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Manatū Ahu Matua

One Billion Trees: Current state of New Zealand Forestry Science

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Prepared for the Ministry for Primary Industries
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Science to support One Billion Trees

The Government has set a goal to plant one billion trees over 10 years (between 2018 and 2027) to deliver a range of benefits including regional economic development, erosion control, ecological and landscape restoration, climate change mitigation, and skills and workforce development.

Science is critical for underpinning the One Billion Trees (1BT) programme and broader transformation of the forestry sector. MPI commissioned Scion to compile a report on the current state of forestry science in New Zealand as it relates to the 1BT programme. Its primary purpose is to summarise current research knowledge that can be used now, as well as knowledge to help better understand the critical science gaps that will need to be filled to meet 1BT programme goals.

Objectives

Key subject matter experts from Scion, Manaaki Whenua Landcare Research, AgResearch, Plant and Food Research and the University of Canterbury have contributed to this review of the current state of New Zealand Forestry Research.

Key findings

The key overall finding of the report is that there is a rich body of knowledge relating to radiata pine and its products, but research into alternative exotics and planted indigenous species is limited.

Summaries of current research are outlined below:

Radiata pine

- Radiata pine has been the cornerstone of the New Zealand forest industry for the past 70 years. Substantial investment in research has resulted in significant improvements in productivity of radiata through a focus on all areas of the forest growing cycle.
- There is information available on selection and tree improvement; nursery production; site preparation; establishment practices; vegetation management; nutrition; stocking control; and forest protection, which have all improved timber yield and quality for this species.
- Much of the information on radiata pine growth and management is stored in the Permanent Sample Plot (PSP) system, a comprehensive database of forest growth data that underpins New Zealand's commercial forest industry. The system contains information dating from the 1920's on the environment, genetics and silviculture regimes. The PSP also includes information on other forest types, including Douglas fir.
- Waste streams from wood fibre processing can be used as a substitute for petroleum-based products and contribute to the development of a circular economy in New Zealand.

Other exotics

- Research on alternative exotic species to radiata pine is increasing, and in some cases is advanced (e.g. eucalypt species, Douglas fir).
- We know that some alternative exotics (e.g. poplar and willows) have a stabilising effect on erosion prone pastoral hill country, and are therefore better suited than pine to this type of land.

Indigenous tree species

- Most research on planted indigenous species in New Zealand has focused on tōtara, and to a lesser extent, rimu and kauri. Compared to exotic planted forest species, the amount of research is small.
- Basic growth and yield models exist for tōtara, and provenance trials have shown differences in adaptation to environmental conditions, growth and form traits.

- Tōtara trials in the 1980s and 1990s showed that seedlings planted beneath existing vegetation successfully established and were able to grow outside of their natural range with the right practices.
- Propagation research has focussed on rates of seed production which are known for rimu, tawa, and the beeches. This is important, as some natives only produce seed every few years.
- Nursery-grown seedlings of indigenous species lack the mycorrhizal communities that allow them to establish and compete against non-native weed species.
- Information is available on how to handle seed of tōtara, kauri, rimu and beech.
- Growth and management has focused on kauri, and studies suggest there are opportunities to grow kauri in plantations on selected good-quality sites over rotations of 60-80 years or less.
- End-use of indigenous forests has focused on tōtara and kauri. A kauri calculator enables growers to determine the economic outcome from planted kauri under different management regimes.
- Management regimes, such as thinning, have been shown to produce positive results in natural and planted forests of kauri and beech.
- Sustainable harvesting has demonstrated that fallen logs from indigenous podocarp forests can be successfully salvaged, delivering economic gains.
- Mānuka and kānuka bioactive properties have been well studied and high-value chemical compounds in honey from these species have been identified. Both mānuka and kānuka medical products are now in the market. Current research suggests that horopito, kawakawa, pukatea, koromiko, poroporo and houhere may also produce valuable bioactive compounds.

Research into nursery and understory crops

- Research into understory crops has led to ginseng being successfully commercially grown under planted forests, free from chemical spraying.
- Truffles are also being successfully commercially grown under a variety of tree species in New Zealand. Research is rarely published, but for most species growth is reliable with inoculation well understood.

Kaupapa Māori

- We know that significant areas of Māori freehold land are suitable for afforestation, and that Māori land owners are seeking to increase their involvement in the forestry sector.
- Research into Māori forestry aspirations has shown that Māori land owners have a preference for permanent mixed indigenous forestry over single species exotic plantation forestry, despite potentially lower economic returns.
- Studies have identified co-benefits (e.g. ecosystem, cultural, biodiversity and carbon offset premiums) of permanent mixed indigenous forestry and single species indigenous plantation forestry (e.g. tōtara).

Land Use/Land Use decision tools

- A number of models and decision support tools have been developed to investigate land use and land use change in New Zealand. Most of these do not incorporate forestry and are not designed to inform decisions at a landscape scale.
- NZ-FARM is one model that is able to accommodate native and plantation forest, and can estimate the potential economic and environmental impacts of land-use change to forestry.

Risk management

- Risk-related forestry research has focused primarily on pests, weeds (e.g. wilding pines) and diseases that impact radiata pine and its products. Key pathogens are Armillaria (root rot); bark beetles and wood borers; Nectria (flute canker); and Phytophthora species. A Significant finding to date is that copper has the potential to control red needle cast and Dothistroma needle blight in pine plantations. Radiata pine showing resistance to red needle cast has also been found, giving a good foundation for research into host resistance.

- It is clear that climate change will impact insect pests, weeds and pathogens. For example, invasive weedy and damaging tree species (e.g. Acacia spp.) are likely to expand their range under climate change and compete more strongly with plantations.
- Kauri dieback and myrtle rust are the focus of more recent research. This research is guided by kauri dieback and myrtle rust Science Plans, which have been developed in consultation with key stakeholders.
- Understanding of risks to forest systems from wind damage and fire is limited by patchy species and area coverage.
- New Zealand is largely ahead of the rest of the world in terms of research on the inclusion of forestry in an Emissions Trading Scheme (ETS). Modelling suggests that an ETS will lead to increased afforestation and rotation age, and decreased silviculture and deforestation.
- A reasonable body of research exists on carbon sequestration, the role of trees in mitigating climate change, potential risks and benefits of climate change on New Zealand's forests.
- Research has also shown that regenerating forest can offset carbon emissions from sheep, beef or dairy operations.
- We also know that forests will need to adapt to climate change scenarios in terms of increases in temperature, changes in rainfall and the wind environment. Temperature changes, atmospheric CO_2 and precipitation will all impact tree productivity. Models indicate that productivity gains resulting from a higher CO_2 environment will likely result in marked increases in the risk of wind throw, due to trees becoming taller and narrower.

Social, environmental and economic considerations

- We know that forests provide many ecosystem services such as carbon storage, soil preservation and enhanced biodiversity.
- Research into non-timber benefits such as carbon storage and improvements in water quality and biodiversity have focused on comparing pasture to forestry. Replacing pasture with trees can decrease soil erosion rates by over 90% on land at risk of erosion, and forests are more effective than other types of vegetation in reducing the incidence of mass movement erosion (landslides, earthflows).
- Both exotic and indigenous forestry plantations can provide a suitable habitat for some native plants and animals, including threatened species, resulting in biodiversity benefits.
- Riparian buffers and their vegetation composition can mitigate some effects of pine plantation logging on New Zealand streams.
- We only have limited research on the cultural services provided by trees, such as recreational opportunities, aesthetic enjoyment, spiritual enrichment, and biodiversity and conservation appreciation.
- Surveys of public perceptions of New Zealand's primary industries indicate that New Zealanders consider positive aspects of forestry to be employment opportunities and mitigation of the impacts of climate change, though New Zealanders are concerned about related damage to land and freshwater plants and animals. Other surveys have indicated a general lack of understanding of who the forest sector is, what it does, how it does it, and what it could do better.
- Economic considerations have focused primarily on radiata pine with a number of models being developed to look at economic benefits at both regional and national scales.

3 Exotic systems and associated value chains

3.1 INTRODUCTION

The New Zealand forest industry is based on sustainable plantations of mainly *Pinus radiata* (radiata pine). Douglas-fir, cypress, and some eucalypt species are also grown for timber. Forestry in New Zealand is geared to both domestic and export demand, with ~44% of harvested logs and varying percentages of processed forest products destined for world markets[1]. Research to improve productivity through breeding, silviculture, and other means has always been a large focus for the forest industry. As a result, New Zealand's research knowledge, especially for radiata pine, is extensive. Currently, the Forest Growers Levy Trust (started 2014) is investing 60% of the available levy to research[2].

3.2 RADIATA PINE

Radiata pine has been the cornerstone of the New Zealand forest industry for the past 70 years, due to its fast growth in this environment, with a relatively short rotation of less than 30 years. Radiata pine in New Zealand started from unimproved seed and initially exhibited poor form. However, substantial investment in research and development over the past several decades has resulted in significant improvements in productivity, stem form, and branch characteristics[3]. These gains have been achieved through focusing on all areas of the forest growing cycle, including: selection and tree improvement; nursery production; site preparation; establishment practices; vegetation management; nutrition; stocking control; and forest protection. New Zealand-grown radiata pine forests are now arguably the most productive softwood forests in the world, with observed maximum mean annual volume increments in experiments being as high as 52 m^3/ha/yr[4].

3.2.1 Current research

A focus of current research into radiata pine is to sustainably increase forest productivity to grow the value and profitability of the forestry industry in New Zealand, supporting the industry's goal of doubling its export earnings by 2022.

Key research includes:

- **Breeding better trees –** This work uses a combination of phenotyping and genetic selection to develop breeding programmes for traits that are of value to the forest industry, particularly in relation to growth and wood quality.

- **Improving timber yield and quality –** This work focuses on understanding and optimising the effects of combinations of genetics, environment, forest management, or silviculture.

- **Boosting forest productivity –** This work is aimed at understanding the effects and interactions of variables such as soil and climate, tree monitoring and management, and efficient harvesting technologies to help create highly productive future forests.

- **Understanding the effect of site and geography –** This work uses information relating to the effect of site and geography to select the species or 'germplasm' for the best results in terms of tree growth and timber yield, for example, from any one site.

- **Understanding how forest management (silviculture) affects tree growth –** This work focuses on understanding how stocking rate (trees per hectare), tree thinning and pruning, weed control, impacts of silviculture on wood quality, species choice and silvicultural modelling affect tree growth.

- **Using growth and yield models to support forest management –** This work is aimed at understanding how to use models and decision support systems to enable forest managers to evaluate the effects of different silvicultural systems on productivity and profitability.

- **Creating hybrid physiological/mensurational[i] growth models -** This work focuses on creating hybrid models that can both support managers' decisions and represent changing climate and seasonal growth processes in sufficient detail to allow the representation of within-tree wood properties.

- **Maintaining healthy soils -** This work aims to understand more about processes that control soil and forest productivity and their interactions. Forest health and productivity is dependent upon topsoil depth, soil structure, rooting depth, hard pans, texture, water holding capacity and nutrient supply.

- **Using precision management approaches –** This work seeks to apply remote sensing technologies, GIS, empirical modelling, unmanned aerial vehicles (UAVs) and computing power to forestry. This is one of the fastest advancing research fields in Forestry.

- **Determining the suitability of radiata pine for a range of products –** This work is aimed at understanding the suitability of radiata pine for a number of products, including appearance and structural lumber, panel products, engineered wood products, and pulp and paper.

3.3 ALTERNATIVE EXOTIC SPECIES SYSTEMS

Douglas-fir, cypresses, and eucalypts as alternatives to radiata pine have been researched through industry co-operatives and later the Future Forest Research (FFR) Diverse Species programme. The recent Ministry of Business, Innovation, and Employment (MBIE) Partnership Programme "Specialty Wood Products" aims to increase the productivity and profitability of these species. Due to the special characteristics of their timber, these species have the potential to generate high returns and diversify the industry. Key activities of the programme are:

- **Improving the value of the current resource –** This work focuses on developing new products and processing techniques primarily for Douglas-fir and non-durable eucalypts.

- **Improving the growth, form and wood quality of future plantings –** This work focuses on developing new tools and screening techniques to identify the best genetic material for the alternative species. This work will be followed by breeding improved planting stock from selected populations.

- **Developing integrated regional strategies –** This work focuses on working with industry partners to get a good fit between regions where the various alternative species grow well, and identifying processing and marketing activities.

Other research in the area of alternative exotic species is carried out through the New Zealand Dryland Forests Initiative (NZDFI), which is a commercially-oriented research and development project. It aims to develop genetically-improved planting stock and management systems for ground-durable eucalypt species suited to New Zealand's dryland regions. This research targets non-forestry clients, such as the wine industry.

3.3.1 Harvesting and forest operations

Harvesting accounts for about half the total cost of wood production in New Zealand[5]. This is partly due to approximately half the current harvest coming from steep terrain[6]. Felling and breaking out in these

[i] The science of measurement applied to forest vegetation and forest products

conditions are very high risk jobs. Current research in harvesting and forestry operations focuses on: cost benefit analysis of new equipment and practices in harvesting systems; mechanisation, including robotics, remote control and teleoperations; and how human factors and ergonomics can be used to improve health and safety. Other ongoing work investigates the environmental impacts of harvesting and how they can be mitigated.

The industry has been working through the Forest Growers Levy Trust[ii] and Ministry of Primary Industries on a Steepland Harvesting Primary Growth Partnership research programme. This is now entering a second phase called "Forestry Work in the Modern Age – Te Mahi Ngahere i te Ao Hurihuri". This phase has three major aims: to create value, improve profitability and enhance sustainability across the forestry value chain through automation. It aims to do this by developing a new integrated forestry value chain from harvest to market, incorporating new technologies that will promote both industry and Government interests.

3.3.2 Wood quality, timber processing and products

Wood quality affects product quality. Timber should be stiff, stable, look good and be free of knots and other defects. Ongoing research is looking into:

- the effects of silviculture and genetics, assessment (and tools and statistical determination) of genetic variation, establishment, and early growth (pines and eucalypts);
- defining and measuring wood quality. An automated system for measuring a range of parameters from discs sawn from logs has been developed. Data from measurements combined with detailed information on silviculture and tree genetics can be used to make recommendations for increasing wood quality forest productivity;
- wood processing, including understanding drying behaviours, and modifying the properties of radiata pine and other timbers to improve strength, durability and appearance to expand the applications for wood products and the places they can be used;
- increasing the cost-effectiveness and performance of wood products, and new product innovation for the use in construction and manufacture; and
- building sustainably to maximise carbon storage and minimise emissions with timber-based materials.

3.4 THE BIOECONOMY AND ITS PRODUCTS

Woody biomass is a form of renewable energy that offers great potential for New Zealand to reduce its dependence on fossil fuels for heat and energy production. Woody biomass includes residues at: processing areas (landings); in the cut-over (harvest area); and in trees removed during thinning operations. Research into the recovery of biomass focuses on integrating recovery systems into active harvest operations to avoid impacts on the quality and quantity of recovered biomass.

3.4.1 Biofuels

The recent "New Zealand Biofuels Roadmap[7]" carried out by Scion, investigated the potential for large-scale biofuel production and its use within New Zealand as a way of significantly reducing our greenhouse gas emissions and improving energy security. It sought to understand: what a large-scale biofuels industry could look like in New Zealand; what available crops could be grown and where should

[ii] The Forest Growers Levy Trust (FGLT) is a statutorily endorsed forest industry organisation that manages the proceeds of the levy on plantation timber products coming from the forest.

they be grown; what technologies should be used to convert these crops to liquid fuels; which liquid fuels should be targeted; and what are the key considerations and implications in developing such an industry.

The Roadmap work showed that if growing biomass was limited to non-arable land, the most likely feedstocks would be forestry residues and fibre logs from existing and new forests grown and processed in Northland, the East Coast, the central North Island, and Nelson/Marlborough.

3.4.2 Bioproducts and the circular bioeconomy

Research into wood fibre processing is contributing to more efficient pulp and paper manufacturing, fibre use in wood-plastic composites, and preparing into biorefinery feedstocks that can substitute for petroleum-based products. A key area of focus is the use of lignin from trees to make new biopolymers, and fermenting the cellulose component to microbial bioplastics.

Circular economies minimise resource input and energy leakage, and use waste streams as resources. A circular bioeconomy focusses on converting renewable biological resources, including waste streams, into bio-based products. Ongoing research investigating the use of side and waste streams from the forest, agriculture and other sectors as feedstocks is developing bioproducts that can compete with petroleum-based counterparts, not only on sustainability criteria, but also on enhanced performance and novelty.

Wood fibre and bioplastics have a number of applications, such as in packaging, which will help grow New Zealand's circular bioeconomy.

3.5 POPLARS AND WILLOWS

Agroforestry research has shown a reduction in animal productivity, adverse effects on wood quality and pasture production when radiata pine is being used[8]. These results have changed practise to utilising poplar and willows for agroforestry, which have shown to be better suited and have a stabilising effect on erosion prone pastoral hill country. Relevant research has focused on the role of poplars and willows in relation to:

- increased soil stability and decreased incidence of landslides;
- modification of livestock behaviour and reduction of pressure on waterways through the provision of shelter away from waterways;
- phytoremediation systems for the treatment of urban, farm and industrial wastewater, and landfill leachate; and
- interception of leached nitrate in shallow subsurface water.

3.6 GENETIC MODIFICATION

Genomic selection and breeding of radiata pine has a long history in New Zealand. Current breeding programmes are carried out by the Radiata Pine Breeding Company. This consortium focuses on research into the genetic improvement of radiata pine and makes improved genetics available to shareholders and customers through their GF Plus scheme.

In 2017, New Zealand researchers successfully completed the draft assembly of the radiata pine genome. This work will provide a basis for understanding the role that each piece of the genome plays and will lay the groundwork for genomic-based selection of trees that are precisely fit for purpose.

The development of gene editing technology for conifers is underway. This will enable targeted genome modifications to be made to produce traits, such as growth and sterility (which could be used to prevent future wilding pines), or alter wood composition, to enable easier processing of fibre of energy trees.

4 Growth and management of indigenous species systems

4.1 INTRODUCTION

There is increasing interest in establishing indigenous forests on marginal pastoral hill country in New Zealand to improve soil conservation, water quality and indigenous biodiversity.

New Zealand's indigenous forests have economic, environmental, cultural and recreational value. Although most of New Zealand's indigenous forests are on conservation land, a significant portion is privately owned[1]. Growth, management, business, and social drivers for forests will differ depending on whether the forest is planted or established via natural regeneration. Research on the two establishment / management systems is summarised below.

4.2 INDIGENOUS PLANTATION SYSTEMS

4.2.1 Establishment

Most research on planted indigenous species in New Zealand has focused on tōtara, and to a lesser extent, rimu and kauri. Research has focused on the ecology, establishment and management of these species. Compared to planted forest species, the amount of research is small.

Provenance trials have been undertaken for tōtara and rimu. These plantation experiments provide an understanding of how trees are adapted to different environmental conditions. For both species, variation has been shown to exist between provenances with respect to growth and form traits. However, the overall amount of research applied to identify provenance variation within indigenous species is small. Research effort and funding applied to provenance variation in tōtara is 5% of that of radiata pine. For kauri and rimu this figure is less than 1-2% of radiata pine.

Rates of seed production are known for several potentially important indigenous tree species. Flowering and seed production by rimu, tawa, and the beeches have been studied over many decades. To a lesser extent, this research exists for hīnau, miro, tōtara, kauri and southern rātā. Research on seed handling of tōtara, kauri, and rimu and beech has also been conducted.

Propagation research for indigenous species has mostly been small scale and focused on evaluating seed relative to other methods of propagation and testing pot systems. Tissue culture techniques have been investigated for mānuka and some *Metrosideros* species. Establishment methods for nursery-raised podocarps on forest, scrub, and open sites were investigated in the 1980s[2].

4.2.2 Growth and management

Growth curves and species-specific growth models for planted indigenous species only exist for kauri. Stand-level models of height, basal area, and whole-tree volume have been developed through research in growth and productivity of kauri in single species planted stands and mixed-aged second-growth natural stands[3,4,5]. This research is part of a program investigating the potential to establish kauri as a short rotation crop (80 years) through active silviculture management. Kauri has also been shown to respond positively to thinning in natural and planted forests, even after long periods of suppression. Similar results have been published from thinning experiments in natural beech forests. A kauri calculator[6] has been developed to enable growers to calculate the economic outcome from planted kauri, and to test various management regimes.

The current knowledge of silviculture and ecology - either in plantations, or in managed, naturally regenerating second-growth stands of tōtara grown for timber, has been reviewed.[4] However, no dedicated research for active improvement exists. Basic growth and yield models for tōtara have been calculated, but these are based on small and variable numbers of stands.[7] Research on the establishment of sample plots throughout the range of naturally-regenerating stands of tōtara on pastoral land in Northland is underway[8].

The ecological and silvicultural requirements for establishment and management of several indigenous species for timber production have recently been reviewed. This summary work includes past and current uses of species, propagation, early planting performance and wood characteristics.

4.3 INDIGENOUS FOREST SYSTEMS

4.3.1 Ecology and establishment

Large-scale reforestation using native seedlings is extremely costly, with costs ranging from $15,000/ha for bare-root stock through to $35,000/ha for container-grown stock. In many areas of New Zealand, the most cost-effective and ecologically resilient method to restore native forest is to simply allow successions to proceed. Large programmes of research exist on New Zealand forest systems and the natural regeneration of these.

Seedling growth and survival of native tree seedlings along environmental gradients at various latitudes throughout New Zealand, and across multiple substrates on which they establish, is well understood. This research has informed the development of models to predict future natural forest developments.

The National Vegetation Survey databank is managed by Manaaki Whenua and contains plots that document rates of secondary succession, with re-measurement intervals of up to 57 years (regeneration through kānuka in northern New Zealand). These data have been used to develop models and information about growth rates of native tree species along successions.

Predictive models of multiple ecosystem services, including erosion control, nitrate loss, and provision of clean water have also been developed (see Section 5). Through Manaaki Whenua's Emissions and Biodiversity Exchange programme, the measurement, quantification, and marketing of carbon credits from regenerating forests has been researched in depth. This programme couples carbon sequestration benefits to biodiversity benefits. A large network of permanent vegetation plots is still maintained and is a resource for further modelling work.

4.3.2 Growth and management

Regenerating indigenous forest systems requires effective risk management. Research relating to key risks is outlined below:

- **Weed spread and competition**: many secondary successions include non-native species, and early successional vegetation can be dominated by non-native species. It is unclear if naturally regenerating forests have greater resilience to non-native species than planted systems. Initial work indicates that nursery-grown seedlings of indigenous species lack the mycorrhizal communities allowing them to establish and compete against non-native weed species.

- **Fire risk:** many native species are highly flammable and can regenerate after fire (e.g. mānuka). Fire-adaptation in the native flora is overshadowed by that of the non-native flora, particularly in species such as gorse and wilding conifers that thrive in secondary successions. The flammability of many indigenous species has been quantified and these data integrated into spatial models of landscape fire risk. Long-term field studies quantifying post-fire vegetation recovery are maintained and used to model positive feedback cycles of flammability in various environments.

- **Disease risk:** natural regeneration allows for genetic variation to be maintained in populations, which is the most likely source for resistance to disease threat. This is currently being investigated in a myrtle rust programme that is screening *Myrtaceae* species for myrtle rust resistance. Studies on the genetic variation in indigenous plant species have been undertaken for a variety of species (e.g. mānuka, kānuka, rewarewa, kauri, and tōtara), building resources to understand local adaption and natural ecosystem resilience.

4.4 PRODUCTS FROM INDIGENOUS SPECIES

Current harvesting research focuses on harvest of natural/old growth forests. There is no research on harvesting indigenous species in planted stands.

Research into the feasibility and economic viability of sustainable silviculture for timber production from indigenous tree species has also been undertaken. It focuses primarily on podcarp trees.

Work has been undertaken on ways to salvage logs from podocarp forests, after periodic disturbance, through sustainable harvesting practices that deliver economic gains while maintaining the ecological integrity of the forests. This includes silver beech forests in Southland, podocarp salvage logging operations in central Westland, coupe harvesting of red/silver/hard beech in north Westland, and tawa harvesting in Te Urewera. This research also has a focus on post-harvesting seedling regeneration and market opportunities for timber products.

The wood properties of most indigenous tree species from natural forests are well known[9]. Few studies exist on wood properties of plantation-grown indigenous tree species. A preliminary investigation has been made into the solid wood properties and merchantable timber of plantation-grown New Zealand kauri[10].

Māori have studied the health implications of many of our indigenous tree species for centuries. More in depth research has been conducted on mānuka and kānuka, knowledge on the bioactive compounds from other indigenous tree species is less detailed, but has been studied for the following species: horopito, kawakawa, pukatea, koromiko, poroporo and houhere.

4.5 ECOSYSTEM SERVICES

Naturally regenerating and established indigenous forests underpin considerable economic value through diverse ecosystem services (see Section 8). Biophysical processes that support forest ecosystems (e.g. nutrient cycling and forest regeneration) have long been studied through work on forest dynamics, mast-seeding (production of seed on mass by a population of plants), soil formation, ecosystem resilience after disturbance, invasions biology, palaeoecology, and plant-soil feedback.

5 Growth and management of mixed species systems

5.1 INTRODUCTION

Mixed species systems include: mixtures of different exotic plantation species; mixtures of native species for plantation purposes; mixtures of native and exotic species; and the harvest of ‘byproducts’ or secondary products out of a forest system, such as truffles or understory plants.

Mixed species systems for plantation purposes are common in other countries. However, due to the favourable growth of radiata pine in New Zealand and a lack of serious threats to this monoculture system, mixed species systems have not been well researched here. Likewise, the use of understorey crops is of interest in general, but has not received a lot of attention. Other mixed systems, such as truffières, are currently being studied.

5.2 MIXED SPECIES TRIALS

Trials on mixing of different species (exotic and native) were established during the New Zealand Forest Service era, but many of these were never completed due to a loss of funding. In the 1950s and 1960s, enrichment plantings into cutover indigenous forests (saleable timber felled and removed) were established. These tested 19 exotic species, out of which *Acacia melanoxylon* (blackwood) was most promising. Follow up trials were initiated, but not continued in the long term. In the 1980s and 1990s, a series of enrichment plantings of native and exotic species into mānuka/kānuka scrublands were established. These trials were also discontinued and results from them are limited or incomplete. However, the original trial sites still exist. In the 1980s, studies were undertaken on performance of podocarps planted underneath *Pinus ponderosa* in a reverted cutover, and on performance of cluster planted rimu and kahikatea in selectively logged forests. Some preliminary studies on planting a mix of Eucalyptus/radiata pine mixes were also undertaken, though only seedling survival was assessed. Some initial or limited results are available for all of these studies. However, full growth or rotation cycles were never observed. No research exists on aspects of the full value chain of mixed species systems.

A recent study in China found that trees grown in an environment surrounded by different species produce more wood than those surrounded by trees of the same species[1]. These findings are explained by reduced competition for resources and improved microclimatic conditions. This includes positive interactions with different types of soil fungi that may not be found in environments where only a single species of tree is found.

5.3 UNDERSTOREY CROPS

Understorey crops are potentially valuable plant species that can tolerate the shade in planted forests. Selective understorey cropping on arable forestry land can utilise the space under trees to promote earlier financial returns and diversified products until the trees are harvested. A Ministry for Primary Industries funded Sustainable Farming Fund project investigated a range of understorey plants (goldenseal, kawakawa, pate) and analysed the crops for site suitability, potential market and economic return.

Ginseng is an understorey species of commercial interest, and growth trials have been established in various parts of New Zealand since the 1970s. Research on growth requirements and market analysis of ginseng under pines was undertaken between commercial companies and crown research institutes in the 2000s[2]. New Zealand Forest

Ginseng is now successfully commercially grown under planted forests, free from chemical spraying. Laboratory tests of these plants have shown very high levels of ginsenosides, the active compounds in ginseng.

5.4 NURSE CROPS

In forestry, a nurse crop is generally a crop of trees or shrubs that fosters the development of another tree species. This is usually by protecting the second species, during its youth, from frost, insolation, wind, and weeds. The shelter provided by the nurse canopy creates microclimate conditions that favour the establishment of intermediate and late-successional woody species with greater shade-tolerance.

Nurse crops may comprise single or multiple species native cover, frequently mānuka and kānuka, or mixtures, with exotic species such as gorse or tree lucerne. Trials were established on the East Coast of the North Island during the 1980s and 1990s, where hardwood seedlings such as tōtara were planted beneath existing vegetation[3]. Other work looked at establishing nurse crops on open pastureland prior to the eventual planting of hardwood timber species. It showed that native hardwood timber species can be successfully established where the aim is long-term specialist timber production. Many of these species will grow successfully outside of their natural range, given appropriate site selection and establishment practices. Their ecology makes them suitable for sustainably managing, as either single or mixed species, in even or uneven-aged planted stands where future harvesting will involve low-impact selection logging techniques.

5.5 HONEY AND BIOACTIVES

Current research on mānuka is mainly focused on honey. Through several programmes, high-value chemical compounds in honey have been identified, and both mānuka and kānuka medical products are now on the market. Some industry-driven research focuses on oil as a by-product.

Research into bioactives and flavour compounds from the native flora has been conducted[4,5], and there is a growing interest from Māori stakeholders in developing these industries.

5.6 TRUFFIÈRES AND OTHER EDIBLE FUNGI

About 50 truffières are productive in New Zealand at present, with many more being established, though not yet producing truffles. Many different tree species can be used as truffle host trees. In New Zealand, these have included: *Corylus avellanal* (hazelnut), *Quercus robur* (common English oak), *Quercus ilex* (holm oak), *Quercus cerris* (turkey oak) *Pinus pinea* (tone pine), *Pinus pinaster* (maritime pine) and radiata pine.

Truffle growing is reliable nowadays, although some species, such as *Tuber melanosporum*, present a higher risk than others. Detailed information about how to grow and inoculate truffle seedlings commercially is rarely published, mainly so that tree suppliers (e.g. in Europe or Australia) can protect their knowledge. Published research on inoculation experiments provides useful information. Within New Zealand, there is scientific capability and experience in inoculating truffle seedlings, and in pure culture inoculation of tree seedlings with other edible fungi, such as milk cap species (*Lactarius*)[6,7].

6 Māori Cultural Connection to the Forest

6.1 INTRODUCTION

Māori have an enduring collective memory of, and affinity with, the indigenous forest ecosystem. This affinity is evident in the connection between the physical realm of tangata and the atua realm of Tāne Māhuta, the guardian of the forest.

In some regions Māori still have a physical connection to the ngahere (bush, forest) which provides both a source of identity and a material culture based on and around it. This forest relationship is embodied in the concept of kaitiakitanga, and has been explored in detail with Tuhoe-Tuawhenua Trust[1].

In other areas, where indigenous forest cover has been lost, the connection to the forest is more spiritual than physical. Either way, it is important to keep this dynamic in mind when engaging Māori, as it provides the lens through which Māori see forestry and forests. To Māori, the forest, particularly the indigenous forest – *te uru rākau* – is not just a functional asset. It has a tapu, a sacredness to it.

6.2 MĀORI FORESTRY ASPIRATIONS

Recent flood events in Te Tairāwhiti and elsewhere illustrate the risks of a clear-fell approach to plantation forestry. These events have raised Māori concerns around forestry. This has come at a time when the government is encouraging forestry as a land-use as well as proposing a range of changes to the Emissions Trading Scheme (ETS). In addition, the Treaty settlement process and greater involvement of Māori land owners in the forestry sector more generally has, in recent years, resulted in interest from Māori in a wider range of forestry options. In a 2014 report, *Mānuka Hēnare* notes that:

> "as the recognition grows that forestry is a longer-term option that fits well with Māori aspirations in terms of spiritual, environmental, social, cultural and economic needs, so too does a lingering dissatisfaction with current forestry practices"[2].

Hēnare also notes that, as Māori move to more directly participate in decisions regarding how their land is used, they are increasingly calling for: (a) novel research around a new vision of forest species diversity and (b) a greater harmonising of exotic species with endemic native species[3].

There has been an increase in requests from Māori land owners wanting to better understand the relative benefits of single species plantation forestry compared with permanent cover mixed indigenous forestry and the co-benefits (ecosystem, cultural, biodiversity and carbon offset premiums[4] etc.) that this form of forestry can provide.

In addition, the Northland Totara Industry Pilot[5] is exploring how a local Māori community might establish and maintain a sustainably managed and locally operated tōtara forestry sector in Northland.

This desire amongst Māori communities to consider more novel approaches to forestry is captured in a recent study in the Waiapu catchment in Te Tairāwhiti[6]. In this study, land owners identified a preference for permanent mixed indigenous forestry (including species such as: mānuka; kānuka; tōtara; matai; pūriri; harakeke; and kawakawa, and the associated benefits of: honey; erosion control; medicinal/cosmetic uses; fibre; kaupapa Māori; timber; and oil). This was preferred to the more conventional, higher economic return, single species exotic plantation forestry.

Another recent review paper[7] argues that sustainable forest management systems (such as Forest Stewardship Council (FSC)) inevitably reflect western cultural values regarding a society's relationship with nature. The authors describe how Māori adapt sustainable forest management systems (such as FSC) to suit their own sustainable values.

Research on this to date is rudimentary and more work is needed to better understand this emerging desire amongst Māori to consider alternatives to conventional exotic plantation forestry. The Primary Sector Science Roadmap acknowledges that Māori need access to science and research that genuinely understands and meets the distinctive requirements of Māori kaitiakitanga-based approaches in the primary sector[8].

6.3 OPPORTUNITIES ON MĀORI LAND

Māori freehold land represents about 1.4 million ha of Aotearoa[9]. An analysis of 2017 Māori Land Court data indicates that about 70% of this land is hilly to steep-land, and about 60% of this can be considered erosion prone and marginal. However, large tracts of Māori land are already covered in permanent native forest (around 460,000 ha) and around 180,000 ha in plantation forest (mainly radiata pine) with a further 196,000 ha in scrub/shrubland[10].

MPI-funded Sustainable Land Management and Climate Change research on Māori land, combined with new 2017 figures using the Land Use Map definitions and layers from the Land Use Carbon Analysis System (LUCAS, see Section 5) show opportunities for some type of forestry or regeneration on about 500,000 ha of available Māori land in Aotearoa[11]. Around 475,000 ha, or 35% of Māori freehold land, is eligible for Kyoto forest and was not in forest in 1990. About 52,000 ha, or 3.8%, is available for reversion to forest (see Figure 1 for the Gisborne Region eligibility map)[12]. This type of data, interpretation, and analysis provides opportunities for discussion and planning around carbon farming, afforestation/reforestation of natives and exotics, sustainable indigenous forest harvest, biodiversity enhancement, and other low impact activities such as rongoā, bioactives, nutraceuticals, and tourism within the realms of Kyoto - on Māori land[13].

The knowledge from this research will provide alternatives and options on Māori land, generating a broader range of economic, social, cultural, and environmental benefits (e.g. to fulfil cultural aspirations, ecosystem services, biodiversity offsets). Evidence-based targeting of trees provides significant benefits in many regions by accurately identifying un-forested (in pasture/grassland/poor vegetative cover) erosion prone, marginal Māori land (not in forest at 1990), such as in the Gisborne-East Coast, Northland, inland Taranaki /Whanganui, and northern South Island. In earlier studies on mānuka regeneration[14], carbon sequestered/hectare/year was between 7-10 tonnes. It is estimated that the return from native forest alone on Māori land could equate to tens of millions of dollars (even at $25 tonne CO^2 equivalent) from just carbon farming alone. The latest carbon sequestration research and modelling of native forest shows relatively high sequestration rates and returns up to and beyond 50 years[15].

6.4 PROPOSED CHANGES TO THE ETS – HIGH IMPORTANCE FOR MĀORI

The current proposed changes to the ETS include a move to encourage permanent forestry as a more attractive option for land owners by making it easier to access the potential revenue stream from New Zealand Units. For the reasons outlined above, this proposal is very significant for Māori because they own much of the land suited to such forestry. Moreover, it is this type of forestry that Māori are beginning to consider, given the additional environmental and cultural benefit it brings.

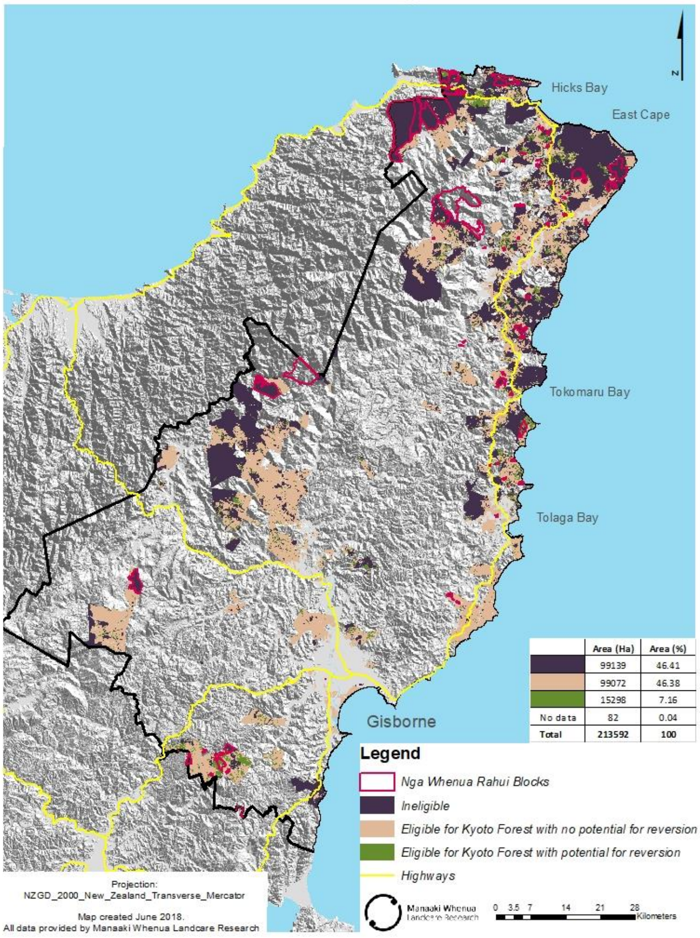

Figure 1. Māori land eligibility for Kyoto forest in the Gisborne region.

7 Optimisation of Land Use/Land Use Decision Tools

7.1 INTRODUCTION

Simplified representations of reality, or models, are often used to identify options and solutions for addressing detailed, complex problems. Predicting the effects of changing land use is one such problem. A range of land use decision tools have been developed to anticipate and diagnose problems, estimate the cost of meeting environmental targets, and simulate different policy options and their likely impacts.

7.2 LAND USE MODELS

A number of models and decision support tools have been used to investigate land use and land use change in New Zealand. A comprehensive overview of these has been compiled elsewhere[1,2], and select key land use models are discussed briefly below.

7.2.1 Data related to land use decisions

Data related to forestry land use decisions include permanent sample plots, the Emissions Trading Scheme (ETS) Field Measurement Approach, Land Use Carbon Analysis System (LUCAS), a collection of swaths of LiDAR over planted forests, and research trials and observational studies within planted forests and other locations. Non-forestry data sources include geology, soil, vegetation, land use, climate, and economic data points, among others.

7.2.2 LURNZ

Land Use in Rural New Zealand (LURNZ) developed by Motu is a computer model that simulates land-use changes at a fine spatial scale (500 m x 500 m) over New Zealand. The model produces dynamic paths of rural land-use change, and maps of annual rural land use change nationwide.

LURNZ empirically investigates the potential impacts of policies that may alter land-use decisions. When combined with additional components relating to specific issues (e.g. LURNZ-climate modules that look at the effects of various emissions trading policies), the model is able to compare environmental policies that relate to land use and affect the environment in quantifiable ways.

LURNZ models land use in dairy, sheep/beef, plantation forestry, and scrub (regenerating native forest). It treats other rural uses, conservation land, and urban areas as exogenous. It also spatially allocates land use change, simulates dairy and sheep/beef production, and simulates greenhouse gas (GHG) emissions and sequestration patterns.

LURNZ has been used in forestry applications, including investigating how sheep and beef farmers would respond to increased carbon prices by abandoning previously grazed pasture or establishing plantation forests on marginal land.

7.2.3 AgInform®

The Integrated Farm Optimisation and Resource Allocation Model (AgInform®)[3,4,5,6], developed by AgResearch, integrates biological data from each land management unit (LMU, defined by similar natural resources and management practices) within the farm. It uses LMU information to identify the mix of production enterprises and management regimes that maximise profit for the business.

AgInform® has been applied to pastoral agriculture, but has not yet incorporated forestry as a land use option. However, it has been used to evaluate on-farm investments, such as planting of a forestry block and sowing a multi-year forage crop, on hill country sheep and beef operations.

7.2.4 NZ-FARM

The New Zealand Forest and Agricultural Regional Model (NZ-FARM)[7,8], developed by Manaaki Whenua, is a catchment-scale spatial model for considering the impact of different policies, resource constraints and prices. It can accommodate arable, horticulture, dairy, sheep/beef, pig, deer, native forest, plantation forest, and scrub land uses. NZ-FARM calculates optimal land use and production under a given policy. It also estimates of nutrient leaching and greenhouse gas emissions. Model inputs include maps of initial land use, land use capability class and soil type, input prices, input use by land use and land management, and output prices.

7.2.5 ARLURNZ

The Agent-based Rural Land Use New Zealand model (ARLUNZ)[9,10], developed by Manaaki Whenua, is a catchment-scale spatial model for considering the response of land owners to different agricultural policies. It extends the modelling of NZ-FARM to allow for the individual decisions made by farmers who differ in their attributes, preferences, behaviour and response to policies over time. ARLUNZ considers the following land uses: arable, dairy, sheep/beef, indigenous vegetation, plantation forest; and scrub. It produces estimates of changes in catchment profitability, greenhouse gas emissions, nutrient loss, management practices, and land use over time.

7.2.6 Forest Investment Framework

The Forest Investment Framework (FIF), developed by Scion, is a modelling framework that informs strategic level planning objectives for a number of radiata pine future forestry regimes[11]. FIF performs a spatial economic analysis of future radiata pine forests in New Zealand. It draws on mapping data to locate potential new forests, accounting for factors such as current land use, climate, and soil type, as well as economic factors, such as cost of land, management costs, roading, carbon credits, and log grade prices. These combined land and economic criteria provide information on the viability of converting pasture to forestry under a range of potential radiata pine-based afforestation scenarios.

7.2.7 Sustainable Land Use Initiative (SLUI)

The Horizons Regional Council Sustainable Land Use Initiative (SLUI)[12,13] is a vehicle for implementing sustainable land management at farm-scale across the Horizons region. The Whole Farm Plan is a mechanism for engaging with farmers to identify the most at risk land on their farm and implement erosion mitigations. As at June 2018, more than 700 farm plans have been developed, covering more than 500,000 hectares. Implementing SLUI has reduced sediment and phosphorus loads in the region's rivers and improved water visual clarity.

7.2.8 Land and Environment Plans (Beef + Lamb NZ)

Beef + Lamb New Zealand's Environment Plans cater for different farm systems and different regions' requirements. They enable farmers to assess and record a farm's land and environment resources, and identify any environmental risks. This information allows farmers to determine how issues will be managed and the timeframes for doing so.

7.2.9 OVERSEER

Overseer[14] farm analysis is New Zealand-based software that calculates the flow of all seven major farm nutrients (nitrogen, phosphorus, potassium, sulphur, calcium, magnesium, and sodium), as well as acidity for pastoral blocks, to provide a full picture of the farm's nutrient health and estimates any loss of nutrient from the farm system. It also delivers greenhouse gas emissions and energy reports. Overseer is being adapted continuously in response to external drivers and new science being available. Agroforestry requirements are currently being improved in the model.

7.2.10 Other models

Genetic algorithms are computer science based tools that generate high-quality solutions to optimisation and search problems. These algorithms have been used to identify optimal land use options. In New Zealand, this approach has been used to model land use solutions over 50 years for a 1500 ha farm with 315 paddocks[15]. The model aimed to maximise: sawlog production; pulpwood production; milk solids; beef; sheep meat; wool; carbon sequestration; water production; income; and earnings before interest, taxes, depreciation and amortisation. It also aimed to minimise: costs; nitrate leaching; phosphorus loss; and sedimentation[16].

Researchers are also beginning to use agent-based simulation models to model the decisions of land owners over time in response to signals like product prices and regulations. In one application of this technology, researchers investigated impacts of nutrient caps and mandated farm practices in the Southland region on its economy and environment[17].

8 Management of biotic and abiotic risks

8.1 INTRODUCTION

New Zealand's planted and natural forests are vulnerable to biotic risks (e.g. pests, weeds, and pathogens) and abiotic risks (e.g. wind, rain, and fire). Due to New Zealand's relative geographic isolation, many potential pests and diseases have not yet reached us. However, there is a persistent risk that new pests and diseases may arrive, damage our exotic and native forests, and negatively impact our ability to export forest products.

8.2 BIOTIC RISKS

8.2.1 Exotic planted forests

Biotic risks to the New Zealand planted forest estate, and the impacts of such risks, are a huge focus for our forest owners and growers. Research into management of the risks and forest health is being funded through the Forest Growers Levy fund, which often co-invests in Ministry of Business, Innovation, and Employment Endeavour programmes. Forest Growers Levy funding also supports surveillance, diagnostics, and reference databases.

Previous research has focused on: *Armillaria* (root rot); bark beetles and wood borers; *Nectria* (flute canker); unwanted organisms and risk analysis; and pest and diseases of *Eucalyptus* species, Douglas-fir, and other minor exotic tree species. Current research programmes include:

- **Healthy Trees, Healthy Future -** This programme aims to improve knowledge of diseases caused by pathogens of the *Phytophthora* species, which can affect indigenous, exotic, and orchard trees.

  The research uses a systems biology approach to understand tree responses to pathogen attack, including how the pathogen infects the tree and tree defence mechanisms. From these findings, it should be possible to select for broad resistance to *Phytophthora*, and/or improved genetic tolerance to improve the overall resilience of New Zealand to new *Phytophthora* biosecurity threats.

- **Needle Diseases -** This programme aims to understand and mitigate the effects of needle diseases on radiata pine. The objective is to improve forest health by an improved understanding of foliar diseases, including mitigation options.

  Work to date has found that copper has the potential to control red needle cast (caused by *Phytophthora pluvialis*), an especially significant finding, as copper is already used to control Dothistroma needle blight in pine plantations. Radiata pine showing resistance to red needle cast have also been found, giving a good foundation for research into host resistance.

- **Bioprotection Research Programme -** This programme aims to establish a long-term symbiotic relationship between radiata pine and beneficial microbes. The main focus is to induce systemic resistance against foliar diseases by using endophytes and elicitors (substances that stimulate a defence response). Induced resistance can effectively 'immunise' trees from a variety of diseases/disorders. It causes a broad-spectrum activity response by the plant, analogous to vaccination.

8.2.2 Indigenous forests

Previous research on biotic risks to indigenous forests has focused on: bark beetles and wood borers in beech; effects of pests and pathogens on biodiversity; vulnerability of native forests to exotic pests and pathogen attack; and pests and diseases of indigenous tree species, such as beech, tōtara and mangeao.

Kauri

Kauri dieback, caused by the soil-borne pathogen, *Phytophthora agathidicida*, is killing trees in many kauri forests. Research undertaken over the past nine years has concentrated on determining the taxonomy, lifecycle, relationships, and pathogenicity of the pathogen. Research has improved diagnostics, detection and surveillance, but further work is required to enable more effective and efficient management tools and strategies, as well as to investigate risk pathways. Research has been undertaken into: the use of phosphite to halt the disease; oospore deactivation; biological control; and track management as a strategy to control humans as a vector. Work on resistance in kauri and alternative hosts is underway but needs further investment.

Myrtle rust

Myrtle rust is a fungal disease that affects *Myrtaceae* species. This includes iconic New Zealand plants such as pōhutukawa, mānuka, and rāta, as well as commercially-grown species such as *Eucalyptus*. Myrtle rust arrived in New Zealand in 2017 and the impact on the wide range of endemic and exotic *Myrtaceae* species found here is largely unknown. In the past year, MPI has commissioned a $4.5 million research programme made up of more than 20 specific projects including: understanding social licence and community involvement; Te Ao Māori implications; host susceptibility; genome sequencing; seed banking, and operational tools such as mapping hosts; surveillance tools; breeding frameworks; and chemical control options.

8.2.3 Biosecurity

Better Border Biosecurity

New Zealand's plant-based border biosecurity research is largely coordinated by Better Border Biosecurity (B3), a collaboration between Plant & Food Research, AgResearch, Scion, Manaaki Whenua, Bio-Protection Research Centre at Lincoln University, and the Ministry for Primary Industries, Department of Conservation and New Zealand Forest Owners Association. B3 delivers science-based solutions for supporting and protecting the international competitiveness of our export industries, and protecting our unique terrestrial ecosystems. Examples of recent research programmes include:

- **Tools informing the risk of establishment** - This programme includes a suite of climate matching software tools that have been developed and partly incorporated into MPI's Emerging Risk System, providing high resolution climate suitability maps for the rapid assessment of the likelihood of alien plant pests and diseases to establish in New Zealand, including their expected distribution.

- **Informing international biosecurity policy** - This programme includes research on quantifying the risks, benefits and costs of potential mitigation measures for 'hitchhiker pests'. The research is ongoing and will inform international sea container standards.

- **Innovative spot spraying technology** - This programme includes the development and effective use of novel aerial spot spaying approaches in several eradication programmes (for example….). These reduce off-target application that occurs via spray drift, thus providing an essential tool for invasive species management in urban and semi-urban environments.

Biological Heritage National Science Challenge

The Biological Heritage National Science Challenge aims to reverse the decline of New Zealand's biological heritage by protecting and managing native biodiversity, improving biosecurity, and enhancing resilience to harmful organisms. The Challenge includes research on ways to reduce rates of incursion or establishment by foreign invader species, and to enhance and restore the resilience of vulnerable ecosystems to prevent biodiversity loss and mitigate the effects of global change. Examples of current research projects relevant to forest biosecurity are:

- **Biosecurity network interventions** - Research in this project focuses on the relative roles that four different human-assisted networks, both individually and together, may play in the spread of pests, weeds, and pathogens (Plant nursery network; Livestock transport network; freshwater recreational user network; natural area visitor network).

- **Community control of kauri dieback: Tiaki mo kauri** - This is developing a programme to enable scientists, communities and mana whenua to work together on the remedial treatment of kauri trees.

- **Stopping kauri dieback in its tracks** - This project is investigating disease-fighting science solutions by combining a biochemical approach with Mātauranga Māori (Māori knowledge).

- **Māori solutions to biosecurity threats and incursions to taonga species (Patua riha rāwaho)** - This research is investigating the protection of taonga species from biosecurity threats and incursions (e.g. pathogens, pests, and weeds) using a combination of contemporary science and mātauranga Māori.

- **Using mobile technology to protect New Zealand from biosecurity threats** - This programme is developing an enduring and flexible model for a fast, easy-to-use system for identifying, reporting, and prompting immediate and appropriate responses to, plant and animal pests.

Pest Eradication in Urban Areas

New insect pest and pathogens are most likely to arrive in New Zealand via seaports and airports, and first establish in the urban areas close to these entry points. The Ministry of Business, Innovation, and Employment (MBIE) Endeavour-funded Pest Eradication in Urban Areas programme is developing new methods of detecting and eradicating pests in these sensitive areas that will cause a minimal disruption to local communities. Research themes are:

- **Alternatives to broadcast aerial spraying**.

- **Active surveillance and rapid detection of new pests** – This theme focuses on developing new ways of actively seeking pests, including using unmanned aerial vehicles and remote sensing for surveillance and rapid detection of pests in urban areas.

- **Community engagement** – This theme focuses on developing tools to help those involved in urban pest control programmes to engage with local communities, including Maori, before and during pest control activities.

8.2.4 Surveillance and diagnostics

New Zealand has a well-developed High Risk Site Surveillance system as well as a recently re-designed national Forest Biosecurity Surveillance scheme. Diagnostic testing of woody plants takes place in the Forest Health Reference Laboratory at Scion.

In addition, national collections and databases are maintained to assist with identification of potential pests and diseases and underpin research. These include: the Forest Health Collection; the National Forestry Herbarium; the International collection of microorganisms from plants; the NZ Fungarium; and the Allan Herbarium.

8.2.5 Market access

The presence of pests on export products can prevent their entry into their destination country. To ensure New Zealand can access overseas markets, it must be shown they are pest free. For example, when red needle cast was discovered, it was necessary to prove the infectious organism could not be transported on export logs.

Methyl bromide gas is used to fumigate export logs to kill a range of insect pests. Methyl bromide is an ozone-depleting compound and the New Zealand Environment Protection Authority have banned its use by 2020. A research programme to find a replacement for methyl bromide is being undertaken by Stakeholders in Methyl Bromide Reduction (STIMBR). This research programme includes: methyl bromide destruction technology; potential alternate chemical fumigants; reduction in methyl bromide fumigation rates; proof of concept for joule heating technology; methyl bromide recapture and debarking options.

8.3 ABIOTIC RISKS

Abiotic risks to the forest system include frost, drought, flood, lightning, salt scorch, nutrient deficiency, fire, animal damage, and wind throw (trees uprooted or broken by the wind). Abiotic risk patterns and their effects are expected to change with climate change. For some parts of New Zealand, climate change is predicted to cause more extreme wind and rainstorms which may increase damage to forest systems. Predicted higher temperatures will likely result in an increased risk of fire.

8.3.1 Wind

Severe winds breaking and uprooting trees can cause considerable losses for forest growers. Extreme winds are predicted to become even more frequent as a result of climate change. Research into the management of wind related risks considering factors such as soil type, species, silviculture activities, and rotation age. This is based in part on understanding the complex physical process of wind flow over forested landscapes, which is helping to understand the factors that contribute to wind damage. Wind flow is also important in other aspects of forest management, including pollen dispersal, spray management, wilding pine spread, and fire risk. However, research in this area is characterised by inconsistent methods and poor species and spatial coverage. The role of wind damage in New Zealand forests has focused on *Nothofagus* (beech) forests and plantations of exotic trees, and few studies have investigated long term dynamics following wind disturbance events[1,2].

8.3.2 Fire

Wildfires are expected to become more frequent and extreme as climate change increases temperatures and drought in some areas. Extreme fires are highly dangerous and unpredictable. Current management strategies cannot suppress these fires, and scientists are working on new models, decision support tools, and methods to better protect our natural environment, primary producers, vulnerable communities, and taonga species.

A current fire research programme is managed through the Fire and Emergency New Zealand. Its main focus is to increase knowledge of fuels and fire behaviour, with a strong focus on the development and improvement of the New Zealand Fire Danger Rating System. These research programmes include:

- **Preparing New Zealand for extreme fire** - This five-year programme is challenging the existing understanding of fire behaviour and aiming to enable New Zealand to identify, mitigate and adapt to the threat of extreme fires.

- **Resilience to Natures Challenges National Science Challenge "Resilience to wildfires"** – This three-year project investigates the shared responsibility, development of community-led protection plans, and community engagement for wildfire resilience.

These major programmes build on more than 25 years of rural fire research in New Zealand, including previous MBIE, Sustainable Land Management and Climate Change, and end-user funded projects.

8.3.3 Wilding pines

Wilding conifers have become an issue for certain areas of the country. If left to spread, they can become a pest - infesting farmland, native ecosystems, and water catchments. A large national programme is currently underway to manage the spread and investigate impacts and new management options of wilding conifers. Two current research programmes include:

- **Winning against wildings** - This programme looks at management strategies that integrate ecology, management and modelling and also investigates options such as developing sterile pines.

- **Beyond Conifer Control** - This project looks at herbicide persistence and if herbicides will pose a long term problem as well as restoration options and how plant succession can be initiated after control has taken place.

9 Climate change, adaptation and mitigation, ETS

9.1 INTRODUCTION

New Zealand is influenced by a number of international policies and climate change accords, including:

- the United Nations Framework on Climate Change COP 21 Paris Climate Change Agreement target;
- the Climate Change Response Act;
- the Intergovernmental Panel on Climate Change;
- the Convention on Biological Diversity;
- the World Business Council for Sustainable Development; and
- the United Nations Sustainable Development Goals.

Forestry is increasingly seen as a potential mitigation to the impacts of climate change and important for ensuring New Zealand meets its climate change obligations.

New Zealand is largely ahead of the rest of the world in terms of research on the inclusion of forestry in an Emissions Trading Scheme (ETS). A reasonable body of research exists on carbon sequestration, the role of trees in climate change, and some of the potential risks and benefits of climate change on New Zealand's forests.

9.2 NEW ZEALAND ETS

The New Zealand ETS is the government's principal policy relating to climate change. The New Zealand ETS puts a price on greenhouse gas emissions and is intended to create a financial incentive for businesses to invest in technologies and practices that reduce emissions and enhance carbon sinks. It also encourages forest planting by allowing eligible foresters to earn New Zealand emission units (NZUs) as their trees grow and absorb CO_2. Forestry entered the New Zealand ETS on 1 January 2008, providing an incentive to establish and manage forests in a way that increases carbon storage. An overview of forestry's place in the New Zealand ETS has been summarised in a Motu working paper[1].

An integrated Land Use in Rural New Zealand (LURNZ) model has been used to analyse the effect of various New Zealand ETS scenarios on land use, emissions, and output in a temporally- and spatially-explicit manner[2]. The effect of carbon price on forest management, afforestation, deforestation, and likely location of planting and harvesting has also been modelled[3].

The New Zealand ETS is predicted to lead to increased afforestation and rotation age, and decreased silviculture and deforestation. According to the LURNZ model, a $20 carbon price or higher would lead to an increase in carbon sequestration by the forestry sector, driven mainly by afforestation on lower fertility sites. The potential impact of carbon trading on forest management (including whether to establish new forest, choice of species and silviculture, and forest rotation length) in New Zealand has been modelled[4]. The effect of the ETS on forest valuation has also been modelled for New Zealand planted forests[5].

9.3 CARBON SEQUESTRATION

Carbon sequestration research in New Zealand’s forests has been reviewed for planted forests, radiata pine, and the inventory of carbon stock in New Zealand's post-1989 planted forest[6,7,8].

Tables to help calculate the amount of carbon stored in forests that are registered in the Emissions Trading Scheme (ETS) have been published as “Look-up tables” for forestry in the ETS” on the MPI website[9]. These are well developed for radiata pine and Douglas-fir, but less so for other species. Research is in progress to gather the best available data to improve or create statistical models for the carbon sequestration capacity of less common species (including several exotic and indigenous forest species). Results from this work will provide look-up tables of growth and productivity for each targeted species/forest types, leading to more certainty in the accuracy of carbon storage for less common species.

9.4 THE ROLE OF TREES IN CLIMATE CHANGE

The Royal Society of New Zealand report: *Transition to a low-carbon economy for New Zealand. Wellington, New Zealand* [10] provides a high-level summary of the role of forestry in New Zealand and the potential impact of forestry on greenhouse gas emissions.

The Parliamentary Commissioner for the Environment (PCE) 2016 report: *Climate change and agriculture: Understanding the biological greenhouse gases*[11] also provides information on the role of trees in offsetting greenhouse gas emissions. The PCE report describes the rate at which regenerating forest can offset carbon emissions from sheep, beef or dairy operations. It discusses carbon accumulation in radiata pine plantations, carbon forestry, and the ETS.

The *Low-emissions economy: Draft report*[12] presented to the New Zealand Productivity Commission in April 2018 includes a modelling exercise of the potential impact of several strategies to reduce greenhouse gas emissions. The report suggests that reducing New Zealand’s emissions will require three key drivers: the expansion of forestry; the electrification of transport; and changes to the structure and methods of agricultural production.

9.5 IMPACTS OF CLIMATE CHANGE ON FORESTS

9.5.1 Risks

Under the projected climate change scenarios, forestry will have to adapt to a variety of climatic changes including increases in temperature, changes in rainfall and the wind environment.

A 2012 review paper[13] summarised the research to date on climate change drivers, how they may impact production forests, the scope of New Zealand research and the anticipated effect of climate change. It covered the temperature impacts on forest productivity, atmospheric CO_2 effects on generic tree productivity, interaction of temperature and CO_2, effects of precipitation on generic tree productivity, drought and future forest productivity under expected climatic changes.

A large body of work[14] has been completed on modelling the effect of climate change on: soil temperature; water shortages; extreme rainfall events; and CO_2, levels. It has also examined how these factors impact on: wood productivity; wood properties (especially density); the land area available for plantation forestry; and biotic and abiotic risk. Models indicate that productivity gains resulting from a higher CO_2 environment will likely result in marked increases in the risk of wind throw, due to trees becoming taller and narrower. The average season length with 'very high and extreme' climatic fire risk is expected to increase by 71% by 2040, and by 83% by 2090[15].

Research[10] shows that climate change will impact insect pests, weeds, and pathogens. Currently, the most significant biotic disturbances to New Zealand plantations come from two needle cast diseases - for which climate projections show slight increases or decreases, depending on the disease and region. Although insect pests currently cause little damage to New Zealand plantations, research indicates that damage may increase in the future with projected increases in insect pest populations and host susceptibility. Potentially invasive weedy and damaging tree species (e.g. *Acacia* spp.) are suggested to expand their range under climate change and compete more strongly with plantations. Climate change is likely to have a marked impact on biodiversity within planted forests. This change is due to changes in management practices, species mixes and distributions, and afforestation/reforestation/deforestation strategies.

The risks and impacts for plantation forestry in New Zealand under climate change have been reviewed[10]. These include risks and impacts related to: site selection; species selection; establishment; silviculture and forest management; fire management; pest and disease management; weed management; forest operations (e.g. infrastructure and harvesting); estate planning; productivity risks; and ecosystem services. The same study describes the barriers of forestry adaptation to climate change, which include: a low level of awareness; lack of understanding of risks, impacts, and adaptation planning; and a lack of tools.

Real Options Analysis is a tool borrowed from the finance industry that has been used to plan infrastructure projects (over a 100-year investment timeframe) for the New Zealand forestry industry, and may help mitigate impacts of climate change.

9.6 CURRENT SUSTAINABLE LAND MANAGEMENT AND CLIMATE CHANGE RESEARCH

The Ministry for Primary Industries Sustainable Land Management and Climate Change (SLMACC) Research Programme is a key funder for climate change research of relevance to forestry. Current projects include:

- investigating the economics and carbon impacts of transitioning clear fell planted forests to permanent cover forests on severely erosion prone steep lands;
- testing the New Zealand ETS to facilitate native forest regeneration on Māori land;
- improving growth models for less common species and forest types for ETS carbon look-up tables;
- identifying the best options for land use following radiata harvesting in the Gisborne District; and
- evaluating profitability and future potential for low emission productive uses of land that is currently used for livestock.

10 Environmental and ecosystem considerations

10.1 INTRODUCTION

Forests play a vital role in New Zealand's economy. They also store carbon, preserve soils, and nurture a diversity of species. These non-timber benefits are known as 'ecosystem services'.

Identifying and calculating the true costs and benefits of different ecosystems and land uses is one of the main objectives of an ecosystem services approach to decision making. Information from ecosystem services analyses can be used to improve land management decisions, as they can help account for both tangible and less tangible benefits over time.

10.2 ECOSYSTEM SERVICES PROVIDED BY INDIGENOUS AND PLANTED FORESTS

A review of ecosystem services provided by both indigenous and planted forests in New Zealand has been carried out[1]. It summarises studies that have examined ecosystem services for general recreation, biodiversity (via possum control), indigenous biodiversity enhancement, recreational hunting, and water quality.

Within the broader literature, four types of ecosystem services are generally examined – provisioning, regulating, cultural, and supporting services. These, and their role in relation to forest science, are discussed below.

10.2.1 Provisioning services

Provisioning services are tangible and direct products extracted from forests to be used or sold, such as logs, wood, fibre and fuel, or heat and power. Provisioning services also include crops such as ginseng and kawakawa, which may be planted or developed in the forest. Most ecosystem services research focuses on this area and is described in greater detail in other chapters of this report.

10.2.2 Regulating services

Regulating services include the ability of the forest to store carbon, improve water quality, enhance biodiversity and reduce the effects of floods.

An ecosystem services approach has been used to estimate the value of carbon capture in New Zealand forests compared to pastoral agriculture[2]. In this study, carbon accumulation, economic value, and potential uptake of a carbon farming management system that utilised native forest regeneration on set-aside land was modelled.

Replacing pasture with trees can decrease soil erosion rates by over 90% on land at risk of erosion, lowering the downstream risk of siltation, flood damage, or the costs of water purification. The value of avoided sedimentation through erosion control in New Zealand is estimated to be $6.50 per cubic metre of sediment[3].

The loss of ecosystem services from grazed pasture or from the same land planted under conservation forestry following an erosion event and recovery of services was modelled[4].

The Forest Investment Framework[5] is a spatial economic tool that has been developed to enable the assessment of key ecosystem services provided by planted forests in New Zealand. The framework has been used to estimate indicative values of carbon sequestration credits and avoided sedimentation of waterways.

10.2.3 Cultural services

Cultural services include social and cultural benefits and are provided by planted forests. They also include recreational opportunities, aesthetic enjoyment, spiritual enrichment, and biodiversity and conservation appreciation.

An ecosystem services approach was used to value some rare and threatened species living in our planted forests, including kiwi, karearea, and Hochstetter's frog[6].

Supporting services

Supporting services include the biological and physical processes in a forest that drive the other three services. Examples include soil formation, nutrient cycling, water regulation, and oxygen production.

A recent study quantified the value of a wide range of ecosystem services for the Ōhiwa catchment in the Bay of Plenty[7]. It covered multiple land uses (including native and exotic forest) and valued sixteen different ecosystem services for this area. The analysis of the possible scenarios has proven to be useful approach to discuss land-use changes and implications.

10.3 BIODIVERSITY IN INDIGENOUS AND PLANTED FORESTS

Biodiversity metrics are central to several environmental certification schemes, including: the Forest Stewardship Council scheme; Sustainable Forestry Initiative; the United Nations Food and Agriculture Organisation's plantation guidelines; and the Montreal Protocol.

Research has shown that biodiversity benefits can accrue from well-managed exotic tree plantations, which can provide suitable habitat for some native plants and animals, including threatened species. Although intensively managed plantation forests do not provide the same quality of habitat that supports the same high diversity of species found in primary forests, plantations can provide opportunities for some species that are not available in other land use options[8].

10.4 IMPACT OF PLANTING AND HARVESTING ON HYDROLOGY

With regard to the impact of planting and harvesting on hydrology, work has been carried out on:

- the hydrological impacts of converting native forests and grasslands to pine plantations in the South Island;
- the hydrological impacts of converting pasture and gorse to pine plantation; and
- forest harvesting in Nelson; and
- comparative sediment yields from plantation forestry and pastoral farming in coastal Hawke's Bay.

Sediment yield response to large storm events and forest harvesting have been quantified for the Motueka River[9]. The hydrology and related changes after harvesting native forest catchments and establishing radiata pine plantations have also been quantified via water balance and changes in streamflow after harvesting[10].

10.4.1 Level of erosion and mitigation during harvesting

All of New Zealand is susceptible to erosion. Regional susceptibility relates to several factors, mainly geological setting, and the incidence of rain events that cause erosion. Hill country erosion processes, mitigation options, social learning, and their long-term effectiveness have been summarised in a review paper[11].

Vegetation is the primary tool to mitigate erosion in rural landscapes. The effectiveness of vegetation-based erosion control is highly variable, and none give 100% ‘control’. Forests provide protection against surface erosion, but are more effective in reducing the incidence of mass movement erosion (landslides, earthflows). The economic costs of hill country erosion and benefits of mitigation in New Zealand have been reviewed[12].

Riparian buffers and their vegetation composition can mitigate some effects of pine plantation logging on New Zealand streams[13]. Late-rotation exotic pine plantations can support very similar stream invertebrate communities to native forests, highlighting the benefit of retaining forested buffers along stream riparian areas to avoid harvesting impacts on stream habitat and invertebrate communities[14].

As LiDAR becomes more commonplace, the ability to detect and monitor erosion events will increase. Using unmanned aerial vehicles, LiDAR has been used to map erosion in planted forests that are otherwise difficult to find or to characterise from ground-based observation.

10.4.2 Impact on water quality from planting through to harvesting

The physical, chemical, and biological water quality attributes of surface waters in New Zealand’s planted forests have recently been reviewed[15]. The review covered: changes in water quality throughout the planted forestry cycle (from afforestation to harvesting); comparisons between water quality of planted forests and other land uses; and identification of knowledge gaps and opportunities for future research. Other studies[16,17,18] have examined the influence of large woody debris on channel morphology in native forest and pine plantation streams in the Nelson region, the effect of radiata pine logging on stream invertebrate communities in Hawke's Bay, and the effects of forest harvesting and woody debris removal on two Northland streams.

Research has been completed on the effect of forest road erosion on broader erosion and sediment flows. A case study on sediment production from forest roads in Queen Charlotte Forest and its potential impact on marine water quality in the Marlborough Sounds showed that sediment load tripled compared with adjacent locations that did not have forestry roads[19].

11 Economic considerations

11.1 INTRODUCTION

Economic models have been built that estimate demand of forest products in our major export markets. Regional-level economic impact studies for forestry have been largely undertaken by consulting firms that provide input to regional councils. Enterprise or catchment-level forestry economic models often include environmental variables and alternative land use options, such as pastoral agriculture.

11.2 REGIONAL ECONOMIC IMPACTS

Regional economic assessments for forestry have been carried out by a number of private consulting firms and independent researchers using a range of models, some of which are proprietary to their host organisations.

The New Zealand Forest and Agriculture Regional Model (NZFARM)[1,2], developed by Manaaki Whenua, helps decision-makers assess the potential economic and environmental impacts of policy scenarios on regional/catchment land use. The model maximises agricultural income across a region/catchment, accounting for a range of environmental impacts from land use and land-use change. NZFARM can currently track environmental outputs such as: greenhouse gas emissions from agriculture and forestry; forest carbon sequestration; water use; and sediment, nutrient and pesticide losses. The results for the regional/catchment agricultural economy can then be used to determine the wider economic impacts of a policy on the community. This model has also been adapted for national and smaller regional applications.

The Agent-based Rural Land Use New Zealand Model (ARLUNZ), also developed by Manaaki Whenua, is a spatially explicit agent-based economic model that accounts for farmer behaviour, such as effect of social and geographic networks or succession planning, on farmer decisions. ARLUNZ links to the NZFARM model to provide an assessment of land use change, farm income, and changes in ecosystem services or environmental parameters using cadastral boundaries.

A simple economic analysis was developed to assess the profitability of a representative dairy farm and a representative steady-state forest in the Central North Island to demonstrate the relative profitability of well-established enterprises[3].

The potential national level land use and forest management implications (e.g. alternative species, silvicultural regimes, and rotation lengths) of different carbon price scenarios have been explored using an econometric-process simulation model[4]. Profit maximising agents that choose between forestry and agricultural land uses were simulated under carbon price scenarios of \$20, \$50 and \$0 per tonne CO_2 equivalent. The model suggests that an Emissions Trading Scheme will lead to increased afforestation and rotation age, and decreased silviculture and deforestation. The model suggested that a \$20 carbon price or higher would lead to an overall increase in carbon sequestration by the forestry sector, driven predominantly by afforestation on lower fertility sites.

Regional Economic Impact Assessments of the forestry industry have been undertaken for the Gisborne Tairāwhiti Region, Marlborough, and the East Coast of the North Island[5,67,].

11.3 VALUING THE BENEFITS OF FORESTS

A 2017 report[8] explored benefits of permanent forests compared with plantation forests and other land uses in erosion-prone pastoral hill country. Comparisons were made at a national level and for the Manawatū catchment. Three scenarios were used: 1) assuming radiata pine is planted, 2) assuming the land is converted to indigenous forest, and 3) assuming some productive uses of land covered in indigenous forest (e.g. honey production).

A range of quantitative geographic, biological, and economic models were integrated, with several related qualitative assessments. In the case of the Manawatū, two out of three afforestation scenarios had a positive net present value across 50 years – even under the most conservative policy assumptions. Exotic afforestation would be the best approach to pursue given it has the highest net-present value and benefit-cost ratio. However, there were many benefits that could not be monetized, including biodiversity, recreation, cultural values, and broader impacts on ecosystem services.

11.4 TRADE AND MARKET PATTERNS

An analysis of New Zealand's major forestry markets used an econometric estimation approach to derive demand functions for broad product categories in each major country of interest. The model was used to estimate demand for a number of forestry products (such as sawn timber and wood based panels) in New Zealand's key export markets[9].

Research[10] has used exploratory data analysis on some available data. It attempted to combine information collected in market with publicly available data. This is an innovative approach – most market studies used either of these methods but not both. The strength of this method is that is combines all available information.

The Global Forest Products Model (GFPM), developed by the University of Wisconsin is a dynamic economic equilibrium model of the world forest sector. It predicts the production, consumption, imports, exports, and prices, of 14 product groups in 180 countries. The GFPM has the capability to explore the potential domestic processing and trade implications of changes in New Zealand's domestic wood supply. It has previously been used to predict the wood product production and export implications of the invasive forest pest fungi *Nectria* in New Zealand[11].

The Lincoln Trade and Economic Model (LTEM), developed by Lincoln University, is an agricultural multi-country, multi-commodity model that uses a partial equilibrium framework to quantify and analyse the price, supply, demand, and net trade effects of various domestic agricultural and border policy changes. The LTEM links trade in New Zealand with our main trading countries overseas, through to production and associated environmental consequences. The model has been extended by including forestry from incorporating the capabilities of the GFPM into the LTEM.

The environmental capabilities of the LTEM have been extended to include the impacts of climate change[12]. This extended model of international trade encompasses forestry, complete with linkages and feedback with the environment and differentiated international markets.

11.5 VALUE CHAINS

The majority of value chain optimisation research in forestry can be found in Canada. New Zealand research is limited in scope.

The Bioenergy Value Chain Model, developed by E4Tech in the UK, was used in the in a Biofuels Roadmap study that investigated feasible biofuels options over space and time[13]. The model includes a broad range of potential crops, feedstocks, transport modes, conversion technologies, and final biofuels that might be relevant to a biofuelled New Zealand. Inputs to the modelling include: land class; crop production; existing forests; and point source feedstocks

The value chain analysis in the Biofuels Roadmap was extended. A more generic and powerful model was built, but it is focused on innovative wood products and optimisation of value chain. A Primary Value Chain (PVC) model has been developed by Scion that identifies: the equilibrium price-quantity bundles; optimal harvest schedules; market destinations; individual processing plant locations; and transportation routes. Results of a regional case study in the forestry sector in the Northland showcase the model's capabilities[14]. The model was used to determine the impact of investments in new capacity of traditional and new high-value technologies on the optimal use of the forest resource and the region's overall profitability. It is flexible enough to include other regions, cropping or farming systems, transportation alternatives, processing technologies, and destination markets.

12 Social considerations

12.1 INTRODUCTION

Social license to operate can be broadly characterised as the informal approval or acceptance that people (e.g. communities, non-governmental organisations, iwi, and the public) grant to a company or industry engaged in the development of natural resources.

The forest industry has a wide range of social licence challenges. These include:

- the ability to use genetic modification and new breeding technologies;
- the application of unmanned aerial vehicles to forest management;
- the health and safety of forestry workers;
- sediment and log slash entering waterways after harvesting;
- the legality of logs entering supply chains;
- the use of chemicals for pest control;
- log fumigation and wood preservatives; and
- building standards.

12.2 PUBLIC PERCEPTIONS OF FORESTRY

UMR Research surveyed public perceptions of New Zealand's primary industries in 2017[1], repeating a similar survey carried out in 2008[2]. Both urban and rural respondents were included in the survey. Surveys were conducted in tandem with a series of focus group discussions. Focus groups considered that the primary sector currently earns its social license to operate by providing employment opportunities, economic stability, and food for New Zealanders.

When asked about forestry, 42% of urban UMR survey respondents viewed forestry favourably (down from 52% in 2008). Fifty two percent of rural respondents said they viewed forestry favourably (up from 47% in 2008).

Survey respondents indicated that the main reasons for a positive view of forestry was that forestry: is good for the economy; provides employment opportunities in rural areas; and is positive for climate change. The main reasons for negative perceptions of forestry related to: poor environmental management; a poor health and safety record; and possible drug use of forestry workers. Drug use had not been a concern in 2008.

Overall, around 50% of respondents to the UMR survey in 2017 felt that water pollution and environmental management were the most significant challenges facing the New Zealand primary sector.

In a different 2016 survey on the New Zealand public's perceptions of the environment[3], forestry was felt to be the second greatest cause of damage to land and freshwater plants and animals. It was also perceived as the third highest cause of damage to National Parks.

Wilding pines, an environmental pest by-product of the forestry industry are considered by some to be serious threat to New Zealand's conservation estate. Farmers, especially those from Marlborough, Southland, and Canterbury, considered that wilding pines were extremely harmful.

Public perceptions of forestry health and safety were discussed in focus groups in 2014[4]. The work used media reports of fatalities in the forest sector in 2013 and asked how widespread those media opinions were among forestry workers and the general public. From the pilot survey, it appears that the public perception of forestry is supportive, although there was some concern expressed over the number of fatalities. Other than the safety issue, there was a general lack of understanding of who the forest sector is, what it does, how it does it, and what it should do better.

For a different point of view, 200 school children in the North Island demonstrated a broad knowledge of key features of their local forests, such as activities within forests and the different living organisms that inhabit them[5]. The study underscored the importance of children as stakeholders in New Zealand forests.

12.3 SOCIAL IMPACTS OF FORESTRY

The social impacts of forestry can be considered at national, community, and individual levels. New Zealand Forest Managers annually completes a survey of the entire workforce within Lake Taupō and Rotoaira Forests. They publish annual employment statistics and call for feedback on logging trucks. The 2011 survey showed 80% of the workforce was Māori, 54% had beneficial owner rights, 56% had more than 10 years' experience and 86% supported a drug and alcohol policy.

Only one very preliminary study[6] has surveyed the public regarding social licence to operate across the forestry value chain where participants were asked who should be held responsible to resolve issues in different parts of the supply chain. With a small sample size this survey is only a starting point for further research.

12.3.1 Employment

Forestry directly employs around 9,000 to 10,000 people[7]. Determining exact figures is complicated by seasonal work and other factors. Indirectly, a further 3,500 are employed in areas related to forestry. Forestry jobs are concentrated on the east coast and the central North Island, Northland, Nelson and Southland.

Many forestry operations, such as planting and silviculture are seasonal, the work is physical, pay rates are low, and the work is carried out by gangs of contractors. Many workers may be transient and not contribute to local communities, and opportunities for families to live near places of employment may be limited.

12.3.2 Effect on communities

A major study[8] carried out in 2000 on the East Coast looked at community perceptions of forestry. The community recognised multiple impediments to the developing forestry industry in Gisborne and the East Coast. Overall, many in the community questioned the region's capacity to adapt to forestry. Other impediments included: the low level of community participation in development; the poor image of forestry for many in the community; and the nature of employment conditions as determined by the contracting system. Recommendations included improved industry and community participation.

More recently, a study[9] looked at Wairoa, the Wairoa District and its agricultural community. It found that a further expansion of forestry in the region is feared and that current perceptions and the potential implications for the resilience of the district needs to be examined to understand agricultural and community development.

The research on the Wairoa catchment has been a catalyst for developing new adaptive governance frameworks to manage the tensions inherent in an increase in forest and agricultural production, while dealing with severe erosion and a range of social, environmental, economic and cultural aspirations.

Waiapu Catchment

Research using a multi-dimensional resilience framework showed the impact of tree planting on vulnerable slopes improved environmental outcomes without harming farm economics[10].

The trade-offs across social, economic and environmental dimensions can be described using a resilience framework and quantified by land-use modelling. Analysis of the Southland region[11,12] has already made linkages from government policies to land-owner decisions to the economic and environmental impacts for the wider region, effectively linking individual decisions and the community consequences.

13 Implementation, monitoring and evaluation

13.1 INTRODUCTION

For the New Zealand plantation context, there is extensive knowledge on how to monitor and evaluate forests, their growth, and performance. Management information systems and inventories are well understood, growth and yield models have been developed, and many tools have been deployed for the use of the exotic forest plantation industry (with a focus on radiata pine). However, for new forest systems in new environments, we know less about how to measure success, and no tools are available.

13.2 PERMANENT SAMPLE PLOT SYSTEM TO UNDERSTAND FOREST GROWTH FOR COMMERCIAL FORESTRY

The Permanent Sample Plot (PSP) system is a comprehensive database of forest growth data that underpins New Zealand's commercial forest industry. The system contains information about the effect that factors, such as environment, genetics and silviculture regimes, have on the growth of stands and trees. The PSP system holds information dating from the 1920s and the current digital platform is a flexible relational database that holds different types of forest data for both experimental research and commercial growth plots. These data are sourced from permanent sample plots that have been established, and regularly measured, in different forest types throughout New Zealand.

Today, the system holds data from 32,000 PSPs of which 11,500 are current and 20,500 historic records. The 300 and 500iIndices (site productivity measure for radiata and Douglas fir) have recently been directly integrated within the PSP system. By integrating both indices within the PSP system, scientists and industry partners are be able to better understand the variation in site productivity, and the drivers of productivity.

13.3 INVENTORY OF THE VALUE OF THE FOREST ASSET

To understand the value of the forest asset, the quantity and quality of it, the log grades of the resource, and make management decisions, inventory of plantations are essential. In New Zealand, key inventories are management inventory (estimation of basic stand parameters used for silvicultural operations, collect stand records and to collect data for growth models), pre-harvest inventory (information on the likely product volume yield shortly before harvesting, informs logging crews on their operations) and Carbon Monitoring Surveys to capture carbon stocks. These measurements are well developed in New Zealand through years of research into this area (see Section 1).

The key focus of research in New Zealand at present is on how new technologies can replace manual data capture and inventory, and make data capture much faster and more precise. Of particular interest are remote sensing techniques (e.g. LiDAR, satellite data, multi-spectral and video and photo-imagery) in order to acquire data from a distance. The challenge is making the best use of these new data to augment or replace existing forest resource assessment procedures and improve efficiency of forest valuation.

Other current research focuses on how to accurately estimate forest yields for small and medium scale forest owners who make up the largest forest owning group in New Zealand. When it comes to measurement, they do not have easy access to the benefits provided by research outputs, and the economies of scale that come with larger plantations. Smaller plantations tend to be located on more variable terrain and have less consistent tree growth and stand management. Measuring these ground based variables is expensive. Current research is working on developing techniques for gathering data remotely and economically specifically for smaller forests.

13.4 GEOSPATIAL & BIOINFORMATION TECHNOLOGIES TO SPATIALLY ANALYSE AND VISUALISE DATA

Geographic Information Systems are being used to spatially analyse and visualise data from a variety of sources, such as aerial photographs, hyperspectral imagery, and LiDAR. Integrating layers of data related to the people, places, environment, and processes of forest into practical management tools is an area of active research in New Zealand. Models can be created that give results across a land surface, allowing more powerful insights than graphs or empirical results. With more and more powerful data capture, it is important to understand how to access, store, process, manage and mine data sets. Some areas of research are: bioinformatics (development and maintenance of databases to store biological information), geoinformatics (concentrating on spatial information of various types including images, maps, and surveyed points), and Ecoinformatics (information in ecology and environmental sciences).

13.5 TOOLS TO AID FORESTRY DECISION MAKING

Through research, key decision making tools for the New Zealand forest industry have been developed and turned into commercial products available for foresters. Some examples of these are:

- **Forecaster -** This is a desktop forest growth and quality decision support system that provides forest managers with tools to create and explore alternative forest management plans. Forest planners can determine the best strategies for their business by creating scenarios of management options, and then simulating outcomes. Silvicultural planners can implement plans correctly by having operations scheduled on time. Using log yields derived from simulated quantities at the time of harvest, resource analysts can manage yields to best meet customer requirements. Forecaster predicts the impacts of site, silviculture and genetics on tree and branch growth and wood properties. This can be used to estimate wood value, internal rate of return and net present value.

- **YTGen -** This software generates yield estimates in a production forestry context. It combines the process of growing and projecting tree volumes with log bucking (cutting a felled and delimbed tree in logs) algorithms to model tree merchandising through to log products.

- **ATLAS product suite –** This suite provides forest information management, planning inventory operations (designing plot layouts), collection of plot data in the field, assessing tending operations, analysing inventory data to forecast growth and yield, planning and tracking harvest operations, managing crew allocation, yield, and out-turn, analysis of permanent sample plot data, management and integration of yield data, and advanced map generation.

- **GeoMaster –** This is also part of the ATLAS product suite, and is an operational tool used to plan, manage, and report on all activity within a forest. It maintains a history of all events, changes in area, changes in structure and structure, and rotations over time. This allows changes in stocked and total area to be tracked.

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