Prosperity from trees *Mai i te ngahere oranga*

SCION
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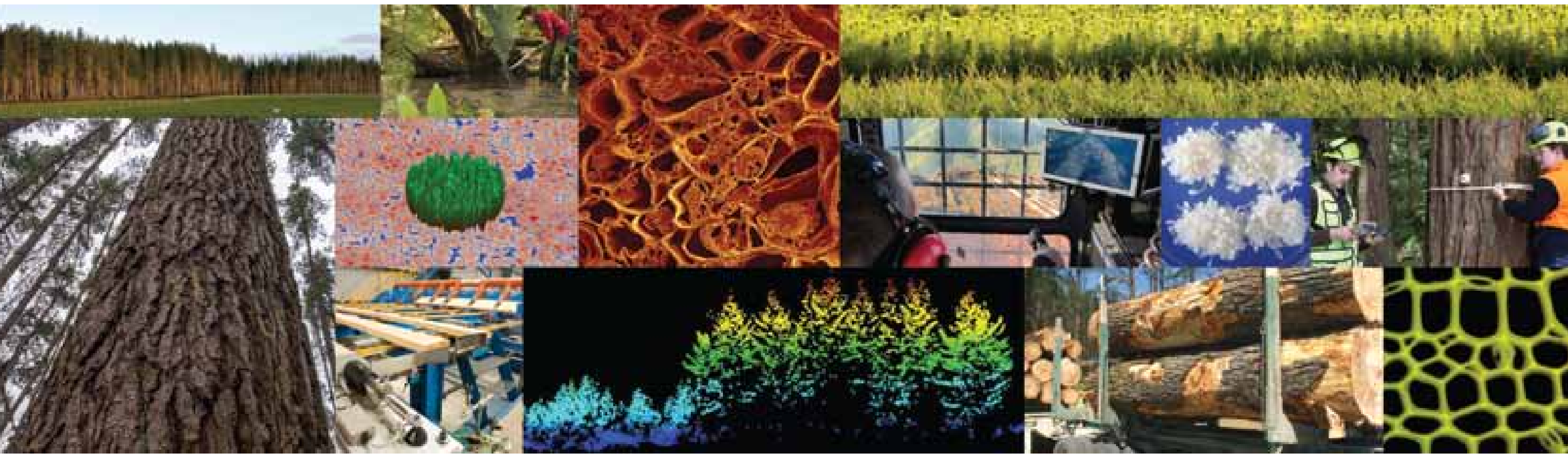
Growing confidence in forestry's future

Research Programme 2013-2019



Growing confidence in forestry's future

Research Programme 2013-2019

Scion, Te Papa Tipu Innovation Park, 49 Sala Street,
Private Bag 3020, Rotorua 3046, New Zealand.
Telephone +64 7 343 5899. Facsimile +64 7 348 0952

www.scionresearch.com

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April 2014 - 02

Foreword

Raising the profitability of commercial forestry investments is an imperative for the entire New Zealand forestry sector. Further investment in forest growing relies on current operations being profitable. To more than double the value of New Zealand's forest industry export earnings requires major investment in new and upgraded processing facilities. The assurance of a sustainable supply of wood will increase investors' confidence to make such investment into the processing sector.

To achieve the above, forestry investments must be competitive with other rural land uses. Land is the single biggest capital cost for forest investors and its value is a major driver of investment return. To secure land for forestry or to retain existing forest land, investors must compete with other users of this land. Other rural land users are striving through research and innovation to improve the value of products produced from each hectare of land through intensification and the forest industry must do likewise. Without these gains other sectors will compete more successfully for forestry land, land use change will continue and forestry's contribution to New Zealand's economy will decline.

Forests play an important environmental role in protecting our soils and water quality and in reducing flooding, and at the same time, providing biodiversity and recreation opportunities. Intensification of forest production therefore must not be at the expense of these important environmental attributes because our access to international wood markets is critically dependent on these credentials being verifiable and at best practice.

This programme, a joint initiative between the industry, Scion and the Ministry of Business, Innovation and Employment, sets out to increase the productivity of and value from our existing and future commercial forest estate through the development and application of world leading technology. This programme is one of the most significant initiatives being taken by forest growers. It has an ambitious target to double the productivity of New Zealand's commercial forests. Achieving this will require access to world class science capability here in New Zealand and internationally. Success in this programme will ensure that forestry continues to play its role as a commercially attractive land use in New Zealand and that it continues to provide a sustainable supply of raw materials to support the future capital investment necessary for the New Zealand forest industry to grow export earnings to more than $12b by 2022.

Warren Parker,
Chief Executive,
Scion

P. S. Nicholls

Paul Nicholls,
President,
Forest Owners Association

Contents

Introduction

Forest growers have a vision to significantly improve profitability by doubling productivity on a per hectare basis while also improving wood quality. Achieving this will provide a stable supply of a consistent raw material to wood processors that will enable them to lift their profitability and encourage future investment. This, in turn, will help to achieve the broader sector goal (as outlined in Woodco's Strategic Action Plan) of increasing export returns from $4.7b to $12b by 2022.

Doubling productivity is an ambitious goal and one that will require significant new research to achieve. This is recognised in the Forest Owners Association's Science and Innovation Plan (S&I Plan), which has research to improve productivity and consistency as its highest priority. It is also important that forest management practices used to improve productivity do not adversely affect the environment and compromise the sustainability credentials of the industry. This is also recognised in the S&I Plan, where sustainability research is recognised as a high priority.

In 2013 two of the key research programmes that underpinned Future Forests Research Ltd came to an end. A successful new 6-year programme is entitled 'Growing Confidence in Forestry's Future' (GCFF) and has been funded by the Ministry for Business, Innovation and Employment (MBIE) with co-funding from forest growers. The programme will focus on how to create more productive and resource-efficient forests, while ensuring that intensification is within environmental limits.

Through the research programme, Scion aims to shift forest management to 'precision forestry' through a system-wide approach integrating the latest advances in sensor technology, tree physiology, genetics, forest ecology and complex problem-solving. Precision forestry has been defined by many groups around the world, but the following definition encapsulates the focus of the research and goals of the industry:

> *Planning and conducting site-specific forest management activities and operations to improve wood product quality and utilisation, reduce waste, and increase profits, and maintain the quality of the environment.*

The 'Growing Confidence in Forestry's Future' research programme also links with other Scion programmes that are supported by forest growers. Two of the key linkages are with the following programmes:

- Prosperity from trees: protection from current and future disease (*Phytopthora* research programme)
- Radiata Pine Breeding Company's genomic selection programme.

In this document, we describe the structure of the programme, give a broad description of the proposed activities in each research area and describe the outputs and outcomes that can be expected during the lifetime of the programme.

The place of research in the forest growing cycle

The ‘Growing Confidence in Forestry’s Future’ research programme targets different intervention points in the forest growing cycle for both current and future forests (Figure 1). Its goal is to increase the returns from existing forests through mid-rotation interventions aimed at increasing productivity and end-of-rotation segregation, while also focussing on how to increase the productivity and consistency of future forests.

The research programme is organised into three main Research Aims (RA) (see below). A fourth research aim focuses on technology translation. Each research aim is comprised of two or three Key Hypotheses (KH). The stage of the current or future forest growing cycle that each KH relates to is shown in Figure 2. Each research aim and key hypothesis is described in more detail in the remainder of this document.

RA1: A systems approach to maximising benefits from existing forests.

- KH1.1 Segregation of the current resource
- KH1.2 Enhancing productivity of older stands

RA2: Building more productive, higher quality forests for the future.

- KH2.1 Phenotyping the forest
- KH2.2 Doubling radiata pine productivity
- KH2.3 Enhanced activity of the soil microbial community

RA3: Sustainability under intensified regimes.

- KH3.1 Sustainability of soil, water and biodiversity
- KH3.2 Sustainability over multiple rotations
- KH3.3 Spatial economic modelling for sustainable forestry

RA4: Closing the gap. Translating science into sustainable business growth.

The development of the forest phenotyping platform is one of the core elements of the programme (Figures 1 and 2) and provides the information resource that forest managers, researchers and tree breeders can use to understand how the interaction of genetics, environment and management affect productivity and wood quality. Recent remote sensing research has enabled individual trees to be delineated from LiDAR images. This will be extended by including attributes about these individual trees, such as genetic origin, site characteristics and management history. With advances in sensor technology and computing power, very large numbers of trees can be assessed in order to better understand the drivers of productivity and wood quality.

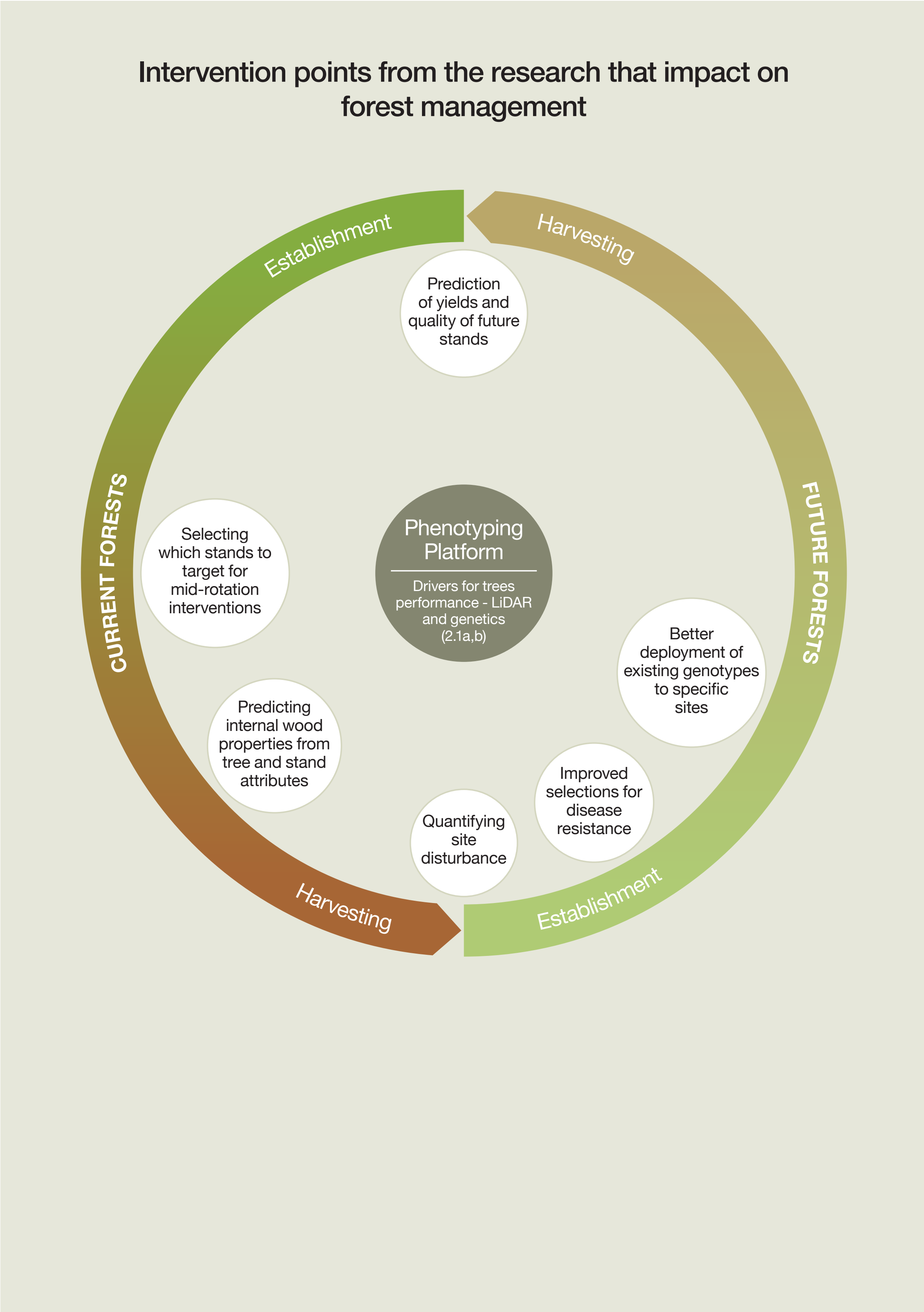

Intervention points from the research that impact on forest management
Establishment
Harvesting
CURRENT FORESTS
FUTURE FORESTS
Harvesting
Establishment
Prediction of yields and quality of future stands
Selecting which stands to target for mid-rotation interventions
Phenotyping Platform
Drivers for trees performance - LiDAR and genetics (2.1a,b)
Better deployment of existing genotypes to specific sites
Predicting internal wood properties from tree and stand attributes
Improved selections for disease resistance
Quantifying site disturbance

Figure 1

Key hypotheses in 'Growing confidence in forestry's future' research programme

- 1.1 Segregation of the current resource
- 1.2 Enhancing productivity of older stands
- 2.1 Phenotyping the forest
- 2.2 Doubling radiata pine productivity
- 2.3 Enhanced activity of the soil microbial community
- 3.1 Sustainability of soil, water and biodiversity
- 3.2 Sustainability over multiple rotations
- 3.3 Spatial economic modelling for sustainable forestry

Figure 2

Research Aim 1

A systems approach to maximising value from existing forests

The forests that will provide the timber harvest for the next 15 years are already growing and have generally received all their silvicultural tending. Two options for increasing the returns from these forests are to extract more value from the wood that is harvested through better describing its utilisation potential, and secondly, is to increase the volume of wood produced through mid-rotation interventions aimed at increasing growth.

Key Hypothesis 1.1

Cost-effective segregation methods that deal with inter- and intra-tree variation in wood properties will improve utilisation of the current resource

- *Segregation of the current resource*

Considerable variation exists in the wood properties, and thus utilisation potential, of the current resource. One approach that has the potential for improving the returns from existing forests is segregation or classification of material based on internal wood properties. To better understand the utilisation potential of the current resource, better information is needed on how different combinations of genetics (G), environment (E) and forest management (S) affect the performance of solid timber. This research is particularly relevant to first rotation forests where wood quality is often unknown and is likely to be variable.

Previous work funded through Future Forests Research has focused on the development of a numerical product quality simulator (PQSim) and associated destructive sampling methodology for cost-effectively measuring wood properties at high resolution on relatively large number of trees. In this programme we will apply this approach to material from the extensive network of silvicultural trials reaching maturity over the next 4-6 years, in order to understand the impacts of genetics, environment and silviculture on key wood properties that affect solid timber performance. Various site, tree and log-level variables that are associated with solid timber properties will be measured for each stand and used to develop different segregation approaches. This will link closely with the phenotyping platform, which focuses on cost-effectively and non-destructively assessing different tree, site and stand attributes.

We will advance technology in both imaging and segregation to determine which approach or combination of approaches can most effectively allocate the resource to processing streams.

Outcomes to 2019

- Quantification of the impacts of GxExS on wood properties and end product quality to ensure that increasing productivity doesn't adversely affect wood quality.
- New knowledge on how to better manage forests for improved wood quality.
- New cost-effective segregation approaches that improve the returns for forest growers, such as remote sensing in combination with a felling head.
- Better knowledge to inform the relationship between forest growers and wood processors.
- Improved knowledge on the drivers of variability within the wood resource and development of strategies to effectively manage this variability.

Activities

- Review of existing and potential new segregation approaches.
- Examine potential of acoustic camera to non-destructively assess wood properties (2 year post-doc with University of Auckland).
- Review of trials to determine suitability for wood quality assessment.
- Development of Product Quality Simulator (PQSim).
- Sampling of trials to obtain wood quality information.
- Analysis of data from trials to determine impacts of genotype, environment and silviculture, and their interactions (GxExS), on end product quality.
- Link stand, site, tree and log-level factors to end product quality and develop cost-effective segregation approaches.
- Operationally assess new segregation approaches.

Timeline

Early 2014	Mid 2014	Mid 2014	2014 - 2015	2014 - 2017	2018	Mid 2018	2019
Workshop with industry held to discuss issues around wood quality	Review of trials to determine suitability for wood quality assessment	Destructive sampling platform for wood properties measurement commissioned	Review of current and potential segregation methods	Sampling of trials to obtain data on the impacts of GxExS on wood quality	Quantify effects of GxExS on wood properties and end product quality	New approaches to segregation have been presented to industry	Segregation approaches have been operationally tested

Linkages

- SWI logs and stems work on in-forest and in-mill segregation.
- Engage with processors to understand what the problem is with variability.
- Fibre-gen (development of acoustic tools).
- Phenotyping platform (remote sensing).
- Productivity gap (relationships between growth and quality and their drivers).
- Universite Laval (wood quality group).
- Log tagging and tracking technology development.
- Waiariki Institute of Technology – operational and economic aspects of segregation.
- University of Auckland (sub-contractor) – evaluation of acoustic camera.

Budget - KH1.1

$650,000 p.a.

Leader

John Moore
Email john.moore@scionresearch.com
Telephone 07 343 5425

Key Hypothesis 1.2

Productivity of older stands can be increased through forest management practices without compromising wood quality or the environment

- *Enhancing productivity of older stands*

Mid-rotation interventions such as fertilisation have been used to try to boost productivity of stands, often with varying success. This is partly due to the inability to correctly determine which stands will respond and a lack of understanding of how the trees are actually responding to different treatments. Most recently, new products such as biostimulants have been tried in the agricultural sector as a means of boosting productivity and improving plant health.

In this research programme, we will identify potential mid-rotation management practices that could increase growth and quality of stands. The most promising interventions (e.g. fertiliser + weed control, or bio-stimulants) will be trialled and their impacts on physiological and plant immune system responses will be examined. Specifically, we will investigate how inputs such as fertiliser affect signalling pathways within a tree and the soil microbial community. Data from these trials will be used to develop models that predict growth responses to treatments. Alongside this we will also develop new assays based on remote sensing of tree health, nutrient status, soil tests and site quality to select those stands that are likely to respond to mid-rotation interventions.

The environmental performance of these interventions (in particular water quality and biodiversity) will be assessed in Research Aim 3.

Outcomes to 2019

- Better understanding of the role of nutrients in wood formation.
- Updated response functions for nutrition decision support tools.
- Environmental credentials sustained for current and future management interventions.
- New understanding of the role of nutrients in signalling environmental conditions to plants.
- New methods for predicting positive responses to mid-rotation interventions.

Activities

- Establish productivity enhancement innovation cluster group.
- Review mid rotation interventions and other management options for increasing productivity.
- Develop work plan for mid rotation interventions.
- Develop work plan for new assays/methods for identifying stands that will respond to mid rotation interventions (linked to remote sensing studies in RA 2).
- Design mid rotation trials and integrate with KH3.1.
- Develop work plan for analysing existing nutritional trials, e.g. Boron, GxE, NxP.
- Develop links into wood quality and segregation studies.
- Systems approach to tree nutrition and wood quality.
- PhD University of Canterbury.
- Develop new research programme linking physiology of wood formation and tree health with a focus on the plant immune system response.

Timeline

2015	2016	2017	2018	2019
New assays for identifying responsive stands tested	New trials established to test interventions established	Evaluation of response assays	Results of new trials reported annually and recommendations made to forest growers on potential interventions that can be used to improve the productivity of mid-rotation stands. New assays for assessing responsive stands have been made available along with methods for analysing the response of stands to treatments	New models of wood formation in response to mid-rotation interventions have been developed

Linkages

Internal to the programme

- KH2.2 Quantifying the productivity gap and forest accelerator trials.
- KH1.1 Quantifying the drivers of wood quality and formation.
- RA3 Sustainability and licence to operate.

External to the programme

- Fertiliser companies.
- National Science Challenge on land and water which has a big focus on sustainable intensification of primary industries.
- Forest Protection group at Scion - biology of tree growth and the interaction between health and productivity.
- International collaboration - Virginia Polytech, School of Forest Resources and Conservation, University of Florida.

Budget - KH1.2

$350,000 p.a.

Leaders

Peter Beets
Email peter.beets@scionresearch.com
Telephone 07 343 5577

Graham Coker
Email graham.coker@scionresearch.com
Telephone 03 364 2987 extn 7740

Research Aim 2

Building more productive, higher quality forests for the future

New Zealand's radiata pine forests cover a wide range of site types, contain different genetic material and are managed under different regimes. All of these factors combine to yield stands which have very different levels of productivity and contrasting wood properties. In order to create future forests that have higher productivity than current forests, we need to better understand the following:

- how the interaction of genetics, environment and silviculture affect productivity;
- what is the potential productivity of radiata pine in New Zealand;
- what is the gap between potential productivity and current productivity;
- what interventions are required to close this gap;
- what are the impacts of these interventions on wood quality.

Key Hypothesis 2.1

By using the whole forest as an experiment we can quantify the drivers of tree performance and productivity

- *Phenotyping the forest*

Much of our existing knowledge on forest productivity and its drivers have come from research trials and a network of growth monitoring plots. While there are more than 30,000 growth plots in Scion's permanent sample plot system, this only represents a tiny fraction of the total number of trees growing across the entire plantation estate. The logistics and costs of sampling larger numbers of trees using traditional measurement techniques have made it impractical to do so. However, recent advances in remote sensing technology coupled with increases in computing power have made it possible to assess multiple traits, e.g. stem and crown size, growing space available, and site characteristics, on large numbers of trees. Information held on stand record systems such as genetic origin and management history can also be associated with individual trees or groups of trees. The ability to rapidly assess multiple traits is being applied to many crop plants and is part of an emerging science area called phenotyping.

Within this project we will create a forest phenotyping platform that integrates remote sensing, assays for wood properties, environmental physiology and genetics in order to quantify the drivers of growth and wood quality. From remotely sensed data, we will obtain information on individual trees and their physical growing environment and quantify relationships between key wood property traits and LiDAR-derived stand-level variables. Wood property data will be collected using Scion's destructive sampling techniques and input into the product quality simulator (PQSim) to predict the key properties that affect solid timber performance, i.e. stiffness, strength and stability. The phenotyping platform will also provide the basis for practical inventory tools for forest managers that can be used to obtain information on the structure and condition of forests.

In the second stream of work we will combine genetics and remote sensing to quantify how the interaction of genetics and environment affect tree growth and performance. We will also examine whether the phenotyping platform can be used as a tool to assist tree breeders through remote phenotyping of RPBC breeding trials. With a focus on tree health, trees of interest (i.e. those trees that exhibit disease resistance) will also be identified and the parentage of these trees will be determined using a SNP panel, available from the RPBC Genomic Selection programme. If enough trees can be phenotyped for traits of interest, this research will not only inform the breeding, but also deployment patterns across different sites. This information will help maximise productivity and profitability of future forests.

Workstream 2.1a Development of an integrated remote sensing platform

Outcomes to 2019

- Forest growers are kept abreast of latest advances in remote sensing technologies with applicability to forestry.
- New inventory tools have been made available to forest growers that enable them to cost-effectively obtain information on the structure and condition of their forests.

Activities

- Alignment with University of Canterbury, School of Forestry PhD programme investigating the use of LiDAR to assess leaf area in forests.
- Create a cluster group of researchers and industry who have an interest in increasing the use of remote sensing technologies in the forest.
- Review sensor technology and data availability.
- Validate the method for delineating individual trees across a broader range of site and stand conditions.
- Develop and validate methods for identifying specific trees on the ground.
- Develop area-based methods to characterise forest and site conditions.
- Determine the error associated with remotely sensed phenotypes.
- Transfer knowledge and technologies to users.

Timeline

Mid 2014	Mid 2014	Late 2014	Mid 2015	Mid 2016	Mid 2017
Cluster group formed	Experimental framework that describes what stands will be sampled as part of the phenotyping platform development has been proposed	Experimental framework for sampling has been agreed	Successful tree delineation from LiDAR and location of subject trees in the forest	Individual tree attributes have been integrated with site and stand level metrics	New inventory tools have been made available for use by forest managers

Linkages

Internal to the programme

- KH1.1 Segregation.
- KH2.2 Productivity gap and forest accelerator trials.
- RA3 Sustainability.

External to the programme

- RPBC, Interpine (LiDAR survey designs), University of Canterbury (PhD programme + supervision), Indufor (processing of satellite imagery), NZ Aerial Mapping & NZ Aerial Surveys (LiDAR acquisition), International collaboration.
- Alternative species research programme (could apply approach to Douglas-fir).

Budget - WS2.1a

$837,000 p.a.

Leader

Mike Watt
Email michael.watt@scionresearch.com
Telephone 03 364 2987 extn 7823

Workstream 2.1b Combining genetics and remote sensing to create a phenotyping platform

Outcomes to 2019

- Proof of concept that genetics information can be integrated into the platform.
- Creation of a trial database.
- Map of genetic potential across New Zealand.
- Recommendations of genetic material for superior health (Dothistroma, red needle cast).
- Recommendations for site-specific deployment of different genotypes.
- Enhanced connections with tree breeding research, e.g. RPBC.
- The phenotyping platform concept has been tested and has led to a better understanding of the drivers of growth and quality.

Activities

- Design an experimental framework for testing the phenotyping concept.
- Select trials, obtain access and collect associated biophysical and climatic and soil data, stand records.
- Obtain LiDAR data, delineate individual trees and locate trees of interest on the ground.
- Phenotype trials on the ground for ground truthing of LiDAR/remote sense data and determine the error associated with remotely sensed phenotyping.
- Determine utility of LiDAR/remote sending for phenotyping genetics trials.
- Build whole-forest data base from LiDAR records available and collate/collect associated biophysical and climatic and soil data, stand records. Obtain genetic identity of stands where possible.
- Where genetic identity not available, collect DNA from selected trials/trees and use the RPBC/Scion DNA panel for parental reconstruction.
- Analyse data from stands in the experimental framework in order to understand the drivers of growth and quality.
- Transfer knowledge and technologies to users.

Timeline

Mid 2013	Mid 2014	Late 2014	Mid 2015	2016 - 2018	Mid 2019
Experimental framework proposed on what trials to phenotype	Initial phenotyping of trials underway using current technology as a proof of concept	Initial phenotyping carried out on a minimum of three trials	First estimate of utility of phenotyping platform for genetics trials and tree breeding presented to phenotyping cluster	Utility of phenotyping platform to assess trees that have better disease resistance has been examined and unique individuals selected	Phenotyping platform has been used to better understand the drivers of growth and quality in radiata pine

Potential trials that could be used to develop and test the phenotyping platform

Progeny trials; (especially RPBC trials to test remote sensing concept). For the wider forest analysis potential trials include: GF plus/ genetic gains trials; clonal stands – either pure clonal stands or mixtures; control plantings; company plantings; Rolleston mega site; long-term site productivity series 3 (LTSP3) GxE trials, other Scion or industry trials with known genotypes/good stand records. Genetic gain plots.

Linkages

Internal to the programme

- KH2.2 Forest accelerator trials.
- LTSP3 GxE.
- KH2.1 Productivity gap.

External to the programme

- Radiata Pine Breeding Company.
- Alternative species programme (could apply the same concept to other species).

Budget - WS2.1b

$689,000 p.a.

Leader

Heidi Dungey
Email heidi.dungey@scionresearch.com
Telephone 07 343 5629

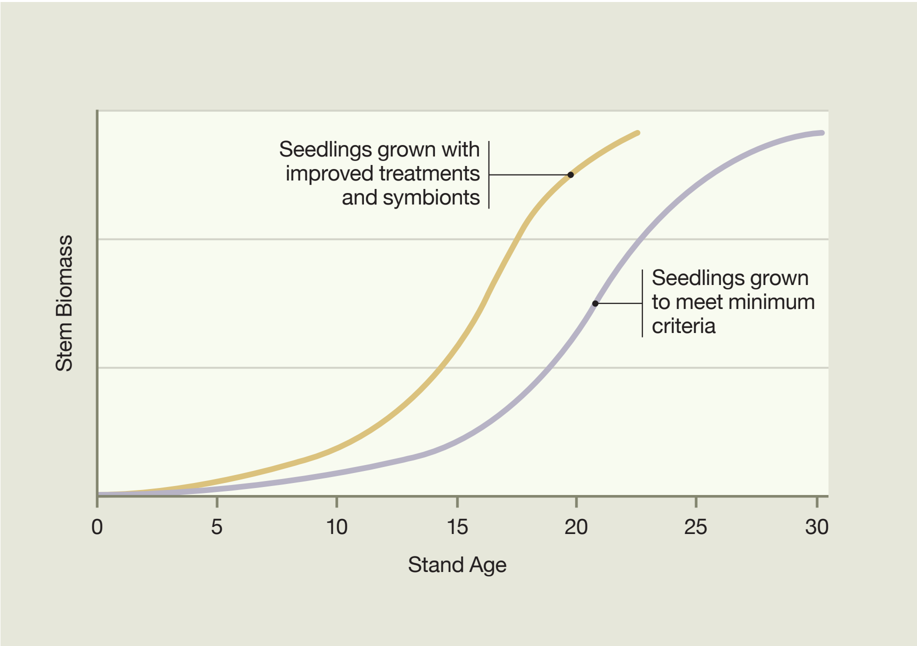
Key Hypothesis 2.2

Radiata pine productivity can be doubled from current levels without compromising wood quality

- Doubling radiata pine productivity

Doubling the productivity of radiata pine forests is an ambitious goal and one that will require us to understand a lot more about the physiology of the species. As a sector we also need to agree on what we mean by the term 'productivity' as there are a number of different definitions. Economic productivity is defined as the value of output created per unit of input (also known as total factor productivity), while in many biological industries the rate of biomass accumulation is referred to as biological productivity (or sometimes as ecosystem productivity). For the forestry sector to improve its profitability it must increase economic productivity and one way to achieve this is through increasing the biological productivity of forests. However, the value of the additional wood created through increased biological productivity must exceed the additional costs incurred to grow it.

A key question that needs to be answered with our research is what is the potential productivity of radiata pine. One work stream (2.2a) will use process-based growth models to predict potential site productivity across New Zealand under current and future climate. These predictions will be compared to maps of actual site productivity to identify the productivity gap. The other two work streams will focus on developing and testing interventions aimed at closing this productivity gap. One set of interventions will occur in the nursery (work stream 2.2c) and aims to produce seedlings that have enhanced early growth when planted in the forest (see figure below).



Interventions in the forest will be tested in a series of forest accelerator trials (work stream 2.2b). These accelerator trials will contain treatments that are specifically focused on overcoming those factors (e.g. water availability, nutrient availability, disease) that limit stands from achieving their potential productivity. We will measure different physiological processes to understand how the trees are responding to the different interventions, which will also enable us to better refine process-based models that are used to predict productivity. These trials are intended to be a long-term source of information for researchers and also serve as practical demonstration sites for the industry.

Key Hypothesis 2.2
(continued)

Given the long-term nature of forestry, it is important to understand both the intended and potential unintended consequences of increasing productivity. We will examine the water use and nutrient use by the trees as well as examining how the various treatments impact physiological and biomechanical drivers of wood formation and those wood property traits that affect utilisation. This includes transcriptomics and proteomics of compression wood and galactan synthesis, both of which are drivers of distortion in sawn timber.

Workstream 2.2a

Defining the productivity gap

Outcomes to 2019

- Quantification of the potential productivity of radiata pine on different sites across New Zealand and the establishment of a target for increasing productivity.
- Spatial map showing the gap between actual and potential productivity.
- Improved knowledge of the processes limiting productivity.
- Development of a strategy for closing the gap and knowledge on the implications of increasing productivity for wood quality.

Activities

- Establish productivity enhancement innovation cluster group.
- Identify the data required to parameterise process-based models and obtain these data.
- Integrate latest advancements in soil fertility and soil properties into available soil maps to increase accuracy of soil spatial data required for model input.
- Run models across a range of different scenarios (e.g. different assumptions around future climate, soil moisture, future forest management) to estimate potential productivity.
- Integrate wood formation models with stand level process-based model to predict wood quality spatially.
- Compare potential productivity with current productivity and estimate the productivity gap across a range of different site types.
- Identify opportunities for closing the gap and addressing implications for wood quality.
- Use model to investigate the underlying drivers of spatial variation of productivity uncovered with LiDAR.

Timeline

Mid 2014	Late 2014	Mid 2015	Mid 2016
Data requirement for process- based models identified and data assembled	Potential productivity estimated across a range of different site types and productivity gap estimated	Potential 'levers' for closing the productivity gap have been identified	A strategy for closing the productivity gap has been developed and implications for wood quality identified

Linkages

Internal to the programme

- Accelerator trials.
- Wood quality and formation (E-cambium).
- Phenotyping platform.

External to the programme

- Land and Water National Science challenge.
- Forest Health.
- International collaboration - CSIRO.

Budget - WS2.2a $350,000 p.a.

Leader

Dean Meason
Email dean.meason@scionresearch.com
Telephone 07 343 5856

Workstream 2.2b

Accelerator trials

Outcomes to 2019

- Trial design and strategy that can be adopted by companies based on their specific productivity gap.
- Initial recommendations for site manipulations to maximise reduction in productivity gap for specific sites.
- Early identification of links between site manipulations (levers) and wood quality.
- Validated process models.
- Indications of productivity gains from specific interventions, implications for tree health and wood quality identified.

Activities

- Review 'levers' - what modifications are possible and what can be done.
  - > Genotype-site matching (what characteristics match particular site types.
  - > Herbicides, nutrients, water, disease resistance/control, cultivation, microbial activity, combinations thereof.
- Plan
  - > Select and grow genotypes for deployment in trials
  - > Find sites based on productivity gap map.
  - > Measurements (growth, physiology, cambial activity, microbial activity, spatial variation, plant health and immune response, epigenetic studies). Pilot studies to develop new techniques for application to field trials.
  - > Environmental impacts (nutrient and chemical movement, functional biodiversity impacts, sediments).
- Report
  - > National and international presentations and field visits.

Timeline

Mid 2014	Late 2014	Mid 2015	Mid 2016	Mid 2018	Mid 2019
Decide on lever aspects to be treated as core factors and non-factorial aspects. Also decide on approach that will source genotypes with the desired attributes (traits) and locate suitable sites	Pilot accelerator trial installed with clones with the desired traits, and site factors assessed, to asses logistical aspects of the approach prior to main installation of accelerator trials.	Identification of potential sites for forest accelerator trials. Choice of genetic material for forest accelerator trials agreed and grown in the nursery	First forest accelerator trial installed	Remaining forest accelerator trials installed. Assessment of future funding options to continue the trial beyond the period of the Growing Confidence programme completed	Growth data and wood samples analysed to provide early assessments of the impacts of treatments on these traits

Linkages

Internal to the programme

- KH 2.1 Wood quality and formation (E-cambium).
- KH 2.1 Phenotyping platform.

External to the programme

- University of Canterbury/ new plant science core.
- Land and Water National Science challenge.
- Forest Health.
- International collaboration - CSIRO, University of Georgia, Oregon State University.
- Radiata Pine Breeding Company.

Budget - WS2.2b

$400,000 p.a.

Leader

Peter Beets
Email peter.beets@scionresearch.com
Telephone 07 343 5577

Workstream 2.2c

Evaluation of nursery treatments to enhance early growth

Outcomes to 2019

- Revised specifications for nursery management for better seedling quality.
- Improved seedling vigour.
- Specifications for specific mycorrhizal symbionts for better seedling growth.
- Specifications for specific plant growth-promoting rhizobacteria for better seedling growth.
- Recommendations on the best symbionts for specific genotypes.

Activities

- Sample existing nursery management out planting trial.
- Install new nursery trials in order to generalise previous results across a wider range of conditions.
- Genotype x management.
- New accelerator trials established using material that has been prepared in the nursery using treatments aimed at enhancing early growth.
- Trials monitored to quantify potential gains when trees are planted in the forest.
- Establish new nursery research innovation cluster.

Timeline

May 2014	July 2014	Mid 2015	Mid 2016	Mid 2016	Mid 2017	Mid 2017
Experimental framework proposed	Experimental programme initiated in nursery trials	Pilot cohort of nursery seedlings planted out, linked to pilot accelerator trial	Interim field results collected	Primary cohort of nursery seedlings planted out, linked to accelerator trials	Interim field results collected	Supplementary cohort of nursery seedling trials planted out

Linkages

- Lincoln University, University of Canterbury, Massey University.
- Swedish University of Agricultural Sciences, Uppsala, Sweden.
- Plant health research.
- Forest health research.
- Plant stress research.

Budget - WS2.2c

$250,000 p.a.

Leader

Simeon Smaill
Email simeon.smail@scionresearch.com
Telephone 03 364 2987 extn 7833

Key Hypothesis 2.3

Enhancing the growth promoting activity of the soil microbial community will improve tree health, wood quality and productivity

- Enhanced activity of the soil microbial community

The relationship between trees and the soil microbial community affects the nutrient uptake, growth and health of the plants. By enhancing the beneficial aspects of this relationship, it is assumed that trees can better utilise site resources resulting in improved productivity. We will quantify how soil microbial activity contributes to tree performance and the expression of realised genetic gain can be increased by modifying site conditions (e.g. through cultivation, rock grinding, slash incorporation), weed control and the use of site amendments such as fertilisers, biochar, biostimulants, and biofertilisers). We will use the forest accelerator trials as a source of data to quantify the economic feasibility of site modifications and amendments that affect soil microbial activity and beneficial plant-microbe interactions.

Outcomes to 2019

Improved seedling vigour

- Identification of links between soil chemical properties and wood quality (e.g. pH).
- Recommendations of physical soil amendments to improve nutrient availability (e.g. coarse soil integration, harvest residue incorporation).
- Identification of most beneficial mycorrhizal system for early plantation performance.
- Identification of most beneficial plant growth promoting rhizobacteria systems for early plantation performance.
- Initial recommendations for site manipulation to maximise benefits from microbial activity.

Activities

- Improving growth and wood quality through manipulation of soil chemistry.
- Physical amendments.
- Identifying the most beneficial plant growth promoting microbes.
- Linking genotypes to plant growth promoting microbes.
- Engage in activities of the GCFF innovation clusters.
- New field trials to test site manipulations.
- Field trials linked to accelerator trials and mid rotation interventions.
- Application of DNA techniques and advance sequencing methods to identify soil microbes for further testing.

Timeline

May 2014	July 2014	Mid 2015	Mid 2016	Mid 2016	Mid 2017	Mid 2017
Experimental framework proposed	Pilot trials commence to test aspects of analytical methodology	Commence site manipulation at accelerator trials to alter soil microbial activity	Interim field results collected	Establishment of second phase microbial manipulation field trials	Interim field results collected	Establishment of third phase microbial manipulation field trials

Linkages

- Accelerator trials (RA2.2).
- Mid rotation trials (RA1.2).
- Future intensification, NuBalM nutrient supply model (RA3.1).
- Maintaining productive capacity – organic matter removal (RA3.2a).
- Wood physiology research.
- University of Canterbury, Lincoln University, Swedish University of Agricultural Sciences.
- Forest health research.
- Plant stress research.

Budget - KH2.3

$650,000 p.a.

Leader

Simeon Smaill
Email simeon.smaill@scionresearch.com
Telephone 03 3642987 extn 7833

Research Aim 3

Sustainability under intensified regimes

Sustainable forest management in a New Zealand context has several aspects including the important environmental role in protecting our soils and water quality and providing for biodiversity. Intensification of production, therefore, must not be at the expense of these important environmental benefits provided by forests as our access to international wood markets is critically dependent on protecting these values. Intensification of production on the same land area will place increasing demands on soil, water and biodiversity resources, particularly over multiple rotations. Many of our planted forests are into their third rotation, with some even entering their fourth rotation. Compared with other land-based industries forestry uses very few inputs, such as fertiliser, and it is important to understand whether there is, or could be, a long-term productivity decline on certain sites under intensified regimes. If productivity is increased then trees will use more water and nutrients, which in some cases may exceed the capacity of sites to supply these resources.

Increasing areas of forests are being harvested on steeplands, and these sites are under increasing risk of accelerated soil erosion from severe storm events. Minimising these erosion risks through improved risk assessment and mitigation options will be important for long term site productivity on sites where erosion risk is high. If soil is lost from the site productivity in subsequent crops is likely to be lowered, and impacts of the soil and harvest debris outside the forests can cause infrastructure damage and also affect the social acceptability or license to operate of the forestry operation.

Intensifying forest management and adopting new risk management and mitigation options to minimise environmental impacts of the new regimes is likely to lead to different operational cost structures, and effects on the overall economics of the forest operations. The trade-offs between intensified production and the potential impacts and mitigation needs will have to be evaluated within an economic context. Given the range of different environments within New Zealand's planted forests a spatial economic modelling approach that incorporates all forest values (timber plus non timber forest products such as erosion and clean water) will provide estimates of the full value and potential returns of planted forests compared to other primary sector land uses.

Key Hypothesis 3.1

Future intensification of forest management practices will not result in degradation of soil, water and biodiversity resources

- Sustainability of soil, water and biodiversity

While forestry is generally considered to have a relatively low environmental impact, intensification of management in existing and new forests could put increasing pressure on soil, water and biodiversity. For example, increased rates of nitrogen application could lead to nutrient leaching and negative impacts on water quality. We need to understand what these potential impacts could be and develop mitigation approaches in order to maintain our licence to operate.

Data, including those from the long-term site productivity trials (RA3.2a), mid-rotation intervention trials, 'Forest Accelerator' trials (RA2.2) and other trials, will be investigated for environmental impacts and considered for incorporation into forestry specific nutrient (NuBalM) and water balance models (SWATBAL), to allow the long-term impacts of intensification to be modelled, inform public debate and modify practices.

Outcomes to 2019

- Forest models that have the ability to evaluate the environmental impacts of intensified regimes.
- Maintenance of licence to operate.
- Improved environmental risk management practices.

Activities

- Establish sustainability innovation cluster.
- Review of literature of the potential impacts of forest intensification on soil, water and biodiversity to inform on an environmental impacts framework.
- Coordination with KH1.2 (mid-rotation interventions) and KH 2.2 (accelerator trials) to design and install experimental trials to assess the environmental impacts of selected intensification interventions.
- Data collection and incorporate findings into nutrient and water model development.
- Regular workshops, innovation cluster meetings, technology transfer and national and international conferences.

Timeline

Late 2014	Late 2014	2014 - 2018	2017 - 2019	2014 - 2019	Mid 2019
Review completed	Trial sites selected and field monitoring programme established	Continued monitoring of trials and annual update of results	Nutrient and water model development and testing	Publications of papers and regular workshops	Data synthesis to support intensification

Linkages

Internal to the programme

- Maintaining productive capacity – organic matter removal (RA3.2a).
- Mid rotation intervention (RA1.2).
- Radiata pine productivity 'Forest Accelerator' trials (RA2.2).
- Growth promoting productivity 'Forest Accelerator' trials (RA2.3).
- Changing expectations, spatial economic modelling of sustainability (RA3.3).
- Drivers for tree performances and productivity phenotyping platform (RA2.1).

External to the programme

- MfE and MPI environmental programmes.
- FOA Environment Committee.
- FSC Cluster group.
- USDA Forest Service.
- Scion weeds programme.

Budget - KH3.1

$235,000 p.a.

Leaders

Loretta Garrett
Email loretta.garrett@scionresearch.com
Telephone 07 343 5596

Brenda Baillie
Email brenda.baillie@scionresearch.com
Telephone 07 343 5506

Key Hypothesis 3.2

Forest management practices will not lead to a decline in the productive capacity of New Zealand's forest sites over successive rotations

- Sustainability over multiple rotations

A key goal of forest growers is to increase the productivity of future forests. While there may be some afforestation of former farmland, most future forests will be established on cutover sites from an earlier rotation. In many cases these sites will be growing their third rotation of radiata pine with some even entering their fourth rotation. Significant areas of forests are also located on steep erodible sites. These forests are at high risk from erosion damage during the inter rotation period, especially with increasing extreme weather events. If erosion does occur, this could lead to a productivity decline for the forest that is subsequently established. This key hypothesis has two work streams that focus on each of these issues. In workstream 3.2a we will assess the impacts of forest management practices on the ability of sites to supply resources for tree growth, while in workstream 3.2b we will focus on developing approaches for minimising and mitigating steepland harvest impacts in order to maintain productive capacity.

Workstream 3.2a

Assessing the impacts of forest management practices on the ability of sites to supply resources for tree growth

A series of long term site productivity (LTSP) trials were established between 1986 and 1996 across a range in climate and soil in New Zealand to investigate the impacts of different levels of harvesting disturbance and organic matter removal on growth of the subsequent crop. We will carry out end-of-rotation assessments on the remaining three LTSP trials that are scheduled for harvest. Data on biomass, nutrient pools and crop value will be collected and analysed alongside data from those trials that have already been harvested. Using these data we will quantify the impacts of different levels of harvesting disturbance on the productivity of the subsequent crop and incorporate the findings into the NuBalM nutrient balance model to support RA3.1.

One of the LTSP trials has also received very large amounts of nitrogen fertiliser (> 1 tonne of elemental N per hectare) and we will also use this trial to examine the effect of fertilisation on wood quality. Results will be used to help parameterise models of wood formation in response to environmental stimuli.

Outcomes to 2019

- Forest models (e.g. NuBalM) for evaluation of long term site productivity scenarios under different regimes are available to forest managers.
- Licence to operate maintained.
- Improve nutrient management approaches – timing of applications based on supply/demand curves.

Activities

- Establish sustainability innovation cluster.
- Develop workplan for sampling the Woodhill LTSP trial to determine rotation age treatment effects on biomass productivity, soil nutrient pools and processes, and wood quality.
- Sample the Woodhill LTSP trial.
- Sample remaining long term site productivity trials.
- End of rotation assessment of site quality and productivity.
- End of rotation assessment of multiple additions of N on wood quality.

Activities
(continued)

- End of rotation assessment of nutrient supply through NuBalM.
- Publication of papers on findings and communication of work to national and international community.
- Synthesis of results from LTSP trials into a readily accessible form.
- Regular workshops, innovation cluster meetings and technology transfer.

Timeline

Mid 2014	2014 - mid 2018	2015 - 2018	2014 - 2019	Mid 2019
Workplan for Woodhill LTSP trial completed and trial sampled	Remaining LTSP trials harvested	Analysis of data from LTSP trials and reporting of results as they become available	Publications of papers and regular workshops	Data synthesis and conclusions made

Linkages

Internal to the programme

- Future intensification, NuBalM nutrient supply model (RA3.1).
- Mid rotation intervention (RA1.2).
- Radiata pine productivity 'Forest Accelerator' trials (RA2.2).
- Drivers for tree performances & productivity 'phenotyping platform' (RA2.1).

External to the programme

- Universities.
- CSIRO.

Budget - WS3.2a

$200,000 p.a.

Leaders

Loretta Garrett
Email loretta.garrett@scionresearch.com
Telephone 07 343 5596

Tim Payn
Email tim.payn@scionresearch.com
Telephone 07 343 5590

Workstream 3.2b

Maintaining productive capacity – minimising and mitigating steepland harvest impacts

Forests on steep sites with erodible soils are at high risk from erosion damage during the period between harvesting of the previous stand and the point at which the new trees can provide sufficient root reinforcement (the 'window of vulnerability'). This is especially the case as the magnitude and frequency of high intensity rainfall events appears to be increasing. We need to better understand and classify erosion hazard, and develop new site management techniques to mitigate impacts where they do occur. Post-harvest erosion on steepland sites presents a significant challenge to future productivity and the sector's licence to operate. This research will seek to create a national database to establish the scale of erosion and debris flows within New Zealand's planted forest stands. The viability of a periodic erosion and debris flow monitoring programme data will be investigated, with the aim of providing robust empirical data that can be utilised in the modelling of risk. The programme will build on recent national and international erosion risk prediction work to more accurately predict forest sites at risk, especially at a finer resolution. For this modelling we will build on international

Workstream 3.2b *(continued)*

linkages. In order to reduce the window of vulnerability we will explore bioengineering and soil amendment practices (predominantly focussing on mixed species plantings) that will help to mitigate erosion events during this period.

Outcomes to 2019

- A national erosion and debris flow database.
- Enhanced ability to model and predict erosion risk nationally, regionally and locally.
- New planting options from a new suite of experiments that reduce the window of vulnerability to erosion following harvesting.
- New site management options to maintain or enhance productivity, and an updated environmental code of practice.
- Spatial economic framework for evaluation of new management options.

Activities

- Establish sustainability innovation cluster, steeplands working group, and agree work programme.
- Creation of national database for erosion and debris flows.
- Implement a process where the database is updated at least once per year.
- Review of current erosion models and methodologies to identify the most appropriate method for New Zealand. Combine erosion susceptibility and debris flows with hazard mapping at fine scale and enhance risk assessment models.
- Reducing the window of vulnerability – testing mixtures and coppicing species for steepland re-establishment – new experiments.
- Incorporating new steepland management options and algorithms into the Forest Investment Finder.
- Workshops (2015, 2017, 2019).
- Scientific publications.
- Development and maintenance of international linkages.

Timeline

Mid 2014	Mid 2015	Mid 2015	End 2015	Mid 2018	End 2018	Mid 2019
Underpinning draft papers for submission to journals	Establishment of national erosion and debris flow data base	Review of erosion and bioengineering methodologies complete	Design and establishment of field experiments completed	Spatial economic assessment of field experiment results (within FIF)	Spatial erosion model(s) tested and validated	Incorporation of findings into forestry codes of practice

Linkages

This research aim is linked to a number of other initiatives that are addressing various aspects of the management of forests on steep erodible lands (see diagram on following page – light blue and yellow bullets in this programme). Scion is also working in partnership with Landcare Research in this area.

Internal to the programme

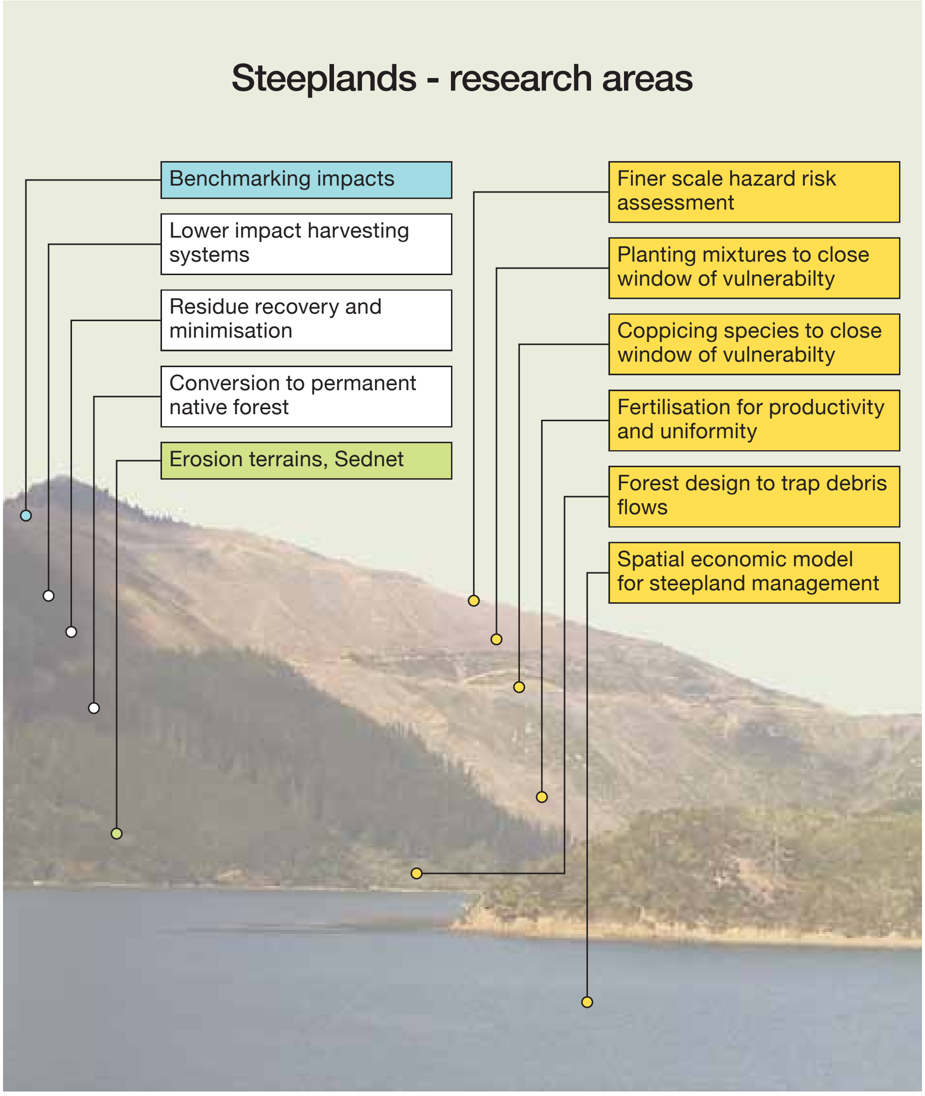
- RA2.1 Development of an integrated remote sensing platform.
- RA2.2 Radiata pine productivity.
- RA3.1 Future intensification.

External to the programme

- "Our Land and Water" National Science Challenge
- SLMACC steeplands projects.
- NZLRI, Erosion hazard, Smap - Landcare Research.
- CWPL - AgrResearch (Clean Water, Productive Land).
- SLURI – poplar and willows.

Linkages
(continued)

- ICM – Landcare Research (Integrated Catchment Management).
- Forest Research (UK Forest Commission).
- HAFL – Massi Schwarz (Switzerland) SoSlope spatial modelling.



Budget - WS3.2b

$250,000 p.a.

Leaders

Duncan Harrison
Email duncan.harrison@scionresearch.com
Telephone 07 343 5848

Tim Payn
Email tim.payn@scionresearch.com
Telephone 07 343 5590

Chris Phillips
Email phillipsc@landcareresearch.co.nz
Telephone 03 321 9775

Key Hypothesis 3.3

A systems approach will enable the New Zealand forest industry to more effectively respond to changing expectations around sustainable forest management

- *Spatial economic modelling for sustainable forestry*

The economic case for forest investment is spatially driven and must include ecosystem services to demonstrate the full value of forests and identification of the mix of products and ecosystem services at any location. Spatially explicit economic models enable better decisions to be made on the establishment of new forests, and for decisions on whether to replant existing forests, change regimes, or change land use entirely.

Under the previous FFR-funded research programme, Scion developed a spatially explicit economic model called Forest Investment Finder (FIF) which can be used by planners, policymakers and forest investors to identify areas where forestry is profitable or unprofitable. The FIF model has been used to estimate the value of ecosystem services which include harvested logs, avoided erosion and carbon in New Zealand's future forest areas. For this project, the model will be refined and used to estimate the value of those three services in selected existing forests. It will also be extended to estimate the value of other ecosystem services, such as recreation, nutrients, water quality and biodiversity in those forests.

A harvested log has a market price and therefore its value can be seen in market transactions. Conversely avoided erosion and recreation do not have a market price but they are also valuable to society. Methods have been developed to estimate their values to allow them to be accounted for in policy decision making. This project will provide recommendations on how each ecosystem service value should be treated and be incorporated into policy initiatives or investment decision making.

Outcomes to 2019

- The ability to make forest investment decisions that incorporate the full value of key ecosystem services (e.g. forest products, recreation, biodiversity).
- Use of FIF by forest companies for investment decisions.
- Use of FIF by central and regional government agencies for strategic planning.
- Better understanding of the full value of planted forests at local and national levels and ability to communicate those values.

Activities

- Establish sustainability innovation cluster.
- Validation of FIF on existing forests to define full value of existing forests.
- Incorporation of findings into FIF and publication of FIF modelling approaches.
- Annual Forest Ecosystem Services Forum and regular innovation cluster meetings.

Timeline

Mid 2014	**Mid 2014**	**Mid 2015 and 2016**	**Mid 2017**	**Mid 2019**
Valuing timber, carbon and recreation in an existing forest	FES forum	Valuing key ecosystem services in existing forests	FIF extended with new scenarios and next steps agreed. Greatly enhanced ability to compare land uses using spatial economic tools	Valuing key ecosystem services under intensified regimes

Linkages

Internal to the programme

- RA3 Sub units.
- Scion Māori agribusiness projects Indigenous forestry programme.

External to the programme

- Forest sector.
- University of Western Australia.
- MPI & SLMACC projects.
- DOC and regional councils – exploring projects on assessing ecosystem services.
- AgResearch, Landcare Research, Victoria University of Wellington.
- USDA Forest Service.

Budget - KH3.3

$165,000 p.a.

Leader

Richard Yao
Email richard.yao@scionresearch.com
Telephone 07 343 5747

Research Aim 4

Closing the gap: translating science into sustainable business growth

To achieve its ambitious goals, the forestry sector must make a deliberate step-change in its approach to production. More efficient technology translation and dialogue between researchers and industry is key to this. Because the sector comprises many parties, including small and large forest growers, iwi, processors and policy makers, we will take a systems approach to technology translation. This recognises that overall levels of innovation will not only be determined by the performance of individual parties, but also by how they interact with each other.

Through early engagement with the sector, we will form innovation clusters around key issues, where information can be shared using mechanisms such as workshops, information notes, field days, case studies and secondments. The effectiveness of this approach will be studied and enhanced as part of the pan-CRI project on primary sector learning and co-innovation.

Activities

- Establish innovation clusters around the key areas of the programme.
- Produce regular newsletters informing stakeholders of recent developments.
- Hold annual programme meeting to discuss research findings.

Timeline

Mid 2014	Mid 2014	Mid 2015	Mid 2014 - 2019
First innovation cluster formed	Kick-off conference for the overall programme held	First science-to-industry secondment has occurred	Regular newsletter produced and programme meetings held

Linkages

- New Zealand Institute of Forestry.
- AgResearch – principal investigator for primary sector learning and co-innovation programme.

Budget - KH4.1

$100,000 p.a.

Leader

Peter Clinton
Email peter.clinton@scionresearch.com
Telephone 03 364 2987 extn 7202

Overall programme timeline

<table>
<tr><th>Research Area</th><th>2014</th><th>2015</th><th>2016</th><th>2017</th><th>2018</th><th>2018</th></tr>
<tr><td rowspan="2">Maximising benefits from existing forests</td><td>Wood quality workshop for industry</td><td colspan="3">Sampling of trials to assess the effects of GxExS on wood quality</td><td colspan="2">New segregation approaches developed and tested</td></tr>
<tr><td>Review of mid-rotation interventions</td><td>Development of assays for identification of stands that will respond to mid-rotation interventions</td><td colspan="2">Establishment of trials to test mid-rotation interventions</td><td>Trials assessed and data analysed</td><td>New methods for identifying responsive stands and guidance on interventions</td></tr>
<tr><td rowspan="5">More productive, higher quality forests for the future</td><td colspan="2">Individual tree detection from LiDAR and location on the ground</td><td>Individual tree attributes integrated with site and stand level metrics</td><td>New inventory tools for forest managers</td><td colspan="2">Predication of wood quality attributes from LiDAR metrics</td></tr>
<tr><td colspan="2">Initial phenotyping of trials as proof of concept</td><td colspan="3">Phenotyping platform used to identify trees that have better disease resistance</td><td>Phenotyping platform has been used to understand drivers of growth and quality</td></tr>
<tr><td>Productivity gap estimated</td><td>Potential levers for closing the productivity gap identified</td><td>Strategy for closing the productivity gap developed</td><td colspan="3"></td></tr>
<tr><td>Design of the forest accelerator trials</td><td>Potential sites for the forest accelerator sites identified</td><td>Strategy for closing the productivity gap developed</td><td colspan="2">Remaining forest accelerator trials installed</td><td>Analysis of preliminary data on growth and wood property responses</td></tr>
<tr><td>Experimental programme to evaluate nursery treatments aimed at increasing growth</td><td>First cohort of nursery seedlings planted out</td><td>Evaluation of treated seedlings</td><td colspan="2">Treated seedlings incorporated into forest accelerator</td><td>Recommendations on nursery treatments and site manipulations to enhance the growth promoting activity of soil microbial communities</td></tr>
<tr><td rowspan="4">Sustainability under intensified regimes</td><td>Establishment of trials to investigate the impacts of intensification on soil, water and biodiversity</td><td colspan="3">Monitoring of trials and analysis of data</td><td colspan="2">Development and testing of water and nutrient models</td></tr>
<tr><td>Woodhill Long Term Site Productivity (LTSP) trial harvested</td><td colspan="3">Remaining LTSP trials harvested and data analysed</td><td colspan="2">Synthesis and presentation of results from all LTSP trials</td></tr>
<tr><td></td><td>Establishment of national erosion and debris flow data base</td><td colspan="2">Establishment and monitoring of field experiments to evaluate treatments to reduce the window of vulnerability to erosion</td><td colspan="2">Spatial economic assessment of risk reduction options</td></tr>
<tr><td>Forest Ecosystem Services forum held</td><td colspan="3">Forest Investment Finder extended to include the value of ecosystem services in current forests</td><td colspan="2">Quantification of the value of ecosystem services under intensified regimes</td></tr>
<tr><td rowspan="2">Translating science into sustainable business growth</td><td>Forest Ecosystem Services forum held</td><td>Science to industry secondments</td><td colspan="3">Regular newsletters and programme meetings held</td><td>End of programme conference and review</td></tr>
<tr><td>Innovation clusters formed</td><td colspan="3">Regular meetings of the innovation clusters</td><td colspan="2">Review and planning for next research programme</td></tr>
</table>

Programme planning

The overall programme contains the following elements:

- The research programme description (which is this document).
- **Project plans** (for the overall make up and scope of each key hypothesis, e.g. KH2.3.
- **Work plans** that contain the detail of a particular activity undertaken within each RA key hypothesis. There may be several work plans per key hypothesis.
- **Programme timeline** that details components of the programme but not activities undertaken as part of work plan. Work plans have their own timelines.
- Average **annual budget** that detail budgets required to complete the work plans.
- Engagement plan.
- Communication plan.

This is the largest programme at Scion and one of the largest MBIE-funded research programmes at any Crown Research Institute.

A fulltime **project manager Dr Annette Brockerhoff** will coordinate the running of the programme.

Dr Peter Clinton is the principal investigator leading the overall programme.

Key programme impacts are detailed for within the programme period and for 2, 5 and 10 years post programme.

Average annual budget over the 6-year programme

Research Aims and Key Hypotheses	
RA1. A system approach to maximising value from existing forests	**$**
KH1.1 Segregation of the current resource	650,000
KH1.2 Enhancing productivity of older stands	350,000
RA2. Building more productive, higher quality forests for the future	
KH2.1 Phenotyping the forest	1,526,000
KH2.2 Doubling radiata pine productivity	1,000,000
KH2.3 Enhanced activity of the soil microbial community	650,000
RA3. Sustainability under intensified regimes	
KH3.1 Sustainability of soil, water and biodiversity	235,000
KH3.2 Sustainability over multiple rotations	450,000
KH3.3 Spatial economic modelling of sustainable forestry	165,000
RA4. Closing the gap: translating science into sustainable business growth	
KH4.1 Closing the gap	100,000
Total	**5,126,000**

Sources of funding for the programme

Source	Revenue ($ p.a.)
Ministry of Business, Innovation and Employment	3,375,000
Forest Growers Levy Trust Board	1,600,000
Others	151,000
Total	**5,126,000**

Impacts within the programme

- By 2019, systems approaches adopted by the industry have moved forest management onto a 'precision forestry' basis.
- The forestry value chain model has been used to identify the strategic interventions needed to realise the Woodco target of $12 billion in forestry exports by 2022.
- At least five companies are applying new segregation approaches that target improved end-product quality.
- At least two major forest growers have changed their management practices and are applying new treatments designed to increase the productivity of mid-rotation stands.
- Remote sensing technologies are being used operationally by at least five major forest growers to obtain quantitative information on the performance of their forests, which is being used to inform management practices.
- The phenotyping platform has been used to identify elite individual trees for at least one key trait of interest and these are in the process of being deployed for planting by forestry companies.
- At least one potential site modification treatment for increasing the productivity of newly-established forests is being tested operationally by a major forest grower.
- The forest industry's licence to operate has been maintained under new intensive management practices.
- There has been a culture change in the industry. Researchers and iwi are working in partnership to identify the pathways for Māori economic development through sustainable forest management. There is better connectivity between forest growers, processors and their end customers, which has resulted in an additional $2 billion per annum in export receipts.

Post-contract outcomes for New Zealand

Two years after contract completion

Better coordination of the small grower resource has reduced supply chain costs by $5/m3 and at least 50% of this resource is being processed on shore. The total value of forestry exports exceeds $8 billion per annum. Māori indicators of wealth and wellbeing related to their forests have improved.

Five years after contract completion

Improved confidence in the long term wood supply has created additional processing investment. More logs are being processed into higher value products and the total value of forestry exports has reached $12 billion per annum.

Management interventions to improve productivity are being applied to existing and new forests. Mass screening of forests using the phenotyping platform is being used routinely by breeders to identify trees with elite phenotypes.

Ten years after contact completion

New forests being established have the potential to achieve productivity levels that are twice those established in 2013.

Improved profitability of forestry has seen new rates of planting increase to 30,000 ha/yr.

Māori have increased the area of planted forests under direct manage-

ment by 100,000 ha and have utilised their natural resource base to locally process timber for export.

The long term sustainability of forest management practices is clearly demonstrated, and new markets have been developed based on improved product performance and sustainability credentials.

The total value of forestry exports exceeds $12 billion per annum.

The research leaders

Dr Peter Clinton, *Science Leader, Forest Systems; GCFF Programme Leader*
Dr Peter Clinton is a forest ecologist who specialises in maintaining the productive capacity of commercial forests. He is one of New Zealand's leading experts in sustainable forest management with more than 80 published papers to his credit. He has led the Government funded national programme on Sustainable Forest Management which provides core capability to support the sustainable management of New Zealand planted forests since 2005. His expertise extends to production ecology, tree nutrition, biogeochemistry, soil organic matter and stable isotope methods. Peter has represented New Zealand on addressing climate change at the 2010 IUFRO World Congress in Seoul, and in four other international congresses and workshops.

Dr John Moore, *Research Leader, Forest Systems*
Dr John Moore has 20 years' experience in forest research and specialises in quantitative silviculture. He is a recognised expert on the risk of wind damage to forests and how this is affected by management activities. John's current research is focussed on quantifying the effects of forest management on wood quality and the resulting impacts on solid timber performance, tree biomechanics and allometry, including the development of tree biomass functions. John spent eight years in Scotland and the Pacific Northwest working on a range of different tree species, including Douglas-fir, Sitka spruce, Scots pine and larch. During this time he managed a wind risk research cooperative, which received both government and industry funding, managed the project to develop an inventory system for planted forests and managed the Strategic Integrated Research in Timber project in Scotland. John is currently research leader for the Tree Growth and Quality group within Forest Systems and an associate editor of the *New Zealand Journal of Forestry Science*. He has published 40 refereed papers on different aspects of forest management.

Dr Peter Beets, *Research Leader, Forest Systems*
Dr Peter Beets was employed by the New Zealand Forest Research Institute in 1974 as a scientist in the soils and site productivity section. Research responsibilities include measuring and modelling biomass carbon, water, and nutrient cycling in *Pinus radiata* plantations and indigenous forest. From 1998 – present he served as Carbon Team leader undertaking underpinning research for the Ministry for the Environment, a Scion-MfE research programme focusing on design and implementation of a national carbon inventory of New Zealand's planted and natural forests, and on developing default lookup tables for NZ's Emission Trading Scheme for the Ministry for Primary Industries. Peter has represented New Zealand on the IPCC, developing Good Practice Guidance for Land-Use, Land-Use Change and Forestry. He currently serves as research leader for the "Site Productivity" theme of the Forest Systems programme at Scion, which is an interdisciplinary team of scientists undertaking research into the biological mechanisms controlling productivity, health and sustainability of plantation forest ecosystems. Peter has published widely in peer reviewed international

journals, and has authored or co-authored more than 60 publications. He currently serves on the editorial board for Forests. His professional international experiences include research projects and consultancies in Australia, USA, France, Portugal and Chile.

Dr Michael Watt, *Research Leader, Forest Systems*
Dr Michael Watt specialises in weed research and in modelling both plantation productivity and wood quality. His research also encompasses application of remote sensing technology to characterise the plantation resource. The 113 papers he has published around these and other topics include 80 published papers over the last five years. As research leader of both the remote sensing and weeds projects within Scion, Michael works extensively with the New Zealand forest industry. He received an industry award in 2011 for research that enhances sector value.

Dr Heidi Dungey, *Science Leader, Forest Genetics*
Dr Heidi Dungey specialises in tree breeding and genetic resource characterisation for commercial forestry species including radiata pine, Douglas-fir, cypresses, eucalypts and redwoods. Her research encompasses quantitative and ecological genetics and breeding. Heidi has published more than 30 refereed papers on forest genetics and aspects of alternative species research. As leader of Scion's genetics research programme, Heidi works closely with New Zealand seed producers and forest growers to ensure breeding strategies are tailored to meet consumer needs.

Dr Dean Meason, *Scientist, Forest Systems*
Dr Dean Meason, has 11 years' experience in forestry based research with expertise in tree physiology, forest ecosystem processes, process-based modelling, productivity and limitations to growth. He has 10 published papers and was the lead author and researcher of the MPI SLMACC 'Improving the *Eucalyptus fastigata* Growth Model', and researcher for the MPI SLMACC 'Douglas-fir Model Enhancement for Carbon'. He was the driving force behind redwood research for Future Forests Research and most recently the lead author of the strategic industry planning document the 'Redwood Development Plan'.

Dr Simeon Smaill, *Scientist, Forest Systems*
Dr Simeon Smaill is a microbiologist who specialises in examining plant-soil-microbe interactions in managed and natural ecosystems. This research is used to identify opportunities to improve the beneficial activity of soil microbes, enhancing plant performance while decreasing reliance on non-sustainable external inputs. His research also encompasses seedling nursery management, and has identified several cost-effective pathways to improve seedling performance in the nursery and subsequently in the field. Simeon has successfully led several multi-year government funded projects investigating various aspects of soil ecology and microbial ecology, and has published 21 papers in peer-reviewed scientific journals. Simeon works closely with organisations representing forest owners and managers to ensure his research delivers outcomes that are relevant and can be implemented with success.

Dr Tim Payn, *Principal Scientist and Research Leader, Forest Systems*
Dr Tim Payn has a wide background in Sustainable Forest Management (SFM) research with a focus on the use of scientific information for forest decision making, forest policy, and strategic planning. He chairs the Technical Advisory Committee of the 12 country Montreal Process which focuses on issues of SFM in temperate and boreal forests and which developed the criteria and indicators of SFM that are used for reporting on the state of New Zealand's forests. In recent years he has coordinated New Zealand and international programmes on forests and climate change which have produced a significant body of work on impacts, mitigation, and adaptation options for New Zealand forestry. Currently he leads Scion's Economics, Ecosystems, and Climate team.

Loretta Garrett, *Scientist, Forest Systems*
Loretta Garrett is a scientist who specialises in soil, woody debris decay, soil sustainability, indicators and ecosystem services. She has 13 years research experience and has published 14 refereed papers. She has been involved in a range of projects that included reporting on soils at a national level as part of the Soil and Land Use Alliance for the Parliamentary Commissioner for the Environment, a review of the impact of climate change on soil processes and services for the Ministry of Primary Industries, and biomass loss and decay rate modelling from forest harvesting for the Ministry for the Environment.

Dr Richard Yao, *Scientist-Resource Economist, Forest Systems*
Dr Richard Yao is an environmental economist who focuses on the valuation of ecosystems services provided by forests such as recreation, species conservation, carbon and avoided erosion. His work encompasses economic valuation, natural resource management, conservation management and cost benefit analysis. He has published eight refereed journal articles. He works closely with fellow scientists, forest managers, national government agencies and regional councils to help incorporate the value of ecosystem services in decision making.

Dr Chris Phillips, *Portfolio Leader, Realising Land's Potential* (Landcare Research)
Chris Phillips is an earth scientist who specialises in studying erosion processes, but particularly how vegetation mitigates erosion. In the early part of his career he worked for the New Zealand Forestry Research Institute studying the relationship between geology and geomorphology and the implications for forest management in the East Coast region of New Zealand. He was more recently involved in a 10-year interdisciplinary study focused on the Motueka River catchment and its connection to Tasman Bay, in the northern part of South Island, New Zealand. Currently he co-leads collaborative research in several inter-CRI research programmes and provides advice for regional and central government and primary sectors through contracted services. He is an honorary member of the New Zealand Association of Resource Management, is a board member of a global community of professionals working on natural hazard risk management

(ecorisQ), and is the current chair of a community research and education organisation - the Styx Living Laboratory Trust. He has published over 40 papers and nine book chapters and contributed to many reports on erosion and sediment issues for a wide range of end-users across New Zealand.

Graham Coker, *Project Leader, Forest Systems*
Graham has 20 years' research experience based around plant soil interactions. He has been involved in vegetation management and site quality studies. Graham has contributed to more than 28 peer reviewed publications across a wide range of topics. His current research focus is on finding solutions which make the Forest Industry more profitable in the short term such as mid-rotation fertiliser applications.

Duncan Harrison, *Scientist, Forest Industry Informatics*
Duncan Harrison has a background in geographic information sciences and spatial modelling. His research involved investigating spatial modelling pest and disease spread and impacts of forest productivity under current and future climate. Duncan also examined spatial modelling of new forestry roads (cost path analysis/network analysis) to connect future forest plantations with existing road networks. This was done in relation to the economic assessment and comparison of sites for timber, bio-energy, carbon, erosion reduction and improvement water quality for the forest industry. Recently, Duncan has been modelling the spatial distribution of erosion risk across New Zealand using regression and geo-statistical techniques.

Dr Brenda Baillie, *Scientist, Forest Systems*
Dr Brenda Baillie has worked in the area of environmental research for over 15 years focusing on the effects of forestry and other land-use practices on riparian and aquatic ecosystems, water quality and woody debris dynamics. She has advised and worked with forest companies and regional councils in the management of woody debris/logging slash in streams. She has participated in a number of advisory groups contributing to the current national freshwater reforms led by MfE and participated in the development of the draft National Environmental Standards for the forest industry of New Zealand. She has researched and advised on environmental indicators for plantation forestry and is an environmental auditor for FSC (Forest Stewardship Council). Brenda has provided expert advice, training, education and knowledge transfer to forestry organisations, governmental organisations, national and international scientific groups, schools, interest groups and the general public. She is a member of the New Zealand Freshwater Sciences Society.

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Scion, Te Papa Tipu Innovation Park, 49 Sala Street,
Private Bag 3020, Rotorua 3046, New Zealand.
Telephone +64 7 343 5899. Facsimile +64 7 348 0952

www.scionresearch.com