One were volume/ yield, growth rate and $NPV / Profit. In Tier Two the priorities were density and volume/ yield and in Tier Three volume/ yield and abiotic/biotic stress tolerance (**Table 8**).

[33] FAO (2007) Global wood and wood products flow: trends and perspectives. 48th session of the FAO Advisory Committee on Wood and Paper Products, Shanghai, China, 6 June 2007.
[34] Carre G (2012) Future development of the pulp market, and technical trends for pulp mills. Congreso Internacional de Celulosa y Papelaño.
[35] Christie S (2008) Energy, chemicals and carbon: future options for the *Eucalyptus* value chain. Southern Forests: a Journal of Forest Science 70: 175–182.
[36] Griffin, A. (2018). Future Prospects for Eucalyptus Plantations and the Role of Genetic Improvement In 'Genetics, Genomics and Breeding of Eucalypts. (Eds R Henry and C Kole) pp. 155-181. (CRC Press: Boca Raton, Florida).
[37] Unaided Awareness = A measure of the number of people who express knowledge of a trait without prompting.

Table 7. Breeding criteria identified by survey and workshop participants

Breeding Criteria (Traits)	Breeding Criteria (Other)
• Growth Rate	• $NPV / Profit
• Climate Adaptability	• Resilience
• Volume / Pulp Yield	• Risk Mitigation
• Quality	• Solid Wood Products
• Density	• Root Soil Carbon
• Increased Stiffness	• Decreasing Seed Cost
• Abiotic/Biotic Stress Tolerance	• Decrease Harvest Costs
• Stem Form	
• Smaller Branches	
• Nutrient Utilisation	
• Reduced Sweep	
• Straightness	

Table 8. Hardwood breeding criteria priority nomination by industry participants.

Breeding Objective	Tier One	Tier Two	Tier Three	Other
Growth Rate	6			
Climate Adaptability	1			
Volume / Pulp Yield	10	4	7	
$NPV / Profit	3	2	1	
Quality		1		1
Density		9	1	
Resilience		1		
Risk Mitigation		1		
Increased Stiffness		1	1	
Abiotic/Biotic Stress Tolerance		1	4	3
Solid Wood Products		1	2	1
Root Soil Carbon			1	
Stem Form /			1	
Smaller Branches			1	
Nutrient Utilisation				1
Decreasing Seed Cost				1
Decrease Harvest Costs				1
Reduced Sweep				1
Straightness				2

When the frequency of traits is collated across the four tiers available for nomination the most frequently nominated traits were volume / yield, density, abiotic / biotic stress tolerance and growth rate (**Figure 8**).

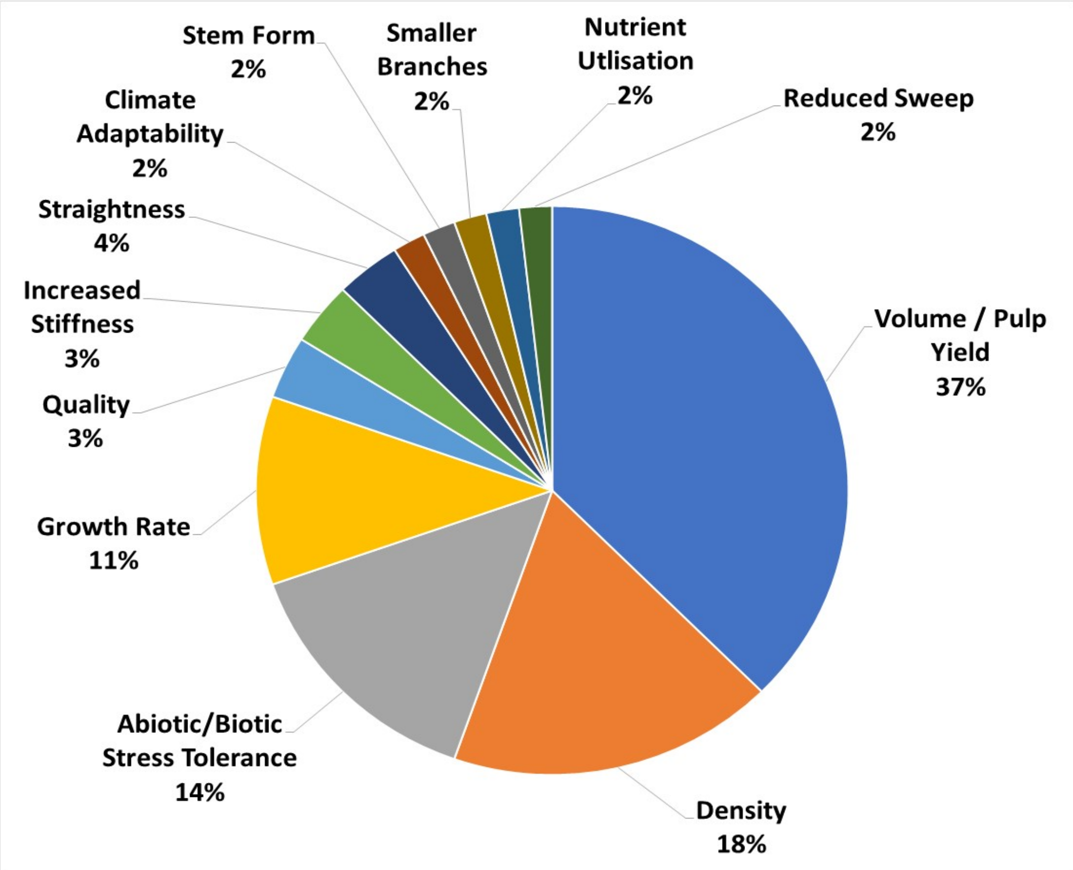
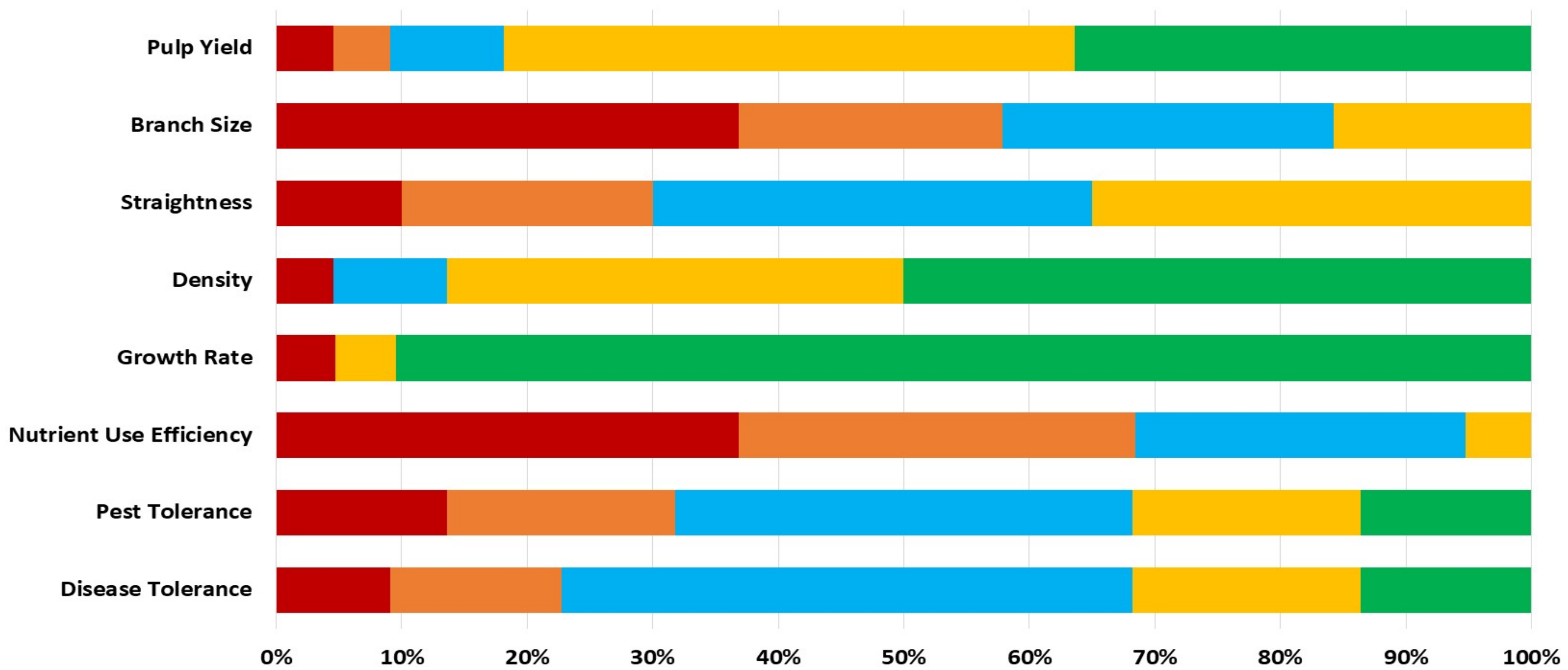


Figure 8. Hardwood Traits of Interest - Frequency of Response (Unaided Awareness)

Industry participants were asked to rate in terms of the level of economic importance a nominated list of traits within a hardwood breeding program (aided awareness). The nominated traits were as follows:

- Disease Tolerance
- Pest Tolerance
- Nutrient Use Efficiency
- Growth Rate
- Density
- Straightness
- Branch Size
- Pulp Yield

Of the nominated traits the growth rate was rated more highly in terms of significant economic importance than all other traits with 90% (18/20) of respondents rating it accordingly. The second most important economic trait was density followed by pulp yield with 50% and 35% of respondents rating these as highly important respectively (**Figure 9**).



	Disease Tolerance	Pest Tolerance	Nutrient Use Efficiency	Growth Rate	Density	Straightness	Branch Size	Pulp Yield
2 = Low Importance	2	3	7	1	1	2	7	1
3	3	4	6	0	0	4	4	1
4	10	8	5	0	2	7	5	2
5	4	4	1	1	8	7	3	10
6 = Highly Important	3	3	0	19	11	0	0	8

Figure 9. Priority of genetic traits of economic importance within current hardwood breeding programs. (Aided awareness)

Industry participants at a hardwood workshop held as part of the background research for the project indicated that they were looking for the inclusion of new traits into TREEPLAN[38]. A key driver for new traits is the desire of the industry to address climate change and opportunities for new hardwood products. Hence, participants were interested in characteristics such as solid wood, veneer and stiffness, together with traits that may be important when selecting tree's for use as bio-refineries. As with the participants at the softwood workshop, they indicated that to be meaningful it was important that these traits be identified and started to be measured early in the life cycle of the tree.

Griffin[39] when considering the future prospects for eucalyptus plantations and the role of genetic improvement suggests that the future for paper is quite unclear and there are moves to consider the tree more broadly as a natural product factory, with all components of wood have potential value, transforming the pulp mill into a bio-refinery.

From a growers' perspective Griffin suggested that the key traits for future focus will be:

- improving yield
- increase production under water stress conditions
- improving cold tolerance, and
- increased tolerance/resistance to pests and diseases
- rooting ability

The latter four traits being a reflection of the need to mitigate the risk in production as they find new areas for plantation production which will be more likely be in marginal environments subject to fluctuations in climate.

3.8 Australian forest plantation tree breeding and genetic improvement sector strengths and weaknesses.

In line with the increase in investment over the previous five years in the field of tree breeding and genetic improvement, at an industry level, FWPA has invested significant financial resources in supporting projects that when completed contributed incrementally to the knowledge and resources of the softwood and hardwood breeding programs across the forest plantation industry.

[38] Tree Breeding Australia (2019) http://www.stba.com.au/page/treeplan
[39] Griffin, A. (2018). Future Prospects for Eucalyptus Plantations and the Role of Genetic Improvement in 'Genetics, Genomics and Breeding of Eucalypts. (Eds R Henry and C Kole) pp. 155-181. (CRC Press: Boca Raton, Florida).

Research reports sponsored by FWPA such as those released by Thavamanikumar et al. (2018)[40], Stone and Osborne (2017)[41], Thumma, Thavamanikumar, and Southerton (2017)[42], Rombouts et al. (2015)[43], Thumma, Thavamanikumar, Brawner and Southerton (2015)[44], Kerr et al. (2014)[45], Kerr et al. (2013)[46], Kerr et al. (2011)[47], Thuma (2010)[48], Ivković (2009)[49], Kerr et al. (2008)[50] and Wu et al. (2005)[51] have contributed to the building of a platform of knowledge and capability within the industry in relation to new modern breeding technologies and disciplines such as genomics, phenomics, bioinformatics, marker assisted selection and genome wide selection that is shared and adopted collegiately across the industry.

In order to build on the current platform for future investment in tree breeding and genetic improvement that FWPA has established within the softwood and hardwood plantation industries the authors sought to establish the current strengths and weaknesses of the sector.

The strengths and weakness have been categorised as those that relate to its capability (e.g. technology and disciplines) and those that relate to its capacity (i.e. people and relationships).

A summary of the responses from industry stakeholders are presented in **Tables 3-6**.

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[40] Thavamanikumar, S, Southerton, S., Southerton, R., Brawner, J., and Thumma, B. (2018) Eucalypt MAS: Implementation of marker-assisted selection in Australia's major plantation eucalypts. FWPA Report : PNC378-1516

[41] Stone, C and Osborne, J. (2017). Deployment and integration of cost-effective high resolution remotely sensed data for the Australian forest industry. FWPA Report: PNC326-1314

[42] Thumma, B., Thavamanikumar, S., & Southerton, S. (2017). Discovery and application of DNA markers for resistance to Teratosphaeria in E. globulus. FWPA Report: PNC363- 1415

[43] Rombouts,J., Melville G., Kathuria, A., Rawley,B., and Stone,C. (2015). Operational deployment of LiDAR derived information into softwood resource systems. FWPA report: PNC305-1213

[44] Thumma,B., Thavamanikumar,S., Brawner,.J, and Southerton,S. (2015) Genetic Selection Tools for Enhanced Wood Properties and Plantation Productivity in Australia's Temperate Eucalypts (Blue Gum Genomics). FWPA Project No: PNC209-1011

[45] Kerr,R., Dutkowski,G., McRae,T., Southerton,S., Thumma,B. and Tier.B. (2014) Utility of molecular breeding in forestry. FWPA Project No: PNC220-1011

[46] Kerr,R. et al (2013) Optimal use of genetics in deployment and tree breeding. FWPA Project No: PNC211-1011

[47] Kerr,R., McRae,T., Li,L., Tier,B,. Dutkowski,G. and Costa e Silva,J. (2011) Industry wide genetic analysis of tree breeding data using TREEPLAN®. FWPA Project No: PNC076-0809

[48] Thumma,B., MacMillan,C., Southerton,S., Williams,D., Joyce,K. and Ravenwood,I. (2010) Accelerated breeding for high pulp yield in E. nitens using DNA markers identified in 100 cell wall genes: The Hottest 100. FWPA Project No: PNC052-0708

[49] Ivković,M. et al (2009) Breeding Radiata Pine to Maximise Profits by Incorporating Risk Traits. FWPA Project No: PNC069-0708

[50] Kerr,R. et al (2008) Genetic gain optimisation in tree breeding (MATEPLAN) and deployment (SEEDPLAN) FWPA Project No: PN07.4025

[51] Wu,H., Ivkovic,M., McRae,T. and Powell,M. (2005) Breeding Radiata Pine to maximise Profit from Solid Wood Production: Summary Report. FWPRDC Project No: PN01.1904

Table 3. Hardwood Plantation Tree breeding and Genetic Improvement - Strengths

Hardwood Plantation Tree breeding and Genetic Improvement - Strengths	

Capability (Technology)
• The industry has well structured (E. globulus) breeding programs that are well based genetically through access to the original resource.
• Having the capability in Dataplan (Tree Breeding Australia) for use in genome wide selection (Australian Tree Breeding)
• The industry now has access to deployment tools that are linked to breeding strategy outcomes.
• The industry has enhanced its capability through its adoption and implementation of new technologies and disciplines. (e.g. LIDAR, Genetic Markers, Bioinformatics, Genomic selection)
• There has been an increasing preparedness by industry participants to incorporate / test new technologies and disciplines.
	Capacity (People)
	• There is good collaboration by researchers across both hardwoods and softwoods due to the broad applicability of genetics training which is acquired during their academic careers at various universities and research institutions across Australia.
	• The hardwood tree breeding and genetic improvement field has 'good well trained people' working and collaborating across all levels of the industry value chain.
	• The link that has been established with animal breeders through AGBU has enhanced the industries knowledge and acceptance of the benefits to the future of the industry of investing in modern breeding strategies
	• The industry in recent years has demonstrated that a co-operative model can work within the industry in relation to tree breeding and genetic improvement. Examples include:
	  ◦ Industry wide participation in Tree Breeding Australia (Formerly Southern Tree Breeding Australia – STBA)
	  ◦ National wide testing and evaluation trials
	  ◦ The contribution and collation of data for use in parental selection
	• The industry is well serviced with highly skilled ''service provider" organisations for example Gondwana Genomics, Seed Energy, Australian Tree Seed Centre (ASTC) and Tree Breeding Australia (TBA)
	• There are strong links between hardwood tree breeding groups within the private sector and those that are located in Universities and the industries three Cooperative Research Centres (CRC's)
	• The industry has strong research links with tree breeding and genetic improvement programs in New Zealand, USA, South Africa, Brazil, Chile and various Scandinavian countries.
	• There is good collaboration in tree breeding and genetic improvement by researchers across both hardwoods and softwoods due to the broad applicability of genetics training which is acquired during their academic careers at various universities and research institutions across Australia.

Table 4. Hardwood Plantation Tree breeding and Genetic Improvement - Weaknesses

Hardwood Plantation Tree breeding and Genetic Improvement - Weaknesses	
Capability (Technology) • The industry is being held back in its ability to progress its tree breeding and genetic improvement capability due to the industries decision to not pursue opportunities with genetically modified technology. This is despite many of its competitors moving rapidly in their adoption of GM technology. • The loss of federal and state government investment both in terms of funding and support of institutions such as various CRC's and CSIRO to maintain their capabilities in a range of forest related research fields has had a significant impact on the industry. An example of the loss or absence of capability is in the fields of clonal propagation and hybrids – both research fields representing significant opportunities for the industry to make meaningful advancements in tree breeding and genetic improvement. • The length of hardwood crop rotations makes breeding for genetic improvement difficult to generate and to demonstrate benefits to value chain – breeding takes time! • There is a relatively low level of investment into tree breeding and genetic improvement due to bottom line pressures from management. As a result breeders are always having to justify the benefits and value of breeding. • It is difficult for tree breeders to respond to market cycles as there is a value chain disconnect primarily due to the lack of vertical integration, resulting in a disconnect in the timely delivery of price signals related to product traits that the breeder can improve in the final product. This is further exasperated by the constant changes in management and volatility of investment which often leads to removal of resources or lack of investment in resources (including people) especially related to forest products. • The size of the Australian hardwood estate, together with the limited number of fully integrated value chain participants is too small on a global basis to achieve the economies of scale required to generate significant investment in tree breeding and genetic improvement. • The hardwood industry is "too" industry focused on *Eucalyptus nitens* and *Eucalyptus globulus* to the extent that it has a short term industry focus versus a more strategic long term set of goals. An example of this is that it has no contingency plan in place for the adoption and development of alternate species.	**Capacity (People)** • There is a generational problem on the horizon with the average age of researchers in the field of tree breeding and genetic improvement increasing in the absence of a succession planning strategy to ensure that these skills and knowledge is retained within the industry. • A key problem with the current education and training programs for forestry within universities is that the majority of new students are focused on the research fields of climate adaption, restoration, landscape – genomics versus research fields that are associated or aligned with tree breeding and genetic improvement. • Due to a combination of low levels of investment, the cost of employment, a limited pool of employers and the capacity of companies to integrate genetics skills into their programs, many students who complete Masters and/or PhD's in research fields associated with tree breeding and genetic improvement many are switching to alternate areas of interest where there are more likely to be positions with commensurate salaries available (e.g. crops, animals etc) or alternatively they may move overseas and obtain positions in tree breeding and genetic improvement programs.

Table 5. Softwood Plantation Tree Breeding and Genetic Improvement - Strengths

<table>
<tr><th colspan="2">Softwood Plantation Tree Breeding and Genetic Improvement - Strengths</th></tr>
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Capability (Technology)

- The softwood industry has well-structured breeding programs with defined breeding goals which provides a platform for the use of customised indices and economic models for consistency in selection which enables the application of a “Rolling front breeding strategy”.
- The rate and value of genetic improvement is high (compared to other sectors e.g. cattle, sheep) primarily due to the genetic diversity which exists within the *Pinus sp.* A key resource for the genetic diversity that exists is the access breeder have to generic conservation populations.
- The industry is well serviced in technical capability with access to genomic platform technologies (e.g. Agriculture Victoria), together with a broad range of integrated breeding tools (e.g. Somatic Embryogenesis capability – SCION in NZ and Arbour in Australia), systems and integrated data management (e.g. Integrated data bases and analysis; BLUP, ssBLUP Platform) which have been adopted nationally.
- It is generally regarded that the move to adopt genetically modified technology is more acceptable in trees – especially pines as seen as tree farms. Some GM technology capability exists however to date it has been restricted to other species.
- A strength of Australia’s softwood industry is its ability to maintain the integrity of its germplasm and estates through the effective implementation of Quarantine standards governing the entry of material into Australia – this keeps the industry safe and must be maintained into the future.
- Pine offers high value/profitability for value chain participants due to the diversity of products that can be generated from the estate. The industry is very scalable in terms of value i.e. more $ in = more $ out (High potential of good IRR)
- With the increasing commitment to government investment to address climate change and as part of that looking for opportunities to sequestrate carbon, *Pinus sp*. offer an excellent opportunity for the industry to capitalise on this trend.

</td><td>

Capacity (People)

- The tree breeding and genetic improvement sector of the softwood industry is well resourced in human capacity with good people who have diverse knowledge and experience.
- A key strength of the industry is the high level of engagement and support across the industry which is in part due to the relatively small numbers of participants that are fully integrated across the value chain. This ensures that each step of the value chain is very aware of the value that tree breeding and genetic improvement can contribute to the overall value of the estate and the products it generates. As a result there is a rapid adoption and uptake of new technologies within the industry. The rapid uptake of new technologies is also due to the history of breeders consistently delivering on the improvement which they forecast/predict.
- A key platform for the future of tree breeding and genetic improvement is that FWPA is driving policy change in R,D and E which is being reflected in their investments in the field of tree breeding and genetic improvement during the previous five-year period.
- A core strength of the softwood industry is the commitment of industry participants to collaborate. There are a number of examples which demonstrate this commitment:
    - Collaboration and commitment of organisations who are members of Tree Breeding Australia (Formerly Southern Tree Breeding Association) to contribute resources to support its operations and outputs.
    - The strong international collaborations that both public and private sector participants in the softwood industry have established and maintained with organisations and individuals in New Zealand, Europe, North America, South America and Asia.
    - The level of collaboration that exists across sectors (e.g. AGBU – livestock)

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Table 6. Softwood Plantation Tree Breeding and Genetic Improvement - Weaknesses

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<tr><th colspan="2">Softwood Plantation Tree Breeding and Genetic Improvement - Weaknesses</th></tr>
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<td>Capability (Technology)

A key challenge for researchers is that the tools that are being applied to tree breeding and genetic improvement in New Zealand are different that being applied in Australia. This is potentially limiting the level of collaboration and transfer of information. This is being further complicated with the lack of ability to transfer material between Australia and New Zealand due to quarantine constraints on both sides of the Tasman.
In contrast to the hardwood industry where the map of the Eucalyptus genome has been completed and is available as a resource to industry for use in breeding and genetic improvement, a key constraint is the lack of genome map for Pinus sp.
Since the demise of investment in CSIRO there has been a significant loss in core capability which has failed to be replaced through institutions such as Universities as the sector is not as engaged with softwoods except on specific projects versus their investment and commitment to as Eucalyptus sp. as they are the core of the native estate in Australia.
Workshop participants identified that there is a deployment bottleneck restricting the advancement of the best genetic material into forest plantations. In part this is due to the lack of understanding in sites and in site diversity
Despite breeders recognising the industry driven need to increase core-wood stiffness, developments in this research are being limited due to increasing trend to shorter rotations which limits the potential to achieve the desired outcome.
A weakness identified by industry participants is the poor documentation of processes together with the management of the data post collection.
It has been identified that a potential issue for reproduction biology is that breeders are still to develop an approach to accelerating flowering due the current poor – variable bud set in Pinus sp.
To date there is no current capability within Australia to undertake genetic modification of Pinus sp. primarily due to the fact that a high value trait is yet to be identified that could justify the investment in research capability.
The lack of domestic processing volume and limited land base to support the expansion of the industry remains in issue for investment in softwood capability

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<td>Capacity (People)

A challenge for the tree breeding and genetic improvement sector within the softwood industry is the lack of a succession plan to train and engage both male and female graduates, PhD’s and Post Doc’s within the sector. This is a growing concern with the ageing male dominated research population within the industry. The issue is in part due to each of the following:

the lack of employment and career opportunities within the industry,
the forest industry is competing with alternate industry sectors (e.g. livestock and crops) within Australia for young people to enter the industry and
the university sector is not as engaged with softwoods (except on specific projects) versus their investment and commitment to Eucalyptus sp. as they are the core of the native estate in Australia.

A key challenge for the softwood sector is its ability to attract and secure long term stable investment for research into tree breeding and genetic improvement. There are multiple reasons that contribute to this strategic issue for the industry:

The industry does a poor job in promoting the value proposition for breeding and the corresponding returns on investment that can be achieved through such an investment to value chain participants, governments and the general public. Hence, research dollars are only suffice to support trials in the near term and not enough to support long-term strategic investment in research capability.
The industry has a fragmented approach to funding for public sector research relying on government grants through the Australian Research Council along with funding for CRC’s and the FWPA to support tree breeding and genetic improvement research – all of which are in decline.
The lack of an effective long term (i.e. versus short term) government policy and strategy for the plantation industry together with the loss of investment from federal, state and territory government along with the asynchrony of political cycles to that of forestry cycles is leading to under resourcing and loss of strategic infrastructure investment for the industry.

The industry has a fragmented approach to funding for public sector research relying on federal government grants through the Australian Research Council

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Softwood Plantation Tree Breeding and Genetic Improvement - Weaknesses	
due to it being regarded as a minor product and not a premium product within the forestry industry.	and funding for CRC's and the FWPA and state government funding – all of which are in decline. • Participants in the workshop were of the view that the lack of effective connection/collaboration between the Australian and New Zealand softwood industries, in particular that between RPBC and Tree Breeding Australia, was inhibiting advancements in tree breeding and genetic improvement research within the softwood industry. • Of concern to workshop participants is the perceived poor reputation of the softwood forestry industry within the general public. • In relation to the information generated from research generated by research organisations (e.g. Tree Breeding Australia) there is sense that much of the value is not getting to the broader industry for adoption because of the lack appropriately skilled people to effectively engage with industry stakeholders. Especially in the adoption and application of modern breeding opportunities such as the use of markers, genome wide selection and breeding values. The lack of effective extension and communication is also impacting on end users not being in a position to take advantage of these tools and customise these to individual breeding programs. • The industry is poor at validating and demonstrating genetic gains that have been achieved in softwood breeding. • A critical issue that faces the softwood industry is the perceived lack of communication between researchers, growers and processers. This has led to the situation where values are not aligned and the establishment of conflicting objectives.

Appendix Four: Tree Breeding and Genetic Improvement - global context and regional perspectives

Planted forests are of increasing global importance with their contribution to addressing major socio-economic and environmental challenges such as poverty alleviation, food security, renewable energy, and climate change and biodiversity conservation widely acknowledged.

In many developing and developed countries planted forests have become a substantial component of the productive and protective forest resources. Various estimates suggest that the global area of planted forests accounts for approximately 7% of total forest area and indicate that they provide between one third to two thirds of the global industrial round wood demand and sequester 1.5 gigatons carbon (1.5 x 10^9 tons) per year.

In some countries in Europe, Latin America, Oceania and the United States the establishment of new planted forests or the replanting of existing ones has decreased due to high land prices, a lack of financial incentives, and environmental restrictions. As such, there are significant efforts in maximising production per unit area through R,D and E.

In order to provide context to the advances and opportunities that exist through Australian forestry it is important to have an understanding of regional perspectives on planted forest development. Importantly, what R,D & E is being undertaken in other jurisdictions, where their focus is, what gains are being made and how are they being achieved?

4.1 South Africa

Africa accounts for 5.8 % of the global planted forest area. Most of Africa's wood is still produced from natural forests with investments in planted forests mainly in countries with relatively low forest cover (e.g. in Algeria, Morocco, Nigeria, South Africa and the Sudan). Most forest planting programs were created in an effort to secure industrial wood and wood fuel sources while some were established to combat desertification.

The majority of planted forests consist of exotic species (Eucalyptus, Pinus, Hevea, Acacia, Tectona) chosen for their ability to rapidly produce wood or other economic products (e.g. gum arabic, rubber). African countries where planted forests rely on only a few tree species tend to focus more on species diversification as a safeguard against pests, diseases and climatic hazards, which may also result in increased market security through product diversification.

The quality of management and productivity of planted forests largely depends on the type of ownership. Most planted forests are established and managed by public forestry agencies with the exception of South Africa. Publicly owned forests were generally reported to be in a poor state due to inadequate governance frameworks, weak forestry departments, inadequate silvicultural management, budgetary constraints, and lack of research.

Privately owned forest plantations are common in South Africa, Swaziland and Zimbabwe. They are generally well managed, display high productivity and aim at profit maximisation often integrating plantations with wood processing plants.

In South Africa, there are three key institutes providing R,D & E effort into forestry.

1. The Institute for Commercial Forestry Research (ICFR; http://www.icfr.ukzn.ac.za) is an independent provider of project-based research solutions and other related services in support of forest management for economic, social and environmental benefit in southern Africa. To achieve desired research project goals the ICFR works closely with other research institutes and universities.

   The ICFR provides research capability to various funding consortia in two key areas; sustainable production and tree improvement. The current sustainable production research focus includes: Eucalypt forest protection, Baboon damage impact, Sirex (wasp pest) control, Multi-rotation site resilience. The focus for tree improvement is having access to wattle and eucalypt planting stock that is tolerant of key pests and pathogens and can deal with abiotic stresses such as drought and frost. This is achieved through research into Eucalypt base populations, Eucalypt hybrid development and Wattle tree improvement.

2. Council for Scientific and industrial Research (CSIR; https://www.csir.co.za) is a leading scientific and technology research organisation that researches, develops, localises and diffuses technologies to accelerate socio-economic prosperity in South Africa. The Forestry and Forest Products Research Centre is a joint venture between CSIR's Natural Resources and the Environment operating unit and the University of KwaZulu-Natal. It is a provider of research and services for plantation forestry and forest products industries. The Centre focus is to maximise value extraction for plantation-grown softwoods and hardwoods, within the solid wood pulp and paper processing sector and the plantation growing industries that support it. Research focuses on understanding basic wood properties and wood ultrastructure, wood chemistry and fibre processing as well as a range of bio-economy related areas such as bio-refinery and recycling.

3. Forestry and Agricultural Biotechnology Institute (FABI; http://www.fabinet.up.ac.za) undertake goal-directed research, in partnership with major players in the forestry and agricultural sectors in South Africa. The institute has several programs focused on forest improvement. In particular, there are several programs focussed on tree health, such as understanding the molecular basis of defence responses of Eucalyptus and pine to pests and pathogens and the possible impacts of soil properties and nutrients, microbial symbioses and climatic factors on the health of woody plants in diverse landscapes.

   Of significant note is the FABI Forest Molecular Genetics Program (FMG) that focuses on the genetic control of growth and development in fast-growing plantation trees. The aim of this group is to develop biotechnology applications to enhance biomass production and improve wood properties for timber, pulp, paper, and other bio- based products.

FMG was instrumental in completing the sequencing of the *Eucalyptus grandis* genome[52]. Together with the completed genome of *Populus*, the *E. grandis* genome resource serves as a model and reference for the study of fast-growing woody plants that are used as renewable feedstocks for a growing number of bio- based products.

The genome sequence has also served as a reference for the development of a genome-wide DNA marker resource for *Eucalyptus*, which we have deployed for genomic breeding and selection in two large pilot projects in *E. grandis* and *E. dunnii* initiated with industrial partners.

Other FMG programs of note include:

- *Systems and Evolutionary Biology of Wood*–modelling the formation of wood, from the determination of cell identities to their development, to the allocation and processing of carbon and other small molecules inside to form these valuable biopolymers in the secondary cell walls.
- *Transcriptional and Epigenetic Regulation of Wood Development*–Woody traits can be manipulated through transcriptional network re-engineering. However, knowledge of transcriptional control of wood development is lacking. As such, FMG uses cutting-edge genomics approaches such as chromatin immunoprecipitation sequencing (ChIP-seq), DNA affinity purification sequencing (DAP- seq), RNA-seq analysis and transgenic approaches to unravel the functions of transcription factors and modified histones involved in wood development in *Eucalyptus*.
- *Population Genomics and Molecular Breeding*–FMG use their molecular tools to understand the genetic control of growth and development in trees with a focus on wood formation in fast-growing Eucalyptus and tropical pine species and their hybrids. DNA marker technologies (such as genome-wide SNP chips) have proven to be a powerful tool to tag genetic variation and develop predictive models of the breeding values of individual trees. By adding molecular traits such as gene expression and metabolite variation, it is possible to gain further biological insight into the molecular basis of quantitative traits. This group have used this approach in an interspecific backcross population of *E. grandis* x *E. urophylla* to map key genomic regions affecting gene expression and metabolic profiles associated with variation in growth and wood chemistry[53]. The systems genetics data is a rich source for identifying individual genes and pathways to engineer wood chemistry traits and identifying targets for precision

[52] Myburg A. A., Grattapaglia D., Tuskan G. A., Hellsten U., Hayes R. D., Grimwood J., … Schmutz J. (2014). The genome of *Eucalyptus grandis*. Nature, 510(7505), 356–362. 10.1038/Nature13308.
[53] Mizrachi, E., Verbeke, L., Christie, N., Fierro, A. C., Mansfield, S. D., Davis, M. F., et al. (2017). Network-based integration of systems genetics data reveals pathways associated with lignocellulosic biomass accumulation and processing. *Proc. Natl. Acad. Sci. U.S.A.* 114, 1195–1200. doi: 10.1073/pnas.1620119114

breeding of cell wall traits such as xylan content and structure affecting pulp yield in trees.

- The Single Nucleotide Polymorphism (SNP) marker chip with 60,000 DNA markers (EUChip60K)[54] to genotype over 3,000 Eucalyptus trees from *E. grandis*, *E. dunnii* and *E. grandis* x *E. urophylla* hybrids. This has provided us with unprecedented resolution to rapidly dissect complex traits in *Eucalyptus* and develop predictive models for genomic selection of growth and wood properties in tree breeding populations. With support from the Forestry Sector Innovation Fund (FSIF) we are expanding this to other Eucalyptus and pine tree species and constructing a Genome Diversity Atlas for Eucalyptus and pine species grown in South Africa. Together with an international consortium of pine genomics researchers, we will generate a multi-species SNP genotyping chip for tropical pines, on par with what is available for Eucalyptus. These resources will be useful for genetic resource management and molecular breeding of pines.

  These tools are useful as they combine population genomics with analysis of interactions with biotic and abiotic stresses such as cold, drought and disease to predict tree genotypes that are best adapted to such environments, or that can be deployed to combat new biotic challenges such as pests and diseases.

- *Bioinformatics and Statistical Genomics*–application and development of advanced data analysis tools for large genomics datasets across many individuals in breeding populations. Research includes the development of systems genetics data analysis pipelines for Eucalyptus data from our breeding populations. This involves the identification of Quantitative Trait Loci (QTLs), i.e. genomic regions containing genetic variation, for phenotypic, gene expression (eQTLs) and metabolite (mQTLs) traits, as well as the visualisation and co-localisation of the different types of QTLs. This platform, together with gene co-expression and correlation analysis, provides an excellent basis for the study of molecular networks underlying our phenotypic traits of interest. The Plant Genome Integrative Explorer (PlantGenIE)[55] is a web resource for searching, visualising and analysing genomics and transcriptomics data from model forest tree species, including spruce, poplar and recently also *Eucalyptus*. Together with integrating EucGenIE into PlantGenIE, we are developing a suite of online population genomics tools. By considering entire populations, we have the statistical power to identify correlations between genotype and phenotype, via QTL or GWAS studies. We are working on two tools: (i) qtlXplorer to browse QTL data and (ii) qtlNet to visualise QTL networks.

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[54] Silva-Junior O. B., Faria D. A., Grattapaglia D. (2015). A flexible multi-species genome-wide 60K SNP chip developed from pooled resequencing of 240 *Eucalyptus* tree genomes across 12 species. *New Phytol.* 206 1527–1540. 10.1111/nph.13322

[55] Sundell D., Mannapperuma C., Netotea S., Delhomme N., Lin Y. C., Sjödin A., et al. . (2015). The plant genome integrative explorer resource: PlantGenIE.org. New Phytol. 208, 1149–1156. 10.1111/nph.13557

- *Functional Genetic Testing Wood Formation Genes*–FMG have established capacity for genetic transformation and gene testing in *Arabidopsis* and *Populus* plants. FMG have also developed capacity for tissue culture and *in vitro* propagation of different Eucalyptus genotypes and established collaborations with Oregon State University and the biotechnology company FuturaGene[56] towards developing a Eucalyptus transgenic platform at the University of Pretoria.

4.2 South East Asia

Asia has nearly half of the global total of planted forests. The planted forest area has recently increased through large-scale afforestation programs, mainly in China, India and Vietnam, which aimed to expand forest resources, protect watersheds, control soil erosion and desertification, and maintain biodiversity.

China's national forestry strategy sets a goal of expanding the planted forest area by a further 40 million hectares by 2020. As more of the natural forests are excluded from production, planted forests are becoming the mainstay of wood production in the region. Future wood supply will depend on improving the productivity of existing planted forests (e.g. through biotechnology), on expansion into urban and peri-urban spaces and on encouraging farm forestry as an important source of wood. Farm forestry is expected to continue to expand as a result of improving security of land tenure, declining profitability of agriculture and increasing demand and prices for wood products. On the other hand, the scope for expansion of commercial plantations is limited. In a changing environment the value of ecosystem services provided by planted forests are increasingly appreciated by policy makers and the general public.

China's forest policies on forest ecosystem services have evolved from an emphasis on timber production and utilisation to ecological improvements. The National Development Strategy of China (2013) emphasises the establishment of an Ecological Civilization. Planted forests are increasingly assigned to protective and multiple-use functions with the objective to optimise land use at a landscape level. Future forestry research will focus on the conduct of long-term monitoring of forest resources, the development of cross-sectoral multi-purpose guidelines, the development of climate change adaptation strategies, and integrated landscape management policies and practices, so that planted forests along with other land uses can ensure sustainable landscape management.

4.3 Europe

Europe has about 26% of the global planted forest area. Most European forests are actively managed and show an enormous diversity in terms of forest types, species and management objectives. The distinction between natural and planted forests is less clear than for other regions as much of the original forest cover was removed hundreds of years ago. The

[56] Anon (2019) http://www.futuragene.com

observed increase in forest area in Europe (on average 400,000 ha per year from 2000 to 2010) results both from the establishment of planted forests using mainly native species and from natural colonisation of former agricultural land. Current trends in European forest management could result in an over-supply of wood from broadleaved species, as well as a shortfall of coniferous timber from European forests, in particular as an increase in harvest is difficult to achieve due to restrictive environmental policies and the fact that many small forest owners prefer to leave a legacy to their children rather than to harvest the timber on their plots.

Many European countries have introduced policies to increase the share of renewable energy in total energy consumption in order to combat climate change and address concerns about rising fossil fuel prices and energy security. These policies have stimulated an increasing demand for wood as an energy source and have led to substantial public and private investments in biofuel production from forest plantations often in the form of fast-growing, short-rotation coppice plantations (e.g. from poplars). It is anticipated that further oil price increases will significantly increase the demand for wood as a source of energy.

The future management of planted forests has to meet a number of challenges, among them the coping with the high fragmentation of private forest ownership, the sluggish demand under the current economic crisis, the creation of innovative products and, with it, the optimisation of the value-added chain, and the increasing role of the forestry sector in the bio- economy

Research and development efforts are largely driven by European Union supported collaborations and consortia.

1. **European Forest Genetic Resources Program** (EuForGen http://www.euforgen.org)

This is an international cooperation program that promotes the conservation and sustainable use of forest genetic resources in Europe as an integral part of sustainable forest management.

Three core Objectives:

a. Collate, maintain and disseminate reliable information on forest genetic resources in Europe.
b. Coordinate and monitor the conservation of forest genetic resources in Europe.
c. Develop guidelines and analyses on topics and issues relevant for the use of forest genetic resources in Europe.

2. **B4EST** (http://b4est.eu).

The B4EST consortium gathers 19 partners comprising public and private partners with cross-cutting complementary skills from 9 European countries (Finland, France, Italy, Norway, Portugal, Spain, Sweden, The Netherlands and The United Kingdom) and one international organisation (European Forestry Institute)

B4EST is an EU-funded Horizon 2020 project which focuses on adaptive breeding for productive, sustainable and resilient forests under climate change.

B4EST aims to provide forest tree breeders, forest managers and owners, and policy makers with:

- Better scientific knowledge on adaptation profiles and sustainable productivity, and added value of raw materials in important European tree species for forestry
- New and flexible adaptive tree breeding strategies
- Tree genotypes of highly adaptive and economical value
- Decision-support tools for the choice and use of Forest Reproductive Material (FRM) while balancing production, resilience and genetic diversity, including case studies developed with industrial partners
- Integrative performance models to guide FRM (forest reproductive material) deployment at stand and landscape level
- Economic analyses of risks/benefits/costs
- Policy recommendations.

3. **European Forestry Institute**–(EFI; https://efi.int).

The European Forest Institute is an international organisation, established by European States. EFI conduct research and provide policy support on issues related to forests.

4. **GenTree** (http://www.gentree-h2020.eu).

Europe–GenTree brings together 22 public and private EU research organisations and enterprises, contributing a wide variety of skills, expertise and long-standing experience in the area of forest genetic resources. The project is coordinated by Institut national de la recherche agronomique (INRA), France. The goal of GenTree is to provide the European forestry sector with better knowledge, methods and tools for optimising the management and sustainable use of forest genetic resources in Europe in the context of climate change and continuously evolving demands for forest products and services.

4.4 Scandinavia

Sweden is the world's second biggest exporter of paper, paper pulp and wood products however, Sweden's forest land makes up just under 1% of all the forest land globally. The composition of Sweden's forest land is coniferous forest (83%), mixed forest (12%) and pure deciduous forest (5%).

Sweden has sustainable forestry that is subject to legislation requiring nature conservation and replanting. All harvested forest must be regenerated either through planned planting or by leaving trees that naturally produce seeds and new seedlings. In addition to the forestry legislation, there are also voluntary international forest certification systems, under which forestry is verified through so-called third-party certification. The two systems used in Sweden are FSC and PEFC. These are both international schemes for forest certification, and around two thirds of Sweden's productive forest land is certified in accordance with these systems.

The Forestry Research Institute of Sweden[57] is a research institute headquartered in Uppsala, jointly financed by the members of the Swedish forestry industry and the Government. The institute aims to provide the industry with knowledge, products, and services, for more cost-effective and sustainable forestry, leading to increased competitiveness and realisation of societal goals. Research efforts are primarily focused on tree breeding, production engineering and logistics. Other important research areas are environmental protection, silviculture, forest bioenergy and utilisation.

Danish forests comprise state-owned forests, managed by the Nature Agency's local units, as well as many privately-owned forests and woodlands. Norway spruce grow on 19% of the forest area and it is the most common tree species in Denmark.

Danida Forest Seed Centre (DFSC)[58] is an institution administered by Danida, the Danish International Development Administration, and is situated in Humlebaek, Denmark. DFSC has been in operation since 1969 and provides advice and guidance and undertakers research on seed procurement, tree improvement, conservation of forest genetic resources for tropical and subtropical developing countries. The Danida Forest Seed Centre was integrated in 2004 into the Danish Centre for Forest Landscape and Planning (Royal Veterinary and Agricultural University), Denmark.

The Norwegian Forest Research Institute is an autonomous institute under the Ministry of Food and Agriculture. The main tasks of the institute are to strengthen the scientific basis for the management of forest resources, the creation of wealth from forests and countermeasures against environmental problems in forests. Research focuses on questions about the establishment of new forests, conditions for the growth of existing forests, ecology economics in forestry and the use of timber. The institute is also responsible for maintaining the Norwegian Forestry Inventory.

Norwegian Institute of Bioeconomy Research (NIBIO) is to contribute to food security and safety, sustainable resource management, innovation and value creation through research and knowledge production within food, forestry and other bio-based industries.

Since the 1950s, afforestation by planting trees has been a priority in Iceland. The principal species planted, besides birch, were exotic conifers like Norway spruce, Sitka spruce, Scots pine, Lodgepole pine and Siberian larch. Iceland once had a forest cover of up to 60%, mostly

[57] Forestry Research Institute of Sweden https://www.skogforsk.se/english/
[58] Anon (2019) http://www.dfsc.dk

with birch forests whereas today, forest coverage is around 2%[59]. Due to extensive logging, land degradation and soil erosion, Iceland faces major reforestation challenge[60] [61]. Some of the most common species included in this challenge are birch, Siberian larch, Sitka spruce and Lodgepole pine.

In 2012, a project financed by Nordic Energy Research was initiated with the prime objective of strengthening the role of Nordic forestry as a significant contributor to the development of competitive, efficient and renewable energy systems.

A primary focus of this initiative was the use of genetically improved material as a way to meet these objectives. The program recognised that breeding is considered to be the most effective and environmentally friendly option to increase sustainable biomass production in forests. Breeding offers significant advantages at little additional cost, since improved material is only slightly more expensive than unimproved material.

A review of breeding activities and genetic gains in Scandinavia and Finland have been recently published[62] highlighting the importance of breeding and the use of new technologies to improve material to reduce the dependence of fossil energy and to combine intensive breeding, gene conservation and preparedness for future climatic changes.

The report emphasises the potential gains, both production and economic, that could be achieved through coordinated and focused breeding efforts.

4.5 Latin America

Forestry in Latin America is relatively small, representing less than 6% of the global planted forest area. However, it continues to expand at a rate of 3% per year and projections suggest this to increase. In Brazil the forest plantation area is anticipated to double by 2020. The region is emerging as a leader in the use of renewable fuels and in the development of high-productivity forest plantations driven by the private sector and supported by favourable government policies and financial incentive schemes. These factors have made Latin America a preferred destination for investments by both regional and global pulp and paper producers and North American investors including timber investment management organizations. Key features of forest plantation development in particular countries such as Argentina, Brazil, Chile, Costa Rica and Uruguay include:

- increasing investments in productivity-enhancing technology, especially clonal propagation, achieving in some cases growth rates of more than 50m3/ha/yr

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[59] Mattsson A (2016) Restoration challenges in Scandinavia. Reforesta 1: 67-85. DOI: http://dx.doi.org/10.21750/REFOR.1.05.5

[60] Arnalds O, Barkarson B H (2003) Soil erosion and land use policy in Iceland in relation to sheep grazing and government subsidies. Environmental Science and Policy, volume 6, Issue 1: 105-113

[61] Eysteinsson T (2013) Forestry in a treeless land. Iceland Forest Service, Egilsstadir

[62] Anon (2019) https://www.skogforsk.se/contentassets/9d9c6eeaef374a2283b2716edd8d552e/the-status-of-tree-breeding-low.pdf

- use of intensively managed short-rotation species such as *Eucalyptus* spp., *Pinus radiata*, *P. taeda*, *P. elliottii* and *Tectona grandis*
- integration of plantation management with wood processing facilities, especially pulp and paper and panel production
- advanced biotechnology and environmental legislation on land use have contributed to reduce the negative environmental impacts of fast-growing forest plantations.

Sustainable intensification based on science and good operational practices has been largely demonstrated in Chile's forestry sector. Forest plantations focusing on wood production form the basis of a vibrant forest industry that has grown to become the 3rd largest exporter in Chile contributing considerably to employment and GDP. International certification schemes recognise that planted forests contribute to the reduction of soil erosion and maintain and increase water quality. In addition, many plantation companies have established successful community support programs.

Recent government regulations in several Latin American countries have discouraged forest investment in agricultural land, as food, fibre and fuel production increasingly compete for limited land resources. Private and corporate companies appear to be making excellent returns based on cheap land costs paid decades ago; new investments in many cases will have smaller rates of return due to higher land costs, but still compare favourably with other asset classes.

The most prominent R,D & E activities in Latin America come from EMBRAPA in Brazil. The ability to effectively translate research and technology to commercial use sets EMPRAPA apart from many other public sector R,D&E organisations. In forestry, EMBRAPA have made significant advances in Eucalyptus breeding and production. In particular, *Eucalyptus urophylla* is one of the most important species for the planted forest sector in Brazil due to characteristics of productivity, adaptation and rusticity.

Eucalyptus improvement has placed the paper and cellulose divisions of the Brazilian forestry industry in a prominent position. Advances in productivity and wood quality are largely due to the development of interspecific *Eucalyptus* hybrids and the cloning of the best individuals from progeny[63]. Hybrids between *Eucalyptus urophylla* x *E. grandis* have been produced with favourable adaptation traits, rooting ability, resistance to *Eucalyptus* canker disease, and high yield.

The vast majority of Eucalyptus improvement programs in Brazil are based on hybrids. In 2005, 84.5% of the clonal plantings of Eucalyptus in Brazil were hybrids, where 66.5% of which were hybrids from controlled crosses. The hybrid *E. grandis×E. urophylla* is most often used, with 65% of the planted area. Fifteen percent of the remainder is still natural and spontaneous

[63] Assis, T.F. and Mafia, R.G. (2007) Hibridac¸ ˜ao e clonagem de Eucalyptus. In: Bor´em, A. (ed.) Biotecnologia Florestal. Editora Universidade Federal de Vic¸osa, Vic¸osa, Brazil, pp. 93–121.

E. urophylla hybrids, 3% Rio Claro hybrids, 0.5% *E. urophylla* × *E. camaldulensis*, 0.4% *E. urophylla* × *E. globulus* and 0.6% *E. camaldulensis* × *E. grandis*[64].

The efficiency of hybridization to produce genetic gains is fully acknowledged, being used by most forestry companies in Brazil. However, since the hybrid offspring are heterogeneous, transforming these gains quickly and effectively into benefits for the industry depends on functional, large-scale cloning methods. Thus, if on the one hand, interspecific hybridisation in Eucalyptus has been the fastest way to achieve genetic gains, cloning on the other hand is the most efficient way to incorporate these gains into the industrial production processes.

Cloning has an important place in the production of forest plants in Brazil, and its use is justified mainly when the availability of high productivity and quality genotypes is limited. It is an important tool to aid the plant breeding programs and mass propagation of plants. However, difficulties in obtaining rooting in some species or clones, mainly adults, have made it difficult to use in many cases. Cloning is responsible today for most of the commercial forest area planted in Brazil, mainly for the genus *Eucalyptus*. Numerous methods have been adapted and developed; among the most used and, or, with greater possibilities of application, we can mention grafting, cuttings, micro propagation, micro-cuttings and mini-cuttings techniques. Species where the objective is the production of wood and leaves (*Eucalyptus* spp and *Ilex paraguariensis*) are propagated by cuttings / mini-cuttings techniques for the formation of high production commercial clonal plantations and by grafting of adult trees for the installation of seed orchards.

4.6 North America

North America accounts for about 14% of the global planted forest area. In Canada, planted forests represent 3% of the total forest area, in Mexico 5%, and in the USA 8%. The area of planted forest shows a slightly increasing trend in the three countries. However, climate change phenomena may intensify threats to forest health. The intensity and frequency of forest fires and pest infestations (e.g. by the mountain pine beetle) have increased in both Canada and the USA, exacerbated by prolonged drought attributed to climate change. In the US large changes in ownership patterns have occurred over time favoring in particular large landowners and resulting in a highly intensive management of planted forests. Thus, substantial gains in productivity have been achieved in Douglas fir and southern pine forests resulting in shorter rotation ages. Increased investment in planted forests followed the pulp and paper boom in the southern US, the Pacific Northwest lumber boom, and the development of the plywood industry and OSB markets. Locally, the contribution of the forestry sector to the overall economy is considerable while the development of markets for ecosystem goods and services still needs to be intensified.

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[64] Assis, T.F. (2004) The current status of Eucalyptus clonal forestry in Brazil. Benchmarking clonal propagation for the blue gum plantation industry. In: Workshop CRC for Sustainable Production Forestry and AusIndustry. August 31, University of Tasmania, Tasmania, Australia.

- US Forest Service (https://www.fs.fed.us). US Government agency that manages and protects 154 national forests and 20 grasslands in 43 states and Puerto Rico. The agency's mission is to sustain the health, diversity, and productivity of the nation's forests and grasslands to meet the needs of present and future generations
- Natural Resources Canada (https://www.nrcan.gc.ca/home) and Canadian Forest Service (https://www.nrcan.gc.ca/forests) Canadian Government agencies that manage forests and forestry in Canada.

Appendix Five: Hardwood & Softwood Workshops Agenda

Development of an Investment Plan for research, development and extension to sustainably maximise value gains through tree breeding and genetic improvement for   ***Forest Wood Products Australia***

Industry Workshop Agenda

Date:	Monday 4th March 2019 (Hardwood)	**Time:**	1.00 pm – 5.00 pm
	Tuesday 5th March 2019 (Softwood)	**Time:**	9.30 am – 4.00 pm
Location:	Offices of FWPA, 10 – 16 Queen Street, Melbourne.		
Facilitators:	David Hudson (DH); Carl Ramage (CR)		
Participants:	Representatives from FWPA GRAC exec members (3) nominated for oversight of the plan and members of the Technical Panel (17).		

Workshop Objectives:

1. Provide a project overview, introduce the PTM Solutions project team, primary objectives and timelines.
2. Gain an insight into the current forest industry objectives related to tree breeding and genetic improvement within Australia/New Zealand.
    a. Are there collective objectives for all participants or are these on an individual company basis?
    b. Confirm the current status of forest industry R, D&E in relation to achieving these objectives.
3. Identify and confirm current capability and capacity for science and innovation within the forest industry.
    a. Is there duplication?
    b. Are there gaps? If so what are these?
4. Review and discuss the forest industry experience and perspective in adopting innovative breeding technologies and strategies.
    a. What has worked well over the last 10 – 15 years?
    b. What have been the learnings?
    c. What are the implications for future tree breeding strategies?
5. Provide a forum to discuss challenges and opportunities in developing future breeding objectives and strategies related to genetic improvement in tree breeding.
    a. Identify issues/barriers limiting breeding/innovation opportunities and explore strategies to address those issues
    b. Identify gaps in existing strategies and activities. What is required to address these gaps?

Workshop Agenda:

<table>
<tr><th>Activity</th><th>Facilitator</th></tr>
<tr><td>Introduction and Welcome – workshop overview / context</td><td>DH / CR</td></tr>
<tr><td>Session 1: Current Status of the Forest Products Industry
Outcomes from forest industry R,D&E capability and capacity questionnaire
What are the current breeding objectives and approaches / innovations?
Capabilities / Capacity – technology / people / germplasm
Collaboration-domestic and international
Barriers to innovation
Industry experience and perspective-where are we and where do we need to go?
Group Discussion</td><td>DH / CR</td></tr>
<tr><td>Session 2: Strengths and Challenges of the Current Industry
Assessment of Strengths and Weakness
Activity: <u>SWOT analysis Part 1:</u> Identify the current strengths and weaknesses of the Forest Industry R, D & E platform for tree breeding and genetic improvement.
Workshop groups present and discuss outcomes</td><td>DH</td></tr>
<tr><td>Session 3: Opportunities and Threats
Opportunities and Threats assessment
Activity: <u>SWOT analysis Part 2:</u> Identify the current opportunities and threats that face the Forest Industry R, D & E platform for tree breeding and genetic improvement.
Workshop groups present and discuss outcomes</td><td>DH</td></tr>
<tr><td>Presentation: What is the current approach to breeding and genetic improvement using innovative technologies and strategies in various plant and animal industries?</td><td>CR</td></tr>
</table>

Session 4: Innovative breeding technologies and strategies • What is the current status of breeding and genetic improvement using innovative technologies and strategies in various plant and animal industries? • What opportunities exist for the use of current and future innovative breeding technologies and strategies for tree breeding and genetic improvement? *Activity:* Discuss the forest industry experience and perspective in adopting innovative breeding and genetic improvement technologies and strategies. a. What has worked well over the last 10 – 15 years? b. What have been the learnings? c. What are the implications for future tree breeding strategies? d. Identify innovative breeding technologies and strategies that are currently not being applied and have potential for adoption *Workshop groups present and discuss outcomes*	CR
Session 5: A Vision for the Future • What should the Forestry Industry R, D &E in tree breeding and genetic improvement look like in 2030? *Activity*: Discuss challenges and opportunities in developing future breeding objectives and strategies related to genetic improvement in tree breeding. a. Identify issues/barriers limiting breeding/innovation opportunities and explore strategies to address those issues b. Identify gaps in existing strategies and activities. What is required to address these gaps? a. What are the implications for future tree breeding and genetic improvement strategies? *Group Discussion*	CR
Workshop summary – next steps and time frame	DH
Close and depart	

Appendix Six: Hardwood & Softwood Industry Stakeholders Consulted

Name	Organisation
Linden Whittle	ABARES
Robert Banks	AGBU
John McEwan	AgResearch
Justin Borevitz	ANU
Ben Bradshaw	Australian Bluegum Plantations
Brent Guild	CEO Radiata Pine Breeding Company
Dot Steane	CSIRO
David Bush	CSIRO
Ange Chandler	Forest Products Commission WA
Mike Sutton	Forestry Corporation NSW
Ross Dickson	Forestry Corporation NSW
Geoff Downes	Forest Quality Pty Ltd
Andrew Jacobs	Forico
Kelsey Joyce	Forico
Andrew Moore	Global Forest Partners
Bala Thumma	Gondwana Genomics
Robert Southerton	Gondwana Genomics
Saravanan Thaavamanikumar	Gondwana Genomics
Wolfgang Drexler	Green Triangle Forest Products
David West	HQ Plantations
Dominic Kain	HQ Plantations
Jake Lazurus	Hume Forests, Southern Cross Forests,
Ross Gillies	HVP Plantations
Kevin Johnson	Midway Plantations
Sandra Hetherington	Norske Skog
Cameron MacDonald	OneFortyOne Plantations
Gary Pearson	OneFortyOne Plantations
Glen Rivers	OneFortyOne Plantations
Allie Muneri	PF Olsen
Greg Dutkowsky	Plant Plan Genetics
Richard Kerr	Plant Plan Genetics

Name	Organisation
Mark Padgett	Radiata Pine Breeding Company
Chris Barnes	RMS
Barry Vaughan	Seed Energy
Carolyn Raymond	Southern Cross University
Dean Williams	Sustainable Timber Tasmania
Don Aurik	Timberlands Pacific
Peter Cunningham	Tree Breeding Australia
Tony McRae	Tree Breeding Australia
Milos Ivkovich	Tree Breeding Australia
David Pilbeam	Tree Breeding Australia
Geoff Downes	Forest Quality
Anatanas Spokevicius	University of Melbourne
Peter Ades	University of Melbourne
Rose Andrew	University of New England
Brad Potts	University of Tasmania
Josquin Tibbits	Victorian Department of Jobs, Precincts and Regions
Paul Rymer	Western Sydney University
Elspeth MacRae	SCION (New Zealand)
Heidi Dungey	SCION (New Zealand)
John Moore	SCION (New Zealand)
Jacquelin Grima-Pettenati	CNRS/University of Toulouse (France)
Alioazabeth Jakobsen Neilson	University of Copenhagen (Denmark)
Melissa Reynolds	University of Pretoria (South Africa)
Julis Candotti	University of Pretoria (South Africa)
Zander Myburg	University of Pretoria (South Africa)
Adam Healey	Hudson Aplha Institute for Technology (USA)

Appendix Seven: Hardwood and Softwood industry tree breeding and genetic improvement survey questionnaire.

Tree Breeding R,D & E in Australia - Capability and Capacity Survey

1. To assist in collating responses to the survey can you please enter your name, your organisations name and your role within your organisation?
2. Which of the following best describes your organisation?
3. What aspects of tree production is your organisation engaged in? (Multiple responses accepted)
4. What fields of forestry R,D & E is your organisation engaged in? (N.b. Engagement' could be at various levels – e.g. funding an external party, collaborative work with others, own in-house researchers, etc)
5. Of the R,D & E fields that your organisation is engaged in has the level of investment during the previous 5 years increased, decreased or stayed the same?
6. Of the R,D & E fields that your organisation is engaged in will the level of investment during the next 5 years be likely to increase, decrease or stay the same?
7. Is your organisation engaged in hardwood and/or softwood/structural timber tree breeding and genetic improvement R,D & E?
8. For what organisation (s) do you undertake tree breeding and genetic improvement R,D &E? (Multiple responses accepted)
9. In the research field of 'Tree Breeding and Genetic Improvement' what are the breeding objectives for hardwood species? (In order of priority)
10. In the research field of 'Tree Breeding and Genetic Improvement' what are the breeding objective for softwood / structural timber species? (In order of priority) Prioritise the following genetic traits in terms of their economic importance within your hardwood tree breeding and genetic improvement program?
11. Prioritise the following genetic traits in terms of their economic importance within your softwood / structural timber tree breeding and genetic improvement program?
12. Which of the following breeding methods and/or tools are utilised within your tree breeding and genetic improvement program?
13. Within in your organisation how many scientists, technical staff and support staff are engaged in tree breeding and genetic improvement?
14. Thinking about your organisations current investment in tree breeding and genetic improvement, where is the current funding derived from and what percentage does it represent of the total budget?

15. Which of the following research institutions does your organisation engage with to undertake collaborative R,D & E related to tree breeding and genetic improvement?
16. From what resources do you obtain information relating to developments in tree breeding and genetic improvement in hardwoods and/or softwoods/ structural timber?
17. What are the key barriers/hurdles to genetic improvement within your tree breeding program?
18. What opportunities exist to enhance genetic improvement within your tree breeding program?
19. What areas of genetic improvement within the field of hardwood and/or softwood/ structural timber tree breeding should FWPA and the industry focus its investments over the next 5 years?
20. Are there any other comments related to tree breeding and genetic improvements that you would like to include?