Forest & Wood Products Australia

Research, development and extension investment plan

Research, development and extension priorities to achieve value gains through Plantation Silviculture.

2020

Adapted from *Investment Plan Plantation Silviculture*, prepared for FWPA by Braden Jenkin, Jim O'Hehir & John McGrath, 2019.

This version of the Investment Plan, adapted by FWPA in December 2020, removes the cost and benefit estimates from the original Investment Plan*, Investment Plan Plantation Silviculture*, prepared for FWPA by Braden Jenkin, Jim O'Hehir & John McGrath, 2019.

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Date of issue: 8 August 2019

Author declaration of interest

The authors, Braden Jenkin, Stefan Peters, Jim O'Hehir, received income in the past year from research, development and extension carried in the technical areas addressed in this investment plan. The authors anticipate receiving income in the next five years from research, development and extension activities carried out in the technical areas addressed by this investment plan.

Forest & Wood Products Australia

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Acronyms

DBHOB	Diameter Breast Height Over Bark
FWPA	Forest and Wood Products Australia
GRAC	Grower Research Advisory Committee
OHS	Occupational Health and Safety
R&D	Research and development
R1	First rotation
R2	Second rotation
RD&E	Research, development and extension
RN	Research need
RT	Research theme
SC	Steering committee

Executive summary

Forest and Wood Products Australia (FWPA) has commissioned the development of a research and development investment plan addressing plantation silviculture. A list of silvicultural research opportunities (Table 1) were identified as a result of a literature review, an industry survey and consultation. The reality of limited budgets and capacity require that investment funds be allocated selectively, with some opportunities fully funded, some partially funded and some not funded at all. This document presents a scoring protocol that allowed an objective ranking of the research opportunities based on impact and research capacity. Each member of the project Steering Committee (SC) was invited to undertake this assessment protocol and submit their responses as per the instructions provided.

TABLE 1: A SUMMARY OF R&D TOPICS AND RESEARCH THEMES; SEE (APPENDIX 2: A SUMMARY OF THE IDENTIFIED RESEARCH NEEDS)

Broad topic	Title	Research theme
Knowledge management	Knowledge management	There is a research need to understand the current state of corporate knowledge retention in the industry and to devise a system for retaining and maintaining future corporate knowledge using modern tools and systems.
Markets and product specifications	Silviculture and wood products	There is a need to better understand the impacts of silviculture on the wood properties within a tree as these relate to the utility of logs to a processor. This will include the attributes of the site, the species grown, the management of the stands and the individual trees. Alternative to the last sentence: Understanding then impact of silviculture on solid wood products is important for both softwood and hardwood resources. Wood properties are also critical to the performance of pulp.
	Application of pruning and the links to the market	A Research theme is required to review the market for pruned logs needs to consider: what is the critical mass (area and wood flows) required to justify pruning; what is the margin on a pruned log; what are the drivers of demand for a pruned log? The practical issues with pruning need to be linked to the market opportunities. These include the application of technology to undertake pruning, OHS issues and costs. The decision-making process requires a revisit – when to commence pruning, the height pruned and the number of lifts to achieve the target height of a pruned tree. A last consideration is whether a change in silvicultural systems will stimulate a need for pruning. For example; a shift to silvopastoral management to increase the up-take of trees into farming systems.
Social license to operate	A focus on social license	There is a research need to understand the human-related aspects of silvicultural practices well in advance of implementation. Based on this understanding there is a research need to continuously assess and where necessary replace or improve silvicultural practices to minimise the risk of any adverse impacts on values across economic, social and environmental considerations.
	Current chemical approaches	There is a need to document the drivers of poor initial survival of planted trees and the interventions known to improve the rate of survival so that this information is available to current plantation managers. This would include current chemical-based interventions (e.g. insecticides; fungicides; nematocides) utilised in plantation forestry (including nurseries). For each current and potential intervention there is a need to understand the degree of exposure to forced reduction in use or loss of the intervention option due to voluntary third-party certification or changes in the regulatory environment. Related to the risk of loss of each tool, alternative strategies are required to address biotic damage agents. These alternatives should be assessed based on efficacy and cost effectiveness.
	A holistic approach to biotic pest control	There is a need to develop strategic and holistic approaches to biotic pests which take account of the trees planted, the management of the trees, limitations placed on intervention options and acceptable outcomes. This includes the need for biological and financial loss modelling at regional levels so that the risks are quantified, and appropriate surveillance systems are implemented. The overall process of interventions in regard to stressors and damage agents needs to be within a framework to allow a systematic and uniform approach to decision making, this includes ensuring there is an biological and economic basis for interventions.
	Alternative weed control methods	There is a need to document the drivers of poor initial survival of planted trees and the interventions possible to improve the rate of survival. There is a need for research into weed control in all plantations and coppice control in eucalypts, with a specific focus on alternative regimes driven and demanded by voluntary third-party certification requirements and environmental constraints (including adjacent land-use). This would include the use of combined cultivation and chemical methods with both manual and mechanical applications for both hardwood and softwood plantations. In regard to the chemical options, forest managers face the issue of off label use and certification. There is a need for research into alternative chemicals (molecules) for use in the various tree crops recognising fundamental differences in the tree

Broad topic	Title	Research theme
		species between softwoods and hardwoods and the climatic zones which determine the spectrum of weeds involved. This need is urgent given the current focus on glyphosate and the utility of this molecule to plantation establishment and management. There are mechanical and chemical options available, and options at different operational stages. The individual treatments require costing and consideration of the impact of the cost and the efficacy of the subsequent operations.
Sustainability and productivity	Site selection and productivity management	There is a need to revisit land capability and suitability for softwood and hardwood plantations in the current and potential zones for plantation development. Within the current plantation zone, the issues of climate change, site management and changes in social licence as they impact on possible (the maximum) and realised site productivity needs to be understood. For the new zones, there is a need to extrapolate the current experience base to these areas to generate a realistic and defendable estimate of site productivity. In both cases, there is a need to better understand site and species (particularly new species) matching. The project should include benchmarking of the current productivity of the Australian plantation estate at the macro scale (nationally) and within the plantation zones as defined by the National Plantation Inventory. A next step is to determine the drivers of productivity (both positive and negative) and to assess any exposure to change (e.g. access to herbicides or fertiliser use). A review is required of the current state of factors that may offer increased productivity (e.g. a focus on the rhizosphere).
	Maintenance of site productivity	There is a need to research the overall management of a site to maintain site productivity. The elements include the management of harvest residues, the application of nutrients, the use of biotic tools such as leguminous plants, and fungi and mycorrhiza in the rhizosphere. Management and enhancement of available water should be considered in parallel to nutrition. The research should consider impacts of alternative harvest residue management methods and their impact on site productivity, operational costs and risks, including to subsequent rotations. The management of harvest residues links to whole silvicultural package including site cultivation methods, weed control and planting.
	Operational capturing of potential yields	There is a need to quantify and understand the gap between research and operational outcomes for the silviculture applied to determine the underlying cause of this gap and therefore the ability to realise the full potential of a plantation site and the management applied.
	Impact of productivity on wood properties	The impact of productivity on wood quality and therefore potential products as a driver of value needs to be better understood. This requires development of a linkage between log wood properties and the price paid.
Biotic agents, pests and disease	Document the drivers of poor survival	There is a need to document the drivers of poor initial survival of planted trees. The outcome would be a catalogue to document and rate the significance of the current spectrum of weeds, insect pests and pathogens associated with plantation forestry at the four identified stages (e.g. pre-plant, post-plant, pre-clearfalling and ad hoc) for the main commercial tree species in the main National Plantation Inventory zones. This should then include a rating of the current status of preventative and control options and any risks to those options. Where a pest species is of significance and the effective control options are at risk, these species should be identified for further research. This should include any impact on and down-grade of products that could be recovered from a tree as a basis of defining the financial impact of a damage agent.
	Silviculture and risk issues	There is a need to better define the relationship between the condition of a plantation as impacted by management interventions and driven by site factors (e.g. current period climate) and tree stress. This should form the basis of documenting the appropriate responses to anticipated or current stress events.
	Management of the risks	There is a need for specific research and refinement of plantation monitoring tools and techniques to anticipate and correct impending issues or to identify actual stress events as a trigger to an intervention. This should be linked to a consideration and review the current state of quarantine management of Australia's borders to minimise the risk of pest insect and disease incursions. Combing the two elements, there is a need to develop and define the intervention points that relate to each species of tree by species of risk organism.
Stand management – stocking	Stand management – stocking	There is a need to include the impact of stocking rates at initial establishment and subsequent management of the stocking levels of a plantation as a variable in many Research themes e.g. site type, genetics and initial stocking rates; thinning and fertiliser application. With a focus on hardwood plantations, there is a need to better understand the options and outcomes of thinning, including the use of non-commercial thinning as a tool. The outcomes of the thinnings are defined by the resulting log piece size and the potential markets for the logs.
Trees into farming	Trees into farming	There is a need to define the differences in farm tree planting and traditional broad-scale plantation development from an agricultural perspective. Based on this analysis, farm specific silvicultural systems can be defined and developed

Importantly this process has captured the views of industry regarding the research needs for silvicultural research and then a steering committee of industry representatives to prioritise these needs. The results should therefore provide a basis for industry researchers to be clear on the types of projects that industry is most likely to support and the reasoning behind this.

The process identifies the 'low hanging fruit' with regard to silvicultural knowledge that already exists but is at risk of being lost through the loss of corporate knowledge and also minimising the gap between research and operational outcomes, so the full benefit of the knowledge is captured. This is of particular relevance with regard to the maintenance and improvement of productivity, which needs to be a clear priority in formulating operational practices to ensure the sustainability of forest plantation businesses.

As clear as possible understanding of the future markets for log and timber products is essential, especially with regard to the impacts of silviculture on wood properties, to ensure an alignment of forest management practices with the desired outcomes. The interactions between silvicultural practices have also been identified as needing to be well understood to ensure the objectives aligned and practices are complementary.

The process identified linkages to other FWPA investment plans as needing to be considered when developing silvicultural research proposals. Interactions between silvicultural and other research and operational activities need to be understood so there is alignment of objectives and outcomes. There may also be efficiencies in multiple purpose trials. Accordingly, this investment plan has been closely linked to the nutrition investment plan using a common literature review and in retrospect may have benefited from a common plan. Other plans such as tree breeding and genetics also need to be consulted when developing silvicultural research proposals. It is recommended that consideration be given to a separate nursery investment plan due to the highly specialised nature of this activity and the related expertise of nursery managers.

Silvicultural risk management arose as a major consideration to business sustainability in relation to ongoing access to methods of weed control; which is such an important factor in ensuring moisture availability, especially in the establishment phase of broadscale crops such as forest plantations. Generally, investor and community support need to be ensured for all current practices and cannot be taken for granted when introducing new practices.

The impacts of silviculture are often long term, particularly on wood properties, and for this reason long term research trials are the only way to adequately address some of the research needs. The implication of this requirement is that long term funding and stable silvicultural research environments exist, which is not currently the case in Australia. Fortunately, this environment does exist in tree breeding and genetics, and accordingly there is a continuously improving understanding of breeding outcomes in regard to and wood property and forest valuation, both aspects also impacted by silviculture. An imbalance therefore exists in the Australian forest industries support for the management aspects it controls. It is suggested that because silvicultural research is largely precompetitive there is a significant opportunity for establishing a cooperative research model, with long term and stable industry and government funding support to guide, commission and undertake silvicultural research. It is also suggested that this is the most cost-effective way for the industry to undertake silvicultural research.

A key point is that each research need will require development of a full proposal with detailed costings. It is likely that some of the identified research needs can be addressed in parallel. The benefits will be dependent on the size and nature of the estate in which changes are implemented and their efficiency will be dependent on the extent which organisations are able to implement what they are planning

Table 2: A summary of logical Research themes relevant to identified silviculture needs.

Broad area	Code	Research theme		Priority			Method	Time (indicative)	Benefit (indicative per company)	Implementation Budget (indicative)
				High	Medium	Low				
Market and product specifications	B1	2	Silviculture and wood products	1			• Industry survey • Literature review • Report	12 months	+5-20% in net log value recovery	Minimal or no additional cost of management with changed prescriptions
	B2	3	Application of pruning and the links to the market		1		• Industry survey • Literature review • Report	6-12 months	+5-20% in net log value recovery	Minimal or no additional cost of management with changed prescriptions
Social license to operate	C1	4	A focus on social license			1	• Industry survey • Literature review • Report	6-12 months	5-20% reduction in cost of operational programs	+10% increase in cost of operational programs per company
	C2	5	Current chemical approaches	1			• Industry survey • Chemical company consultation • Literature review	6-12 months	5-20% reduction in cost of operational programs	+20% to operational weed control budget per year for 5 years as new methods are bedded down per company
	C3	6	A holistic approach			1	• Industry survey • Literature review	6-12 months	5-20% reduction in cost of operational programs	+10% per year to operational program to ensure integrated planning & implementation occurs per company
	C4	7	Alternative weed control method	1			• Industry survey • Chemical company consultation • Literature review • Field trials • Cooperative data and trial management • Reporting and model development	2-5 years	Neutral	Minimal or no additional cost of management with changed prescriptions Best done in a cooperative arrangement
Sustainability and productivity	D1	8	Site selection and management	1			• Industry survey • Literature review • Report	12 months	+5-20% in net log value recovery	+10% per year to operational program to ensure optimum planning & implementation occurs per company
	D2	9	Maintenance of site productivity	1			• Industry survey • Literature review • Report	6-12 months	+5-20% in net log value recovery	+10% per year to operational program to ensure optimum planning & implementation occurs per company
	D3	10	Operational capturing of potential yields	1			• Industry survey • Literature review • Report	6-12 months	+5-20% in net log value recovery	+10% per year to operational program to ensure optimum planning & implementation occurs per company
	D4	11	Impact of productivity on wood properties		1		• Industry survey • Literature review • Cooperative data and trial management • Reporting and model development	10-30 years (depends on rotation length)	+5-20% in net log value recovery	Best done in a cooperative arrangement
Biotic agents, pests and disease	E1	12	Document the drivers of poor survival			1	• Industry survey • Literature review	6-12 months	5-20% reduction in cost of operational programs	Minimal or no additional cost of management with changed prescriptions

Broad area	Code	Research theme		Priority			Method	Time (indicative)	Benefit (indicative per company)	Implementation Budget (indicative)
	E2	13	Silviculture and risk issues			1	• Industry survey • Forestry Standards Consultation • Literature review • Report	6-12 months	5-20% reduction in cost of operational programs	+10% increase in cost of operational programs per company
	E3	14	Management of the risks			1	• Industry survey • Forestry Standards Consultation • Literature review • Generic risk management guide	6-12 months	5-20% reduction in cost of operational programs	+10% increase in cost of operational programs per company
Stand management – stocking	F1	15	Stand management – stocking	1			• Industry survey • Literature review • Field trials • Cooperative data and trial management • Reporting and model development	10-30 years (depends on rotation length)	+5-20% in net log value recovery	Minimal or no additional cost of management with changed prescriptions
	F1 A1*	1	Knowledge management	1			• Industry survey • Literature review • Generic management tool	12 months	5-20% reduction in cost of operational programs	
Trees into farming	G1	16	Trees into farming			1	• Farmer advisor survey • Industry survey • Literature review • Generic report & business models	12 months	+5-10% of land available to forest industry for planting	

Introduction

The total woodflow from Australia's forests was 33.1 M m^3 of logs harvested in 2016/17 with a gross value of $2.6 billion: 4.1 M m^3 of natural forests logs with a gross value of $0.4 billion; 11.4 M m^3 of plantation hardwood logs with a gross value of $0.8 billion; 17.7 M m^3 of plantation softwood logs with a gross value of $1.4 billion.[1] Australia's forest estate includes 1.95 million ha of plantations.[2] The total Australian hardwood plantation estate was 908 500 ha in 2016/17 and *Eucalyptus globulus* (51.7%: 469 800 ha) and *E. nitens* (25.7%: 233 600 ha) were the dominant species. The balance of the area includes *E. dunnii*, *E. pilularis*, *E. grandis*, *Corymbia maculata*, and other species (including Acacia, African mahogany and teak).[3] The total Australian softwood plantation estate was 1 036 900 ha in 2016/17 and *Pinus radiata* (74.5%: 772 300 ha) and the Southern Pines (15.1%: 156 400 ha) were the dominant species. The balance of the area includes *Araucaria cunninghamii, P. pinaster*, and other pines.[4] The rate of first rotation establishment for 2016/17 of hardwood and softwood plantations was 100 ha[5], with the balance of the operations conducted on second or greater rotation sites. A range of species have been established in northern Australia: the 2016/17 estate in north Queensland is 4900 ha of hardwoods and 1900 ha of softwoods; in the Northern Territory the 2016/17 estate was 14 400 ha of hardwoods and 2300 ha of alternative softwood species.[6]

Maintenance and enhancement of site productivity is a focus of managers following on from evidence in the 1960's[7] of a R2 decline for radiata pine growing in South Australia. Subsequent research resulted in management practices changing (e.g. genetics and site specific management) and an analysis[8] of operational results indicates a 60 to 70% increase in productivity for the land-base which had successively carried plantations for a century or more. The improvement for South Australian equates to an annual rate of 0.6 to 0.7% /y; driven by genetics and silvicultural improvements. The importance of adoption of judicious and site-specific silviculture is well recognised[9] including conserving a site resources during the inter-rotation phase, organic matter, nutrients and moisture conservation (control of weeds).[10] The separation (attribution) of growth enhancement to genetics compared to silviculture is fundamental to an estimate of benefits and costs. A New Zealand trial of radiata pine found that genetic impacts were broadly uniform across six sites and silvicultural treatment, with similar relative performance of seedlot, and differences in tree growth was more driven by differences in the sites.[11] The attribution of growth improvements to a cause (e.g. the contribution of silviculture) requires specific trials and the South Australian experience recognises this point:[12]

> *'A significant contribution to the increased rates of growth on 3R sites would have come from the use of improved genetic stock (Wu et al., 2007) and their deployment with improved silviculture (Boardman, 1988; Cellier et al., 1985), but it should be noted that the gains in production between 2R and 3R in plots planted with the bulked planting stock from the same nursery and in the same year, ranged from 57% to 227%. This wide range underlines the impacts of site by management interaction on production.'*

Gains in volume can be achieved by increasing overall biological stem volume, improving the recovery of merchantable volume from each stem up to a defined limitation (e.g. log small-end diameter) or by a change of product mix (e.g. recovery of residual stem-wood for biomass). The process of productivity improvement can be continuous and be maintained by the infusion of new genetic materials and silviculture, with the realisation of the improvement at rotation.

[1] ABARES (2018: Table 6 & Table 7).
[2] Downham & Gavran (2018: Table 4).
[3] Downham & Gavran (2018: Table 9, p.9).
[4] Downham & Gavran (2018: Table 10, p.10).
[5] Downham & Gavran (2018: Table 6, p.6).
[6] Downham & Gavran (2018: Table 9, p.9; Table 10, p.10).
[7] Keeves (1966: p.51).
[8] O'Hehir & Nambiar, 2010: p.1,857).
[9] O'Hehir & Nambiar (2010: p.1,857).
[10] Wu et al. (2007); O'Hehir & Nambiar (2010: p.1,857).
[11] Carson (1999).
[12] O'Hehir & Nambiar (2010: p.1,864).

Forest and Wood Products Australia (FWPA) has developed a series of industry advisory committees and supporting research and development investment plans covering strategic elements of the industry (Box 1) and this document forms the plantation silviculture Research and Development Investment Plan.

Box 1: The FWPA segmentation of research and development into a series of discrete research investment plans. [13]

- Soils and nutrition
- Damage agents (pests, disease, extreme climatic events)
- Fire
- Operations and supply chain
- Genetics and tree breeding
- Plantation silviculture
- Native forest silviculture
- Remote sensing and resource modelling.

Objectives

An important element in research planning and priority setting that links the strategic context to priority activities is the industry's vision. The relevant vision for the development of a silviculture research, development and extension (RD&E) investment plan is the FWPA's vision and mission (Box 2). The FWPA Grower Research Advisory Committee (GRAC) has articulated a specific vision for Australia's commercial forests [14]: *'Our Vision is to double the value of Australia's commercial forests by 2040, by fostering an innovation culture in our enterprises, applying world's best practices, collaborating and investing into research and development as appropriate.'* The specific objective of this Investment Plan is to enhance silvicultural practices and capacity s to enable industry to meet its compliance obligations (e.g. contracted wood supply of fit for purpose logs), statutory requirements (e.g. appropriate use of herbicides) and management objectives (e.g. thinning regimes) while reducing risk from a range of damage agents.

BOX 2: THE FWPA VISION AND MISSION STATEMENTS. [15]

'Our Vision: The forest and wood products industry will grow as a result of increased demand for its market-oriented, sustainable and competitive products and services.

Our Mission: FWPA collaborates with government and industry stakeholders to determine strategy and deliver programs designed to grow the market for forest and wood products, increase productivity and profitability across the value chain, and ensure positive environmental and social outcomes.'

Background

There are a number of definitions of a plantation (see Box 3, Box 4 and Box 5) but the key element of the definitions is that plantations are the result of human actions to plant or sow resulting in trees in a regular spacing. Silviculture was defined in 1910 as[16].

> *'Silviculture literally means the culture of forests, that is to say all measures connected with the formation, preservation and treatment of forests. In practice, however, the word forestry is used to express and comprise all this, while by silviculture, in its narrower sense, is understood the formation, regeneration and tending of forests, or woods, until they become ripe for the axe. Silviculture, in the latter sense, teaches how a forest, or wood, can be produced and guided to maturity so as to realise in the most advantageous manner the object which the proprietor has in view.'*

A range of references have been produced documenting plantation softwood[17] and hardwoods[18].

BOX 3: A DEFINITION OF A PLANTATION AS APPLIED BY THE FEDERAL GOVERNMENT. [19]

CLASS 3 Production from dryland agriculture and plantations[20]

3.1 Plantation forests

Land on which plantations of trees or shrubs (native or exotic species) have been established for production, or environmental and resource protection purposes. This includes farm forestry. Where

[13] Downloaded from https://www.fwpa.com.au/about.html on the 13/03/2019.
[14] Downloaded from https://www.fwpa.com.au/forwood-newsletters/1695-fwpa-grower-members-aim-to-increase-investment-in-rd-e.html on the 26/043/2019.
[15] Downloaded from https://www.fwpa.com.au/about.html on the 13/03/2019.
[16] Schlich (1910: p.2).
[17] For example see Lewis & Ferguson (1993).
[18] For example see Florence (1996) or Jacobs (1979).
[19] ABARES (2016: p.8).
[20] ABARES (2016: p.8).

planted trees are grown in conjunction with pasture, fodder or crop production, class allocation should be made on the basis of prime use.

3.1.1 Hardwood plantation forestry—area managed for hardwood sawlogs or pulpwood.

3.1.2 Softwood plantation forestry—area managed for softwood sawlog or pulpwood.

3.1.3 Other forest plantation—area managed for non-sawlog or non-pulpwood production, including oil, wildflowers, firewood and fence posts.

3.1.4 Environmental forest plantation—area managed for environmental and indirect production uses (e.g. prevention of land degradation, windbreaks, shade and shelter). This also includes trees planted for carbon credits.

CLASS 4 Production from irrigated agriculture and plantations[21]

4.1 Irrigated plantation forests

Land on which irrigated plantations of trees or shrubs have been established for production or environmental and resource protection purposes. This includes farm forestry.

4.1.1 Irrigated hardwood plantation forestry—area managed for hardwood sawlogs or pulpwood.

4.1.2 Irrigated softwood plantation forestry—area managed for softwood sawlogs or pulpwood.

4.1.3 Irrigated other forest plantation—area managed for non-sawlog or non-pulpwood production, including oil, wildflowers, firewood and fence posts.

4.1.4 Irrigated environmental forest plantation—environmental and indirect production uses (e.g. prevention of land degradation, windbreaks, shade and shelter). This can also include trees planted for carbon credits.

BOX 4: A DEFINITION OF A PLANTATION AS APPLIED BY THE FOREST STEWARDSHIP COUNCIL. [22]:

Plantation: A forest area established by planting or sowing with using either alien or native species, often with one or few species, regular spacing and even ages, and which lacks most of the principal characteristics and key elements of natural forests. The description of plantations may be further defined in FSC Forest Stewardship Standards, with appropriate descriptions or examples, such as:

- *Areas which would initially have complied with this definition of 'plantation' but which, after the passage of years, contain many or most of the principal characteristics and key elements of native ecosystems, may be classified as natural forests.*
- *Plantations managed to restore and enhance biological and habitat diversity, structural complexity and ecosystem functionality may, after the passage of years, be classified as natural forests.*
- *Boreal and north temperate forests which are naturally composed of only one or few tree species, in which a combination of natural and artificial regeneration is used to regenerate forest of the same native species, with most of the principal characteristics and key elements of native ecosystems of that site, may be considered as natural forest, and this regeneration is not by itself considered as conversion to plantations.*

BOX 5: A DEFINITION OF A PLANTATION AS APPLIED BY THE AUSTRALIAN FORESTRY STANDARD.[23]

"establishment" The creation of a new forest or plantation arising from the treatment, seeding or the planting of a site with trees.

"plantation" Stands of trees of either native or exotic species, created by the regular planting, sowing or control of cuttings, seedlings, seed or coppice.

[21] ABARES (2016: p.13).
[22] FSC (2016: p.22).
[23] AS (2013: p.18)

The aim of plantation silviculture is to generate a woodflow and returns to a plantation owner. The treatment of forest management as a business with specific goals was noted by William Schlich in 1895:[24]

> *"Economic forestry, to be successful, must be conducted on true silvicultural principles, and the yield must be so regulated, that, approximately, the same quantity of material may be brought into the market every year: in other words, the principle of a sustained and well-regulated yield must be recognized."*

Percival T. Maw in 1909 reinforced the importance of the business aspects of silviculture and the reliance on good data:[25]

> *"An estimation of the exact financial position which attends the execution of any planting operations is one of the most important subjects relating to Sylviculture.*
>
> *It is unlikely that any extensive works of afforestation will ever be carried out, unless there be sufficient evidence to prove that a reasonable return may be anticipated on the outlay expended. Occasionally those who contemplate works of this nature seek expert advice as to the probable financial returns: but, only too often, the advice tendered is absolutely worthless, and the estimated returns are never likely to be realised."*

The complete integration of forest management and the financial aspects of each activity was an underlying principle of P.L. Buttrick's 1943 reference on forest economics and finance:[26]

> *"Every single operation in forestry, from the largest to the smallest is immediately or remotely controlled by economic and financial considerations. Trees grow by processes of nature, which are only partly, and always indirectly, under man's control, but it costs money to acquire, establish, improve, protect, harvest, and secure the reproduction of a forest".*

As indicated the science and art of forestry calls on a variety of skills combining knowledge of biology, ecology, soils and other applied and social sciences (including economics) as each discipline provides a different set of tools and methods to the task.[27] An insight into the gaining of technical knowledge in regard to forest management by Percival T. Maw in 1909 suggested that:[28]

> *"It is very necessary to realise that a complete knowledge of the correct practice of forestry can only be obtained by approaching the subject from a scientific attitude."*

A conceptual framework for silviculture is presented in Figure 1, noting that the contributing factors which determine a plantation silvicultural regime (see Figure 2 for a schematic of the elements of a silvicultural regime). Based on discussions with the FWPA, the industry vision is to double its value by 2040 across both natural and planted forests which equates to a real annual compounded interest growth rate of 3.5% from 2020 to 2040. It is recognised that value can be improved by changing financial considerations (e.g. costs and returns) and product mix outputs (e.g. volume and different products). The value of the estate can be defined based on accounting standards as interpreted in '*A standard for valuing commercial forests in Australia*' (version 2.1).[29] The methods developed by the proposed investment plan will contribute to robust and defendable forest estate valuation.

[24] Schlich (1895: Volume III, p. vii).
[25] Maw (1909: p.231).
[26] Buttrick (1950: p.3).
[27] Pearse (1990: p.4).
[28] Maw (1909: p.v).
[29] A publication of the Institute of Foresters of Australia Limited, Association of Consulting Foresters of Australia Division, July 2012.

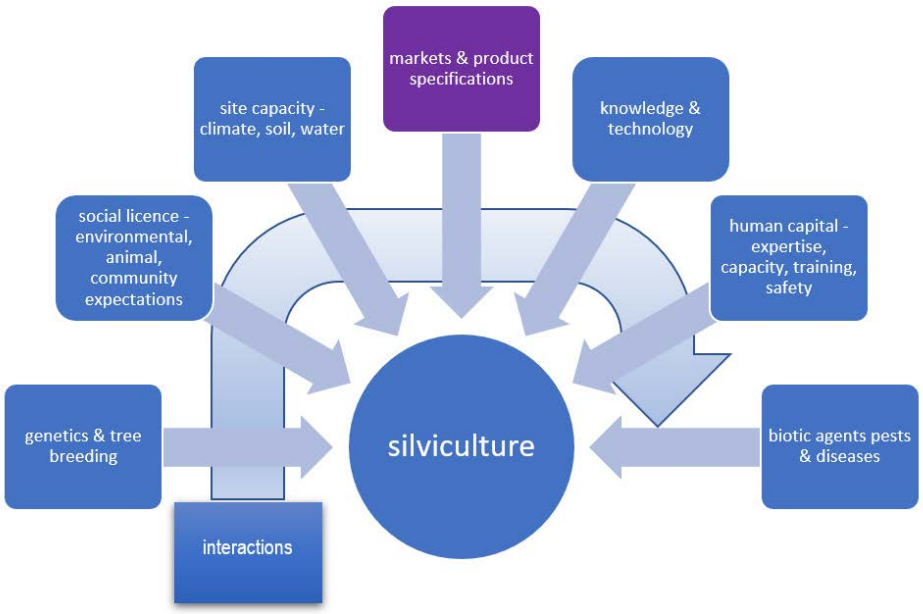

FIGURE 1: A SUMMARY OF THE ELEMENTS OF A SILVICULTURAL SYSTEM.

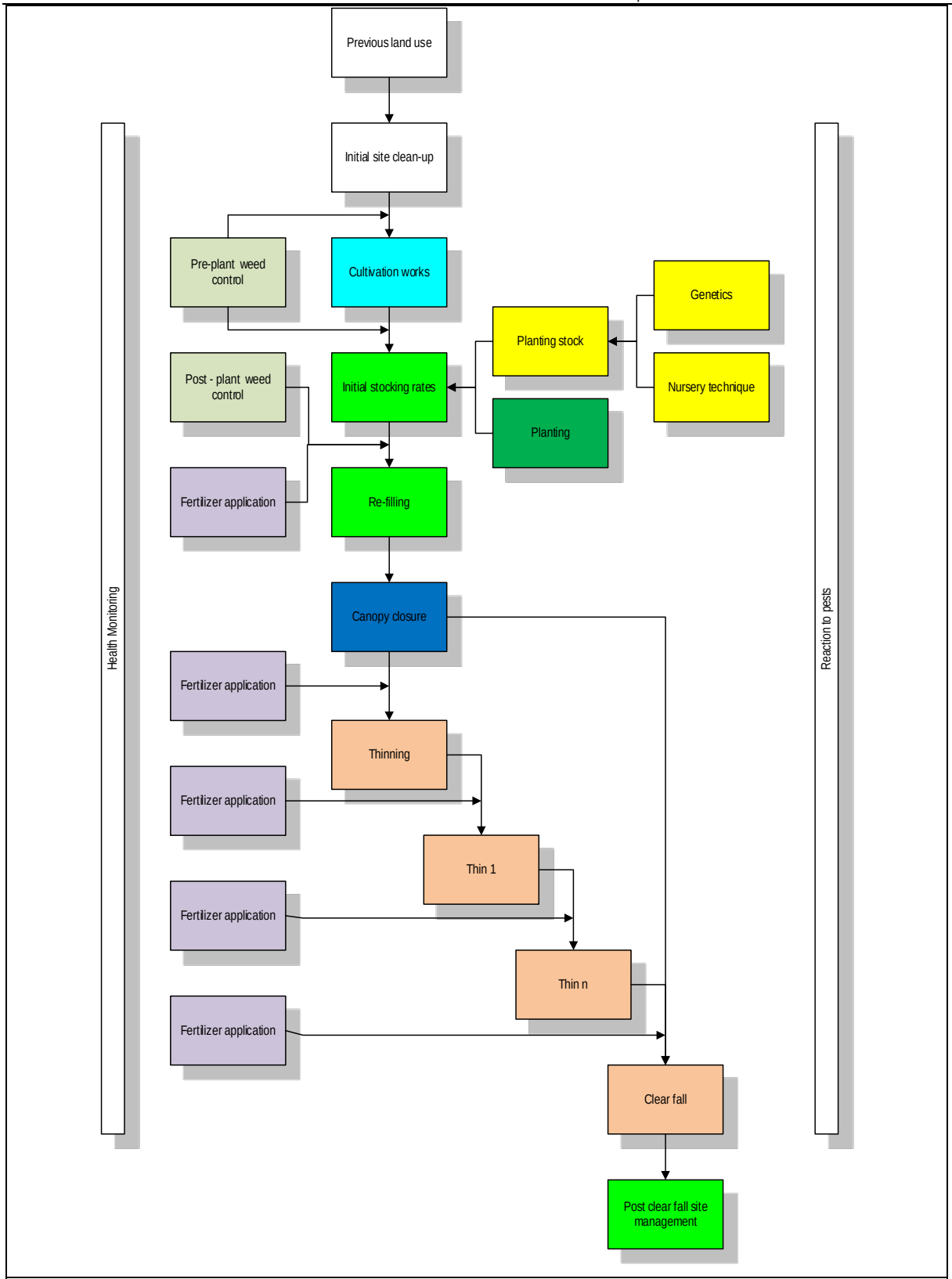

FIGURE 2: A SUMMARY OF THE ELEMENTS OF A SILVICULTURAL SYSTEM.

Methodology

The aim of the methodology developed was to facilitate a participatory process to develop the R&D investment plan for plantation silviculture. The process included seven broad stages and as outlined in Figure 3. A three-step process was undertaken: 1) Identifying the research needs; 2) Scoring the research needs; 3) Moderating the scores and assigning priorities. The development of a R&D investment plan commenced with a two-part inception meeting held on 20/12/2018 and 09/01/2019 with participants joining the meeting either in person or remotely. The inception meeting participants formed a project

Steering Committee (SC) and included the FWPA GRAC representatives and other interested parties. This commenced the participatory phase of the project and was under-pinned by a short pre-meeting survey to gain an understanding of the needs of the industry. The meeting outcome was a sign-off on the proposed methodologies and direction of the investment plan. A range of information was collected via industry consultation, a literature review process and an industry survey. Information was sourced from a literature review[30]. Industry consultation was ongoing throughout the process commencing with the project inception meeting. The information collected by each method was collated and aggregated and distilled into a series of 37 research needs.

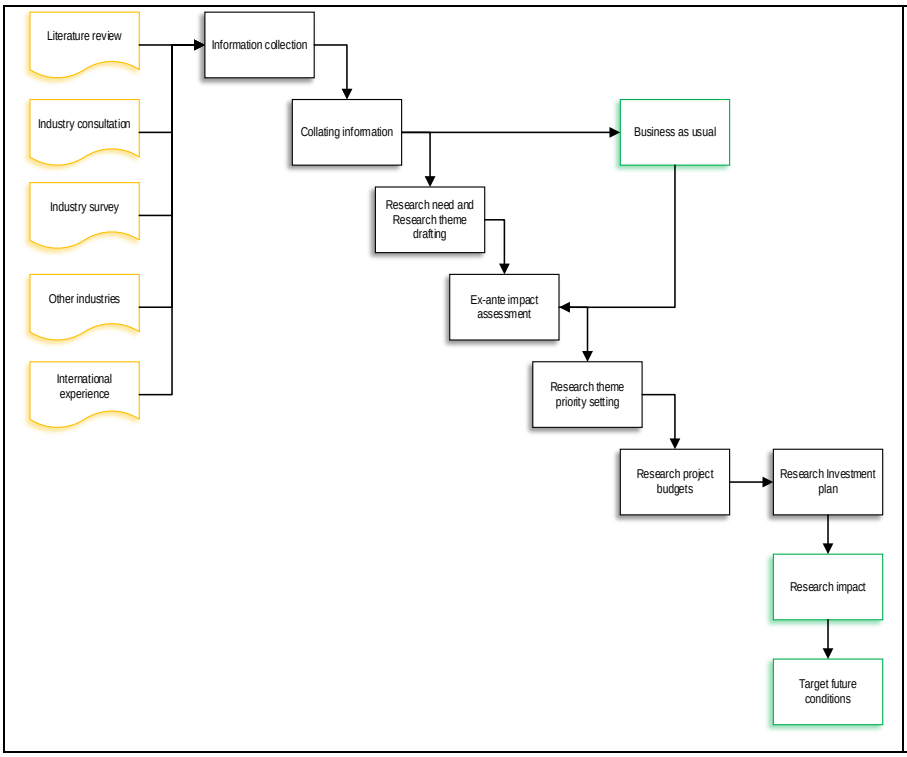

FIGURE 3: AN OVERVIEW OF THE RESEARCH METHODOLOGY TO GENERATE THE RESEARCH INVESTMENT PLAN.

The insights and research needs were combined in one document and distilled to a list of 16 research themes (see Figure 4). A narrative and a succinct statement of each research theme was prepared for each of the 16 identified research themes. Each SC member was provided with a summary document and scoring pro-forma Excel file.[31] To determine the relative priority of each research themes, a two-stage process was undertaken. In the first stage the SC members independently assessed each research need for each of the impact (potential benefits and ability to capture the benefits) and capacity (research capacity and delivery) (see Box 6 and Table 3) and recorded their scores on a score sheet. The score sheets were collected, and the scores were entered into an overall spreadsheet. Aggregated average scores were determined and a preliminary overall priority assessment was prepared. This preliminary assessment provided a basis for discussion and debate. An online workshop was held (24/06/2019), where members of the SC reviewed the aggregated results of each research need and provided comments and feedback. The ranking of the research themes was adjusted to reflect this feedback.

[30] McGrath et al. (2019)
[31] Jenkin et al. (2019).

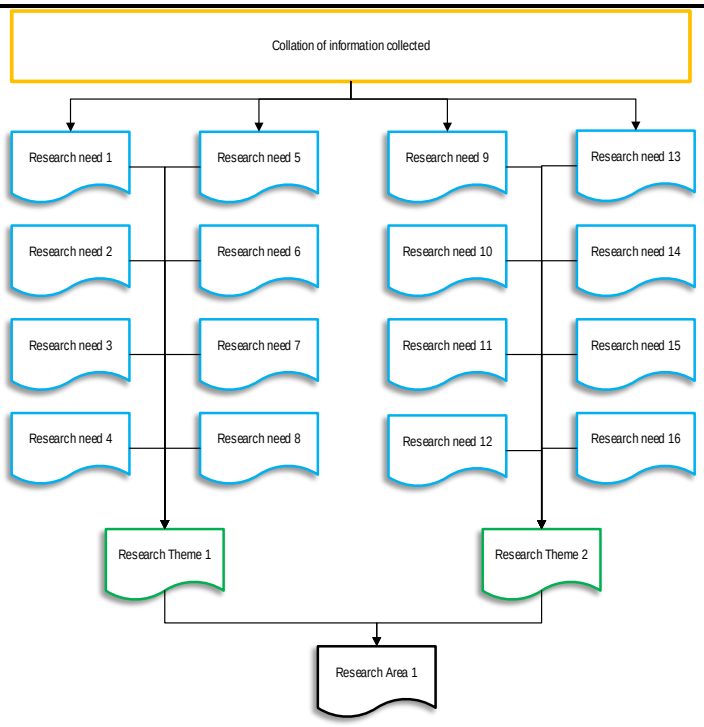

Figure 4: An overview of distillation of information into research themes and research areas.

BOX 6: THE DEFINITION OF IMPACT AND CAPACITY AS USED IN THE ANALYSIS AND PRIORITY SETTING PROCESS.[32]

Impact is based on assessment of two criteria – *potential benefits* and *ability to capture* (

Table 3). Impact combines assessment of the potential economic/financial, environmental/ecological, social and knowledge benefits from investment in R&D in each research need with assessment of the ability to capture or realise those benefits. Realising potential benefits can be influenced by physical conditions, institutional factors, access to resources to assist adoption (human, physical, financial, knowledge), cultural factors and the attitudes of those who could utilise or benefit from (improvements associated with) the research need. These influences may be positive or negative.

Capacity is based on assessment of two criteria – *research and development capacity* and *delivery capacity*. Assessment of R&D capacity accounts for the scientific and technology capabilities and the knowledge and technology transfer capabilities of relevant R&D providers, to make a positive difference for a research need within a reasonable timeframe and budget. Capabilities comprise skills, experiences and competencies as well as the quality of R&D infrastructure, equipment and services. It also includes continuing collaborations and partnerships with external organisations and established knowledge networks. Capacity assessments must also consider the ease of mobility of capabilities (between organisations) and the factors influencing collaboration and integration. It is not sufficient to consider research capacity alone to make valuable improvements in a particular R&D area but the capacity to deliver research outputs in a time frame must also be considered in the overall assessment of capacity. Assessment is made of the effectiveness and efficiency of the use of skills, facilities, networks and services to deliver or disseminate the outputs from improvements in a particular research need in a series of time frames.

[32] Building on a foundation based on insights and experience provided by Dr Michael Blyth, Four Scenes

Table 3: A summary of the impact and capacity elements.

Criteria	Element	Narrative
Impact:		A measure of the likely economic, community or social, environmental and scientific/knowledge benefits from successful technology advances within a particular research and development area.
	Potential benefits	Maximum additional benefits (economic, social, environmental and knowledge) for your industry from investment in R&D for the particular research and development area.
	Ability to capture	Likelihood of your industry capturing the estimated benefits from successful R&D for the particular research and development area.
Capacity:		Capacity is a measure of the competitive position of the R&D provider(s) to generate scientific and technical progress for the industry, environment and community.
	Research capacity	Ability to conduct research competently and efficiently for the research and development area by Australian researchers and their collaborators
	Delivery capacity	Ability to deliver research outputs in set time frames to the satisfaction of users and beneficiaries by Australian researchers and their collaborators.

Analysis of current state of RDE, operational practice and gains (avoided losses)

Summary of silviculture literature review

We have not provided a comprehensive review of literature as this was provided in the FWPA Nutrition Investment Plan. As background to this plan, we have provided the key messages from the previous review here.

Key messages from the Nutrition Investment Plan Review

Combined benefits:

Improvements in (softwood) plantation yield at the estate level have resulted from the combined effects of improved genetic material and silvicultural systems for (site selection, site preparation, weed control, nutrient management and within-stand competition.

Knowledge on hardwood plantations still developing:

There has been less focus on the development of silvicultural systems for the more recently developed hardwood plantations due to the decline in both State and Commonwealth resources available for plantation research that was not substituted by industry funding. Due to the different land use history, with resultant higher fertility and often lower rainfall, the hardwood plantation systems present different challenges to the softwood estate.

Knowledge delivery and preservation is critical:

For the softwood resource, a major task is the effective provision of extensive knowledge gained through R&D programs directed at these plantations and the preservation of this information into the future. For hardwood plantations, there remain considerable knowledge gaps about the optimization of plantation yield through the conservation of existing nutrient resources and the enhancement of yield through fertilization.

Wide range of effective delivery models:

The improvement in plantation performance due to better management systems based on research and development has been effectively delivered with a wide range of investment models being used in different countries. The development of successful softwood silvicultural systems in Australia was based on strong, coordinated, long-term investment by State and Commonwealth governments in both the research personnel and the resources to implement the R&D programs. Internationally the models vary considerably with strong government support remaining a feature of the New Zealand system. In the USA and Brazil industry funded (and in some cases industry-managed) cooperatives are common, while in South Africa much of the R&D is conducted directly by plantation companies.

Sustained effort is critical:

Common features of the systems are strong and sustained support for the research programs and a substantial collaborative component. The long-term nature of plantations means that having on-ground custodians of the R&D programs is important in maintaining an effective trial base.

Understanding potential yield is critical in assessing progress:

In order to assess the potential gain in yield from silvicultural interventions it is necessary to understand the limits to production and the gap between potential and current production. For both softwood and hardwood plantations, defining this yield gap provides a framework for decision making based on the potential improvement in yields due to nutritional management and other factors.

There is a gap between research outcomes and operational implementation of the outcomes (Figure 5). For most of Australia's plantation resource, potential yield is limited by water (Yw), as it is unusual for timber plantations to be irrigated, except in limited circumstances where wastewater is available. In the water limited environments in which most of Australia's plantations are grown, understanding the interaction between plantation density, nutrient supply, water availability and other growth moderating

factors (pests and diseases) will be critical in developing the knowledge required to define potential yield and hence estimate the yield gap.

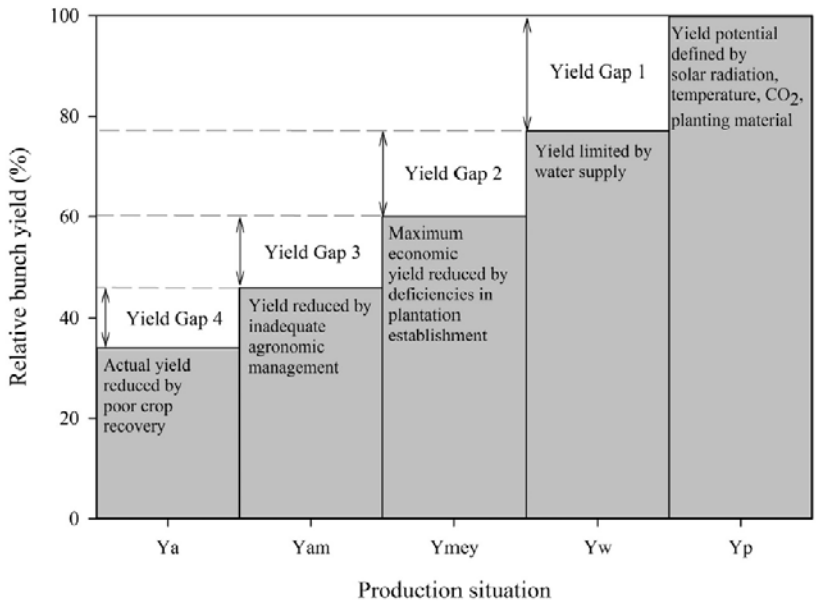

FIGURE 5: MODIFIED YIELD GAP MODEL FOR PERENNIAL CROPS USED TO PARTITION POTENTIAL YIELD (YP) AND ACTUAL YIELD (YA) INTO FOUR GAPS WITH THE SIZE OF EACH GAP DEPENDING ON SITE SPECIFIC FACTORS.[33]

In plantation forestry, the yield gap approach is a quantification that can contribute to site-specific (precision) silviculture. Using the yield gap approach provides managers with a useful framework for identifying potential gains that can be achieved through better silvicultural management to

1. Quantify potential gains from improved silvicultural management,
2. Identify the most profitable target sites, and
3. Identify management actions that will close the yield gap.

The survey outcomes

A detailed online survey was conducted to seek information on current silviculture in place and the needs of the industry. The survey included all aspects of silviculture rather than a narrow focus on the FWPA investment plan demarcation (see Box 1). A total of 63 individual responses were received providing significant information and insights. Of the responses, 17 parties who initiated undertaking the survey did not provide any responses, hence the effective survey participation was 46 parties. The number of responses to the questions varied. A key question (Q.38) asked the respondents to list the top five research needs for silviculture. The respondents to the survey (n=25) provided key insights to specific research needs in a narrative format. Each response was analysed and the issues raised categorised (e.g. a single sentence may include a number of areas of interest). A total of 150 individual issues were identified. The data was segmented by the main type of plantation managed by the respondent (e.g. hardwood or softwoods). The frequency of reference data was captured for silviculture and an analysis indicated the frequency of reference as a proxy to interest and importance of a topic: the results are presented in Figure 6 (by area of interest) and Figure 7 (by research needs). The most frequently referenced needs for silviculture were as listed in Figure 6.

[33] From Rhebergen *et al*. (2018).

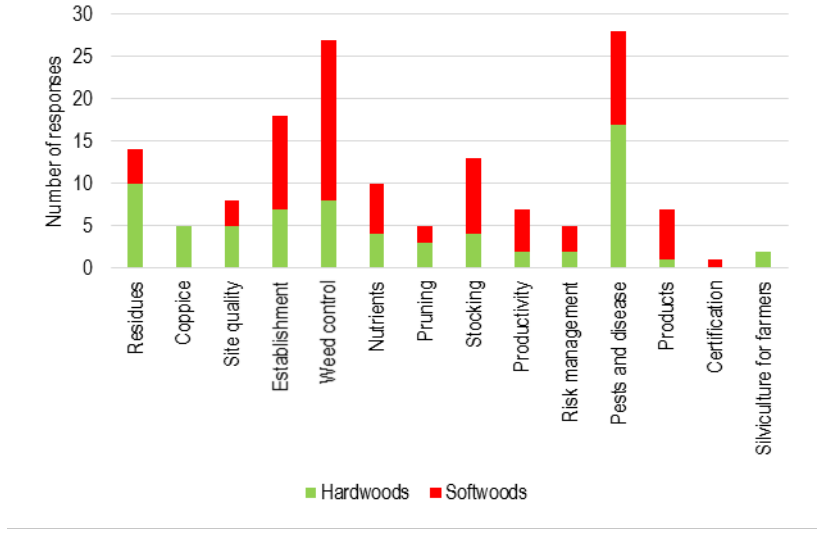

FIGURE 6: A COLLATION OF THE SURVEY STATED UNMET NEEDS FOR SILVICULTURE.

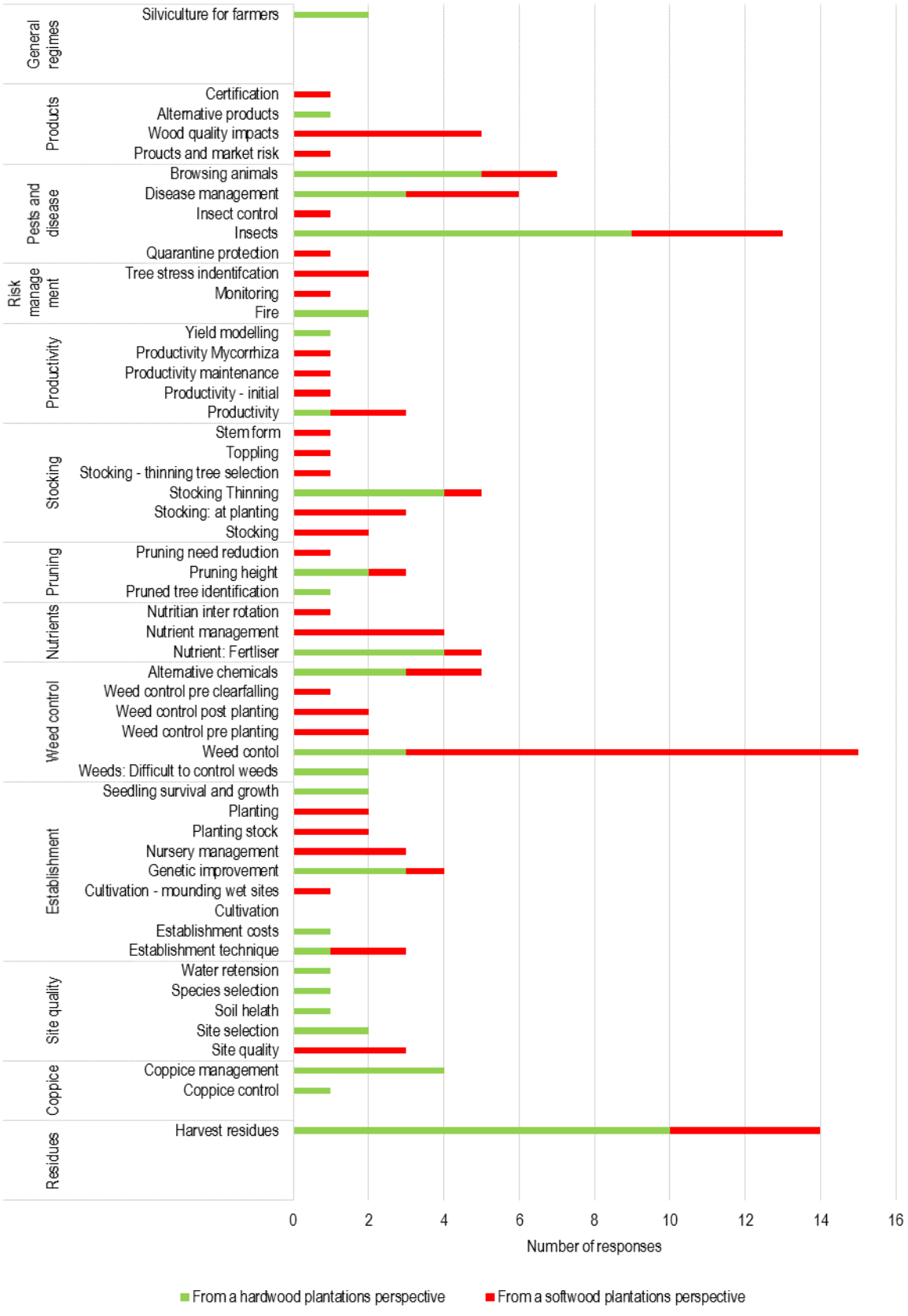

Figure 7: A collation of the survey stated unmet needs for silviculture.

The identified research themes

The outcomes of all consultations were combined into the narratives presented in 'Appendix 4: The identified research needs issues and opportunities' commencing on page 44. The identified research needs were aggregated into research themes and these are presented in 'Appendix 3: The initial identified research themes' commencing on page 38 and Table 4 presents the titles to each research theme.

TABLE 4: A SUMMARY OF IDENTIFIED RESEARCH THEMES AND THE CODES APPLIED.

Broad topic	Code	Research theme number	Title	Research theme
Knowledge management	A1	Research theme 1	Knowledge management	There is a research need to understand the current state of corporate knowledge retention in the industry and to devise a system for retaining and maintaining future corporate knowledge using modern tools and systems.
Markets and product specifications	B1	Research theme 2	Silviculture and wood products	There is a need to better understand the impacts of silviculture on the wood properties within a tree as these relate to the utility of logs to a processor. This will include the attributes of the site, the species grown, the management of the stands and the individual trees. Alternative to the last sentence: Understanding then impact of silviculture on solid wood products is important for both softwood and hardwood resources. Wood properties are also critical to the performance of pulp.
	B2	Research theme 3	Application of pruning and the links to the market	A Research theme is required to review the market for pruned logs needs to consider: what is the critical mass (area and wood flows) required to justify pruning; what is the margin on a pruned log; what are the drivers of demand for a pruned log? The practical issues with pruning need to be linked to the market opportunities. These include the application of technology to undertake pruning, OHS issues and costs. The decision-making process requires a revisit – when to commence pruning, the height pruned and the number of lifts to achieve the target height of a pruned tree. A last consideration is whether a change in silvicultural systems will stimulate a need for pruning. For example; a shift to silvopastoral management to increase the up-take of trees into farming systems.
Social license to operate	C1	Research theme 4	A focus on social license	There is a research need to understand the human-related aspects of silvicultural practices well in advance of implementation. Based on this understanding there is a research need to continuously assess and where necessary replace or improve silvicultural practices to minimise the risk of any adverse impacts on values across economic, social and environmental considerations.
	C2	Research theme 5	Current chemical approaches	There is a need to document the drivers of poor initial survival of planted trees and the interventions known to improve the rate of survival so that this information is available to current plantation managers. This would include current chemical-based interventions (e.g. insecticides; fungicides; nematocides) utilised in plantation forestry (including nurseries). For each current and potential intervention there is a need to understand the degree of exposure to forced reduction in use or loss of the intervention option due to voluntary third-party certification or changes in the regulatory environment. Related to the risk of loss of each tool, alternative strategies are required to address biotic damage agents. These alternatives should be assessed based on efficacy and cost effectiveness.
	C3	Research theme 6	A holistic approach to biotic pest control	There is a need to develop strategic and holistic approaches to biotic pests which take account of the trees planted, the management of the trees, limitations placed on intervention options and acceptable outcomes. This includes the need for biological and financial loss modelling at regional levels so that the risks are quantified, and appropriate surveillance systems are implemented. The overall process of interventions in regards to stressors and damage agents needs to be within a framework to allow a systematic and uniform approach to decision making, this includes ensuring there is an biological and economic basis for interventions.

Broad topic	Code	Research theme number	Title	Research theme
	C4	Research theme 7	Alternative weed control methods	There is a need to document the drivers of poor initial survival of planted trees and the interventions possible to improve the rate of survival. There is a need for research into weed control in all plantations and coppice control in eucalypts, with a specific focus on alternative regimes driven and demanded by voluntary third-party certification requirements and environmental constraints (including adjacent land-use). This would include the use of combined cultivation and chemical methods with both manual and mechanical applications for both hardwood and softwood plantations. In regards to the chemical options, forest managers face the issue of off label use and certification. There is a need for research into alternative chemicals (molecules) for use in the various tree crops recognising fundamental differences in the tree species between softwoods and hardwoods and the climatic zones which determine the spectrum of weeds involved. This need is urgent given the current focus on glyphosate and the utility of this molecule to plantation establishment and management. There are mechanical and chemical options available, and options at different operational stages. The individual treatments require costing and consideration of the impact of the cost and the efficacy of the subsequent operations.
Sustainability and productivity	D1	Research theme 8	Site selection and productivity management	There is a need to revisit land capability and suitability for softwood and hardwood plantations in the current and potential zones for plantation development. Within the current plantation zone, the issues of climate change, site management and changes in social licence as they impact on possible (the maximum) and realised site productivity needs to be understood. For the new zones, there is a need to extrapolate the current experience base to these areas to generate a realistic and defendable estimate of site productivity. In both cases, there is a need to better understand site and species (particularly new species) matching. The project should include benchmarking of the current productivity of the Australian plantation estate at the macro scale (nationally) and within the plantation zones as defined by the National Plantation Inventory. A next step is to determine the drivers of productivity (both positive and negative) and to assess any exposure to change (e.g. access to herbicides or fertiliser use). A review is required of the current state of factors that may offer increased productivity (e.g. a focus on the rhizosphere).
	D2	Research theme 9	Maintenance of site productivity	There is a need to research the overall management of a site to maintain site productivity. The elements include the management of harvest residues, the application of nutrients, the use of biotic tools such as leguminous plants, and fungi and mycorrhiza in the rhizosphere. Management and enhancement of available water should be considered in parallel to nutrition. The research should consider impacts of alternative harvest residue management methods and their impact on site productivity, operational costs and risks, including to subsequent rotations. The management of harvest residues links to whole silvicultural package including site cultivation methods, weed control and planting.
	D3	Research theme 10	Operational capturing of potential yields	There is a need to quantify and understand the gap between research and operational outcomes for the silviculture applied to determine the underlying cause of this gap and therefore the ability to realise the full potential of a plantation site and the management applied.
	D4	Research theme 11	Impact of productivity on wood properties	The impact of productivity on wood quality and therefore potential products as a driver of value needs to be better understood. This requires development of a linkage between log wood properties and the price paid.

Broad topic	Code	Research theme number	Title	Research theme
Biotic agents, pests and disease	E1	Research theme 12	Document the drivers of poor survival	There is a need to document the drivers of poor initial survival of planted trees. The outcome would be a catalogue to document and rate the significance of the current spectrum of weeds, insect pests and pathogens associated with plantation forestry at the four identified stages (e.g. pre-plant, post-plant, pre-clearfalling and ad hoc) for the main commercial tree species in the main National Plantation Inventory zones. This should then include a rating of the current status of preventative and control options and any risks to those options. Where a pest species is of significance and the effective control options are at risk, these species should be identified for further research. This should include any impact on and down-grade of products that could be recovered from a tree as a basis of defining the financial impact of a damage agent.
	E2	Research theme 13	Silviculture and risk issues	There is a need to better define the relationship between the condition of a plantation as impacted by management interventions and driven by site factors (e.g. current period climate) and tree stress. This should form the basis of documenting the appropriate responses to anticipated or current stress events.
	E3	Research theme 14	Management of the risks	There is a need for specific research and refinement of plantation monitoring tools and techniques to anticipate and correct impending issues or to identify actual stress events as a trigger to an intervention. This should be linked to a consideration and review the current state of quarantine management of Australia's borders to minimise the risk of pest insect and disease incursions. Combing the two elements, there is a need to develop and define the intervention points that relate to each species of tree by species of risk organism.
Stand management – stocking	F1	Research theme 15	Stand management – stocking	There is a need to include the impact of stocking rates at initial establishment and subsequent management of the stocking levels of a plantation as a variable in many Research themes e.g. site type, genetics and initial stocking rates; thinning and fertiliser application. With a focus on hardwood plantations, there is a need to better understand the options and outcomes of thinning, including the use of non-commercial thinning as a tool. The outcomes of the thinnings are defined by the resulting log piece size and the potential markets for the logs.
Trees into farming	G1	Research theme 16	Trees into farming	There is a need to define the differences in farm tree planting and traditional broad-scale plantation development from an agricultural perspective. Based on this analysis, farm specific silvicultural systems can be defined and developed

The outcomes of the priority setting process

Step 1 – the scoring process

Building on the industry consultation from the survey respondents and the inception meetings, five completed scoring files were returned of the 12 invited and these were entered into a master file to combine all scores. One respondent was reluctant to complete the capacity scoring (see Box 6 and

Table 3) and an average for the other four responses was used to complete the datasets. The aggregated scoring for impact and capacity are presented in Figure 8 and the combined impact and capacity scoring is presented in Figure 9. The combined scoring was segmented into 'Low', 'Medium' and 'High' based on the relative aggregations for the 16 research themes. In the development of actual Research themes, it is highly likely that research needs could and will be combined from the high, medium and lower ranked cohorts. The priority setting process provided a transparent and participatory assessment of the 16 research themes presented in Table 5.

TABLE 5: A SUMMARY OF THE MODERATED RANKING OF THE IDENTIFIED RESEARCH NEEDS.

			Combined			Time till impact			Ability to capture		
			Low	Medium	High	Immediate	short-term	Long-term	Low	Medium	High
B1	Research theme 2	Silviculture and wood products			1		1				1
C2	Research theme 5	Current chemical approaches			1		1				1
C4	Research theme 7	Alternative weed control method			1		1				1
D1	Research theme 8	Site selection and management			1		1			1	
D2	Research theme 9	Maintenance of site productivity			1		1				1
D3	Research theme 10	Operational capturing of potential yields			1		1			1	
B2	Research theme 3	Application of pruning and the links to the market		1			1			1	
D4	Research theme 11	Impact of productivity on wood properties		1			1			1	
A1	Research theme 1	Knowledge management	1				1			1	
C1	Research theme 4	A focus on social license	1				1		1		
C3	Research theme 6	A holistic approach	1					1	1		
E1	Research theme 12	Document the drivers of poor survival	1					1		1	
E2	Research theme 13	Silviculture and risk issues	1				1		1		
E3	Research theme 14	Management of the risks	1				1			1	
F1	Research theme 15	Stand management – stocking	1				1				1
G1	Research theme 16	Trees into farming	1				1		1		

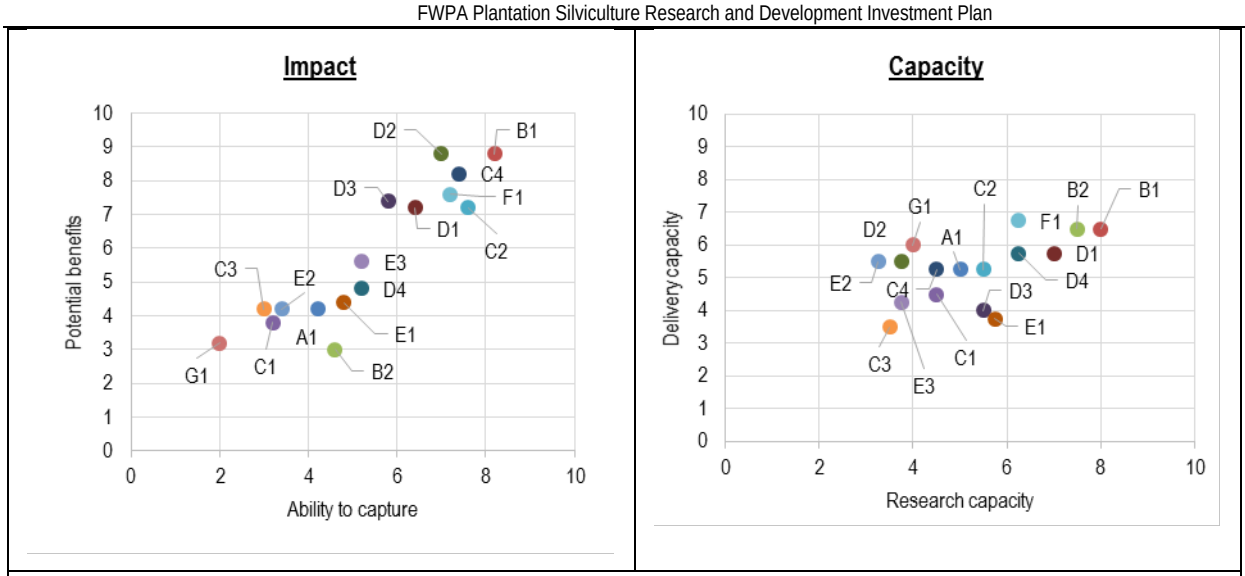

FIGURE 8: THE COLLATED SCORING OF IMPACT AND CAPACITY

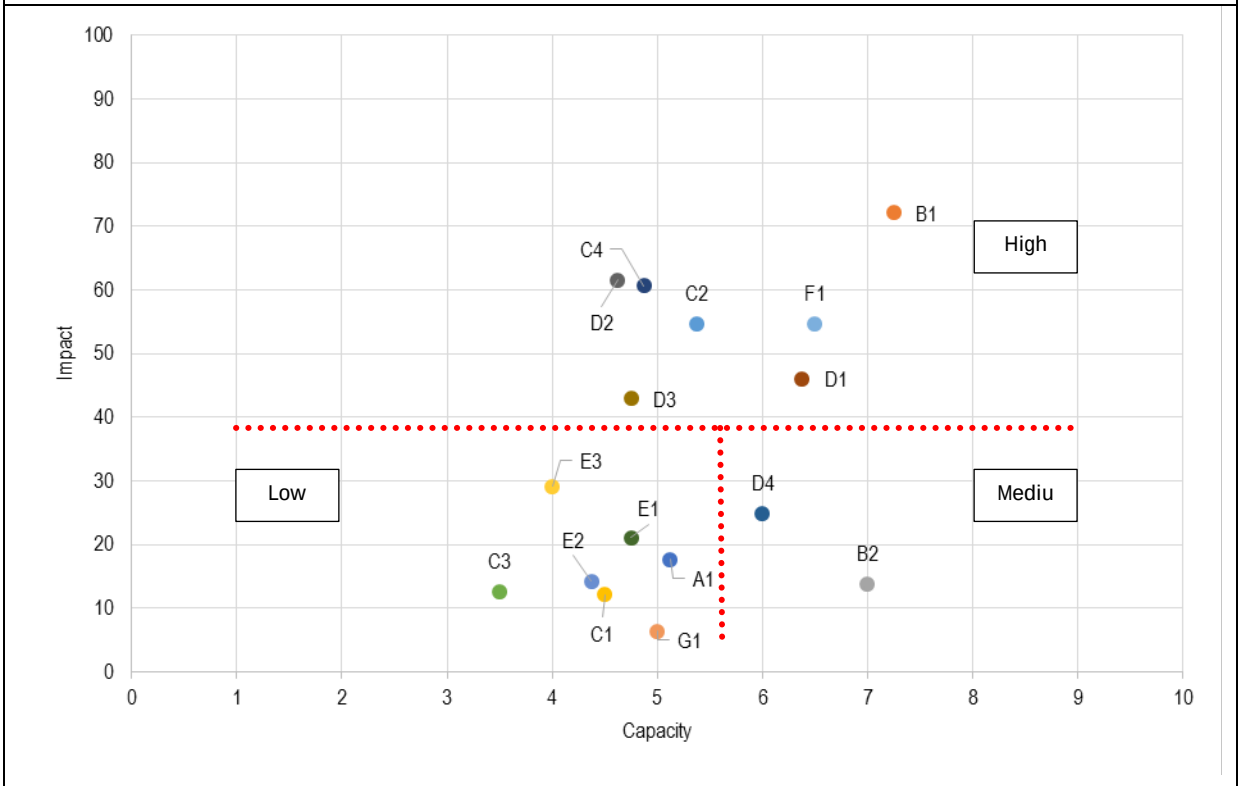

FIGURE 9: THE PRIORITY SETTING OUTCOMES FOR THE 17 IDENTIFIED RESEARCH NEEDS – IDENTIFIED AS 'HIGH', 'MEDIUM' AND 'LOW'.

Step 2 – the Steering Committee review

The review of the initial project rankings provided the following comments and views.

- Research theme 15: It was suggested that Research Theme 15 (stand management - stocking) was under rated based on the potential impact of the softwood industry move to containerised planting, issues associated with poor planting espacement and cross tracking, issues associated with mechanised thinning and operator selection of trees (resulting in suboptimal tree selection) and the subsequent risk of toppling. This Research Theme was elevated to 'High' status.
- Research theme 1: Research Theme A1 (Knowledge management) was scored as a low priority research theme by the process. Discussions with the SC considered where this was an accurate

reflection. This research theme could logically be combined with Research Theme D3 (operational capturing of potential yields) as both are knowledge based and complementary. This Research Theme was combined with D3 and the combined theme (still titled D3) would be classed as a 'High' priority.

- Research themes 5 & 6: The SC considered that these two themes could be combined, and a decision was made to maintain separate identities.
- Research theme 3: The SC challenged the medium ranking of the 'B2: Application of pruning and the links to the market' and felt this had a very narrow application to hardwoods in very specific circumstances. The SC resolved to maintain the scoring and allow interested parties to convert the research plan into research projects.

The SC discussions raised the following issues.

- Nurseries: The Research Themes identified include many elements of nursery management as they link to the planted trees (e.g. Research Theme F1: Stand management – stocking) but it was considered that there is a need for a dedicated approach to nurseries and planting stock production. This was based on the unique nature of nurseries and the issues faced (e.g. the range of chemicals used, water consumption and the short time cycles of nursery production systems).
- Remote sensing: There is potential to increase the resolution of plantation management to the individual tree level and this has implications for Research Themes 9, 10 and 15). An enabling factor is access to and implementation of remote sensing technology. It was proposed that this R&D investment plan should be conscious of the outputs of the Remote Sensing and Resource Modelling Investment Plan.
- Alternative species and plantation systems: Currently plantation timber production comes largely from the 1.95 M ha of plantations in the higher rainfall coastal regions of southern Australia with the value of woodflows from the plantations split 60/40 between softwood and native hardwoods plantations. Due to the competition for land from alternative production systems (e.g. agriculture) in the regions of the current estate, the expansion of the Australian plantation area will likely occur in non-traditional areas and potentially with alternative or modified management systems. In southern Australia a move towards plantation forest expansion in drier areas has been advocated while in northern Australia the plantation areas of *Santalum album* (Indian sandalwood), *Tectona grandis* (teak) and *Khaya senegalensis* (African mahogany) have all expanded in the last 15 years. If plantation forestry is to reach its full potential across Australia, then it will be necessary to invest in the development of species and systems that can optimise production in areas that have previously not been used for commercial timber plantations. Often these alternative areas have harsher soil and climatic conditions than current plantation regions and developing systems that are both commercially viable and environmentally sustainable will require significant investment. It is recommended that FWPA develop mechanisms to promote the development of these new plantation systems in parallel with the further development of traditional plantation systems.

Estimate of the quantum of gains achievable in Australia

From 2018 to 2023

The gains and avoided losses from enhanced plantation silviculture include:

Business risk

- Market access can be impacted on by a loss of voluntary third-party certification. The Research Themes identified include addressing and minimising adverse impacts due to; chemical use in plantation management which will provide guidance as to fit for purpose options with justifications; impacts on the environment including fauna and flora; impacts on cultural and social values.
- The assessment needs to consider both silvicultural activities on managed lands and impacts on adjacent lands. For example, managers of food crops, especially organic ones, will be particularly sensitive to adjacent plantation activities.
- It is essential to understand the potential impacts of silvicultural activities on values held in urban areas even though these are substantially separated from the plantation sites. Members of the public or even plantation investors located in other countries may become aware of unacceptable practices through [or 'open communication networks'] social media or other means via a 24/7 news cycle which may result in challenges to plantation management.

Biological risk

- The realisation of maximum commercially achievable productivity gains by translation of research into operational implementation is a cross cutting issue across all silviculture and other plantation activities. This plan seeks to specifically address these issues and the knowledge loss that has the potential to erode gains.
- A key element of the plan is maintenance of access to and the appropriate use of a range of inputs (e.g. herbicides) by better understanding the status quo usage and the options should the current range of chemicals cease to be available.
- The Research Themes include a specific focus on maintaining site productivity between rotations, hence there is a focus on maintenance of plantation yield. Recognizing that in some systems there will be an inevitable decline in productivity between rotations, e.g. where available water is reduced between rotations either through climate drying or utilisation of stored water[34].
- The Research Themes address the potential drivers of a loss of productivity within a plantation due to management actions and inputs and more importantly the linkages between the elements (e.g. implications of poor planting and survival on later age management and productivity).

Beyond 2023 (an outlook)

A vision of beyond 2023 is that the Australian plantation forest industry has available to it a full range of silvicultural tools that can be applied based on evidence-based business decisions. The risk of impacts of the silvicultural tools on other values will be known and accepted by stakeholders.

[34] Mendham et al. (2011).

Barriers to achieving potential gains

A primary barrier to achieving the potential benefits (either as avoided losses or actual gains) is evidence on which to base business decision making. The issues that need to be addressed include the following.

Current systems

The application of current silviculture will result in predictable outcomes and can be a barrier to the introduction of new and improved systems. Where improvements are possible, they need to be compared with the current systems on a business case basis detailing benefits, costs and risks so a rational decision can be made. Buy in from existing staff must be achieved by involvement in the development and adoption of the new system. Staff must receive adequate training in the implementation of any new systems to support their ongoing use.

Lack of in-house expertise

It might be that there is no single person in an organisation who understands all aspects of the silviculture or of how the components interact. This is obviously risky where changes to one silvicultural practice may have unknown adverse impacts on others. An example is when operational cost reduction imperatives drive unsustainable practices such as burning of post-harvest residue leading to nutrient and organic matter depletion in plantation soils. The loss of nutrient and organic matter from the site is likely to reduce the productivity of subsequent crops. The second rotation productivity decline problem that arose in South Australian radiata pine plantations in the 1950s is an example.[35]

A lack of time to address issues

Business imperatives can often be short-term and need to be addressed in a shorter timeframe than structured system development or replacement can allow. However, it can be reasonable to implement a new system where a justified imperative to depart from the current system exists. This may be on the understanding that a parallel R&D program is warranted and as a further evidence-based refinement to the new system may be necessary. An example of this situation is the implementation of the full suite of maximum growth sequence silvicultural practices that were known in South Australia to correct the second rotation productivity decline problem. If this change had not been adopted, then many plantations would have been established and grown at rates half of the previous rotation and the business sustainability of the industry based on radiata pine would have been in question. As more research evidence became available a move to site specific silviculture and the application of adaptive management principles was applied which reduced costs substantially by only applying treatments (mainly young age fertiliser) where they were likely to be necessary.[36]

A lack of available technology

The forest industry has a long history of developing new technologies and systems and adapting existing technology. In addition to investing in specific forestry related programs this means the industry must continuously scan developments in other industries such as agriculture and mining, for new developments and be prepared to trial these developments in forestry situations. Lack of access to digital networks due to the remote areas in which forestry operations occur can be a barrier to adoption of improved silvicultural systems where these rely on accurate spatial positioning and data transfer. The scale of precision forestry development and adoption is particularly constrained where under canopy positioning is typically +/- 20m compared with +/-2.5cm as quoted for precision farming. Data transfer rates are constrained where operations are conducted outside of 3/4G networks. The combination of these factors limits the use of well-established agricultural tools such as variable rate spray technology. While the constraints on precision provided caused by forest canopies is an impediment to fine scale

[35] O'Hehir & Nambiar (2010).
[36] O'Hehir & Nambiar (2010).

variation in product delivery, implementing silviculture at 10-20 m scales is a considerable improvement on silviculture that is delivered at a compartment or plantation (regional) scale.

Inadequate technical support

Inadequate technical support can be a barrier to improvement of silvicultural systems. A well-documented shortage of forestry technical capacity exists in the Australian forest industry and due to an aging cohort of existing forest scientists that are not being replaced this shortage can be expected to become more acute. A solution applied in tree breeding and genetics is Tree Breeding Australia (TBA) which operates as an industry cooperative whose services include providing technical support to members and also mentoring and training for member and for a fee, non-members. The same solution could be used in silviculture by establishing a cooperative to pool and concentrate the scant silvicultural expertise that still exists. This could also be a method of supporting the long-term research programs essential to property understanding the impacts of alternative silvicultural treatments on plantation growth and yield.

Not knowing how to address an issue

The forest industry can be isolated from mainstream technical developments; which can lead to a lack of awareness of potential solutions to problems that may be already be solved, for example, in military, mining and agriculture. Sometimes this lack of connectedness can result in unawareness that a problem even exists and the chances of this increase as more technology is adopted without the necessary due diligence being done to understand the full risks.

The priority RDE needed from 2018 to 2023, and beyond

The participatory process of development of this R&D investment plan has resulted in three levels of moderated research priorities (see Table 6). The six highest priority areas are focus on the maintenance and capturing of site productivity and the exposure faced by the industry from a loss of access to effective herbicides. It is likely that the development of research projects around the high priority research themes will include elements of the medium and lower research priorities.

TABLE 6: A SUMMARY OF THE MODERATED RANKING OF THE IDENTIFIED RESEARCH NEEDS.

			Combined			Time until impact			Ability to capture		
			Low	Medium	High	Immediate	short-term	Long-term	Low	Medium	High
B1	Research theme 2	Silviculture and wood products			1		1				1
C2	Research theme 5	Current chemical approaches			1		1				1
C4	Research theme 7	Alternative weed control method			1		1				1
D1	Research theme 8	Site selection and management			1		1			1	
D2	Research theme 9	Maintenance of site productivity			1		1				1
D3	Research theme 10	Operational capturing of potential yields			1		1			1	
F1	Research theme 15	Stand management – stocking	1		1		1				1
A1*	Research theme 1	Knowledge management	1				1			1	
B2	Research theme 3	Application of pruning and the links to the market		1			1			1	
D4	Research theme 11	Impact of productivity on wood properties		1			1			1	
C1	Research theme 4	A focus on social license	1				1		1		
C3	Research theme 6	A holistic approach	1					1	1		
E1	Research theme 12	Document the drivers of poor survival	1					1		1	
E2	Research theme 13	Silviculture and risk issues	1				1		1		
E3	Research theme 14	Management of the risks	1				1			1	
G1	Research theme 16	Trees into farming	1				1		1		

- F1 and A1 are combined into one Research theme based on the project SC feedback.

Table 7 presents the research theme priorities and suggested methodologies and timeframes for RD&E projects.

TABLE 7: A SUMMARY OF LOGICAL RESEARCH THEMES RELEVANT TO IDENTIFIED SILVICULTURE NEEDS.

Broad area	Code	Research theme		Priority			Method	Time (indicative)	Benefit (indicative per company)	Implementation Budget (indicative)
				High	Medium	Low				
Market and product specifications	B1	2	Silviculture and wood products	1			• Industry survey • Literature review • Report	12 months	+5-20% in net log value recovery	Minimal or no additional cost of management with changed prescriptions
	B2	3	Application of pruning and the links to the market		1		• Industry survey • Literature review • Report	6-12 months	+5-20% in net log value recovery	Minimal or no additional cost of management with changed prescriptions
Social license to operate	C1	4	A focus on social license			1	• Industry survey • Literature review • Report	6-12 months	5-20% reduction in cost of operational programs	+10% increase in cost of operational programs per company
	C2	5	Current chemical approaches	1			• Industry survey • Chemical company consultation • Literature review	6-12 months	5-20% reduction in cost of operational programs	+20% to operational weed control budget per year for 5 years as new methods are bedded down per company
	C3	6	A holistic approach			1	• Industry survey • Literature review	6-12 months	5-20% reduction in cost of operational programs	+10% per year to operational program to ensure integrated planning & implementation occurs per company
	C4	7	Alternative weed control method	1			• Industry survey • Chemical company consultation • Literature review • Field trials • Cooperative data and trial management • Reporting and model development	2-5 years	Neutral	Minimal or no additional cost of management with changed prescriptions Best done in a cooperative arrangement
Sustainability and productivity	D1	8	Site selection and management	1			• Industry survey • Literature review • Report	12 months	+5-20% in net log value recovery	+10% per year to operational program to ensure optimum planning & implementation occurs per company
	D2	9	Maintenance of site productivity	1			• Industry survey • Literature review • Report	6-12 months	+5-20% in net log value recovery	+10% per year to operational program to ensure optimum planning & implementation occurs per company
	D3	10	Operational capturing of potential yields	1			• Industry survey • Literature review • Report	6-12 months	+5-20% in net log value recovery	+10% per year to operational program to ensure optimum planning & implementation occurs per company
	D4	11	Impact of productivity on wood properties		1		• Industry survey • Literature review • Cooperative data and trial management • Reporting and model development	10-30 years (depends on rotation length)	+5-20% in net log value recovery	Best done in a cooperative arrangement
Biotic agents, pests and disease	E1	12	Document the drivers of poor survival			1	• Industry survey • Literature review	6-12 months	5-20% reduction in cost of operational programs	Minimal or no additional cost of management with changed prescriptions

Broad area	Code	Research theme		Priority			Method	Time (indicative)	Benefit (indicative per company)	Implementation Budget (indicative)
	E2	13	Silviculture and risk issues			1	• Industry survey • Forestry Standards Consultation • Literature review • Report	6-12 months	5-20% reduction in cost of operational programs	+10% increase in cost of operational programs per company
	E3	14	Management of the risks			1	• Industry survey • Forestry Standards Consultation • Literature review • Generic risk management guide	6-12 months	5-20% reduction in cost of operational programs	+10% increase in cost of operational programs per company
Stand management – stocking	F1	15	Stand management – stocking	1			• Industry survey • Literature review • Field trials • Cooperative data and trial management • Reporting and model development	10-30 years (depends on rotation length)	+5-20% in net log value recovery	Minimal or no additional cost of management with changed prescriptions
	F1 A1*	1	Knowledge management	1			• Industry survey • Literature review • Generic management tool	12 months	5-20% reduction in cost of operational programs	
Trees into farming	G1	16	Trees into farming			1	• Farmer advisor survey • Industry survey • Literature review • Generic report & business models	12 months	+5-10% of land available to forest industry for planting	

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Appendix 1: Stakeholders consulted

The project Steering Committee members

Table 8: The project Steering Committee (participants in the project inception meetings).

Person	Company	State	Forest type	Climate zone
Ange Chandler	FPC	WA	Plantation pine / Native	Temperate
Graeme Hobson	FPC	WA	Plantation pine / Native	Temperate
Gary Pearson	OFO	SA/VIC	Plantation pine	Temperate
Ross Gillies	HVP	VIC	Plantation pine	Temperate
David West	HQP	QLD	Plantation pine	Sub-tropical
Allie Muneri	PFO	VIC/SA	Plantation eucalypt	Temperate
Kevin Johnson	Midway	VIC	Plantation pine	Temperate
Mike Sutton	FC NSW	NSW	Plantation pine / Native	Temperate/ Sub-tropical
Jodie Mason	FWPA	National	National	National
Glen Rivers	OFO	SA/VIC	Plantation pine	Temperate
Ross Dickson	FC NSW	NSW	All	Temperate
Ian Telfer	WAPRES	WA	Plantation eucalypt	Temperate

The survey respondents

A total of 63 people responded to the survey but only 46 parties completed the survey. Of the 46 parties that completed the survey, not all completed all questions. The survey respondents included parties from all National Plantation Inventory zones except Mount Lofty and Kangaroo Island (Table 9). The respondents included 56 people with interests in softwoods and 66 people with interests is hardwood plantations (note: parties could nominate more than one area of interest).

Table 9: A summary of the number of survey respondents in each area of interest.

National Plantation Inventory Region	Softwoods	Hardwoods
Tasmania	5	12
Western Australia	3	8
Mount Lofty Ranges & Kangaroo Island	0	0
Green Triangle	9	8
Central Victoria	5	6
Central Gippsland	5	7
East Gippsland	1	3
Murray Valley	7	1
Southern Tablelands	4	0
Central Tablelands	3	0
Northern Tablelands	3	0
North Coast	2	7
South East Queensland	4	3
North Queensland	3	3
Northern Territory	0	3
International	2	5
Totals	56	66

Note it was possible for respondents to nominate more than one NPI zone.

Appendix 2: A summary of the identified research needs

Area of interest		Project No.	Research theme
Knowledge management		***Research theme 1***	***There is a research need to understand the current state of corporate knowledge retention in the industry and to devise a system for retaining and maintaining future corporate knowledge using modern tools and systems.***
Markets and product specifications		***Research theme 2***	***There is a need to better understand the impacts of silviculture on the wood properties within a tree as these relate to the utility of logs to a processor. This will include the attributes of the site, the species grown, the management of the stands and the individual trees. Alternative to the last sentence: Understanding then impact of silviculture on solid wood products is important for both softwood and hardwood resources. Wood properties are also critical to the performance of pulp.***
		Research theme 3	***A Research theme is required to review the market for pruned logs needs to consider: what is the critical mass (area and wood flows) required to justify pruning; what is the margin on a pruned log; what are the drivers of demand for a pruned log? The practical issues with pruning need to be linked to the market opportunities. These include the application of technology to undertake pruning, OHS issues and costs. The decision-making process requires a revisit – when to commence pruning, the height pruned and the number of lifts to achieve the target height of a pruned tree. A last consideration is whether a change in silvicultural systems will stimulate a need for pruning. For example; a shift to silvopastoral management to increase the up-take of trees into farming systems.***
Social license to operate	A focus on social license	***Research theme 4***	***There is a research need to understand the human-related aspects of silvicultural practices well in advance of implementation. Based on this understanding there is a research need to continuously assess and where necessary replace or improve silvicultural practices to minimise the risk of any adverse impacts on values across economic, social and environmental considerations.***
	Current chemical approaches	***Research theme 5***	***There is a need to document the drivers of poor initial survival of planted trees and the interventions known to improve the rate of survival so that this information is available to current plantation managers. This would include current chemical-based interventions (e.g. insecticides; fungicides; nematocides) utilised in plantation forestry (including nurseries). For each current and potential intervention there is a need to understand the degree of exposure to forced reduction in use or loss of the intervention option due to voluntary third-party certification or changes in the regulatory environment. Related to the risk of loss of each tool, alternative strategies are required to address biotic damage agents. These alternatives should be assessed based on efficacy and cost effectiveness.***
	A holistic approach	***Research theme 6***	***There is a need to develop strategic and holistic approaches to biotic pests which take account of the trees planted, the management of the trees, limitations placed on intervention options and acceptable outcomes. This includes the need for biological and financial loss modelling at regional levels so that the risks are quantified, and appropriate surveillance systems are implemented. The overall process of interventions in regards to stressors and damage agents needs to be within a framework to allow a systematic and uniform approach to decision making, this includes ensuring there is an biological and economic basis for interventions.***
	Alternative	***Research theme 7***	***There is a need to document the drivers of poor initial survival of planted trees and the interventions possible to improve the rate of survival. There is a need for research into weed control in all plantations and coppice control in eucalypts, with a specific focus on alternative regimes driven and demanded by voluntary third-party certification requirements and environmental constraints (including adjacent land-use). This would include the use of combined cultivation and chemical methods with both manual and mechanical applications for both hardwood and softwood plantations. In regards to the chemical options, forest managers face the issue of off label use and certification. There is a need for research into alternative chemicals (molecules) for use in the various tree crops recognising fundamental differences in the tree species between softwoods and hardwoods and the climatic zones which determine the spectrum of weeds involved. This need is urgent given the current focus on glyphosate and the utility of this molecule to plantation establishment and management. There are mechanical and chemical options available, and options at different operational stages. The individual treatments require costing and consideration of the impact of the cost and the efficacy of the subsequent operations.***
Sustainability and productivity	Site selection and productivity management	***Research theme 8***	***There is a need to revisit land capability and suitability for softwood and hardwood plantations in the current and potential zones for plantation development. Within the current plantation zone, the issues of climate change, site management and changes in social licence as they impact on possible (the maximum) and realised site productivity needs to be understood. For the new zones, there is a need to extrapolate the current experience base to these areas to generate a realistic and defendable estimate of site productivity. In both cases, there is a need to better understand site and species (particularly new species) matching. The project should include benchmarking of the current productivity of the Australian plantation estate at the macro scale (nationally) and within the plantation zones as defined by the National Plantation Inventory. A next step is to determine the drivers of productivity***

Area of interest		Project No.	Research theme
			(both positive and negative) and to assess any exposure to change (e.g. access to herbicides or fertiliser use). A review is required of the current state of factors that may offer increased productivity (e.g. a focus on the rhizosphere).
	Maintenance and site productivity	***Research theme 9***	***There is a need to research the overall management of a site to maintain site productivity. The elements include the management of harvest residues, the application of nutrients, the use of biotic tools such as leguminous plants, and fungi and mycorrhiza in the rhizosphere. Management and enhancement of available water should be considered in parallel to nutrition. The research should consider impacts of alternative harvest residue management methods and their impact on site productivity, operational costs and risks, including to subsequent rotations. The management of harvest residues links to whole silvicultural package including site cultivation methods, weed control and planting.***
	Operational capturing of potential yields	***Research theme 10***	***There is a need to quantify and understand the gap between research and operational outcomes for the silviculture applied to determine the underlying cause of this gap and therefore the ability to realise the full potential of a plantation site and the management applied.***
	Impact of productivity on wood properties	***Research theme 11***	***The impact of productivity on wood quality and therefore potential products as a driver of value needs to be better understood. This requires development of a linkage between log wood properties and the price paid.***
Biotoc agents, pests and disease	Documenting the drivers of poor survival	***Research theme 12***	***There is a need to document the drivers of poor initial survival of planted trees. The outcome would be a catalogue to document and rate the significance of the current spectrum of weeds, insect pests and pathogens associated with plantation forestry at the four identified stages (e.g. pre-plant, post-plant, pre-clearfalling and ad hoc) for the main commercial tree species in the main National Plantation Inventory zones. This should then include a rating of the current status of preventative and control options and any risks to those options. Where a pest species is of significance and the effective control options are at risk, these species should be identified for further research. This should include any impact on and down-grade of products that could be recovered from a tree as a basis of defining the financial impact of a damage agent.***
	Silviculture and risk issues	***Research theme 13***	***There is a need to better define the relationship between the condition of a plantation as impacted by management interventions and driven by site factors (e.g. current period climate) and tree stress. This should form the basis of documenting the appropriate responses to anticipated or current stress events.***
	Management of the risks	***Research theme 14***	***There is a need for specific research and refinement of plantation monitoring tools and techniques to anticipate and correct impending issues or to identify actual stress events as a trigger to an intervention. This should be linked to a consideration and review the current state of quarantine management of Australia's borders to minimise the risk of pest insect and disease incursions. Combing the two elements, there is a need to develop and define the intervention points that relate to each species of tree by species of risk organism.***
Stand management – stocking		***Research theme 15***	***There is a need to include the impact of stocking rates at initial establishment and subsequent management of the stocking levels of a plantation as a variable in many Research themes e.g. site type, genetics and initial stocking rates; thinning and fertiliser application. With a focus on hardwood plantations, there is a need to better understand the options and outcomes of thinning, including the use of non-commercial thinning as a tool. The outcomes of the thinnings are defined by the resulting log piece size and the potential markets for the logs.***
Trees into farming		***Research theme 16***	***There is a need to define the differences in farm tree planting and traditional broad-scale plantation development from an agricultural perspective. Based on this analysis, farm specific silvicultural systems can be defined and developed***

Appendix 3: The initial identified research themes

Knowledge management

Research theme 1: There is a research need to understand the current state of corporate knowledge retention in the industry and to devise a system for retaining and maintaining future corporate knowledge using modern tools and systems.

Research need 10: There is a research need to understand the current state of corporate knowledge retention in the industry and to devise a system for retaining and maintaining future corporate knowledge using modern tools and systems.

Markets and product specifications

Research theme 2: There is a need to better understand the impacts of silviculture on the wood properties within a tree as these relate to the utility of logs to a processor. This will include the attributes of the site, the species grown, the management of the stands and the individual trees. Alternative to the last sentence: Understanding then impact of silviculture on solid wood products is important for both softwood and hardwood resources. Wood properties are also critical to the performance of pulp.

Research theme 3: A Research theme is required to review the market for pruned logs needs to consider: what is the critical mass (area and wood flows) required to justify pruning; what is the margin on a pruned log; what are the drivers of demand for a pruned log? The practical issues with pruning need to be linked to the market opportunities. These include the application of technology to undertake pruning, OHS issues and costs. The decision-making process requires a revisit – when to commence pruning, the height pruned and the number of lifts to achieve the target height of a pruned tree. A last consideration is whether a change in silvicultural systems will stimulate a need for pruning. For example; a shift to silvopastoral management to increase the up-take of trees into farming systems.

Research need 1: There is a need to better understand the impacts of silviculture on the wood properties within a tree as these relate to the utility of logs to a processor. This will include the attributes of the site, the species grown, the management of the stands and the individual trees. While this may be more critical for softwoods, there is also a need to better understand these relationships for hardwoods when considering alternative products and markets to the current woodchip trade.

Research need 25: A Research theme is required to better understand the practical issues with pruning need to be linked to the market opportunities. These include the application of technology to undertake pruning, OHS issues and costs. The decision-making process requires a revisit – when to commence pruning, the height pruned and the number of lifts to achieve the target height of a pruned tree. The market for pruned logs needs to be assessed and considered: what is the critical mass (area and wood flows) required to justify pruning; what is the margin on a pruned log; what are the drivers of demand for a pruned log? A last consideration is whether a change in silvicultural systems will stimulate a need for pruning. For example; a shift to silvopastoral management to increase the up-take of trees into farming systems.

Social license to operate

A focus on social license

Research theme 4: There is a research need to understand the human-related aspects of silvicultural practices well in advance of implementation. Based on this understanding there is a research need to continuously assess and where necessary replace or improve silvicultural practices to minimise the risk of any adverse impacts on values across economic, social and environmental considerations.

Research need 9: There is a research need to continuously assess and where necessary replace or improve silvicultural practices to minimise the risk of any adverse impacts on values across economic, social and environmental considerations.

Research need 11: There is a research need to understand the human-related aspects of silvicultural practices well in advance of implementation.

Current chemical approaches

Research theme 5: There is a need to document the drivers of poor initial survival of planted trees and the interventions known to improve the rate of survival so that this information is available to current plantation managers. This would include current chemical-based interventions (e.g. insecticides; fungicides; nematocides) utilised in plantation forestry (including nurseries). For each current and potential intervention there is a need to understand the degree of exposure to forced reduction in use or loss of the intervention option due to voluntary third-party certification or changes in the regulatory environment. Related to the risk of loss of each tool, alternative strategies are required to address biotic damage agents. These alternatives should be assessed based on efficacy and cost effectiveness.

Research need 34: There is a need to document current chemical-based interventions (e.g. insecticides; fungicides; nematocides) utilised in plantation forestry and determine the risk of loss of each tool and alternative strategies to address

Research need 15: There is a need to review the current inputs and operations in hardwood and softwood nurseries to understand the impact of loss of access to a range of chemicals and practices. Other linked operations need to also be considered. The outcome of the different nursery strategies on growth and performance in the field needs to be reviewed: does a cost-effective planting stock maximise the value recovered from the area of land planted?

Research need 22: There is a need to document the drivers of poor initial survival of planted trees and the interventions possible to improve the rate of survival. This will link with the question management (e.g. weed control) and damage agents (e.g. browsing animals). For each current and potential intervention there is a need to understand the degree of exposure to forced reduction in use or loss of the intervention option due to voluntary third-party certification or changes in the regulatory environment.

A holistic approach to biotic pest control

Research theme 6: There is a need to develop strategic and holistic approaches to biotic pests which take account of the trees planted, the management of the trees, limitations placed on intervention options and acceptable outcomes. This includes the need for biological and financial loss modelling at regional levels so that the risks are quantified, and appropriate surveillance systems are implemented. The overall process of interventions in regards to stressors and damage agents needs to be within a framework to allow a systematic and uniform approach to decision making, this includes ensuring there is a biological and economic basis for interventions.

Research need 28: The overall process of interventions in regards to stressors and damage agents needs to be within a framework to allow a systematic and uniform approach to decision making.

Research need 31: There is a need to develop strategic and holistic approaches to biotic pests which take account of the trees planted, the management of the trees, limitations placed on intervention options and acceptable outcomes.

Alternative weed control methods

Research theme 7: There is a need to document the drivers of poor initial survival of planted trees and the interventions possible to improve the rate of survival. There is a need for research into weed control in all plantations and coppice control in eucalypts, with a specific focus on alternative regimes driven and demanded by voluntary third-party certification requirements and environmental constraints (including adjacent land-use). This would include the use of combined cultivation and chemical methods with both manual and mechanical applications for both hardwood and softwood plantations. In regards to the chemical options, forest managers face the issue of off label use and certification. There is a need for research into alternative chemicals (molecules) for use in the various tree crops recognising fundamental differences in the tree species between softwoods and hardwoods and the climatic zones which determine the spectrum of weeds involved. This need is urgent given the current focus on glyphosate and the utility

of this molecule to plantation establishment and management. There are mechanical and chemical options available, and options at different operational stages. The individual treatments require costing and consideration of the impact of the cost and the efficacy of the subsequent operations.

Research need 14: There is a need to better understand the options to kill coppice and the rootstock of a regenerated stool to allow a change in crop. There are mechanical and chemical options available, and options at different operational stages (e.g. at harvest, soon after harvest or after coppice regeneration). In regards to the chemical options, forest managers face the issue of off label use and certification. The individual treatments require costing as well as consideration of the impact of the cost and the efficacy of the subsequent operations.

Research need 19: There is a need for research into weed control in plantations with a specific focus on alternative regimes driven and demanded by voluntary third-party certification requirements and environmental constraints (including adjacent planted crops). This would include the use of combined cultivation and chemical methods with both manual and mechanical application. This is for both hardwood and softwood plantations.

Research need 20: There is a need for research into alternative chemicals (molecules) for use in the various tree crops recognising fundamental difference in the tree species between softwoods and hardwoods and the climatic zones which in turn will dictate the spectrum of weeds involved. This need is of some urgency given the current focus on glyphosate and the utility of this molecule to plantation establishment and management.

Research need 22: There is a need to document the drivers of poor initial survival of planted trees and the interventions possible to improve the rate of survival. This will link with the question management (e.g. weed control) and damage agents (e.g. browsing animals). For each current and potential intervention there is a need to understand the degree of exposure to forced reduction in use or loss of the intervention option due to voluntary third-party certification or changes in the regulatory environment.

Sustainability and productivity

Site selection and productivity management

Research theme 8: There is a need to revisit land capability and suitability for softwood and hardwood plantations in the current and potential zones for plantation development. Within the current plantation zone, the issues of climate change, site management and changes in social licence as they impact on possible (the maximum) and realised site productivity needs to be understood. For the new zones, there is a need to extrapolate the current experience base to these areas to generate a realistic and defendable estimate of site productivity. In both cases, there is a need to better understand site and species (particularly new species) matching. The project should include benchmarking of the current productivity of the Australian plantation estate at the macro scale (nationally) and within the plantation zones as defined by the National Plantation Inventory. A next step is to determine the drivers of productivity (both positive and negative) and to assess any exposure to change (e.g. access to herbicides or fertiliser use). A review is required of the current state of factors that may offer increased productivity (e.g. a focus on the rhizosphere).

Research need 7: There is a need to revisit land capability and suitability for softwood and hardwood plantations in the current and potential zones for plantation development. From the current plantation zone perspective, the issue of climate change, site management and changes in social licence as it impacts on possible (the maximum) and realised site productivity potentials needs to be understood. For the new zones, there is a need to extrapolate the current experience base to these areas to generate a realistic and defendable estimate of site productivity. In both cases, there is a need to better understand site and species (particularly new species) matching.

Research need 2: Research is required to benchmark the current productivity of the Australian plantation estate at the macro scale (nationally) and within the plantation zones as defined by the National Plantation Inventory.

Research need 3: A next step is to determine the drivers of productivity (both positive and negative) and to assess any exposure to change (e.g. access to herbicides or fertiliser use). A review is required of the current state of factors that may offer increased productivity (e.g. a focus on the rhizosphere).

Maintenance and site productivity

Research theme 9: There is a need to research the overall management of a site to maintain site productivity. The elements include the management of harvest residues, the application of nutrients, the use of biotic tools such as leguminous plants, and fungi and mycorrhiza in the rhizosphere. Management and enhancement of available water should be considered in parallel to nutrition. The research should consider impacts of alternative harvest residue management methods and their impact on site productivity, operational costs and risks, including to subsequent rotations. The management of harvest residues links to whole silvicultural package including site cultivation methods, weed control and planting.

Research need 16: There is a general research need to consider plantation establishment

Research need 6: There is a need to research on a holistic basis, the overall management of a site to maintain site productivity. The elements include the management of harvest residues, the application of nutrients, the use of biotic tools such as leguminous plants, and fungi and mycorrhiza in the rhizosphere. Management and enhancement of available water should be considered in parallel to nutrition

Research need 17: There is a need to revisit the current cultivation strategies and options to better determine the fit for purpose options available matching plantation outcomes to the site requirements. This should be considered within the context of the whole silvicultural package including weed control issues and sustainability related issues. This should be linked to the attributes of first rotation forestry sites and the treatment of harvest residues on subsequent rotation sites.

Research need 12: There is a need to better understand the impacts of the different harvest reside management strategies and the impact on site productivity, the cost of the operation and the risks posed. Any analysis should consider the cost impacts to the overall rotations (the one harvested and the subsequent rotations) and not just the costs of the single operation.

Research need 13: There is a need to revisit the management of postharvest residues in softwood plantations and to consider the application of advances in technology. This should consider the impacts on site productivity, particularly where possible the impacts between rotations.

Research need 21: There is a need to consider the options and technology available to reduce reliance on manual planting during the establishment of a plantation. This research should focus on second and subsequent rotation sites and be linked to consideration of the treatment of the harvest residues on that site.

Operational capturing of potential yields

Research theme 10: There is a need to quantify and understand the gap between research and operational outcomes for the silviculture applied to determine the underlying cause of this gap and therefore the ability to realise the full potential of a plantation site and the management applied.

Research need 4: There is a need to quantify and understand the gap between research and operational outcomes for the silviculture applied to determine the underlying cause of this gap and therefore the ability to realise the full potential of a plantation site and the management applied.

Impact of productivity on wood properties

Research theme 11: The impact of productivity on wood quality and therefore potential products as a driver of value needs to be better understood. This requires development of a linkage between log wood properties and the price paid.

Research need 5: The impact of productivity on wood quality and therefore potential products as a driver of value needs to be better understood. This requires development of a linkage between log wood properties and the price paid.

Biotoc agents, pests and disease

Documenting the drivers of poor survival

Research theme 12: There is a need to document the drivers of poor initial survival of planted trees. The outcome would be a catalogue to document and rate the significance of the current spectrum of weeds,

insect pests and pathogens associated with plantation forestry at the four identified stages (e.g. pre-plant, post-plant, pre-clearfalling and ad hoc) for the main commercial tree species in the main National Plantation Inventory zones. This should then include a rating of the current status of preventative and control options and any risks to those options. Where a pest species is of significance and the effective control options are at risk, these species should be identified for further research. This should include any impact on and down-grade of products that could be recovered from a tree as a basis of defining the financial impact of a damage agent.

Research need 18: There is a research need to catalogue, document and rate the significance of the current spectrum of weeds associated with plantation forestry at the four identified stages (e.g. pre-plant, post-plant, pre-clearfalling and ad hoc). This should then include a rating of the current status of control options and any risks to those options. Where a weed species is of significance and the effective control options are at risk, these species should be identified for further research. For example, blackberry is a weed species of specific interest at present.

Research need 30: There is a need to document and understand the range of biotic risks to plantations on a species of tree by species of risk organism. This should include the stage of tree growth and tree condition at which the tree species are at risk.

Research need 36: The issue of fire management in plantations including preventative and response requires research for softwoods and hardwood plantations.

Research need 32: There is a need to document and define the impacts of each species of risk organism on the different species of tree planted. This should include any impact on and down-grade of products that could be recovered from a tree as a basis of defining the financial impact of a damage agent.

Research need 22: There is a need to document the drivers of poor initial survival of planted trees and the interventions possible to improve the rate of survival. This will link with the question management (e.g. weed control) and damage agents (e.g. browsing animals). For each current and potential intervention there is a need to understand the degree of exposure to forced reduction in use or loss of the intervention option due to voluntary third-party certification or changes in the regulatory environment.

Silviculture and risk issues

Research theme 13: There is a need to better define the relationship between the condition of a plantation as impacted by management interventions and driven by site factors (e.g. current period climate) and tree stress. This should form the basis of documenting the appropriate responses to anticipated or current stress events.

Research need 35: There is a need to better define the relationship between the condition of a plantation as impacted by management interventions and driven by site factors (e.g. current period climate) and tree stress.

Research need 26: There is a need to document all the stressors (current and on the horizon) of trees in plantations in different areas and under different management. This should form the basis of documenting the appropriate responses to anticipated or current stress events.

Research need 22: There is a need to document the drivers of poor initial survival of planted trees and the interventions possible to improve the rate of survival. This will link with the question management (e.g. weed control) and damage agents (e.g. browsing animals). For each current and potential intervention there is a need to understand the degree of exposure to forced reduction in use or loss of the intervention option due to voluntary third-party certification or changes in the regulatory environment.

Management of the risks

Research theme 14: There is a need for specific research and refinement of plantation monitoring tools and techniques to anticipate and correct impending issues or to identify actual stress events as a trigger to an intervention. This should be linked to a consideration and review the current state of quarantine management of Australia's borders to minimise the risk of pest insect and disease incursions. Combing the

two elements, there is a need to develop and define the intervention points that relate to each species of tree by species of risk organism.

Research need 29: There is a need to consider and review the current state of quarantine management of Australia's borders to minimise the risk of pest insect and disease incursions.

Research need 33: There is a need to develop and define the intervention points that relate to each species of tree by species of risk organism.

Research need 27: There is a need for specific research and refinement of plantation monitoring tools and techniques to anticipate and correct impending issues or to identify actual stress events as a trigger to an intervention.

Stand management – stocking

Research theme 15: There is a need to include the impact of stocking rates at initial establishment and subsequent management of the stocking levels of a plantation as a variable in many Research themes e.g. site type, genetics and initial stocking rates; thinning and fertiliser application. With a focus on hardwood plantations, there is a need to better understand the options and outcomes of thinning, including the use of non-commercial thinning as a tool. The outcomes of the thinnings are defined by the resulting log piece size and the potential markets for the logs.

Research need 30: There is a need to document and understand the range of biotic risks to plantations on a species of tree by species of risk organism. This should include the stage of tree growth and tree condition at which the tree species are at risk.

Research need 8: There is a need to include the impact of stocking rates at initial establishment and subsequent management of the stocking levels of a plantation as a variable in many Research themes e.g. site type, genetics and initial stocking rates; thinning and fertiliser application.

Research need 24: With a focus on hardwood plantations, there is a need to better understand the options and outcomes of thinning, including the use of non-commercial thinning as a tool. The outcomes of the thinnings are defined by the resulting log piece size and the potential markets for the logs.

Trees into farming

Research theme 16: There is a need to define the differences in farm tree planting and traditional broad-scale plantation development from an agricultural perspective. Based on this analysis, farm specific silvicultural systems can be defined and developed

Research need 37: There is a need to define the differences in farm tree planting and industrial plantation development from an agricultural perspective. Based on this analysis, farm specific silvicultural systems can be defined and developed

Genetics and tree breeding

Not part of this investment plan

Appendix 4: The identified research needs, issues and opportunities

Markets and product specifications

Commercial forestry aims to grow and sell log products to customers. The sales can be based on long-term contracts or short-term spot sales. Silvicultural practices aim to satisfy market requirements (log dimensions and quality) by the manipulation of the growing stock. Silviculture can aim to maximise volume or value and it is possible that the best value outcome may be achieved by compromising the volume of resources grown; this is part of the commercial decision making. A critical first step is to understand the relationship between the silviculture applied and the tree outcomes. For example:

- Maximising fibre production per hectare may reduce structural wood properties.
- Pruning to remove branches to improve wood properties may decrease productivity.
- Wider initial stockings to increase tree and log piece size may reduce structural wood properties.

Satisfaction of contractual obligations is likely a first priority, while also considering alternative markets. A consideration of alternative markets is also a risk management tool given that while a contract may be in place, there remains the possibility that a market may disappear for a range of reasons.

Research need 1: There is a need to better understand the impacts of silviculture on the wood properties within a tree as these relate to the utility of logs to a processor. This will include the attributes of the site, the species grown, the management of the stands and the individual trees. While this may be more critical for softwoods, there is also a need to better understand these relationships for hardwoods when considering alternative products and markets to the current woodchip trade.

Site Capacity

Productivity and yield

The gross value equation for a plantation is: Yield (volume X products) X net harvest proceeds (mill gate price – haulage costs – harvest costs). Net harvest proceeds are the sum of the individual supply chains linked to customers. The net value of a plantation is the net harvest proceeds per hectare less the growing costs taking account of the time value of money. A key driver is the gross volume but segmented into products, hence productivity is an area of interest. Productivity is an outcome of site and management interventions, with interventions possible at each stage of a rotation and between rotations. The impact on subsequent rotations of management interactions is well documented for radiata pine in Australia, with the insights gained informing the development of eucalypt silviculture. That said there are specific issues that have arisen with eucalypt plantation rotations (e.g. evidence of second rotation decline on some sites with coppice and seedlings). In realising the benefits of the outcomes of research, there is a need to understand the yield gap between potential productivity as demonstrated by research outcomes and the productivity achieved under operational conditions. There is a need to understand the factors contributing to this gap, which should be multi-disciplinary including the building of capacity to identify where and when nutrient and organic matter management will be beneficial economically.

The evolution of consideration of productivity can be stimulated by other considerations. For example, the use of herbicides in plantation management has exposed regulatory and voluntary third-party certification pressures with threats to access to some herbicides. Therefore, one strategy is to accelerate initial tree growth above weed competition, reducing reliance on herbicides: while the duration of hardwood exposure to weeds is c. 12 months, slower growing softwoods may require release for greater than 2 years. With accelerated growth, tree wood properties can change by increasing the percentage of juvenile wood for a target tree size (e.g. DBHOB) achieved at an earlier age. The issue of

productivity links to; harvest residue management, nutrition and weed control as post plant interventions; pre-planting impacts include the genetics used and the nursery strategy.

Research need 2: Research is required to benchmark the current productivity of the Australian plantation estate at the macro scale (nationally) and within the plantation zones as defined by the National Plantation Inventory.
Research need 3: A next step is to determine the drivers of productivity (both positive and negative) and to assess any exposure to change (e.g. access to herbicides or fertiliser use). A review is required of the current state of factors that may offer increased productivity (e.g. a focus on the rhizosphere).
Research need 4: There is a need to quantify and understand the gap between research and operational outcomes for the silviculture applied to determine the underlying cause of this gap and therefore the ability to realise the full potential of a plantation site and the management applied.
Research need 5: The impact of productivity on wood quality and therefore potential products as a driver of value needs to be better understood. This requires development of a linkage between log wood properties and the price paid.
Research need 6: There is a need to research on a holistic basis, the overall management of a site to maintain site productivity. The elements include the management of harvest residues, the application of nutrients, the use of biotic tools such as leguminous plants, and fungi and mycorrhiza in the rhizosphere. Management and enhancement of available water should be considered in parallel to nutrition.

Site productivity and selection

In Australia, during the renaissance of interest in eucalypt plantations and as part of expanding the softwood estate, a usual first step undertaken supported by agencies was to undertake and publish plantation land capability (e.g. the climatic and biotic factors around tree growth) and suitability (e.g. the financial considerations such as harvest and haulage costs) studies. During the Managed Investment Scheme era, with development of new species in new plantation zones, estimates of site productivity underpinned the investment and were often found to be incorrect.

Site factors and climate at an appropriate resolution provide a basis for precision management. Site factors include soil characteristics, water availability, climate variability and change. Previous land use will influence site factors and these influences must be understood before undertaking plantation establishment programs. Large plantations, particularly of hardwoods, are established on ex agricultural and sometimes irrigated sites with past land use histories that are relevant to silvicultural treatments. Stand description data must be maintained to describe the existing stand state to allow appropriate silvicultural treatments to be prescribed. This data will need to be located at an appropriate spatial resolution to allow operational planning to occur.

The current plantation estate land base is close to fully occupied: that is the available suitable land within existing forestry regions has been established. Increases in land costs have become a barrier to land purchase for plantation development. Within current plantation zones, change in climate poses a risk to productivity (e.g. reduced rainfall) and if land is secured in new areas, plantation experience is limited, hence productivity is an unknown through to rotation. A layer of consideration over this issue is that a strategy of land leasing or joint venture on farmland which may or may not include full property planting should be based on an understanding of site productivity. This is the macro level of consideration. A range of silvicultural options can be deployed to ameliorate site attributes to enhance productivity (e.g. mounding of a site with water-logging to allow tree establishment).

Research need 7: There is a need to revisit land capability and suitability for softwood and hardwood plantations in the current and potential zones for plantation development. From the current plantation zone perspective, the issue of climate change, site management and changes in social licence as it impacts on possible (the maximum) and realised site productivity potentials needs to be understood. For the new zones, there is a need to extrapolate the current experience base to these areas to generate a realistic and defendable estimate of site productivity. In both cases, there is a need to better understand site and species (particularly new species) matching.

Interactions

The outcomes at rotation (e.g. product volumes) of silviculture are the cumulative and additive impact of the individual interventions undertaken. With change in one component the impact of that change can be neutralised by failure to act in another input or amplified by an appropriate adjustment to other

critical elements. A classic example and often the subject of factorial experiment is weed control and fertiliser inputs, or consideration of inputs at different stocking rates. The question of stocking rates has an additional impact in that the number of trees will drive the costs where unit pricing activities are undertaken. That is the number of trees pruned per hectare compared to the broadcast application of fertiliser to a hectare of plantation.

Research need 8: There is a need to include the impact of stocking rates at initial establishment and subsequent management of the stocking levels of a plantation as a variable in many Research themes e.g. site type, genetics and initial stocking rates; thinning and fertiliser application.

Social licence

Better access to information by communities and mechanisms for a broad range of groups to provide input to policy development and management of the environment has increased the need to focus on providing high quality environmental outcomes. An extension of the need to consider the views of neighbours is to consider the views of all stakeholders and in particular those with a special interest in social and environmental impacts. This is a diverse group including investors, federal, state and local governments, community and political groups. Silvicultural activities by their nature will involve an intervention in a site or crop which may be visually detected and may influence cultural, aesthetic and recreational values. Alternatively, environmental values can be impacted by silvicultural activities that may not be obvious such as off target chemical application. It is necessary to identify values that may be impacted by silviculture and some activities may need to be avoided or modified because they are assessed to pose unacceptable risk to loss of values. Where chemical weed control is used the fate of the active ingredients needs to be understood under the various circumstances in which the chemicals are applied. Additional risks may be identified where chemicals are being used within water catchments or near to high value environmental assets. This may require silviculture prescriptions to be altered to meet appropriate risk controls and monitoring to ensure the controls are effective. Where silvicultural activities are applied in high-risk situations the responsible manager may work with an independent party to ensure they have proof that no adverse impacts were caused. Wildlife will need to be considered where silvicultural activities are noisy as this may cause stress to animals and birds. The economic values of adjacent land use activities can be negatively impacted by the presence of plantations and the undertaking of silvicultural activities. For instance, where adjacent uses may rely on organic status for marketing of food crops.

Research need 9: There is a research need to continuously assess and where necessary replace or improve silvicultural practices to minimise the risk of any adverse impacts on values across economic, social and environmental considerations.

Knowledge and technology

The development and application of silvicultural practices historically relied on models of mentoring and university and other forms of training. These models are becoming less relevant as workforces become more mobile, employment expectations are greater, the regulatory environment increases and in other industries this is leading to the development of artificial intelligence which will increasingly replace human decision making. To remain competitive as an industry and an employer of choice the forest industry must consider future models of learning, knowledge retention and development. Cooperative industry development of these systems may make sense to share the high costs development of what probably will be a generic outcome.

Silviculture as much a human related activity as it is plantation resource related. Overall, the human resources of an organisation must be developed and maintained to ensure adequate capacity, capability and expertise to support the silvicultural systems that are required. The human resources must be sufficiently expert to ensure they understand the evidential basis of the silviculture used, there are many examples of well-founded silviculture being discontinued through lack of understanding in what it was necessary to apply, and the consequences have been loss of value and/or exposure to addition risk. Adequate safety and other risk management protocols must be considered and continually revisited to

ensure that silvicultural practices are consistent with safety and other related requirements to ensure organisations are not exposed to inadvertent risk. There will probably be compromises necessary between what might be the economically or financially optimal silviculture and what can be implemented safely and at acceptable levels of risk.

Research need 10: There is a research need to understand the current state of corporate knowledge retention in the industry and to devise a system for retaining and maintaining future corporate knowledge using modern tools and systems.

Human Capital

Silviculture as much a human related activity as it is plantation resource related. Overall, the human resources of an organisation must be developed and maintained to ensure adequate capacity, capability and expertise to support the silvicultural systems that are required. The human resources must be sufficiently expert to ensure they understand the evidential basis of the silviculture used, there are many examples of well-founded silviculture being discontinued through lack of understanding in why it was necessary to apply it. Adequate safety and other risk management protocols must be considered and continually revisited to ensure that silvicultural practices are consistent with safety and other related requirements to ensure organisations are not exposed to inadvertent risk. There will probably be compromises necessary between what might be the economically or financially optimal silviculture and what can be implemented safely and at acceptable levels of risk.

Research need 11: There is a research need to understand the human-related aspects of silvicultural practices well in advance of implementation.

Genetics and tree improvement

The question of genetics and tree improvement is the subject of a separate research investment plan. The survey respondents considered that there was a need for overall improved genetic materials for the hardwood plantation estate. A specific area of tree improvement was noted for softwoods with an interest in development of longer internodes to reduce the level of pruning required.

Nutrients

The question of genetics and tree improvement is the subject of a separate research investment plan. The survey respondents expressed an interest in general in the management and maintenance of site productivity and the use of fertilisers as a tool to achieve this end.

Silviculture

Harvest residues

To ensure at least sustainable production outcomes silvicultural management prior, during and post rotational change must be actively managed. There is a need to better understand how to anticipate issues and apply treatments to avoid them before they arise to maximise production outcomes and minimise intervention costs. Management of harvest residues and impacts on soil nutrition and structure can often be a basis for treatments.

Hardwood plantations

Harvesting of eucalypt plantations (mostly *Eucalyptus globulus*) generates harvest residues. Depending on the system the residues remain at the stump (with cut to length harvesting) or are accumulated at the roadside (with infield chipping). There are three basic residue management options depending on the harvest system. With the cut to length harvest, the residues across a site can be left to decay and this is the usual practice. A site could be burnt either broadcast or with rough heaping or windrows but this would be limited where coppice management is the objective. The accumulated harvest residues located at the roadside with an infield chip operation can either be left at the roadside or more usually now, returned to the plantation area using the grapple skidder which recovered the stems to roadside for

chipping. Once accumulated in piles, the materials can either be burnt or remain. If they remain, they take up potential plantation land and pose a fire risk.

Research need 12: There is a need to better understand the impacts of the different harvest reside management strategies and the impact on site productivity, the cost of the operation and the risks posed. Any analysis should consider the cost impacts to the overall rotations (the one harvested and the subsequent rotations) and not just the costs of the single operation.

Softwood plantations

The impact of the different softwood plantation harvest residue management is well understood and documented in regards to site productivity impacts and subsequent rotation declines. The current practice of harvest residue management is to retain the materials onsite with or with-out chopper rolling and to let the materials decay. The decay process is relatively rapid.

Research need 13: There is a need to revisit the management of postharvest residues in softwood plantations and to consider the application of advances in technology. This should consider the impacts on site productivity, particularly where possible the impacts between rotations.

Coppice

Management of hardwood coppice is a traditional silviculture applied to many species around the world. Coppice is the regrowth of the tree from the same rootstock by the stimulation of the axial buds beneath the bark located at the base of the tree. Once the tree is cut down, the buds activate and grow as a survival strategy. Multiple buds grow resulting in a multiple stem tree from the stump or 'stool'. The management of the coppice depends on the objectives for the site. If the site is to be converted to pasture, another tree crop or replanted with new seedlings (and genetics) the coppice must be killed. If the coppice is the subsequent crop there is a need to understand the options to manage the stems: the two options are to allow the stems to grow and self-thin or to intervene.

Research need 14: There is a need to better understand the options to kill coppice and the rootstock of a regenerated stool to allow a change in crop. There are mechanical and chemical options available, and options at different operational stages (e.g. at harvest, soon after harvest or after coppice regeneration). In regards to the chemical options, forest managers face the issue of off label use and certification. The individual treatments require costing as well as consideration of the impact of the cost and the efficacy of the subsequent operations.

Nursery

There are three basic strategies to generate planting stock. The first is direct seeding of sites and management of the germinants: this is more an option for 'landcare' or not for harvest tree systems. The second is the use of open beds in a nursery to produce open rooted plantation stock and the third is the use of containers. A layer over the last two options is the use of seed compared to vegetation productions systems (e.g. cuttings). Each system has a unique combination of inputs and costs. The up-front cost of plantation stock is a significant percentage of establishment costs and efficiencies (e.g. mechanisation) and economies of scale (e.g. large nurseries) have contributed to reducing the unit cost of plants. While a cost-effective plantation stock supply is the objective, there is potential that the cost effectiveness of one cost centre may compromise the overall plantation outcomes. Another consideration is the change in the ability to utilise a range of inputs to planting stock production. For example, limitations on the use of herbicides, fungicides and insecticides either by changes in legal availability or by social licence limitations (e.g. under voluntary third-party certification) can impact production and plantation stock quality. Occupational health and safety issues must also be addressed for the people working in a nursery and for the planters handling the plants in the field.

Research need 15: There is a need to review the current inputs and operations in hardwood and softwood nurseries to understand the impact of loss of access to a range of chemicals and practices. Other linked operations need to also be considered. The outcome of the different nursery strategies on growth and performance in the field needs to be reviewed: does a cost-effective planting stock maximise the value recovered from the area of land planted?

Establishment: overall

Establishment is the initial development of a plantation from an empty section of land to a stand of young trees. Establishment may occur on land which previously carried a tree crop of the same or different species or a land use other than forestry. Depending on the regime, establishment inputs are usually defined as actions and activities in the first year. In some cases, this is extended to consider the first two years. There may be legal limitations (e.g. under taxation treatments) that define the duration of establishment. There are a range steps in the process of establishment and the industry survey suggested that there was a need to explore the issues of site preparation in general (initial clean up, cultivation and weed control). A final point is that there is a desire to achieve an acceptable outcome at least cost.

Research need 16: There is a general research need to consider plantation establishment.

Cultivation

The question of cultivation did attract some attention with specific reference of mounding and wet sites.

Research need 17: There is a need to revisit the current cultivation strategies and options to better determine the fit for purpose options available matching plantation outcomes to the site requirements. This should be considered within the context of the whole silvicultural package including weed control issues and sustainability related issues. This should be linked to the attributes of first rotation forestry sites and the treatment of harvest residues on subsequent rotation sites.

Weed control

While the target crop on a site is the planted trees, other vegetation on a site will complete for the site's resources (e.g. water and nutrients) and at various stages and depending on the location, other vegetation may cause mechanical damage to the planted trees. For example, bracken can mechanically damage the growing tips of eucalypt seedling or an aggressive vine may strangle a young sapling in a tropical situation. In other situations, companion plants under a plantation may enhance tree growth where the companion plant can fix nitrogen. Weed control is defined as the intervention to reduce or control competition and damage cause by other plants on a site. There are four broad timings of weed control. The first is pre-establishment where difficult to eradicate species are controlled often with treatments that would damage or kill the planted tree crop. The second stage of weed control may be required post planting and this requires care to minimise collateral damage to the planted trees. The third stage of weed control is the control of weeds under the trees just prior to clearfalling with the aim to benefit the subsequent crop rather than the current standing trees. The last timing of weed control is ad hoc and reactive treatments of pest plant infestations. For example, there is current interest in re-visiting blackberry control in plantations.

The methods of weed control can be split into two techniques: mechanical and chemical. Mechanical weed control includes manual weed removal and the use of machinery. In some respects, soil cultivation of a site to enhance the growth of planting stock is part weed control. Chemical weed control involves the use of herbicides which kill the plants via chemical mechanisms. Herbicides can be sprayed for foliage contact, applied in granular format with the chemical leaching into the soil and taken up by the weed roots or by spraying chemicals (e.g. with a clay bonding) to contact the bare earth and remain as a residual weed control to kill weed seeds as they germinate. The issue of weed control is a sensitive topic from voluntary third-party certification requirements and environmental perspectives. The question of social licence and legal obligations adds to the complexities with perceptions and fears sometimes replacing science and analysis.

Research need 18: There is a research need to catalogue, document and rate the significance of the current spectrum of weeds associated with plantation forestry at the four identified stages (e.g. pre-plant, post-plant, pre-clearfalling and ad hoc). This should then include a rating of the current status of control options and any risks to those options. Where a weed species is of significance and the effective control options are at risk, these species should be identified for further research. For example, blackberry is a weed species of specific interest at present.

Research need 19: There is a need for research into weed control in plantations with a specific focus on alternative regimes driven and demanded by voluntary third-party certification requirements and environmental constraints (including adjacent planted crops). This would include the use of combined cultivation and chemical methods with both manual and mechanical application. This is for both hardwood and softwood plantations.
Research need 20: There is a need for research into alternative chemicals (molecules) for use in the various tree crops recognising fundamental difference in the tree species between softwoods and hardwoods and the climatic zones which in turn will dictate the spectrum of weeds involved. This need is of some urgency given the current focus on glyphosate and the utility of this molecule to plantation establishment and management.

Planting

Planting was another issue raised, with specific reference to a reduction in manual activities (assumed associated with OHS issues) and the overall shift into second rotation (R2) and subsequent crops. The planting of first rotation (R1) grass paddocks was and is usually a simple operation with minimal hazards to operators whereas R2 sites with retained harvest residues and stumps increases the risk of injury. The stated target outcomes of initial establishment were improved survival, trees growing with straight stems and trees with less risk of toppling (a tree that leans will grow but with defect in the bottom log of the tree resulting in lost resources in the most valuable part of the tree).

Research need 21: There is a need to consider the options and technology available to reduce reliance on manual planting during the establishment of a plantation. This research should focus on second and subsequent rotation sites and be linked to consideration of the treatment of the harvest residues on that site.

Initial stocking

The number of trees planted on a site will define the subsequent management requirement and options and the potential product mix at rotation. This then defines the cost of management and the returns from an investment in a plantation. The number of trees planted initially is a fundamental decision which can be compromised by available germplasm limiting availability of planting stock, budget constraints and expected survival (e.g. if survival is expected to be compromised, more trees are planted to compensate for the expected losses).

Research need 22: There is a need to document the drivers of poor initial survival of planted trees and the interventions possible to improve the rate of survival. This will link with the question management (e.g. weed control) and damage agents (e.g. browsing animals). For each current and potential intervention there is a need to understand the degree of exposure to forced reduction in use or loss of the intervention option due to voluntary third party certification or changes in the regulatory environment.
Research need 23: There is a need to better understand the options of the whole of rotation management of stocking rates from initial planting through to final clearfalling.

Thinning

Thinning is applied to manipulate the number of trees in a plantation to achieve target basal areas and tree volume at harvest (e.g. piece size). There are two approaches. The first is a non-commercial thin or thin to waste where the operation is a pure cost and does not generate a product for sale. The second is a commercial thinning where products are recovered and supplied to a customer. A commercial thinning may aim to be on a least loss basis (e.g. the cost of the operation are in excess of the returns) with a focus on improvement of the subsequent harvests. A thinning regime will include the four elements: timing and frequency of the thinnings and the number and basis of selecting the stems removed.

Research need 24: With a focus on hardwood plantations, there is a need to better understand the options and outcomes of thinning, including the use of non-commercial thinning as a tool. The outcomes of the thinnings are defined by the resulting log piece size and the potential markets for the logs.

Pruning

Tree growth will include branches originating from the stem which defines the architecture of a tree. Pruning occurs naturally (self-pruning) in some species dependant on the growth habit and the situation of a tree (e.g. open grown versus close grown). The degree of branch development can be influenced by the spacing of trees in a plantation and by the genetics used (e.g. trees selected for small branching as part of a tree improvement program). Pruning of trees aims to reduce the presence of knots in the products derived from a log on processing. It is a mechanical intervention that can be a significant cost

to tree owners. The current status in Australia is that there is very limited pruning of softwoods and some pruning of hardwoods in Tasmania. Occupation health and safety issues are critical: workers operating at heights; use of saws and pruning implements all add to the risk in the operations. This is reflected in the cost of the operations. If only some trees are pruned there can be an issue of tracking the pruned trees through the rotation as with self-pruning, all trees appear similar. Pruning is only justified if there is a commercial benefit: health and hygiene; fire risk management; a commercial return for clearwood. The height of pruning varies as does the techniques used. There is also an issue of when and how much of the green crown to remove at pruning.

Research need 25: A Research theme is required to better understand the practical issues with pruning need to be linked to the market opportunities. These include the application of technology to undertake pruning, OHS issues and costs. The decision-making process requires a revisit – when to commence pruning, the height pruned and the number of lifts to achieve the target height of a pruned tree. The market for pruned logs needs to be assessed and considered: what is the critical mass (area and wood flows) required to justify pruning; what is the margin on a pruned log; what are the drivers of demand for a pruned log? A last consideration is whether a change in silvicultural systems will stimulate a need for pruning. For example,e a shift to silvopastoral management to increase the up-take of trees into farming systems.

Monitoring

Silvicultural interventions can be scheduled and fixed or adaptive and variable. A fixed and rigid regime has significant potential to waste inputs. A flexible and reactive approach to silviculture and management is less likely to miss opportunities and / or waste inputs as the input and the timing of the input is specific. A reactive silvicultural strategy also provides greater ability to justify interventions to voluntary third-party certification groups, to the government and to the general public (social licence issues). A specific group who must receive specific consideration is the neighbours to a plantation, where if a relationship exists (a social licence), there is less likely to result in obstruction of actions and operations. This requires three areas of knowledge. The first is to document and understand the stressors of trees in plantations, the second is determine the most cost-effective responses and the thirds is the signs or indicators of an impending (most ideal) or current stress event. The process of monitoring can be enhanced by the use of surveillance tools such as SILVICULTURE, application of diagnostics and reporting for forest health and condition. This would include a need to:

- Continuously monitor stand condition using risk-based methods,
- Detect changes in condition,
- Identify those needing silvicultural intervention,
- Select and apply appropriate intervention
- Monitor outcomes
- Capture any additional knowledge

Research need 26: There is a need to document all the stressors (current and on the horizon) of trees in plantations in different areas and under different management. This should form the basis of documenting the appropriate responses to anticipated or current stress events.
Research need 27: There is a need for specific research and refinement of plantation monitoring tools and techniques to anticipate and correct impending issues or to identify actual stress events as a trigger to an intervention.
Research need 28: The overall process of interventions in regards to stressors and damage agents needs to be within a framework to allow a systematic and uniform approach to decision making.

Biotic agents pests and diseases

Plantations are modified biological systems which include a range of biota (some beneficial and some which can adversely impact a planted tree and a plantation – mammals; birds; insects; fungi; bacteria;

viruses) and physical elements (e.g. climate and fire). While a range of biotic issues are present in Australia, there are many more literally over the horizon which if they enter Australia, could create significant issues. There is a need to quantify the benefits, costs and risks of silviculture so that biotic issues can be modelled for financial analysis and incorporated in wood flow modelling systems to forecast future resource availability and characteristics important to processors. Data-model fusion and artificial intelligence approaches are possible to improve forecasting capacity and identify uncertainty.

A key question to understand is how much damage is too much damage? The first step in considering this question is to define the types of impacts that can damage a tree and the outcomes of that damage. For example, insects or pathogens may damage the foliage of a tree but at what stage does this damage impact on tree growth? In an alternative scenario an insect may bore into a tree's stem and damage the wood resulting in a log down grade from a pruned sawlog to pulpwood. Physical elements can also impact a plantation. At an early stage of growth frost may kill a planted tree or later, a hail stone storm may damage a tree's bark and allow a pathogen to enter the tree and cause either wood stain, stem deformation or death. Climate conditions and localised weather combined with fuel loads will dictate the level of fire risk. In a similar manner to insect damage, fire can impact productivity and products (e.g. a burnt plantation may not be able to supply logs due to charcoal). There has been a long and effective history of research and development in all areas of risk to plantations.

Research need 29: There is a need to consider and review the current state of quarantine management of Australia's borders to minimise the risk of pest insect and disease incursions.
Research need 30: There is a need to document and understand the range of biotic risks to plantations on a species of tree by species of risk organism. This should include the stage of tree growth and tree condition at which the tree species are at risk.
Research need 31: There is a need to develop strategic and holistic approaches to biotic pests which take account of the trees planted, the management of the trees, limitations placed on intervention options and acceptable outcomes.

Research need 32: There is a need to document and define the impacts of each species of risk organism on the different species of tree planted. This should include any impact on and down-grade of products that could be recovered from a tree as a basis of defining the financial impact of a damage agent.
Research need 33: There is a need to develop and define the intervention points that relate to each species of tree by species of risk organism.
Research need 34: There is a need to document current chemical-based interventions (e.g. insecticides; fungicides; nematocides) utilised in plantation forestry and determine the risk of loss of each tool and alternative strategies to address biotic agents, pests and diseases.
Research need 35: There is a need to better define the relationship between the condition of a plantation as impacted by management interventions and driven by site factors (e.g. current period climate) and tree stress.
Research need 36: The issue of fire management in plantations including preventative and response requires research for softwoods and hardwood plantations.

A specific case: Trees on farms

Industrial plantation silviculture is well advanced and in place for many operations across Australia. The development of trees on farms as part of agricultural systems may take advantage of this knowledge but there is a need to consider the adaption and modifications required to generate a stand of trees that best fit with agriculture. Trees are planted on farms in a range of silvopastoral systems with grass production (e.g. single trees; clumps of trees; boundary plantings; shade and shelter belts; one or two row strip planting) or as woodlots (e.g. where the primary focus is wood production with time to time animal access).

Research need 37: There is a need to define the differences in farm tree planting and industrial plantation development from an agricultural perspective. Based on this analysis, farm specific silvicultural systems can be defined and developed.