Indigenous Forestry

A review of forestry knowledge in native forests

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Report information sheet

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Introduction

This review is a on indigenous forestry. The context was to provide the Parliamentary Commissioner for the Environment with the best summary available in the time provided. The timeframe was short and as a result the scope was not to provide a comprehensive review of the topic, but to provide the best possible information based on the experience of the authors.

We fully acknowledge that this topic could benefit from even more time to be more comprehensive. While we attempted to collaborate, we were unable to do so because of the timeframes involved. We recommend using this review as a forestry perspective, building on this to include forest reversion and forest restoration perspectives which are not adequately covered here.

Indigenous forestry in this review is the sustainable utilisation of native forests. The focus here is on utilisation and management for timber, as this is the majority of the experience of the authors, looking backwards to perhaps re-invent this experience for future generations. The opportunity for New Zealand is to build on this, and other knowledge to provide economic, cultural, social and environmental outcomes, building existing and new value-chains for our future generations and in order to provide resilient rural communities under climate change.

This review summarises what the authors know about native forest seed, propagation, establishment, forest management, silviculture, forest health, wood products and utilisation, harvesting and to the best of our ability, a representation of native forestry for Māori. We would have preferred to have the time to properly represent balanced views across all the themes in this report. We do, however, hope that this report will be a foundation or catalyst that will allow a more balanced conversation to occur. We are very grateful for the PCE to have enabled this piece of work and look forward to the opportunities and conversations that result.

We acknowledge that mana motuhake is therefore not evident throughout the review due to the limited timeframe, and evident only in the section on Māori perspectives.

Executive summary

There is a growing interest in the role that indigenous forests could play in large-scale afforestation. This review sets out the state of our current knowledge of how to grow and manage indigenous forests, their multiple uses, and Māori perspectives. The review sets out to identify what we know and don't know and in doing so, proposes individual research area pathways.

There are significant knowledge gaps, particularly when our native forestry knowledge is compared with the depth of information available about *Pinus radiata*. The scale of investment in native forest research of the last three decades, compared with research in exotic species, is orders of magnitude different. This imbalance presents a barrier that would need to be addressed if indigenous forestry is to play a greater role in the future.

Māori perspectives on native forests must be interwoven into all discussions. The importance of Te Tiriti and Wai 262 are critical to consider and may have implications such as how indigenous forest seed and/ or plants are sourced and where they are planted. Māori, as kaitiaki may have a primary role in how this should effectively happen and in how benefits are shared. Māori values, such as whakapapa connection to indigenous ngahere can make replanting with native species an attractive option. Cashflow and available investment capital, make replanting difficult. Systems that support Māori landowners, iwi and hapū in making informed decisions about land use and forest management are required for success.

In addition, it will be important to consider the desired outcomes for new forests and plant accordingly – the ideal characteristics of forests which will be harvested for timber is very different from those which will remain in ground for environmental and social benefits. Māori perspectives may provide a different paradigm that provides for multiple uses, functions and provisions from forests.

Growing native trees requires being able to collect and germinate seed and propagate seedlings or cuttings; there is very limited ability to do this, at scale and it is limited to a very few species. While the Government is intending to invest in this area, it has been delayed. There are also logistical challenges in seed collection related to many indigenous trees only producing seeds every few years and land ownership issues. Ecosourcing and cultural sourcing requirements or expectations also create challenges in growing new trees.

Growing native trees in the nursery is still behind current nursery practice for exotic trees. This means that native trees are more expensive and often grown over multiple years before dispatching from the nursery. While some research and innovation exist in this space, it is limited in scope, and some is still not in the public domain. Urgent work is required to ensure sustainable and cheap native plant growing approaches are available to the public across the country.

Planting native trees can have variable success rates. This sector needs to be trained in professional planting techniques, use of the best plants for planting, and site preparation and post-planting care. Urgent operational research and technical transfer of existing techniques is needed. Pest control is an essential part of this process.

Regeneration is one mechanism used to expand and maintain indigenous forests, but it can be slow or even unsuccessful if weeds are not managed well. Significant disturbance may be required for successful regeneration in many indigenous ecosystems and the timeframe of trees to maturity is many decades to centuries. We need to know far more about the conditions under which indigenous forests regenerate successfully, as well as the related conditions in which newly planted forest will establish and expand. It should be noted that, while indigenous species can be mixed with exotic species at planting, this is challenging and not widely tested and will require long-term research investment for successful implementation.

Higher priority than mixed plantings is examining how to transition from radiata forest to indigenous forest; to achieve this we need to know more about conditions required by indigenous trees and how radiata forest can be manipulated to facilitate growth of native plants underneath the canopy. Such knowledge includes key physiological and phenological traits and requirements of native species, but also soil conditions, topography, micro- and macroclimate, rainfall, and humidity, light and effects of browsing animals.

Tools for native forestry should adapt and adopt those from exotic forestry, including remote sensing and building models that allow for testing of planting/intervention scenarios. The most effective models would include the physiological requirements of species and how they interact with the environment. Visualisation would really help the testing of scenarios with communities to facilitate decision making for landowners and for policy makers.

Although New Zealand has a considerable number of native trees, kauri, tōtara and black beech are the only species for which we have much information regarding growing or harvesting forests. Large organisations/collaborations holding significant knowledge include Scion, University of Canterbury, Auckland University of Technology, Plant and Food Research, Manaaki Whenua – Landcare Research, Department of Conservation, nurseries, Tāne's Tree Trust, the Tōtara Industry Pilot run by the Te Tai Tokerau Forestry Collective. There are also many small groups managing and regenerating areas of forest across the country. There is a critical need for more expertise in all aspects of growing and managing indigenous forests.

Threats to native forests include extreme weather, fire, pests, and disease. All of these will change in a warming climate, with extreme weather events and fire becoming more common, new pest and pathogen incursions and existing pests and pathogens expanding their ranges. Generally, exotic pests and pathogens pose a far greater risk to indigenous trees than indigenous pests and pathogens, who have co-evolved with their indigenous hosts over time. We need to grow our ability to predict and mitigate incursions and spread of pests and pathogens, having seen the impact of kauri die-back disease, and watching myrtle rust's impact increase. Action on post-border incursions continues to need on-the-ground support to avoid serious biodiversity loss.

Indigenous forestry can provide economic benefits – including high value timber; carbon sequestration; environmental benefits – including biodiversity, habitat for native fauna, management of water; social and cultural benefits – including mahinga kai, rongoā, recreation. We need far greater knowledge of how to harvest timber without significantly disturbing the forest, as well as more about qualities of native timbers, their uses and best processing approaches. There is some indication that high quality wood may provide sufficient returns to justify establishing indigenous forests for harvesting, however economic modelling needs far better input data to provide believable models to investors. Further, non-market environmental values may be from four to twelve times as large as the value of timber; much more quantification is required on this to make best decisions on use of indigenous forests.

The knowledge on timber properties, markets and utilisation exists, but is very limited. A guidebook is needed based on existing information. Urgent research and documentation of native forest wood properties across a wide range of species is needed.

We hope that this information will help to re-frame the discussion on conservation versus utilisation, to perhaps include sustainable utilisation. If done cautiously, this has the potential to build resilience into regional communities, while diversifying the current perception of forestry.

We are very grateful for the opportunity that the Parliamentary Commissioner for the Environment has given Scion to write this report. We would like to acknowledge that the speed of this review has meant that we have been unable to properly consider native forestry with a culturally appropriate lens. We acknowledge that mana motuhake is therefore not evident throughout the review but limited only to the section on Māori perspectives.

Background

What does 'indigenous forestry' mean?

Indigenous forestry refers to deliberate growing and management of trees that are native to New Zealand for multiple outcomes, including economic, environmental, social, and cultural benefits. Indigenous forestry involves active management of forests and can include growing, harvesting and/or management of:

- Forest ecosystems reminiscent of past ecosystems.
- New types of species combinations in planted forests.
- Indigenous tree monocultures for wood production.
- Indigenous trees in association or mixed with exotic species.

In the context of this review, indigenous forestry does not include the management of the conservation estate or reversion of land to forests.

Restoration planting in this document means a planting designed to re-create current or past ecosystems.

Why focus on indigenous forestry?

The Climate Change Commission (2021) assumed an additional 300,000 ha of indigenous afforestation would be needed by 2035 in their modelled pathway. This amount of forest was assumed as part of long-term offsetting against residual long-lived greenhouse gases and areas that are difficult to abate, as well as supporting the pathway to meet the 2050 emissions targets that New Zealand has agreed to. This would require a large increase in native afforestation rates. We will have to work from many angles to achieve this, including planting and reversion of land now used for other purposes.

What species are included in indigenous forestry?

The species that could be included in indigenous forestry include all of those that exist in New Zealand. The potential scope of this area is therefore huge. The directions that this could take either require focus or require empowering landowners to decide and develop their own solutions As Carbon was not in the scope of this review, this section focuses on indigenous forestry from a wood production perspective.

Table 1 provides a list of tree species currently harvested from indigenous forests which are actively managed. Figure 1 provides a breakdown of the proportion of the different species that arrive at sawmills for processing. The properties and uses of these are further considered in section 0. Of these, the species that have forestry information and landowner enthusiasm are silver beech, red beech, tōtara, rimu, kahikatea, and kauri. Due to the passion of a few key people and organisations, the existing harvesting permissions and the majority of current forestry knowledge is around tōtara, beech and kauri (e.g. (Bergin, 2001; Steward & Beveridge, 2010; Steward & Firm, 2020; Wardle, 2005). Table 2 provides a list of additional tree species with potential for harvesting but which are not currently harvested in any significant volumes.

Species	Volume (m3)
Tōtara	259
Hard Beech	95
Kahikatea	93
Kauri	132
Matai	214
Pink Pine	540
Red Beech	1,033
Rimu	1,898
Silver Beech	16,216
Kānuka	239
Other	169

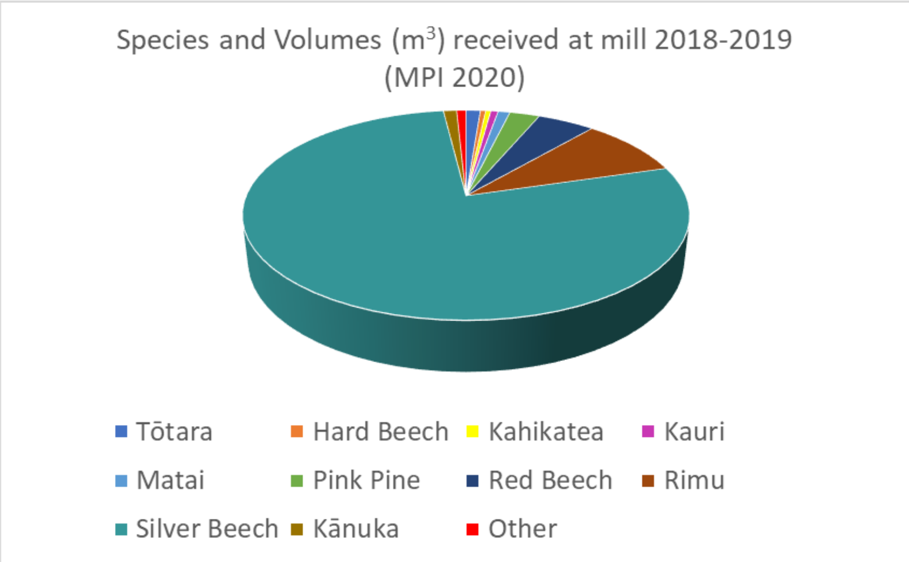

Figure 1: Indigenous trees currently milled in New Zealand – total of 5000 m^3 c.f. 4.5 million m^3 of exotic species (Te Uru Rākau, 2020)

Table 1: Indigenous trees currently harvested

Name	Current State
Red beech *Fuscospora fusca*	Red beech timber is sourced from sustainably managed forests. Used for interior joinery, decking, cladding and flooring.
Silver beech *Lophozonia menziesii*	Silver Beech timber is sourced from sustainably managed forests. Used for indoor applications, including turnery and cabinetry, brushes and dowels.
Black beech *Fuscospora solandri*	Black beech timber is sourced from sustainably managed forests, particularly from the South Island. Used for tool handles, furniture, exposed floors, panelling, and bench tops.
Hard beech Fuscospora truncata	Hard beech timber is sourced from sustainably managed forests. The timber is used for bridge building and poles, fence posts and sleepers as well as for finer uses such as furniture, decking and cabinet making.
Black maire *Nestegis cunninghamii*	Black maire timber is from sustainably managed forests. It is used in flooring and has potential for high value use in veneer, turnery and cabinet making.
Kauri *Agathis australis*	Kauri timber is sourced from sustainably managed forests and from swamps. It is suitable for many interior purposes, veneering, When the timber is durable (heartwood) it is used for boatbuilding.
Mataī *Prumnopitys taxifolia*	Mataī timber is sourced sustainably managed forests or is salvaged from. Mataī is highly durable and is used mainly for flooring as it is particularly hard wearing and durable.
Rimu *Dacrydium cupressinum*	Rimu timber is sourced from sustainably managed forests – also salvaged. It is used as flooring or a finishing timber (can also be used as structural timber).
Tōtara *Podocarpus totara*	Tōtara timber is harvested from plantations, from farms and sourced from sustainably managed forests. It is suitable for all interior uses and can be preservative-treated for use in-ground or in exterior joinery.

Table 2: Indigenous trees with potential but not currently harvested at any significant volume

Name	Current State
Hinau *Elaeocarpus dentatus*	Hinau timber dries, machines, and finishes well.
Kahikatea *Dacrycarpus dacrydioides*	Kahikatea timber is easy to dry, light and easily worked, does not taint food, and carves well. Kahikatea was the timber used to export butter to England and has little taste, so has potential for food applications. Durable (heartwood) timber is used for boat building.
Kaikawaka *Libocedrus bidwillii*	Kaikawaka may have uses where lightness and moderate durability are desirable e.g. roof shingles.
Kānuka *Kunzea ericoides*	Kānuka is currently grown primarily for its honey and essential oil (non-destructive). Kānuka is also used for firewood but larger diameter trees have potential for a number of hardwood applications.
Kōwhai *Sophora spp*.	This group of species has naturally durable heartwood and the potential for chemical extracts (Nguyen et al., 2021).
Manoao *Halocarpus kirkii*	Manoao is durable and chemical extracts are used in the perfume industry.
Pink pine *Halocarpus biformis*	Pink pine is not currently harvested at scale but has potential for chemical extracts used in the perfume industry.
Pōhutukawa *Metrosideros excelsa*	Pōhutukawa is suitable for boat framing, and piles, stringers and wharf and mining timbers.
Pukatea *Laurelia novae-zelandiae*	Pukatea is easily worked, stable and light and resistant to marine borer.
Pūriri *Vitex lucens*	Pūriri is durable, dense and strong and has potential for use in furniture and decoration.
Rewarewa *Knightia excelsa*	Rewarewa has potential for use in veneer and in honey production.
Tanekaha *Phyllocladus trichomanoides*	Tanekaha can be used for decking and roof, bridge, railway and marine timbers.
Tawa *Beilschmiedia tawa*	Tawa can be used in flooring, furniture timber, turnery and interior finishing.

Organisations currently undertaking research in aspects of indigenous forestry

There is currently a considerable amount of research on indigenous forestry and indigenous restoration being undertaken in New Zealand. A summary of the organisations who are working in this area includes:

A number of Crown Research Institutes are undertaking research of relevance to indigenous forestry. Manaaki Whenua Landcare Research has initiated an MBIE research programme to start to measure and model mechanistic processes on small groups of trees in the landscape, key microbial relationships, soil and carbon cycling using largely empirical data. Manaaki Whenua hosts the National Science Challenge – Biological Heritage, which has a strong focus on pests and pathogens of key native species, particularly kauri dieback and myrtle rust.

Scion has extensive experience in forestry research and the relevant trees species including native and exotics, with more than 75 years of forestry research history. It has initiated work on assisted migration of trees to combat climate change (O'Neill et al., 2014, 2017). Scion's focus is on planted forests and, in this context, has also been researching tree propagation, establishment, and use, in partnership with Māori. Scion has also submitted an MBIE proposal to look in depth at how climate change will affect the establishment of significant native tree species in human-modified environments across New Zealand. Scion has been working through four 1BT projects on the propagation, establishment and development of forestry practice with indigenous trees.

Plant and Food Research has recently moved into Forest Pathology and undertakes some research on population genomics of forest trees.

Various University groups are also researching the planting of native trees. The key Universities are:

- University of Canterbury, which has a long history of forestry research, and expertise in native forestry, particularly in modelling.
- Auckland University of Technology, which has a small group undertaking establishment research through One Billion Trees funding and is developing an App to identify native trees.

University of Otago has a One Billion Trees Seeds Project, Ngā Kākano Whakahau is a collaboration between the QEII National Trust, Department of Conservation and University of Otago. The project is developing practical methods for the large-scale establishment of native forest from seeds, with a particular focus on below-ground rehabilitation as it is about above ground revegetation and is especially focused on understanding of how to enable germinating seeds to reconnect with essential mycorrhizal fungi.

Tāne's Tree Trust (Tāne's Tree Trust, 2023) is an important, not-for-profit organisation that undertakes operational research on the growing, establishment and silviculture of native trees (Aimers & Bergin, 2023). Tāne's Tree Trust is a key conduit of information to landowners regarding indigenous forestry and a good source of practical information.

The Tōtara Industry Pilot is an initiative now driven by the Taitokerau Māori Forests Inc in Northland in which Scion was involved in, which is investigating the viability of a sawn-timber industry based on tōtara.

Smaller groups, private companies, communities and Māori organisations are also carrying out research and development in this area. Forest Growers Research has done some research, but small-scale and usually historically funded by MBIE or co-funded with MPI compared with their multi-million-dollar research programme on exotic forestry. The New Zealand Farm Forestry Association has an indigenous species action group, which is looking to become more active in future years. The new Te Uru Rākau New Zealand Forestry Service is commissioning new research on indigenous forestry and is leading the final phase of the 1BT projects across the country.

Growing indigenous forests

Sourcing and germinating seeds

Why does this matter?

The primary mechanism for creating new forests or regenerating existing forests through silviculture is by planting or direct seeding Sourcing, storing and germinating seeds are all critical areas of knowledge underpinning forestry. Each species is different, dictated by its distribution and unique ecology. Until the indigenous forestry industry is properly established, seed collection will rely solely on collection in existing natural habitats.

Further, there are social issues around eco-sourcing, which is used to maintain/protect biodiversity in an ecological district, and cultural sourcing, which is used to protect cultural values. Eco-sourcing and cultural sourcing may conflict with the practicalities of successfully scaling up the production of native seedlings to allow large forests to be established cheaply and easily.

Sourcing and germinating seeds for exotic forests is easy in comparison. There are a number of commercial seed orchards. The seed orchards are predominantly radiata pine, as this has been most of seed required for forestry as it currently is in New Zealand. Radiata pine seed is all genetically improved, and genetics are sourced directly from the breeding programme through membership of the Radiata Pine Breeding Company. Genetically improved seed is also available for eucalypts, cypresses and several other ‘alternative’ species. The availability of genetically improved seed in reliable and sufficient quantities drives one of the first decisions in planted forestry – what to plant.

What do we know?

Apart from a few notable exceptions (rimu, and beech (Allen & Platt, 1990; McEwen, 1983; Norton & Kelly, 1988; Poole, 1948), little is known about the biological drivers of flowering, pollen, and seed production for most of the New Zealand indigenous tree species considered as suitable for planting/seeding at scale (Table 1). For those species affected by mast years (when plants flower *en masse* and produce large quantities of high-quality seed every few years, such as beech and podocarps), the onset of flowering is thought to be driven by seasonal variation, with warm summers being the primary cue (Kelly et al., 2013). In reality, flowering is not that simple, and local conditions are important, with flowering also driven by allocation of resources within the plant (Bogdziewicz et al., 2018).

Challenges in sourcing seeds and propagating seedlings that we know of include:

- Natural seed production is highly variable between seasons in both volume and viability of seed produced. In some years, almost no seed is found, particularly in conifers such as rimu, kahikatea, and kauri as well as beeches (all considered ‘masting' species). ‘Mast’ years, when seed is produced, may be separated by decades (Franklin & Beveridge, 1977; McEwen, 1983; Wardle, 1984). Mast seed years are typically associated with rapid increases in seed predators, particular mustelids.
- Mature seeds may only be readily collectible for one month or less in many species.
- For many species, e.g. kauri and rimu, seed viability is variable, can be extremely poor, and declines rapidly after collection. An example is given in Beveridge (1964), where only 1.4kg of viable seeds were recovered from 45kg of rimu seed collected.
- Seed is generally developed in the outer part of the canopy where flowers are accessible to pollinating vectors. For mature conifers and hardwood species this generally means that seed is often difficult, and potentially dangerous, to access.
- There is a wide range of land and forest ownerships making access to seed complex.

- Many regional and local governments have ecosourcing regulations, and there is a general public and governmental perception that ‘local is best’ for planting/revegetation e.g. (Department of Conservation, 2023a). However, climate change will impact where trees grow best, as climatic regions shift, challenging the concept of eco-sourcing which assumes local adaptation and local genetics are best for a site.
- Historical planting programmes by the New Zealand Forest Service from the 1940s moved many podocarp species considerable distances from their parent populations through replanting areas that had been harvested. Central-North Island rimu (Dacrydium cupressinum) has been established in Westland, while kauri can be found growing in Dunedin and on Stewart Island, in the southernmost parts of mainland New Zealand. Beachman (2017) reviewed the dispersal of kauri from the Waipoua and Sweetwater nurseries, both in Northland, to assess the potential spread of kauri dieback (Figure 2). Some 15 million or more kauri of Waipoua origin were planted in more than 250 sites throughout the species’ current natural range, and beyond. Many thousands of seedlings are established in gardens and parks throughout the country annually. These transplantations are more than likely to be serving as modern seed sources within their new locations and, in some instances, are driving regeneration (Steward et al., 2003).
- Existing and historical native plant nurseries have sold many native plants around the country (NZPPI, 2019) with not all nurseries producing with ecosourcing.
- Native seed may be already available commercially for some species, including those in Table 1 e.g. Seed Source New Zealand Native Seeds www.seedsource.kiwi, NZ Seeds www.nzseeds.co.nz and possibly Proseed (Native Trees/Grasses (Proseed (2023)). Seed availability is not at the scale currently coordinated for large-scale plantings.
- Genetic variation underpins resilience in species. Understanding genetic variation in a population maximises likelihood of survival during relocation. This has been thought through in many endangered bird species, but not in tree species (e.g., kakapo (Dussex et al., 2021), takahe (Department of Conservation, 2023b; Grueber & Jamieson, 2011) .

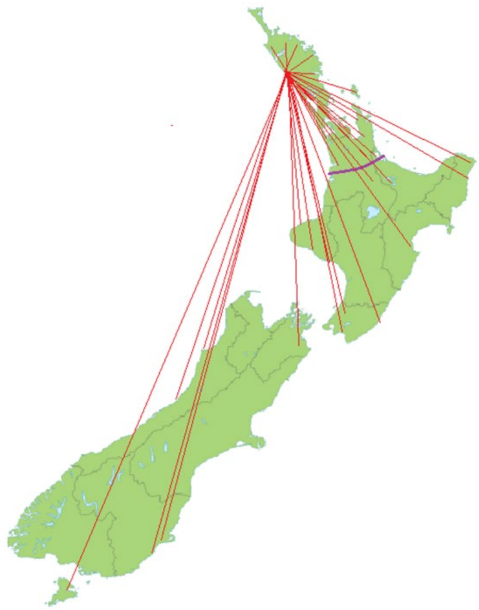

Figure 2: Waipoua Forest-sourced kauri seed and seedlings from New Zealand Forest Service nurseries. The purple line represents the indicative southern end of the natural distribution of kauri

What's currently being investigated?

There is only a small amount of research being undertaken in this area, although no doubt there is practical knowledge being developed every day in the nursery industry and seed production companies.

Essential research is required

To scale up, and in the context of Te Tiriti, we need to build on the historical knowledge to document and deliver the range of current best practice from multiple perspectives. We need to:

- Learn about seed, starting with the most promising species (e.g. tōtara) to:
  - Create seed collection areas and/or seed orchards
  - Induce/create consistent seed crops of quality seed with consistent and high germination rates.
  - Learn how to successfully store seed, or cryopreserve the embryonic tissue, and ensure tissue can successfully be revived from storage.
  - Identify optimal sowing times and parameters influencing germination and survival.
- Talk about and decide on rules for ecosourcing. When is it appropriate? Data is needed on tree population variation (genetics), dispersal mechanisms and distances to inform this conversation. This should also consider the effects that climate change will have on the underlying physiology and phenology of native forests and whether assisted migration of whole forest types may be needed.
- Understand the pollination and dispersal mechanisms of pollen and seed. Develop guidelines for where gene flow might occur naturally and how it will intersect with ecosourcing and rohe boundaries to inform policy.
- Work in partnership with Māori to integrate cultural sourcing as related to ecosourcing.
- Investigate and then implement appropriate legislation/policy ensuring that native afforestation is enabled.
- Clarify ownership of trees and their seed so seed collection does not become a barrier to propagation.

Growing plants in the nursery and early establishment

Why does this matter?

To reforest large areas of New Zealand at scale, we need to do everything to establish trees, but particularly, plant trees. This is because all the experience in exotic forestry has shown that planting trees has the best opportunity for immediate success. We therefore need young trees to plant. We also need to ensure trees survive once planted. While many species can also be grown from cuttings, not all species will be amenable at scale. Each species may require different treatment to grow seedlings and/or cuttings, and grow up to a sustainable size to plant, and then require different management shortly after planting.

What do we know?

Until the late 1980s, the NZ Forest Service was the largest planter of native trees to replace species removed during logging and land clearance. Millions of podocarp seedlings were established in the forests of central North Island and South Island. Plants were grown in both bare-root (grown in open bed) and containerised systems. The Kauri Management Unit, of the NZ Forest Service, was responsible for establishing and maintaining kauri replanting programmes (e.g. see Kauri Management Unit 1983). These programmes tended to target single species plantings with known commercial properties and values based on historical usage. Latterly, mixed species stands were established, where species removed by logging were replaced by planted seedlings in the proportion that they had been harvested. Many of those plantings remain and are documented in archived records which can be accessed for information that may inform any future planting strategies. These archives are a combination of archives from organisations ex the NZ Forest Service (Scion, Manaaki Whenua, DOC) and the personal records of foresters involved in indigenous forestry at the time. Examples include the Kauri Management Review (Kauri Management Unit 1983); early reports of the Indigenous Forestry Unit (Herbert 1987-88), the evolution of ecological districts (Herbert 1987). Management plans for various species are often in personal records (e.g. Timberlands West Coast Ltd (1998), Donnelly 2011 [beech]).

A 1980's Scion project reviewed plantings of native species to begin assembling a database to underpin an indigenous forestry plantation programme. It revealed widespread interest in planting native species for both commercial and conservation reasons. It also identified more rapid growth of selected species with commercial potential than had previously been reported, despite the lack of after-planting care. Research in the 1990s included a focus for rehabilitation of lowland indigenous forest after mining in Westland (Davis & Langer, 1997; Davis et al., 1997; Langer et al., 1999).

Growing plants for planting out

There has been relatively little recent research on growing plants from cuttings, or growing up germinated seed, until the One Billion Trees Programme rejuvenated interest in native nurseries, in 2018, particularly within iwi. Competition to supply seedlings has the potential to drive efficiencies, reducing cost. However, there is a risk that plant quality may reduce to meet increased demand and returns on investment. There is also ongoing risk that nurseries are a source of pathogen spread.

Scion has been leading a new wave of research to improve native seedling quality and reduce the cost per plant by reducing the pot size and increasing the amount of automation in the production system. We have partnered with Ngāti Whare Nursery at Minginui and developed new techniques to raise seedlings from cuttings. We have also been working with Te Uru Rakau - New Zealand Forestry Service to develop improved propagation techniques for twelve native species (Table 3, Figures 3 and 4). After trialling raising species in different container types and planting out across 6 sites around Rotorua, unpublished results indicate (e.g. (Ford & Lloyd, 2022; Ford, Lloyd, & Dungey, 2022; Ford, Lloyd, & Klinger, 2022):

- Larger pots result in larger plants, but larger plants are only necessary for good survival in the field when site quality is low (weedy, poor site preparation and poor soil quality). Smaller capacity paper pots (~700cm^3 capacity) can grow plants equivalent in size to those in a standard native tree pot in the nursery i.e. a PB2 (plastic bag type 2 with 1.5 litre soil capacity).
- Some species grow well in smaller, forestry-grade (approximately 125cm^3 or less) 4cm diameter paper pots (P4.0 soil volume 125 cm^3) and survive well in the field (Figure 4). On average, the growing systems have not yet been developed to facilitate good growth and survival for all species. It is unlikely that all native trees will be suited to these systems (e.g. Matai), but these species can be planted using different species mixes to mitigate the additional costs of larger pots.
- Most species tested (Figure 3), including revegetation plants e.g. ribbonwood (*Plagianthus regius*) and mānuka (*Leptospermum scoparium)*, grow and survive well across a range of site qualities (>80%, Figure 3) in forestry-grade pots (approximately 125cm^3 or less) on high quality sites (sites with good site preparation, weed control, good soil and experienced planting crews).
- In one-year tōtara can be grown in 5cm paper pots to be ready for planting (Figure 5).
- Planting forestry-type seedlings across all 10 species (approximately 125cm^3 or less; Figure 4) has been successful across 6 experimental sites, with >75% survival one year after establishment in the field.

Taking cuttings from native species does work for some indigenous species and tōtara and hakapere (Chatham Islands) have been shown to be highly amenable (unpublished data). Any concern on diversity can be managed by ensuring the mother plants are genetically diverse. A large number of mother plants are required for cuttings production at scale. Mother plants can be carefully selected to be diverse. Diversity may be greater in this type of system than seed that has been ecosourced from small, isolated populations with unknown relationships and a high risk of inbreeding. Cuttings systems could be developed for a number of species to ameliorate the lower reliability of native seed availability compared with exotic species. Cuttings systems also allow the opportunity to produce plants that might be identified as healthier or superior for ecological traits through an ecologically driven breeding programme.

Growing seedlings and cuttings involves the investigation of a large number of parameters to obtain success, as can be seed from the above study. Pot size, pot type, root behaviour, media type, media porosity, growing conditions, fertiliser requirements are all key parameters. For forestry-scale production (greater than 500 thousand plants per annum), systems are needed that are reliable and produce robust plants that will survive on transplantation. Cost of production is implicit in production systems, as nursery production is also a highly competitive industry.

Table 3: Recommended pot size to grow high-quality native trees, based on expert opinion (Nursery grower group recommendation) and results from Ford (Ford, Lloyd, & Klinger, 2022). Smaller volume pots are considerably cheaper and will make the establishment of native forests considerably cheaper. The differences in recommendations between the project and experts indicate that nursery growers are hesitant to quickly adopt new technologies (pot size) as their reputations are on the line, and the necessity for research to be extended to the pre-commercial size to show that success will be a commercial reality. Pre-commercial or small-scale commercial demonstrations of the success of smaller container sizes are required to build nursery grower confidence and demonstrate to buyers that the plants will establish well

	Group recommendation		Project recommendation	
Species	**Container Vol. (cm^3)**	**Raising Period (months)**	**Container Vol. (cm^3)**	**Raising Period (months)**
Aristotelia serrata	500	8-12	125	8-10
Coprosma grandifolia	700	10-16	700	10-16
Coprosma robusta	90	7-9	125	8-10
Cordyline australis	90	6-9	310	9-12
Dodonaea viscosa	150	6-9	150	6-9
Hoheria angustifolia	125	7-9	125	7-9
Kunzea ericoides	500 +	10-12	310	10-12
Leptospermum scoparium	90	6-9	310	10-12
Melicytus ramiflorus	310	9-11	700	10-12
Plagianthus regius	310	10-12	310	10-12
Podocarpus totara	125	11-12	125	11-12
Sophora microphylla	700	11-13	310	11-13

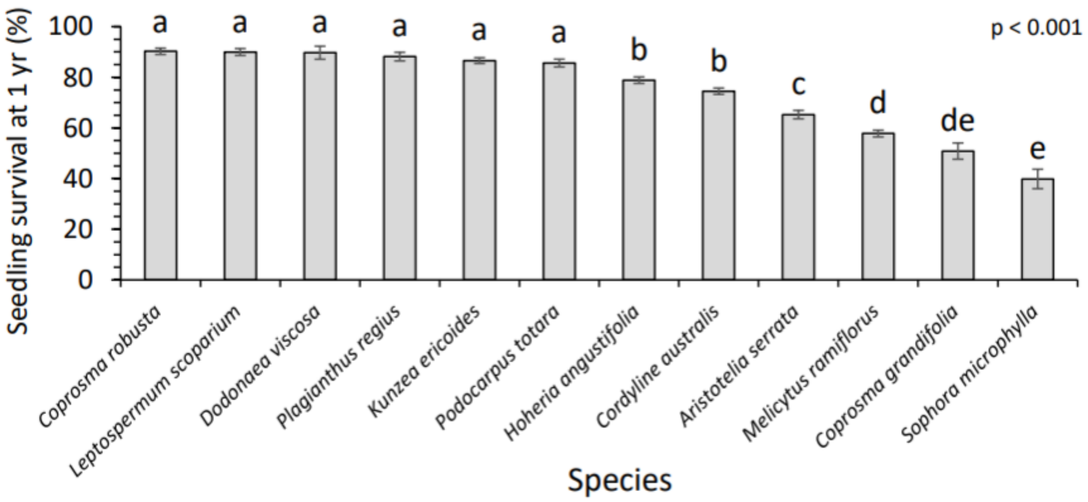

Figure 3: Species survival (%) across 6 sites established around Rotorua, one year after establishment averaged over forestry grade, retail/revegetation and large forestry grade pots [see Figure 4 for pots tested]. Letters above bars represent significant differences among species (P ≥0.001);(Ford, Lloyd, & Klinger, 2022)

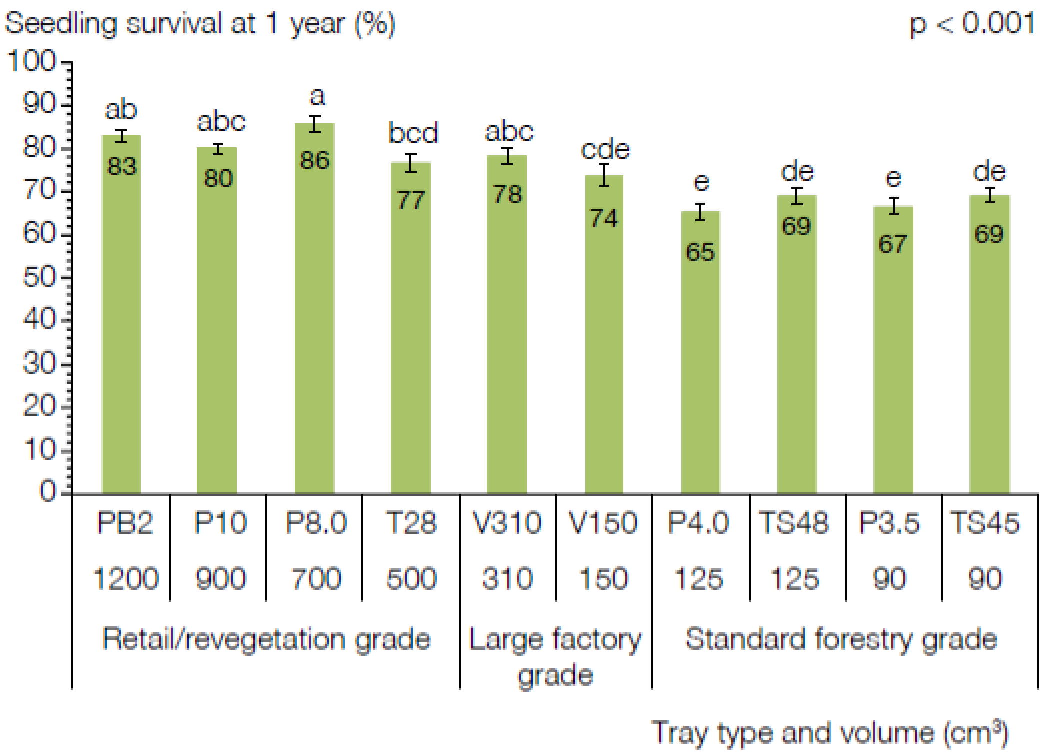

Figure 4: Average seedling survival (%) for all species, by container type, after one-year measurement. Letters above bars represent significant differences among different container types (P ≥0.001; (Ford, Lloyd, & Klinger, 2022)

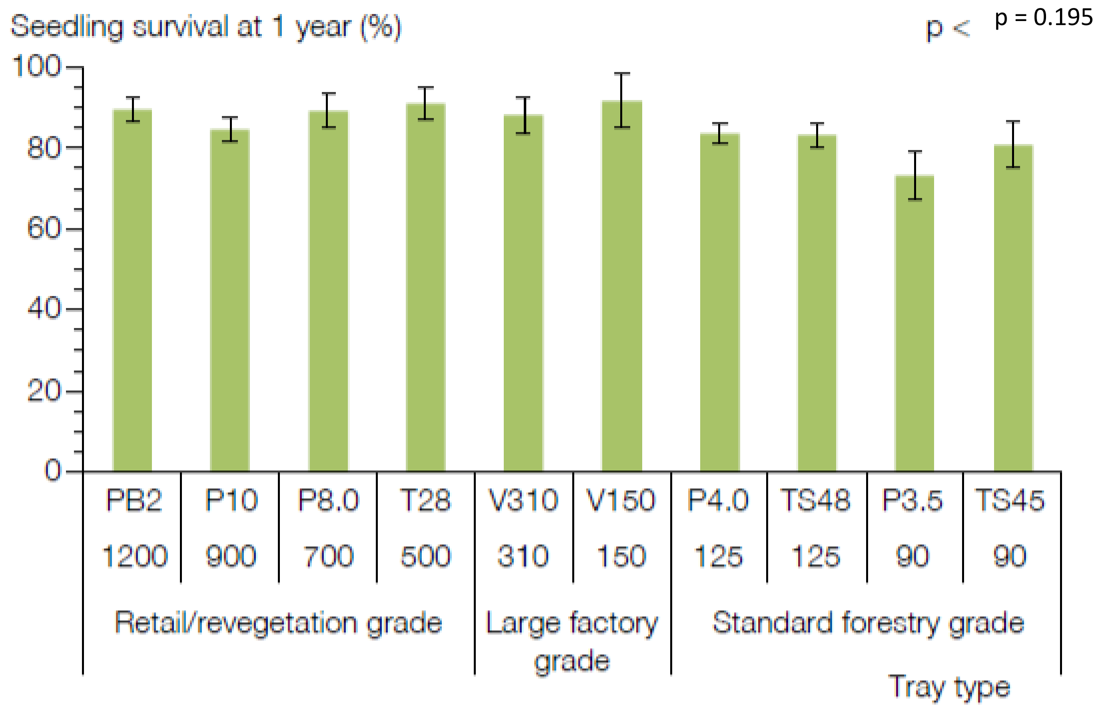

Figure 5: Seedling survival (%) in tōtara (*Podocarpus totara*) by container type, one year after planting in the field across 6 sites. No significant difference was found among treatments (p-0.195) (Ford, Lloyd, & Klinger, 2022)

Growing plants as 'bare-root' plants, or via cuttings is a well-known option for native species (Cole & Bergin, 2014; Hosking & Bergin, 2016; Morton, 2016). However, there is considerable variability in rooting habit that makes some species less suitable or more difficult to raise as bare-rooted plants (i.e. kauri, rewarewa etc) Bare-root plants are produced by first germinating seed in small pots. Once the roots have occupied the soil, the plants are put into open nursery beds. Under-cutting and trimming of roots can be used during the growing cycle, then pots with plants are lifted prior to dispatch to the planting site (Cole & Bergin, 2014) and the soil is removed from their roots. Bare-root plants can be cheaper than larger volume (i.e. PB2) container-grown planting stock but are also much more susceptible to stress on planting. Good planning and logistics are required, as this is most successful when the process from nursery to planting only takes a few days.

Cuttings have potential to augment propagation from seed, including when species have limited seed supply, seed is not viable and/or where copies are required of taonga individuals (e.g. pōhutukawa, rātā) or individuals with important properties (cultural and/or economic). Cuttings are relatively successful on a number of indigenous species (Craig Ford, pers comm) – tōtara and pōhutukawa have been remarkably successful (unpublished data). Cuttings are likely to be more expensive than seedlings, particularly if the early germination and pricking out is done by hand.

There is often considerable difference in physiology between seedlings raised in a nursery, and those arising through natural regeneration. Nursery-raised seedlings have all their nutrient and water provided artificially and are grown at speed, to reduce their time in the nursery. Consequently, they are rarely exposed to the same climatic perturbations found in the environment where they will be planted out which may impact survival. Good nursery operations managers will ensure that the plants are hardened up outside, to withstand outdoor environments and full sun, prior to dispatch. These conditions may still not be difficult enough for more extreme sites. Withdrawal of nutrients and water later in the raising of some nursery stock provide additional hardening. In comparison, cold nights, frosting and a closed winter growing season often means regenerated seedlings in natural forest of less than 1m in height can be many decades old. An example of this is rimu seedlings in Pureora and Whirinaki Forests which were up to 50 years old in one unpublished study (Scion), were lower in nutrient levels and physically harder to the touch. This comparison means that nursery seedlings are often more susceptible to browsing animals soon after planting.

Methods of planting out

Currently, plantings (private and public) tend to be restoration plantings attempting to re-create an existing (and nearby) ecosystem, rather than plantings on greenfield sites or for production. Restoration plantings are often small scale with plants at high density (Forbes & Norton, 2021). The establishment of new indigenous forests for either production or revegetation are hampered by a lack of quantitative based guidelines and recommendations. Low expectations of native plant survival often means that more seedlings are planted than are required to meet desired outcomes.

The cost of restoration planting using current pricing and techniques can vary greatly, from $6,100 to $188,000 per hectare (Table 4, (Dungey et al., 2023; Forbes & Norton, 2021) . High planting costs, combined with low survival rates, which can be under 50% for some species (Figure 3), means large-scale planting is often not seen as economically feasible, therefore restoration often focuses on natural regeneration or a combination of planting and natural regeneration (Forbes & Norton, 2021) .

Choice of species, good site preparation, vigorous plants, and a professional planting crew all increase success rate. Pest control is also essential. This includes managing possums, wallabies, rabbits, hares and particularly goats. In one Scion nurse crop trial established in the northern Waikato, mānuka and kānuka seedlings were destroyed by rabbits in the first night after planting (Steward & Firm, 2020).

Timing is also important. In Scion’s experience, planting during droughts and/or in late-winter in drought-prone areas often results in poor survival after planting.

Table 4: Average, low and high costs ($) of native restoration plantings (Dungey et al., 2023; Forbes & Norton, 2021) .These establishment costs are summarised by Dungey et al., 2023 from data summarised in Forbes and Norton, 2021. Stems per ha are the number of plants planted per ha. Releasing means herbicide control to 'release' trees planted from weeds and is a cost per ha. Blanking is the replacement of dead trees, usually occurring the following winter planting window and represents a cost per ha

	Low	Current average	High	Aspirational forestry model
Stems/ha	1,100	4,444	10,000	1,100
Cost/plant	0.6	3.77	10.23	1.50
Transport cost/plant	3.5	2.26	5	1.00
Planting cost/ha	1,250	7,044	21,717	1,250
Releasing	40	2,649	12,500	40
Blanking	300	667	1,500	300
Total/ha	6,100	37,157	188,017	$4,340

It is also important to consider the core purpose of a forest before establishment. This will help to maximise the outcomes, for example wood production, biodiversity, protection of vulnerable landscapes. A planted forest leaves the most potential options open through the life of the planting, including timber. Establishing mixed or random species in a revegetation programme is likely to significantly reduce future options for certain outcomes.

Work has been done on alternatives to the very common method of high-density re-vegetation planting (often 1x1m). Te Tipu Whenua have developed a methodology for planting at scale based on forestry practises adapted for native trees (Dewes et al., 2022), to make planting cheaper and more achievable. This group recommends planting no closer than 2x2 metres (2,500 stems per ha) and using forestry-grade seedlings to minimise cost. Mānuka and kānuka are recommended for at least 70% of the plants in the planting 'recipe', with the remainder being bird-dispersed species. This approach appears to be very successful, with establishment costs approaching the Aspirational forestry model in Table 4. The number of species may be limited where planted stands are isolated from existing indigenous forests that can act as natural seed sources and/or where bird dispersal is limited.

What's currently being investigated?

All nurseries do operational research on seed for their own purposes and much applied research in this space is likely to be commercially sensitive and not in the public domain.

Scion has done some very preliminary work on seed, testing several stratification and seed treatments and has a small seed store facility, used primarily for exotic trees. Scion is continuing its work in propagation for indigenous trees through their One Billion Trees funded programme through to 2024, including planting and cuttings research and weed control scenarios.

Te Tira Whakamātaki (www.ttw.nz) is an indigenous environmental not-for-profit organization with a goal of reversing the decline in biodiversity. They have a seed bank project, empowering people on the ground to collect and store their own seed.

Movement of tree species in the landscape to mitigate climate change is under investigation internationally – sourcing seeds from climatic envelopes matching future climates (Benomar et al., 2022) and references therein, (Aitken & Whitlock, 2013; O'Neill et al., 2017). In Canada, significant research has already been undertaken, the change in climate will be significant, and species are already being planted across the landscape in new, projected ecological zones.

Work has been initiated by Scion through Strategic Science Investment Funding and MBIE grant on adaptation of indigenous trees for climate change, with a new MBIE proposal focused on modified environments, e.g. farms, being submitted to MBIE in 2023. The research is aimed at filling some of the knowledge gaps on how climate change might impact our native forests. It aims at building fundamental knowledge on the intrinsic physiology of native trees. The programme will run for 5 years from October 2023 if it is successful. Scion is working with several Māori partners to re-vegetate through planting their land to a forest with multiple species, multiple ages, described as being close to nature. The majority of these are investigating how to propagate, plant and grow in the early years to ensure forest survival. Most are on ex-agricultural land, but some are ex-radiata pine forest and planting desired species in regenerating forests.

Direct seeding has been tested for establishing native plants into pastoral landscapes. Douglas et al., 2007 has done a recent review of the technique, recommending it as having a lot of potential for relatively cheap establishment at scale. Survival of trees established using this technique has not been as high as hoped, one reason that this method is not widely used.

'Living Laboratories' – long term forest restoration sites –have been planted at three farmland sites by Auckland University of Technology and partners Ngāti Whātua Ōrākei, Ngāti Manuhiri and Ngāti Pāoa. They are monitoring carbon sequestration, ecological functions and outcomes including biodiversity. Auckland University of Technology (2019).

Specific mycorrhizal associations are often required for vigorous growth and even survival (e.g. beech, Strawsine 2022; kauri, Steward and Beveridge 2010).

What do we need to find out or do?

Assuming that the objective is to plant a substantial area of indigenous forests by 2035, along the lines of the 300,000 ha suggested by the Climate Change Commission, then the focus will need shift to a large-scale plant production framework. This will require the modernisation of New Zealand's native plant production methods so that plants can be successfully grown at scale.

A wide range of growing and planting recipes for new native forests on different site types are needed to ensure successful establishment (>80% survival). Considerations include:

- Some plantings seek to replicate natural forest that used to exist within the local area therefore follow an ecosystem approach, whereby early successional species are planted (as a nurse crop) with selected native hardwoods and/or conifers established later.
- Not all plants work well on all sites.
- Many native conifers have characteristics resembling early pioneer species i.e. they grow best when sunlight and growing space is available and may suit single-species plantings for wood production. Some native species suitable for single-species and production forestry planting, such as tōtara on some sites, may not require a nurse crop for protection at planting.
- In contrast, beeches, pūriri and tōtara all appear to benefit from either a nurse crop or planting at close spacing to create a straight trunk.

More work is needed in the following areas:

- Improving the propagation recipes of all native species (both seedling and cuttings, including different pots and media) that are used for planting for all native forest types. Some really good work has been done by multiple organisations and practitioners, but more information is needed.
- Further testing of the Tipu Whenua approach (wider planting spacings) across more sites in combination with findings from other studies would be really beneficial, especially in a collaborative and operational research programme.
- Exploring ways to use tissue culture as a means of propagation (and/or conservation). Particularly to augment the propagation of favoured taonga trees. This would need to be done in partnership with Māori.
- Further research on nurse crops is needed – to help understand the best species to use, and optimal stocking rates and mixes of species across a wide range of sites. Selective breeding of native trees and needs to be researched so important traits, including those that provide better outcomes for maximising within-species diversity and biodiversity and/or growth and wood quality.
- Greater documentation and outreach and some research on the costs and where to make significant savings in planting programmes.
- Research on automation and technology and where this will help to make another step-change in plant production and establishment of native forests.
- Much more information on weeds, weed competition and the difference between a weed that is a nurse and a weed that competes and reduces the survival and success of a planting. Chemical-free control methods need research, documentation and outreach programmes.
- Linking to Predator Free 2050 and ensuring that planting programmes are utilising the best pest control.
- Develop knowledge on mycorrhizal associations that are specific to site and species. Methods and protocols to safely bring these mycorrhizae into nursery productions systems are needed to improve plant health, growth and establishment success.

Natural regeneration after selective logging of native forests – past experiences

Why does this matter?

One mechanism of creating and maintaining indigenous forests after selective logging is by encouraging natural regeneration to occur – rather than planting seedlings.

What do we know?

Regeneration often goes through long phases of pioneer or early successional vegetation, particularly in landscapes where natural forest persists. Where landscapes are dominated by exotic vegetation (both production and weed species), these often overwhelm native plants. For regeneration to occur, native species must be locally available to a disturbed area from an existing seed source, which may require transport by wind or birds. Furthermore, regeneration can require specific nutrient conditions e.g. in mature mountain beech forest there is more than 1200 kg/ha of calcium in the biomass compared with 300-600 kg/ha in newly eroded subsoils (Nordmeyer, 1997).

Presence and management of browsing animals can also make a critical difference to regeneration. A common example is deer, which can completely supress any podocarp regeneration (Richardson et al., 2014). Canopy dieback is common with over-browsing in many species. In rātā-kamahi forests, introduced possums have been shown to cause complete canopy dieback through persistent browsing and high possum population numbers (Payton 1990; Cowan et al., 1997; Nugent et al., 1997). A similar situation has been observed for pōhutukawa

Bergin and Hosking, 2006). Domestic stock has the potential for significant negative impact on newly planted seedlings where fencing is not adequate (Steward and Firm 2020). Deer are very destructive for regeneration and will affect the ecology of the forest long-term (Forsyth et al., 2015; Husheer et al., 2003; Nugent et al., 1997). Good fencing and control of all introduced browsing animals one key contributor to success. Without this key intervention, planting may be a waste of time.

Exotic weed species can be a hindrance, through competition, or a help, as in nurse crop, to establishing native plants, depending on the combination of species and whether the exotic species establishes before or after the establishment of the natives. Smale (1990) investigated the role of butterfly bush *Buddleja davidii*, an exotic weed species invading streambeds and natural habitats in the Urewera National Park. While it excluded native pioneer species, eventually a native cover established and overtopped the *Buddleja.* The same can be true for gorse. In trials on the East Cape and the Wairarapa regions, Scion established trials where lanes of varying widths were cut into regenerating mixtures of gorse, mānuka, kānuka and tauhinu. Native conifers and hardwood seedlings were planted within these lanes. Some of these plantings were successful and are growing, even though resources were not available for follow-up maintenance, (Steward & Firm, 2020). The major problem with exotic weed species is the speed and density (stems/ha) at which they establish. Further, where they establish in an indigenous planted area, they can act as a reservoir from which they invade surrounding productive agricultural sites. Mixed species forests created through the planting of both exotics and natives is discussed in the next section.

Finally, using the definition of a weed "as a plant growing where it is not wanted and in competition with cultivated plants", some early successional native species could be seen as a weed, depending on the desired outcome of a planting given they aren't production species.

Regeneration within indigenous forests has been studied for a range of tree species in forest ecosystems that are both actively managed (i.e. most forests -planted for timber) and those that are not actively managed (i.e. many conservation forests). Regeneration can occur where parts of the forest canopy is opened such up when trees die or are otherwise disturbed (gap theory). These gaps can be caused by natural events as storms or droughts, or by deliberate intervention. It is a continuous process. Depending on what species are preferred, regeneration can be protracted over periods of decades or centuries depending on species and competition from pioneer regenerating species such as toetoe and bracken fern. slow and highly variable (McGlone et al., 2022). Natural regeneration also requires the biological, geological, and climatic factors to interact constructively. Biological factors include seed sources, mechanisms of dispersal, disturbance and low numbers of browsing mammals. In central North Island podocarp forests, regeneration has been closely linked to the level of disturbance caused in the forest by either human or natural processes (Veale 1986).

New Zealand forest classification and the structure of native forests have been well described (e.g. Nichols 1976, Wardle 1984). Many New Zealand podocarps can struggle to regenerate beneath a largely intact tall canopy of native trees in numbers sufficient to replace trees lost through natural mortality or after harvesting (Steward and Van der Colff, 2006). Single tree death or small clusters of tree death through localised storm action does not always create disturbance enough to trigger regeneration of canopy species, significant disturbance is required, where a significant disturbance is site and species specific.

Much larger disturbances are typically needed before canopy species can emerge.

Prior to humans arrival to New Zealand, significant disturbance in New Zealand native forests was from through storms (cyclones), volcanic and seismic activity (ground shaking and landslips), but only rarely fire (as e.g. ignited by lightning; (Smale & Kimberley, 1983; Veale, 1986; Wardle, 1963).

- In podocarp dominated forest at Whirinaki, several surveys of the logged natural mature forest indicated regeneration of all species is occurring with 20,000+ seedlings found per hectare. However, conifer regeneration was found to be low with fewer than 10 rimu seedlings/ha (greater than 30 cm tall) and no podocarps greater than 1.5 m tall (Figure 6). Over 42 years later, regeneration patterns have not changed (unpublished data). In other Central North Island selection logging trials in podocarp forest where harvesting rates were up to 60% of merchantable stems, regeneration of podocarps has been more prolific, although slow in growth due to competition and lack of light in the lower canopy (Beveridge and Herbert 1978).

- In a selective logging trial at Whirinaki Forest, the effect of creating gaps in the canopy was tested by removing up to 10-12 mature podocarps in one location over approximately 42 ha and including buffers, over 100 ha. Gaps were subsequently planted with nursery- raised podocarps (Smale et al., 1985). The conifers planted in harvested gaps had minimal subsequent releasing and initially performed well, with overall survival of ~80% and mean annual growth increments of 15 cm in 1981 (G.A. Steward, unpubl. data). Rimu was considered the key species for planting because it has the widest site tolerance, survives long periods of suppression, is the least palatable to introduced mammals, and its overall performance is the best of the conifers (Beveridge et al., 1985). However, these gaps were invaded by dense stands of wineberry (Makomako) that rapidly over-topped the developing seedlings. As this wineberry matured and collapsed, it destroyed most of the planted seedlings. These gaps are now largely covered in tree ferns and no regeneration of podocarps is occurring (Figure 6).
- By contrast, limited experimental planting of tawa elsewhere in the region has been less successful (Knowles & Beveridge, 1982).
- In earlier trials in Whirinaki, Tihoi, Pureora and Mamaku forests, human-disturbed sites (logging tracks, skids and clearings) were quickly invaded by early successional species and weed including wineberry, toetoe, blackberry, and gorse. On these sites, planted seedlings required intensive management to ensure the regenerating and planted podocarps were remaining the dominant tree in the stand. Eventually, shade tolerant species such as karamu (*Coprosma robusta)* and fivefinger have begun to overtop and suppress these early successional species. However, this process of over-topping has taken over 45 years.
- At Mamaku, observations of forests repeatedly cutover in the last century suggests another high-density podocarp forest will eventually emerge over the next 100-200 years. But the elevation of 750 m has reduced growing and seed production.

Figure 6: A large (approx 0.25 hectares) logging gap in 1980 created in mature podocarp forest in Whirinaki forest (top) and again in 2005 (bottom). Planted seedling were suppressed by wineberry and then tree ferns. Little regeneration of podocarps can be found. Planted rimu and kahikatea seedlings had grown up to three to five metres tall prior to the collapse of the wineberry. These seedlings were snapped at the base by the weight of the collapsing material

What's currently being investigated?

There are many scientific, council, iwi-hapu and community-led forest restoration projects that have not included selective logging around Aotearoa New Zealand. Observations of regeneration patterns and frequency are ongoing at the species and forest systems levels but are sporadic and un-coordinated and appear to be revealing the same, or similar results i.e. little successful regeneration in mature forests and dense regeneration in highly disturbed second-growth forests

Natural regeneration is ecologically the method that native forests re-establish. However, with the significant human-based disruption of our ecology, natural regeneration is now not necessarily a reliable method for new indigenous forests. Without supplementary planting, it is unlikely that new indigenous forests will establish in the timeframes currently being discussed.

Examples include:

- Tāne's Tree Trust is working with partners to investigate and undertake forest restoration (Tāne's Tree Trust 2023).
- Riparian restoration is ongoing to restore the Waikato River https://waikatoriver.org.nz/wp-content/uploads/2020/02/Waikato-Waipa-Restoration-Strategy-NEW.pdf
- kauri restoration is ongoing, an example being on the Coromandel Peninsula (Bergin 2003; Kauri 2000, 2023).
- Fonterra farming is advocating for riparian restoration by contributing to restoration projects through funding native trees in a range of regions (Trees that Count 2023).

What do we need to find out or do?

- Re-visit the existing harvesting/regeneration trials mentioned here (Whirinaki, Tihoi, Pureora and Mamaku Forests), as well as forests that are re-generating and determine the parameters for success.
- Investigate the difference between weeds acting as competition and nurse crops, combined with the basic physiology and light requirements of key tree species and consideration of future climates.
- Understand/research how to control pests in weedy environments, which should be done with Predator Free 2050.
- This review has not focussed on the opportunity for establishing indigenous forests using natural regeneration and a complementary review in this area would be appropriate.

Creating mixed forests of natives and exotics

Why does this matter?

While the section above discussed the varying impacts of exotic weeds on natural regeneration, at times it may be desirable to establish mixed species forests by planting mixtures of exotic and native species. Mixing native with exotic species in forests may promote forest establishment and allow transitioning to a native forest, with the opportunity for thinning the exotic trees providing some economic and social benefits. Exotic species may be cheaper to plant and provide more rapid carbon sequestration for the first reporting period while native trees are growing. Planting mixes are likely to be more financially viable than planting pure native stands. The science of this is not well understood, however, and there is a risk of failure.

What do we know?

Combined planting of natives and exotics creates both opportunities and complexity, depending on which species are grown, how they are mixed, and how they are managed. Mixing stands of indigenous and exotic species of greatly different growth rates is most likely to result in the suppression of the target indigenous species. This has been seen in a number of stands and is due to the fact that most exotic tree species grown at scale are pioneer species and highly competitive for site resources (Steward and Firm 2020). It is also a case of mixing exotic trees that have had several generations of genetic improvement, with wild populations. Even within the same exotic species, this will result in stand failure. Mixed forests have to have careful selection of tree species with complementary traits. This is to maximise positive interactions among species and minimise negative effects such as competition, creating resilient systems with greater combined resource use efficiency (Forrester & Bauhus 2016; Huang et al., 2019; Leathwick & Austin 2001). The functional traits (affecting fitness or adaptation) of mixed-species forests can increase forest resilience and resource use efficiency (Forrester & Bauhus 2016; Huang et al., 2019), and increase rates of soil organic matter accumulation.

Overseas evidence indicates mixed species forestry is possible. Careful selection of tree species mixtures with complementary traits or ecological niches can be co-planted to maximise positive interactions and minimise negative effects such as competition, creating resilient systems with greater combined resource use efficiency (Forrester & Bauhus, 2016; Huang et al., 2019; Pretzsch et al., 2015) . The functional traits (affecting fitness or adaptation) of mixed-species forests can increase forest resilience and resource use efficiency (Forrester & Bauhus, 2016; Huang et al., 2019; Pretzsch et al., 2015); , and increase rates of soil organic matter accumulation (Jandl et al., 2007; Jones et al., 2021). Mixed species plantation forests of *Eucalyptus* in Australia were found to outperform monocultures by 10-30% (Forrester & Smith, 2012), due to less intense intra-specific competition in mixtures as opposed to planted monoculture stands.

Very little mixed species forestry is undertaken in New Zealand. The main obstacle to commercial uptake of mixed species forestry here in New Zealand is the lack of evidence that this practice works at large operational scales here, particularly with a pioneer species such as radiata pine. Lack of physical or robust theoretical demonstrations that the mixed model can be financially viable add to uncertainty for any forestry investors (Nichols et al., 2006).

Therefore, uncertainty and risks in a new forestry model compared with a proven single-species exotic radiata pine forestry system is perhaps the biggest barrier to mixed forests.

Mixed species plantation forests of *Eucalyptus* in Australia were found to outperform monocultures by 10-30%, due to less intense intra-specific competition in mixtures as opposed to planted monoculture stands. This reveals the complexity of mixed forests and the need to understand the species biology and site limitations. Even within mature mixed native forests, all the species are not of the same age but there is a natural progression from establishment through different ecological stages of forest composition e.g. forest aging studies in the Central North Island reveal age differences among species of several hundred years.

Mixing of pioneer species such as radiata pine and more shade-tolerant species such as rimu means that the exotic species will always win. However, exotic species (e.g. eucalypts) that let more light through the canopy can allow indigenous species growth. Silviculture (stand management e.g. thinning to lower stand density) can also be implemented on any species in order to manage the light quality under canopy. Examples of co-plantings are:

- Tihoi Forest, where *Eucalyptus regnans* and *E. fastigata* were planted as nurse crops for planted rimu, tōtara and kahikatea seedlings and where bracken fern (*Pteridium esculentum*) created a dense low cover.
- Pine species were used as nurse crops for kauri at Waipoua, Coromandel and Hunua Forests with poor results for kauri survival and growth.
- In Kaingaroa Forest, *Pinus ponderosa* suffers from needle disease, which results in a lighter canopy and more light reaching the understorey. It appears to have greater indigenous understory comprised mainly of tree ferns (*Dicksonia squarrosa*) in the centre and blackberry, gorse and broom on the margins.
- Near Minginui village, eucalypts (which typically have a thinner canopy and let more light through) were used to shelter indigenous forest after burning by Māori on more exposed colder sites (Katz, 1980), plot R.221. This was a test plot established in 1950 in regenerating podocarps where *E. delegatensis* were planted as an attempt to provide shelter. Long strips of bark shed from the trunk and falling dead branches significantly impacted the form and survival of podocarps beneath, as did the invasion of the site by bracken fern (Steward Pers. Obs.). The study was initiated by the installation of plots in regenerating forests in 1950.
- In a recent study (Steward & Firm, 2020) of mixed exotic and native plantings for Te Uru Rākau, it was found that a range of exotic conifer and hardwood species suppressed pre-existing native vegetation, related to faster growth rates of exotic species, stocking and establishment treatments.
- Most New Zealand native forests are derived from mixed species assemblages. However, planting mixed species forests adds significantly to the management and complexity of these forests. To date, most of the major plantings by the New Zealand Forest Service (prior to 1987), attempted to replicate the forest that previously existed. However, current plantings where a timber or economic outcome is the goal of the forest, then there has been a tendency to shift towards single-species stands in an attempt to better understand individual species growing and management requirements.
- The definition of a mixed forest is still elusive and is likely to mean several visually different scenarios. These may include recreations of historical native forests, or mixed monoculture stands.
- Redwood (Sequoia sempervirens) is particularly suitable in New Zealand to create silvicultural mixtures with native species because it is shade tolerant (Wilson & Memon, 2016).

Overall, most mixed planting trials have been unsuccessful, due to lack of knowledge and research that has been enabled in the last 75 years.

What's currently being investigated?

The failure of many multi-species stands with New Zealand natives have resulted in little ongoing scientific research in this area.

What do we need to find out or do?

Documentation, monitoring and research in existing stands of exotic species with native understorey will inform whether this is a technique worth reviving. Scion's opinion is that this is less urgent than transitioning from radiata pine to natives – in the next section.

An alternative approach to consider may be establishing exotic production species alongside indigenous plantings as a revenue source for landowners who desire or are transitioning to a native forest cover. A patchwork structure would be created where exotics mature and are removed, and revenue generated could be put towards to establishment and maintenance of further areas of indigenous trees. This model is promoted by Ekos (2023).

New Zealand-wide survey and research on what existing mixed species plantings and stands exist and their success as well as interviews with practitioners in order to gather anecdotal evidence that will guide the development of recommended mixes to plant, as well as demonstration plantings that aim at validating the approaches.

Transitioning from Exotic Species to Natives

Why does this matter?

Transition forests has been well reviewed recently by (Forbes and Norton 2019, Forbes 2021). Transition forests differ from mixed forests described above. In mixed forests all species are planted /established in some form together. Transition forests are initially mono-specific and are managed to encourage the development of other species within the canopy, at later ages.

Transitioning exotic plantations to native forests could become an important method for developing forests with long-term carbon storage conserved over a timescale of centuries, together with increased forest resilience and greater indigenous biodiversity, compared with single-species exotic plantations. This could also provide an economically viable pathway to establishing native forests, with profits generated through the rapid carbon sequestration and potential selective harvest of exotic trees being used to fund native planting/ regeneration, and long-term management. This is a relatively novel approach that is attracting widespread attention at present, with a particular focus on *Pinus radiata* as the exotic species. Transition forests could also be the result of natural regeneration of native trees under an existing canopy, although this is not a focus of this section.

What do we know?

'The topic of transitioning exotic plantations to native forest is relatively new and there has been insufficient time and a lack of coordinated research to determine the actual timeframes required to transition exotic plantations to native forest' (Forbes 2021).

Forest transitioning exploits the natural dispersal of native seed from proximal areas of native forest by native fauna such as kererū. Such transitions are likely to take between 100 and 150 years (Forbes & Norton, 2021).

Forest transitioning processes are affected by numerous factors which means that this approach will not be applicable to all non-harvested stands of exotic trees (Forbes & Norton, 2021; Jones et al., in press). Factors affecting the likelihood of success include:

- Availability of viable seed sources from existing mature native forest.
- Proximity of new area for afforestation to native forest.
- Presence of native fauna seed-dispersers and control of their predators.

- Size of the exotic forest and the level of native seed penetration throughout the forest.
- Maturity and structure of the existing exotic pine plantation – shade-tolerant native tree seedlings e.g. titoki may be able to establish under a closed pine canopy, however opening of the canopy can encourage establishment of more light-demanding species and allow existing native trees to form a canopy.
- Soil conditions, topography, microclimate and macroclimate – mid-slope topography, higher rainfall, high humidity and soil moisture assist.
- The intensity of mammalian herbivory – lower browsing assists.
- Disturbance or intentional silvicultural management of the forest to create the light conditions for native forest growth.
- Presence of weed species that may smother/stifle native tree growth and the resources available for weed control.
- Long-term/inter-generational thinking for land use outcomes and sustained funding for ongoing management.

Rimu, kahikatea, tōtara, red beech and silver beech require large scale disturbance for establishment (Forbes & Norton, 2021). It may be possible to use existing exotic pine canopy as a nurse crop, with enhancement planting, pest and weed control taking place over several decades, allowing understorey establishment of native tree species with interventions to mimic disturbance (Jones et al., 2021). There is no documentation easily available that describes a complete transition from exotic to native forest that shows clearly how to use the processes listed above. There are likely to be local forests that are known by local experts that may be available to learn from.

Trials which provide useful observations include:

- A review of native regeneration under pines in three North Island forests including Pureora, Gwavas and Mangatu (Compton & Steward, 1993), identified that age and mean top height of radiata are the greatest limiting factors in successful establishment of indigenous regeneration. The review found that when the radiata pine are 10 years old, there is maximum species diversity but, by age 25, both diversity and cover values have halved. They concluded/recommended? that in order to retain or increase native tree species diversity in radiata stands, thinning should take place before 10 years or >16 m in height.
- In Pureora Forest, intact mature native forest was immediately adjacent to pines. Little regeneration occurred beyond early seral succession species, despite proximity to sources of native seed.
- Recent research work in Kinleith Forest in the central North Island found competition between pine and indigenous seedlings was strongly influenced by the stand age of overlying *P. radiata* trees – the older the radiata stand, the greater the light available in the lower canopy, and hence the better the opportunity for native recruitment into the stand. The greater light availability was likely from stand management – i.e. thinning. Nevertheless, non-harvested *P. radiata* stands could provide viable nurse areas for the emergence of native tree species (Forbes et al., 2019). It is likely such stands will have a lifetime of between 70 and 150 years before the pines reach the end of the natural lifespan (Forbes et al., 2019). Intentional transitions will need to be managed Through thinning. The use of other exotic species (MPI & Scion 2023) as nurse crops may have different results depending on their ecology.
- Following the Marlborough Sounds pine poisoning project, where all pines in a block were poisoned, a dramatic canopy transition from conifers to natives took place (Ledgard & Dungey, 2010). This demonstrated that mature radiata can be used as a nurse crop to quickly develop areas into a mixed native canopy under some circumstances. The precursors for success in this case were abundant birdlife and local seed sources, adequate regular rainfall of a mild coastal climate and weed control.
- Natural regeneration occurring within *Pinus radiata* stands in Mangatu, Gwavas and Pureora Forests was assessed to identify the factors which may influence the development of a healthy and permanent indigenous understorey. In stands aged 10-25 years, up to 79% of species are either exotic grass or predominantly light-

demanding indigenous hardwoods. Indigenous hardwoods and conifer tree species comprised less than 4% of all species recorded (Compton & Steward, 1993).

- The structural and compositional aspects of indigenous forest regeneration in a single stand of older radiata pine stands was shown to be broadly comparable to New Zealand's mid-successional natural forest communities (stands of 1, 13 and 29 years of age were studied) (Allen, Platt, & Coker, 1995; Ogden et al., 1998). It is not known how transferrable these results are to other stands at other sites. A close inspection of the paper indicates that these results are comparable to the Compton & Steward study described above.
- Radiata pine stands can support a native understorey and could provide an opportunity for restoration of native forests where the radiata pine is not harvested, although accelerating the forest succession is likely to be needed (Forbes et al., 2019).

Whakarewarewa Forest shows that more than 50 years after establishment of exotic redwoods, Douglas-fir as well as other exotic conifers. The understorey comprises a mixture of native tree ferns, short lived native shrubs and invasive exotic hardwoods and weeds. Few if any native conifers appear to have established. Rimu seedlings planted 10-15 years ago appear to be not actively growing beneath a very tall canopy of redwoods. Nevertheless, exotics other than pine have a lot of potential for mixed forests if interventions can be devised to open up the canopy to provide more light for either planted or regenerating natives.

Allen et al, (2013) have noted that there are also extensive areas of shrublands undergoing successional changes, progressing to forest. These forests are often composed of novel mixtures of indigenous and exotic species. These are not intentional forests but reverting from agriculture or cleared forests.

Distilling this information down indicates that newly established pine plantations have open, disturbed soil. Without weed control, these sites are rapidly invaded by grass and weeds. As the pine ages, and begins to shade the site, the light-demanding weeds and grasses (exotic and native), begin to be supressed from the site. As the pine develops further, native shrub and hardwood species are likely to be recruited into the stand by bird dispersal if adjacent native seeding stands exist. There would be few examples where pine stands have significant quantities of native conifer regeneration. Radiata stands do exist, that have been thinned to lower stocking levels (e.g. 300-400 stems per ha). These stands would provide an excellent research resource to help understand potential interventions and effective transitions from exotic species to native forests.

Demonstration sites – both existing and new, are critical better understand and facilitate the future success of transition forests. This can be done immediately.

What's currently being investigated?

Trial sites are underway across New Zealand to evaluate the abiotic and biotic requirements of exotic forest transitions. These have been established across realistically large climatic gradients and involve the introduction of different native forest species (Forbes, 2021; Forbes & Norton, 2021).

What do we need to find out or do?

We do not know how to successfully transition from pines to native forest, due to a limited understanding of the regenerative capacity of native species under exotic pine plantations and the conditions in which they will survive or thrive.

It would be relatively quick and easy to establish trial sites where selected native species are established in transects from a fully open environment into pine stands of different ages. (Three to five years with seedlings in existence, 3-7 years if seed sourcing is required). This would identify the effect of exposure and on light demands of indigenous species. Minimum funding of 1 million per annum would be required per year for 7 years to ensure this research was robust. Ideally, ongoing funding to monitor and learn from the trial sites would need a minimum of 500k per year after 7 years.

Ideally, a collaborative MPI-funded research group would be formed amongst Scion, Manaaki Whenua, Tane's Tree Trust, University of Canterbury, University of Waikato, Otago University, Auckland University of Technology and the Forestry Industry among others to undertake New Zealand-wide demonstration plots, pool transition forest data and make significant progress in this area.

Skilled people

To grow indigenous forests requires people with the knowledge and forestry skills. The skills needed range from propagation science, forest mensuration, forest management and silviculture, forest harvesting, processing and utilisation, forest ecology and a cultural context including mātauranga of the forest. While some of these are transferrable from the current exotic forestry paradigm, there are specifics of native forests that would need to be learned, in particular ecology and continuous cover forestry.

The New Zealand Government would also need to develop policy, so expertise in Policy development and regulation with forestry knowledge is clearly required and is the understanding of public funders of the needs.

As with exotic forestry, the learnings from these skill sets should inform policy.

It's Scion's view that forestry in native forests requires a conglomerate of expertise and ultimately could be constructed virtually in a collaborative entity. This would be effective at removing the perceived (or otherwise) competitive research environment.

What do we know?

Current capability and capacity are limited. The pool of people with skills in indigenous forestry research for production forests is dispersed and aging, from Scion's viewpoint. This is due to the lack of investment in indigenous forestry (compared with *Pinus radiata*) over the last 75 years. Many practitioners are retired or at the point of retirement. Indigenous forestry expertise about permanent and production forests sits largely in a small Scion research group and conservation and biodiversity management with Department of Conservation and Manaaki Whenua. University of Canterbury has expertise in forestry that at times is applied in post-graduate research projects and in a relatively small number of research projects. Indigenous forestry does not appear to be actively promoted as a career. There is considerable competition for funding between organisations which is unhelpful to re-establishing indigenous forestry for production. It is Scion's opinion that the total funding available for native forestry research and development is less than 1% of the total research funding for forestry and forestry related activities.

There is a large practitioner community in New Zealand. They are often organised in collectives or incorporated learned societies, such as the New Zealand Farm Forestry Association (NZFFA) which support farmers, foresters, or investors keen on getting more trees in the ground - and the New Zealand Institute of Foresters (NZIF) that represents New Zealand's forestry professionals. Forest Advisory Companies often have a small indigenous forestry component. There are many forest restoration practitioners and companies. Tāne's Tree Trust has some research capacity but has a large network of enthusiasts and on-the-ground experience that is important to realising large-scale afforestation. The biggest impact to scale up these efforts would be to increase research and development. This requires a re-prioritisation of research funding or increase of funding to areas that will help New Zealand underpin its new strategic intent under its international climate change agreements. Creating a collaborative capacity building institute for native forestry plant production and establishment among existing, and possible new providers would really help accelerate the people limitations of native afforestation at scale.

Competenz Skills for industry	Competenz The forestry industry provider of career training in New Zealand.
	Toi Ohomai Institute of Technology Provider of practical training courses in Forest management and Forestry operations.
Telford Te Whare Wānaka o Puerua A Division of Lincoln University	Telford - a Division of Lincoln University Provider of practical training courses in forestry.
EIT EASTERN INSTITUTE OF TECHNOLOGY	Eastern Institute of Technology No specific forestry/farm forestry courses but agricultural courses include some tree-related modules.
TARATAHI Agricultural Training for New Zealand	Taratahi Agricultural Training Centre No specific forestry/farm forestry courses but agricultural courses include some tree-related modules.
UC UNIVERSITY OF CANTERBURY Te Whare Wānanga o Waitaha CHRISTCHURCH NEW ZEALAND	University of Canterbury Undergraduate and post-graduate degrees in forestry and forest engineering.
Lincoln University Te Whare Wānaka o Aoraki CHRISTCHURCH·NEW ZEALAND	Lincoln University A range of forestry and farm-forestry related and wood papers are offered by the faculty of Agriculture and Life Sciences
MASSEY UNIVERSITY TE KUNENGA KI PŪREHUROA UNIVERSITY OF NEW ZEALAND	Massey University Trees on Farms paper is part of undergraduate agriculture course.

Figure 7: Current education providers of forestry skills provided by NZ Farm Forestry (nzffa.org.nz)

Training also is limited (Figure 7). There are no indigenous forestry courses, with under-graduate courses appearing to focus on exotic forestry.

The only university-level forestry degree delivered in NZ is that of the University of Canterbury. Toi Oho Mai, the Rotorua branch of Te Pūkenga- New Zealand Institute of Skills and Technology, teaches many forestry related courses and is intending to open an Applied Masters course in 2023 which could include forestry topics. Other Universities have courses related to forestry, but more in the conservation and ecology sphere. They often target single species or an aspect of a selected species.

Auckland University of Technology offers research topics on plant pathogens on forest functions, carbon dynamics in mangroves, urban forests, ecohydrology and fire as well as other associated topics.

Massey University has a Bachelor of Science in Ecology and Conservation, with a paper in Urban and Farm Forestry. Lincoln University offers a course in Agroforestry.

The WIDE Trust (Wood Industry Development and Education Trust) was formed in 2018 and considers applications from students, academic institutions, business and industry associations associated with education and development in the wood industry sector. While not explicitly, support for study in native forestry could be sought from this organisation.

Te Uru Rākau are considering how to help build capacity in indigenous forestry. Greater diversity is being fostered through forestry scholarships from Te Uru Rākau: Mā ngā ka rahipi ngahere e nui ake ai te kanorautanga providing undergraduate support across the University of Canterbury and Toi Oho Mai.

Forest Growers Research provide some forestry post-graduate scholarships at the University of Canterbury. There appears to be no species limitation to these scholarships, so that they could potentially be accessed for native forestry postgraduate study.

MPI awards scholarships for master's and PhD candidates. The scholarships promote research that will advance the primary industries and highlight the diverse range of science-based career opportunities across the sector. These scholarships could be accessed for study in the native forestry area.

What do we need to find out or do?

New Zealand lacks indigenous forestry education at tertiary level with a curriculum covering topics from the nursery to forest products and use in a collaborative framework. Such material could be integrated into existing forestry teaching programmes. It's Scion's perspective that we need to preserve and honour the knowledge from the remaining indigenous foresters from CRIs, DOC and Universities. Creating a centre of native forestry excellence with these individuals supported in emeritus-type positions would help to transfer and even co-innovate and adapt this knowledge. Alternatively, creating a series of oral history videos would equally help to preserve at least some of the knowledge.

Scholarships for practitioner training and for forestry science training at universities is needed to help fill specific capability gaps in native forestry, particularly in propagation, afforestation, silviculture, harvesting, wood properties and utilisation as well as landscape-level evaluations. The result will be people who can support and work in a re-imagined native forestry economy. Linking CRIs, universities, Māori Trusts and iwi organisations may ensure competition is minimised and forestry knowledge from exotic species can be adapted.

- We need to develop career pathways for people working in indigenous forestry.
- We need to identify where indigenous forestry education can and should link with other disciplines and activities and foster such linkages:
  - Use of wood in architecture and creative arts.
  - Bridging the gap between western forestry knowledge and practice and Māori tikanga and aspirations.
  - Indigenous forestry in a circular economy, underpinned by sustainable practice.
- Consider best mechanisms to bring together researchers and practitioners in all aspects of indigenous forestry as a group who can undertake research.
- Provide resources and equivalent career pathways for Māori to lead native forestry that follows their values and tikanga.
- Government support would be ideal to actively promote indigenous forestry as a viable land use/industry/career option.
- Scion has expertise across the forestry cycle that could be incorporated/used directly in order to upskill indigenous forestry expertise. The technician /woodsman training scheme was and exemplar methodology to stream people to all areas of forestry post high-school. Re-imagining this scheme for today's needs would be extremely useful.

Managing indigenous forests

Vegetation management and harvesting

Why does this matter?

Any forest, exotic or indigenous requires some form of management. Management can make or break a forest. If there's not enough management, particularly when the forest is young, the forest can fail to grow or perhaps even fail to establish altogether. The result of poor management is that the site is overtaken with weeds and any native plants seeded, planted or otherwise can disappear from the site.

Harvesting methods can have major impacts on the long-term sustainability of land and can affect forest outcomes. Examples of harvesting methods include such as those used for regimes such as clear cutting, strip cutting, selective logging, and continuous cover forestry.

Vegetation management is about weed control and interventions in the growing forests that allow it to grow better, and to its potential.

What do we know?

Silviculture of indigenous forests is complex and difficult. This is because we are used to single-species stands of exotic forests in New Zealand. The multi-species nature of native forests automatically makes them more complex to manage. Silvicultural interventions depend on the forest assemblages (i.e. species and ages present), , the ecology of the species present, site, climate and pest and weed pressure. Management of these forests requires extensive scientific knowledge complemented by, or even built on extensive observational knowledge from people working and living in these forests. In Scion's experience good stand management and silviculture information is available for only a few indigenous species, as the result of the passion and careers of a few people:

- Kauri (Agathis australis) (Barton, 1999; Hutchins, 1919; Steward, 2011)
- Tōtara (Podocarpus totara) (Bergin, 2001; Bergin & Kimberley, 2009; Steward, 2019) and;
- Beech (Franklin, 1981; Franklin & Beveridge, 1977; Halkett, 1983; Wardle, 1984; Wardle, 2016; Donnelly 2011; Smale et al., 2012; Stewart et al., 1992) ; see also Tāne's Tree Trust resources). (Noting that beech species are distinct, and each species requires individual consideration).

Vegetation management

If the goal of creating a new indigenous forests is to achieve a stable, self-regenerating ecosystems, then the reality is that initially almost all forms of indigenous afforestation will require some form of vegetation management, including chemical and physical weed control, planting, planting densities and species choice, stock exclusion, pest control, forest health monitoring and interventions, forest growth monitoring and modelling of potential outcomes, thinning, and removal of poor trees harvesting. These interventions are required to promote the desired pathway to native forest establishment, including tree survival, types of species mixtures, canopy structures and light availability, silvicultural and early week management interventions. For the early phase of seed/seedling establishment, the management of competing weeds is one of the most important factors influencing subsequent tree survival and growth (Mason & Whyte, 1997; Mason et al., 1997; Pardy et al., 1992; Smaill et al., 2011). Competitive weeds, such as grasses and herbaceous plants, blackberry and woody brush weeds (broom, gorse, woody nightshade, lantana, wild ginger in later growth phases), can hinder or kill a seedling by physical smothering, competing for moisture, light and nutrients, and by chemical allelopathic interactions between plants (Watt et al., 2007; Watt et al., 2004). Fast establishing pioneer indigenous trees, such as mānuka and kānuka, may only require management for 1-2 years but many slower growing conifer species may require 5+ years (Bergin & Steward, 2004).

Planting of native species to replace forest lost during land clearance has been occurring since the late 1800s. Large areas of Northland were replanted in tōtara to replace kauri forest, while large management plantings of all "commercial" species were undertaken by the NZ Forest Service throughout the country where they were the land administrator. While resources were available for the establishment phase, little effort was available for the ongoing maintenance to maximise survival, growth, and productivity. Many of those plantings also followed what were perceived to be the best ecological approach, using nurse crops. Consequently, many of these indigenous plantings failed, or appeared to, due to lack of adequate weed control [Kauri: ecology, establishment, growth, and management. (Bergin & Steward, 2004). Planting and managing native trees: technical handbook, Bergin et al (Tāne's Tree Trust).

Suitable vegetation management methods, and the required intensity of interventions, will depend on the nature of the afforestation, the purpose, the site size and history and the local environment and vegetative pressures present. Broadly, there are two main approaches to establishing indigenous forests which require very different management.

Herbicides, applied as broadcast or spot sprays using the best, currently available information, are the most cost-effective method of vegetation management at scale to kill or hinder growth of competitive vegetation, and when carefully selected can avoid significant harm to desired species. Drill and fill and cut and paste methods are effective for a small areas but is not really feasible at scale. Production forestry has spent many years fine tuning herbicide regimes for managing *P. radiata* establishment. The use of modern herbicides to help encourage the growth of indigenous species and avoid weed competition could benefit significantly with some more research and development (Nairn et al., 2020). The use of herbicides with non-soil active, foliar herbicides such as glyphosate in native or other sensitive forest species are preferred.

The alternative method to control undesirable vegetation is manual release (weed eaters/strimmers, hand pulling, loppers). All these are labour-intensive and expensive and not very feasible at scale, primarily because of the cost. If finances are not limiting, then these methods are applicable. Different areas will have different weed challenges and the desires of the landowners.

Nurse cropping is a method that could reduce management labour, as referred to in sections **Error! Reference source not found.** to 0 by reducing planting density, and to improve tree form. Nurse crops exclude fast-growing competitive weed species, reducing or eliminating the need for releasing. Suitable nurse species are fast and cheap to produce and can be mass planted or be a naturally seeded population pre-existing on a site such as gorse or 'scrub' species. Some nurse crops, like mānuka, offer an early revenue stream for landowners. The nurse-crop itself may need management to ensure indigenous trees establish. Cutting lanes into nurse crops of scrub and/or weeds such as gorse, have been trialled to introduce indigenous forest. This method has had mixed success (Steward & Firm, 2020).

Forest Management can be applied to second-growth native forest stands, following previous land clearance. This is usually to enhance growth and productivity but can be to enhance diversity and forest health. Actions can include excluding grazing, thinning to reduce competition and removal of poor form trees. In the case of tōtara on farmland in Northland such stands are often highly stocked (5-10,000 stems per ha), and open to grazing, with little regeneration or developing understory structure. At the canopy level, many of the stands function almost as monocultures, common in second growth stands of other species also, including kauri and kahikatea in the Waikato and *Fuscospora* and *Lophozonia* (beech) in the South Island. Silviculture can be applied to these types of indigenous forests and can be relatively easily managed for timber production.

Remote sensing for forestry management

Remote sensing, which can be as simple as using aerial imagery, or as intensive as single-tree high-density scanning with remote and networked real-time sensors that can report in real time. Remote sensing has been actively used in forestry for some time (e.g. Pont et al., 2015; Pont et al., 2017; Pont et al., 2015). A large-scale LiDAR acquisitions across exotic forests has recently been used to measure and investigate whole forest health and dynamics in almost real time (Bombrun et al., 2020). New opportunities and technologies constantly emerge e.g.

Sentinel-2 Satellite data, already tested in New Zealand for land cover/use (Phiri et al., 2020). Technologies like this has the potential to be a game-changer in detection and monitoring of trees species, ecosystem types and stand structure in native forests. Although application is not as advanced in native forests, the only barrier to uptake is the research and development of new native-forest methodologies.

In any native forest, remote sensing has not yet been widely used to look at the forest itself, whereas application of remote sensing in planted forests is advanced e.g. (Bombrun et al., 2020). Dealing with data in a multiple-species multiple-aged forest is a lot more complex than a single-species single-age stand of exotic trees. The pathway to this is really only a matter of research and development funding. There are some existing examples of application:

- *Pōhutukawa*: (Pearse et al., 2021) A Deep learning model was developed that identifies pōhutukawa from aerial images with 95.3 per cent accuracy, although a higher accuracy was possible when flowering phenology was added to the model (97%), even where flowering intensity varied widely.
- *Kauri*: (Meiforth et al., 2019) A model developed from a five-band multispectral sensor can detect up to 93.8% of kauri trees.
- High-resolution on-ground laser scanning of indigenous forests has been found to both characterise the forest and measure above-ground individual stem volume (David Pont pers. comm.).
- Remote sensing has recently been tested for the early detection of myrtle rust and has been shown to be successful under controlled conditions (Watt et al., in press).
- Airborne LiDAR data that has been used to estimate the number of tall trees in indigenous forest in the Wellington Region (Zörner et al., 2018).
- Hyperspectral and thermal imaging, which can detect subtle changes in spectral reflectance of plant tissue, is showing promise in detecting plant disease such as myrtle rust infection before, or soon after, visible symptoms develop.
- Many other research institutes and now remote sensing companies are also innovating in this space.

Harvesting

Forms of harvesting for indigenous trees historically include **clear-cutting** (in various coupe sizes, as commonly practiced in New Zealand for *Pinus radiata***)**, **strip-felling** and **continuous cover** (where individual trees are selectively removed). Selective harvesting refers to removal of individual stems selected for their growth and straight form of the trunk- normally an indicator that the wood retrieved will be a reasonable and thus profitable percentage of the log volume. Widespread harvesting of indigenous trees was mostly abandoned in the 1980s due to political pressure from the conservation movement. As a result, New Zealand ceased researching selective harvesting methodologies and there is very little national innovation occurring in this area.

There is no one simple answer as all methods have not been properly assessed for New Zealand native forest types with contemporary machinery and technology and indigenous species/ecosystems require the development of bespoke harvesting that will allow the forest to recover in a short period of time. The closest regimes that exist are for beech in the South Island that have low harvest rates and/or employ non-destructive harvest methods such as using wood cores. There is good information to start from, but more will be needed to ensure sustainability. Trials of different methods include:

- Strip-felling, leaving wide bands of untouched forest, was trialled in Westland terrace rimu forest (Chavasse, 1954), but there was only sparse regeneration in the cleared strips and wind damage in the untouched strips, so this practice was abandoned in favour of selective harvesting in 1965 (McGlone et al., 2022).
- Selective harvesting was first trialled in the 1930's in podocarp forests of the Whirinaki River Valley. This was later expanded into the forests of the central North Island, the West Coast and Southland. Due to technological limitations of the available selective harvesting methods at the time, substantial collateral damage was caused

to the surrounding forest ecosystems and the approach was not sustainable. These trials were not maintained once the Forest Service was disbanded, and Government policy changed. Several re-visits to the site in recent years by Scion, is attempting to resurrect the research.

- Another selective harvesting trial in Whirinaki Forest established by the Forest Service in the 1980s tried different types of harvesting, with the individual-tree harvesting treatments causing the least amount of canopy gaps and being the most successful (Steward, 2020b). Small groups of trees were harvested (**Error! Reference source not found.**6) to allow regeneration, but the result was that tawa, rather than podocarps, filled the gaps (Figure 8). The age-structure of at least some of these Whirinaki forests suggests they were already in decline –continuous cover forestry harvesting might have been possible if started earlier in the forest lifecycle. Regeneration is occurring in this forest but does not develop as a replacement 'crop' of podocarp seedlings. The forest is old and is in a natural process of change, potentially to another forest type/species assemblage.
- This suggestion is supported by the finding that younger forests are likely to be more resilient to selective harvesting (Barton, 2008).
- An excellent study on thinning trials in silver beech, *Lophozonia menziesii (Syn = Nothofagus menziesii*) (Easdale et al., 2022) showed that thinning had a minimal effect on mortality, alleviating concerns about stand survival. Stem densities that optimised growth (c. 570 stems per ha). Ninety percent of cumulative yield was modelled to be at 80 years of age. A sevenfold gain in merchantable stem volume at 58 years was estimated at this stand density from the thinning undertaken. These results suggest that any harvest would be best below 80 years of age.
- Selective harvesting at Pureora demonstrated that successful removal of one-third of the timber volume was possible, while initially retaining forest structure (Beveridge, 1975).

Figure 8: Regeneration in the podocarp-dominated forest in the harvesting trial showing regeneration of trees dominated by tawa (1979; (Steward, 2020a)).

Recently, experimental harvesting has occurred in relatively young stands of tōtara found on private farmland in Northland. Permitted harvesting rates under the 1949 Forests Act have been extremely low (<1% of standing merchantable volume) but recovery rates from standing volume to lumber has been 55%. This figure cannot be meaningfully compared with e.g. radiata, as harvesting of tōtara was from a wild population c.f. a highly managed species. Te Taitokerau Māori Forestry Inc are pursuing funding to take this opportunity forward as a new business enterprise. As a follow up to this recent feasibility study, Scion remeasured harvest sites for 3-5 year regeneration (Steward et al., 2022). Little regeneration occurred in either disturbed (harvested) or undisturbed sites. It was concluded by the authors that "The lack of growth, regeneration and retained volumes indicate that all sites could have tolerated a significantly higher volume removal which … would have likely encouraged better growth and more regeneration".

To minimise collateral damage, tree selections were made well in advance of harvesting and individual trees to be harvested were mapped. Trees selected for harvesting were generally on the margins of the stand and trees were felled, where possible, into surrounding pasture. Logging machinery was generally confined to the pasture, minimising soil disturbance (which recovered within a few weeks to months depending on the season). Physical management and harvesting of individual native trees normally uses traditional forestry equipment (Dunningham et al., 2020; Steward et al., 2018) which is large, heavy and expensive and time-consuming to move between harvesting sites on farmland. However, Europe and North America produce tractor add-on winches that significantly reduce costs and increase profits, while reducing environmental damage. In this study, some trees were winched out and very few trees were damaged. In fact, unfenced stands had greater damage from browsing stock (Dunningham et al., 2020). At the time of the study biodiversity was not mapped, and similarly cultural values were not considered. A great deal could be learned by re-examining these sites through these lenses.

What's Currently Being Investigated?

Currently several indigenous nurseries, Tāne's Tree Trust and forest management companies are trialling vegetation management methodologies. There is a handful of research trials investigating the management of nurse crops and herbicide releasing.

In terms of harvesting, little research is underway, Scion has started several other small projects over the last year on characterisation of young tōtara resource from log disks, including supply chain logistics (e.g., regional mills and manufacturing facilities).

What Do We Need to Find Out or Do?

Here we are recommending some needed actions. These should be driven by the Government, and by policy makers. We recommend, however, that there is a panel of forestry experts that advise the policy in order to avoid any perverse outcomes.

We need to invest in a forest modelling system for indigenous trees that allows us to test and visualize forest scenarios – one that can handle monocultures but also species mixes of multiple ages. In order to understand the impact of climate change on forest survival, the system would be ideally one that incorporates the physiological characteristics of native tree species. Using remotely sensed data to build and validate these models would be extremely useful, so extension of the exotic forest methodologies built to measure individual trees to native forests would be timely. The ideal modelling system would need to be able to predict growth of stands of mixed forests now and under future climate change scenarios. This includes mixed species and mixed ages. It's likely that physiological models might need to be hybridized with typical empirical (models based on historical data) and ecological approaches, such as the following:

- Models exist that will be useful to contribute to a large-scale forestry modelling system.
  - Ecological simulation models that can handle up to two or three species are very useful (Brock et al., 2020), and the principals are needed to contribute to build whole-forest models at larger scales.

- A model of small forest fragments that takes spatial arrangement of trees in the forest into account has been applied in a podocarp-tawa forest in NZ (Morales & Perry 2017). The model predicted the stand structural dynamics well but did not capture the increase in stand basal area.
- Different approaches to modelling tree growth have been developed, including using the life history of a tree and the Leslie matrix in kauri (*Agathis australis*) (Ogden 1983) and in tawa (*Belschmiedia tawa* (West et al., 1983).
- *In silico* experiments such as Brock et al., (2020) are useful to build dynamic understanding of species interactions in mixed forests.

- Find existing recommended best practice for vegetation management and disseminate the information while improving this to minimize herbicide use or other treatments.
- Determine the best planting stock to provide the best establishment chances that minimizes post-planting vegetation management.
- Determine where the balance between nurture and competition is for weeds and forest plants across a range of typical planting/restoration sites and determine recommendations to improve growth and survival.
- Continue a support the work alongside Predator Free 2050 and plan to determine best practice for pest management– particularly goats, possums, wallabies, and hares.
- There is a real need for information on harvesting and wood properties of the species beyond kauri, tōtara and beech.
- Investigate the impact of management, silviculture and harvesting interventions on timber characteristics and extracts (bark, needles, branches, wood).
- Build a stocktake of existing sawmillers and their capabilities for indigenous timber.
- Identify, learn and teach different sawing techniques for best recovery of the log to sawn timber for different indigenous timber species.
- Address logistical challenges in regional supply chains, exploring smaller regional processing options and establishing manufacturing hubs. This would include suitable sawmills and drying facilities, and expertise to apply to native species.
- Characterise the wood properties of different species across the country under different silviculture treatments.
- Determine the cost/benefit economic and social benefits of small-coupe harvesting at different spatial levels – small community, regional and national levels. Determine, test and develop, if necessary, the technology to harvest at small scales.
- Determine what type of harvesting would be socially and culturally acceptable
- Investigate and facilitate the adoption of small-coupe or single-log harvesting techniques into New Zealand.
- Determine the biological benefit of having native forest that is harvested, its contribution to biodiversity and management potential for improving community and national resilience.
- Undertake a technology scan world-wide, leveraging current forestry knowledge, for low-impact and new harvesting techniques that could be used in some future low-impact harvesting of native forests.

Threats to indigenous forestry

Why does this matter?

Many forests in New Zealand are already being adversely affected by fires, pests, and pathogens. These challenges are being exacerbated by global travel bringing new pests and diseases, and climate change allowing new pests and diseases to thrive in New Zealand (Goldson et al., 2015; Pawson et al., 2013; Sheppard et al., 2016).

Further, climate change will alter key growing parameters for all plants, including maximum and minimum temperatures, rainfall patterns, and drought periods. Research remains divided on the effects rising CO_2 levels will have on El Niño/Southern Oscillation (ENSO); however, current models suggest a longer, "more permanent" El Niño, associated with warmer, wetter weather (Callahan et al., 2021), which will increase severe weather events, such as tropical cyclones in the southern pacific (Lin et al., 2020).

The long life-histories of our native trees, often exceeding multiple centuries, combined with slow growth traits, makes it a challenge for them to adapt to climate change, severe weather events, and pest and pathogen pressure.

What do we know?

There are many abiotic and biotic factors that negatively impact forest health. Globally, biotic factors, such as invasive fungal, bacterial, and viral pathogens, as well as insect pests, are responsible for the loss of millions of trees annually. In natural forest systems, native insects and microorganisms that negatively impact tree health are usually not considered a problem, being an important component of the ecosystem – driving important processes, such as diversification, natural selection, and nutrient cycling. Fire can also be a natural process; however, it still can be quite damaging to forests. Between 2001 and 2021, fire was responsible for almost a quarter of all tree cover lost globally (Global Forest Watch, 2023). In New Zealand, there are 4100 rural wildfire events a year, burning ~5,500 ha a year (Anderson et al., 2008), not including controlled burn offs of 60,000 ha per year of crop residues, 23,000 ha/y tussock and 13,000 ha/y of other standing vegetation (which includes the diminishing practice of burning slash after forest felling) (Guild & Dudfield, 2010). We believe forest ageing, disturbance, simplified forest ecosystems, introduced exotic pests and pathogens, and climate change may limit indigenous forestry now or in the future.

Native pests and pathogens that harm native trees

There are many native species that are harmful to native tree species; however, none of them have been associated with any significant shifts in vegetation. Some of the best-known native pathogens are the four species of the root-infecting honey fungus, *Armillaria,* found here, *A. aotearoa*, A*. hinnulea*, *A. limonea* and A*. novae-zelandiae.* These species are associated with *Fuscospora* and *Lophozonia* (beech), although *A. novae-zelandiae* has been found on wider number of hosts, including indigenous *Pittosporum* and *Weinmannia racemosa* and exotic *Quercus* and *Pinus.* These fungi are known to kill trees; however, their impact is more severe on exotic hosts e.g., pine and oak, than native species. *Armillaria* infection of *Pinus radiata* planted on recently cleared indigenous forests has caused up to a 27% mortality (Shaw III & Calderon, 1977). While *Armillaria* is seen growing in the topsoil of indigenous forests and adhering to the roots of healthy trees, there is no clear evidence it invades healthy tree roots (Hood, 1989a, 1989b); mortality is associated with trees with dead and weakened roots.

There are at least 23 known indigenous bark beetles and ambrosia beetles, not all formally described. At least four of the Scolytinae attack native trees of current interest for indigenous forestry purposes (Brockerhoff et al., 2003). Three of the Platypodinae are known to attack native beech trees (Brockerhoff et al., 2003). These three also have weak to strong associations with native podocarps, typically attacking dead wood rather than living trees (see Plant-SyNZ). The ambrosia beetle *Platypus apicalis* possess an aggregation pheromone, which can lead to mass attack of host trees and large-scale mortality of native beech. *Platypus apicalis* is also a species of phytosanitary concern for the EU territory (EFSA Panel on Plant Health, 2022).

Other cases of sudden and significant declines of native tree health have been reported and appear to be mostly related to habitat disturbance reducing forest resilience and/or drought:

- Reports from the 1950s-70s of Tawa **(***Beilschmiedia tawa*) dieback were found to be linked to habitat modification and exposure to cold, with pathogens being a secondary problem (MacKenzie & Gadgil, 1973).
- Mortality in New Zealand Beech (*Fuscospora* spp. and *Lophozonia meinziesii*) in the 1960s and 1970s were usually the result of attack by pinhole borers and pathogenic sapstain fungi (Faulds, 1977; R. Milligan, 1974; R.H. Milligan, 1972; Robert Hartley Milligan, 1972; R. H. Milligan, 1974). Mortality from these beetles may seem alarming but is usually driven by a local disturbance event and generally occurs in older trees (Hosking, 1989).
- Major concerns in the 1980s and 1990s about cabbage tree - tī kōuka (*Cordyline australis*) decline in rural settings has been linked to habitat modification and disturbance (Hosking & Hutcheson, 1992; Rees-George et al., 1990), or a phytoplasma (Anderson et al., 2008), depending on the specific situation.

Exotic pests and pathogens

There are more than 180 exotic insects established in New Zealand potentially harmful to native forest species and timber products. The vast majority of these have only been found on exotic plants to date, but a few have also been associated with indigenous plants (Ridley et al., 2000). So far only one of these, a sap sucking scale insect (*Acanthococcus orariensis*), has had any substantial impact on an indigenous forestry species (mānuka), causing mānuka blight. Impacts of this pest are now moderated by a fungal parasite (*Angatia thwaitesii*) (Ridley et al., 2000).

The exotic longhorn beetles (Cerambycidae) are a major group of insects that affect many of the native tree species of current indigenous forestry interest (Sopow & Bain, 2017). These beetles infest stressed and dead and fallen trees, and can damage wood and wood products, rather than impacting healthy standing trees. In our opinion, other exotic insects that are already established in NZ, such as sap suckers and moths/caterpillars, pose a small risk, mostly during the establishment phase. Some introduced species are still in a 'lag phase' (the time between a species introduction and its recognition as an invasive species) – it could be more than 100 years before we see any significant impact (e.g., (Kowarik, 1995).

Kauri dieback and myrtle rust (caused by *Phytophthora agathidicida* and *Austropuccinia psidii*, respectively), are two of the most important diseases affecting indigenous species.

Myrtle rust is a pathogen causing a global plant disease pandemic. The rust causes dieback and even death of our Myrtaceae species, many of which are endemic and ecologically important (Insu, 2022). Since its detection in New Zealand in 2017, myrtle rust has infected several indigenous species of Myrtaceae, including *Lophomyrtus* spp., *Metrosideros* spp., and *Leptospermum scoparium* (mānuka). Monitoring of myrtle rust has shown that *Lophomyrtus* spp. are highly susceptible and are facing localised extinction (Sutherland et al., 2020).

Phytophthora species cause various diseases, from fine root rot, foliage blights and casts that reduce productivity to stem cankers and tree mortality (Scott & Williams, 2014). *Phytophthora agathidicida* was first found on declining kauri on Great Barrier Island in the 1970s (Gadgil, 1974). In 2006, *P. agathidicida* was confirmed on the NZ mainland and has now been reported in many locations across the native range of kauri (Bradshaw et al., 2020). There remains significant work to be undertaken to ensure kauri remains in our landscape and while some rongoā cures have been found (Kowhai, 2022), executing these at scale across the kauri forest remain problematic, primarily as there is limited funding to facilitate this. Variation in the putative tolerance to *P. agathidicida* has been found through studies in the Healthy Trees Healthy Futures programme, but the on-going co-development of how this might be implemented also suffers from insufficient funding.

In addition to *P. agathidicida*, there are more than ten other *Phytophthora* species (some native and some exotic) (Scott & Williams, 2014) associated with natural systems in New Zealand. These include *Phytophthora cinnamomi* – one of the world's top 100 invasive alien species. While damaging to more than 1,000 plant species around the world, *P. cinnamomi* has only been reported causing localised damage in New Zealand. The temperate climate of New Zealand does not support severe disease development ((Johnston et al., 2003). A changing climate could alter conditions providing new opportunities for establishment/spread of other pathogens and pests for which New Zealand conditions are currently not conducive. Another recently described species of *Phytophthora* deserves mention, *Phytophthora podocarpi*, which has been associated with foliage blight and twig dieback of tōtara (Dobbie et al., 2022). Little is currently known of this pathogen, but high levels of moisture appear to be required for disease, with most detections in wet years (e.g. 2017).

New Zealand continuously faces the threat of new invasive pests and pathogens. The polyphagous shot hole borer (PSHB) is a highly invasive ambrosia beetle that attacks more than 400 plant species globally and has recently arrived in Western Australia. Its arrival in a new country is typically succeeded by the addition of new host associations. So far, Australia has added eight new tree species to the global host list of this pest (Department of Primary Industries and Regional Development, 2023). The beetle was reported in South Africa in 2017 where it has significant impacts on London plane trees. It is still too early to assess its impact in indigenous forests (Van Rooyen et al., 2021). In Southern California, it has reportedly killed hundreds of thousands of trees across riparian ecosystems (Boland, 2016; Parks, 2023).

Recent work has highlighted the pest and pathogen risks Pacific countries pose our native plants, as well as the paucity quality of information available (Soewarto et al., 2021). In Hawai'i, *Ceratocystis lukuoia* and *C. huliohia*, two recently described fungi associated with ambrosia beetles, are killing *Metrosideros polymorpha* trees. These pathogens are considered a threat to other Pacific *Metrosideros* species and given their association with invasive ambrosia beetles, can spread rapidly (Roy et al., 2021).

Fire

Fire was used in Aotearoa New Zealand by Māori following their arrival in ~1250–1300 CE (Stone & Langer, 2015). Fire was the principal tool for clearing land and preparing gardens (Best E, 1924). By the time of European settlement around 1840, approximately 40% of New Zealand had been deforested, down from 85-90% of land cover (McGlone, 1989). Land clearing by European settlers rapidly decreased forest cover further from 45-50% to 25% of its original coverage (Perry et al., 2014), p. 157. In the future, climate change is predicted to substantially increase the wildfire risk of indigenous forests in many regions, through increase in frequency, severity, and season length of fire weather conditions until at least 2050 (Langer et al., 2021; Melia et al., 2022).

New Zealand vegetation is not adapted to resprouting after fires c.f. Australian vegetation, where buried tubers/buds resprout and buried seeds germinate, triggered by fire. In New Zealand, it takes centuries to regain former forest structure and composition (Ogden et al., 2003). New Zealand's indigenous beech species are easily destroyed by fire due to their thin bark and shallow roots. Post-fire, early successional vegetated ecosystems (dominated by bracken, tussock and shrubland communities) are inherently more flammable than native forests with a canopy cover (McWethy et al., 2010; Perry et al., 2014; Wyse et al., 2016) and also more susceptible to pests e.g. rats and mice that eat seeds and seedlings. Large burnt areas may stay fire-prone for decades or more, unlike Nothofagaceae elsewhere (Lord et al., 2022), and regeneration is generally limited to tens of meters of seed sources along margins of unburned forest stands (Tepley et al., 2016). The opportunity for beech recolonisation after fire is often impacted by competition by thick grass swards and greater susceptibility to frost and summer drought. Fires also reduce avian pollinators and seed dispersers (Baillie & Bayne, 2019).

Shifting climate zones

Shifting climate zones may mean that indigenous species become stressed, die, or cannot regenerate in areas they currently occupy. A solution considered by international forest adaptation research is the assisted migration of native tree stock – seedlings with existing pre-adaptations to climatic stressors are translocated to locations modelled as suitable for their traits (O'Neill et al., 2017; O'Neill et al., 2014). Assisted migration needs to carefully consider degree of adaptation of species (O'Neill et al., 2017; O'Neill et al., 2014; Poupon et al., 2021), disease spread, potential invasiveness of tree species in new areas and cultural values (such as eco- and cultural-sourcing). In Canada and Mexico, field trials of native coniferous tree species have illustrated the benefit of this approach (O'Neill et al., 2017; Sáenz-Romero et al., 2020). Some maladaptation of trees in the short term is likely, for example frost damage to native white spruce in Canada in field trials of translocated populations (Benomar, Bousquet, et al., 2022; Benomar, Elferjani, et al., 2022).

On top of shifting temperature envelops and rainfall patterns, extreme weather events are predicted to increase in frequency and severity. Storm damage has affected podocarp forest in the Whirinaki River Valley, although that may also be related to its age. As climate change sees more ex-tropical cyclones affecting the forests of NZ, damage caused to forests increases, e.g., Cyclone Ita, West Coast (2016/17); Cyclone Hale, Coromandel/East Cape 2023; Cyclone Gabrielle, East Cape/Gisborne 2023. Damage to crowns and stems can lead to attack by sapwood boring insects, followed by fungal entry and plant ill health/death. Flooding will also increase the likelihood of attack by root rotting pathogens, such as *Phytophthora* spp.

What's currently being investigated?

Effective management options are being sought for myrtle rust and kauri dieback, using a combination of science, citizen science and mātauranga Māori. In the short- to medium-term, chemical controls will still be used to manage these diseases in nurseries and important areas, at least until more environmentally friendly alternatives are found. An epidemiological model (Beresford et al., 2018) and digital decision tool has been developed to guide growers on the timing of their sprays, reducing spray applications and disease incidence. Examples of future management strategies being researched include RNAi (Degnan et al., 2023) to limit infection by myrtle rust, biological control agents such as the hyperparasite (*Sphaerellopsis*) and the fungus eating gall midge (*Mycodiplosis constricta* (Kolesik et al., 2021) to reduce myrtle rust impact.

Research is underway by multiple organisations to improve accuracy and speed of diagnostics and detection of *Phytophthora agathidicida* and *Austropuccinia psidii* including:

- A review of the current *Phytophthora agathidicida* soil baiting protocol.
- Introduction of a routine LAMP (Loop-mediated isothermal amplification) assay to rapidly identify *Phytophthora agathidicida*.
- The National Science Challenge, New Zealand's Biological Heritage programme Better Border Biosecurity (B3) is developing an eRNA tool to identify viable pathogens in soil.
- Hyperspectral and thermal imaging, which can detect subtle changes in spectral reflectance of plant tissue, is showing promise in the detection and monitoring of forests (Watt et al., 2023, Meiforth et al., 2020).
- Monitoring of the state of forests can be supported by 'app'-based citizen science monitoring schemes, such as the Living Ash Project (livingashproject.org.uk), or within New Zealand, the 'Kauri Dieback App' (The Tindall Foundation, 2021).

Research has also been completed by Scion and Manaaki Whenua in partnership with Māori to identify individual trees with greater resistance to these pathogens, and to understand the underlying mechanisms. The research remains unpublished.

What do we need to find out or do?

New Zealand has some good baseline general knowledge around the potential for native species to become problematic for indigenous forestry, but not a lot of specific details that are fundamental for important decision making (right tree, right place, right purpose). For instance, we have a good idea of pest host plant ranges, but not necessarily the host plant preferences. We do not know the spatial or temporal responses of pests to an indigenous plantation setting, whether that be monoculture or mixed species. There is a risk, that just one or two pest attacks of a healthy tree could lead to a large reduction in wood quality and usability (e.g., sapstain fungi from *P. apicalis* attack).

There are gaps in our fundamental knowledge with regards to kauri die-back and myrtle rust. We do not know if there are alternative hosts of the kauri dieback pathogen, are any interactions with other co-occurring *Phytophthora* spp. (Horner & Hough, 2014; Waipara et al., 2013), the rate of dispersal across the landscape, distribution at site and landscape level, disease progression over-time. In terms of myrtle rust, disease severity among and within species and sites varies, but the drivers have not been well identified. We are only just beginning to unravel the ecological factors that exacerbate impacts, such as a potential interaction with an invasive insect pest.

The availability of a high-quality genome for both *Phytophthora agathidicida* (Cox et al., 2022) and *Austropuccinnia psidii* (Tobias et al., 2021) is supporting ongoing research on host-pathogen interactions, the pathogen life cycle and population genetics. Another gap in our research is host population genetics. Some analyses have been done (Heenan et al., 2021) but are limited for the species most at risk. This work will contribute greatly to research already studying resistance mechanisms of hosts species, e.g., manuka (Smith et al., 2020). Developing biocontrol options by identifying natural enemies, such as hyperparasites and predators, is an effective means of controlling pests and pathogens; however, in the case of *Sphaerellopsis* and *Mycodiplosis*, little is known of their biology, potential as biocontrols, and wider ecosystem impacts. Propagating and screening tolerant material for planting is a long-term solution for disease free forests; however, knowledge of seed development, germination and storage is only known for some species (Van der Walt et al., 2020)

The same work required for kauri and vulnerable Myrtaceae needs to be replicated for other species and their current or potential pests and pathogens (PSHB, Rapid ʻŌhiʻa Death). We need to identify which native forest species we are investing in and the high-risk pests and pathogens that threaten those species, their identification, characteristics and effects.

Breeding and genetics offers a real mechanism for developing resistant or tolerant plants that can be repatriated. This is an option where the host species are already under threat and at risk of local or national extinction. Breeding programmes can be actively managed for diversity and other characteristics of interest and would need to be led or co-developed with Māori, within or among rohe. This is a long-term applied option.

Benefits and uses of indigenous forestry

National and legislative context

Harvesting and milling of indigenous timber from natural stands on private land is managed under Part IIIA of the Forests Act (Forest Act, 1949). The Act specifies that harvesting is not permitted without a sustainable management plan, or a sustainable forest management permit reviewed by the Secretary in consultation with the Director-General of Conservation and the chief executive of the Ministry of Māori Development if the area includes any Māori land (67F Procedure for approval of sustainable forest management plans, https://www.legislation.govt.nz/act/public/1949/0019/latest/DLM256611.html).

The Act recognises landowners' right to recover an economic return from their privately-owned asset with their responsibility to maintain a healthy forest and functioning ecosystem. Part IIIA of the Act primarily contains three types of controls which restrict the harvesting of native trees for timber production, the sawmilling of native logs, and the export of native timbers. Conditions are placed on the volume harvested and the size of harvested areas, varying by species. There are also requirements intended to ensure adequate regeneration after harvest. The Act does not differentiate in its approaches to harvesting and managing between comparatively young second-growth stands and old-growth forest.

The rapid loss of forests in early colonisation has meant that there is now a social dichotomy between harvesting and/or utilisation and conservation. Conservation is important to ensure that we have intact ecosystems but it would be good to debate whether conservation can also work together with sustainable utilisation, thus expanding the area of native forest, increasing biodiversity under sustainable management. This is because conservation can mean that native forests actively degrade, caused by human interference i.e., predators, browsing mammals, and changes to ageing and natural forest dynamics.

The Treaty of Waitangi and the "Wai262" claim will have significant implications for research into indigenous forestry in terms of ownership of intellectual property, germplasm and movement and use of species within and between rohe, ecosourcing of seeds.

Pending changes to the Resource Management legislation in New Zealand, if enacted, will have implications to land use and therefore indigenous forests. This review has not reviewed the impact of this, and Scion recommends that a review be undertaken under the indigenous forestry lens.

Indigenous trees for products and processing

Why does this matter?

The primary current economic use of indigenous forests has been for wood products, with the more recent rise of honey, carbon and economic benefits of tourism still emerging (and still relatively low in relative scale). Properties that affect the value of wood are density, durability, stability, and appearance. However, there are other products that come from indigenous timbers such as extracts, fibre, food and rongoā. It is important to remember that, considering only economic benefit from indigenous species neglects the important environmental and cultural benefits they bring.

Wood products from our native species have the potential to substitute for high-value imported timbers such as Western red cedar. These native products often have appearance and other characteristics than radiata pine does not have untreated, such as durable heartwood, beautiful colours and grain patterns.

The economic viability of indigenous wood products is highly dependent on having suitable processing infrastructure within the vicinity of the source of wood, good alignment of product attributes with market requirements and the regional logistics that stitches this all together.

What do we know?

Native timber datasheets are available from the National Association of Woodworkers New Zealand, www.naw.org.nz, excluding? mechanical properties and https://www.nzffa.org.nz/specialty-timber-market/showcase/. Wood products from our native species have the potential to substitute for high-value imported timbers certified by the Forest Stewardship Council (FSC®) and the Programme for the Endorsement of Forest Certification (PEFC™), such as western red cedar, kwila, oak, walnut, cherry, and karri used in interior products and furniture and for a wide range of products manufactured in New Zealand. A summary of wood properties is given in Appendix one.

An estimated 3% of our domestically used specialty timbers currently come from NZ grown timbers. In contrast, the total value of imported timber products in 2017 was around $648.859 million, excluding pulp, paper and paperboard products (Figure 9). There is the opportunity to develop more of New Zealand’s indigenous timbers to substitute some of these imported timbers and products.

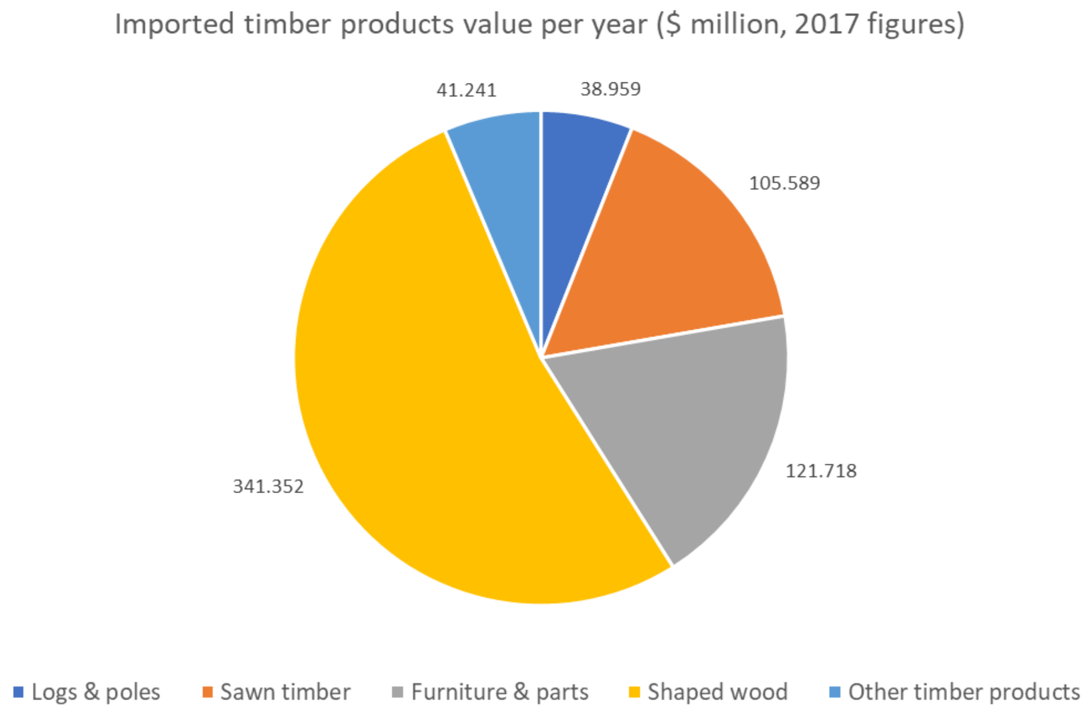

Figure 9: Value of timber products imported 2017, excluding pulp, paper and paperboard products (MPI, 2022)

Extensive research into native wood products and wood properties of old growth timbers (rimu, beech, tawa kauri along with minor timber species) was published during the mid to late 20th century (e.g. (Clifton & Harris, 1990; Hinds & Reid, 1957; Ward & Reid, 1949). Most of the limited volume of younger and plantation native products research in New Zealand remains unpublished as internal or contract reports (we are aware mostly of those at Scion, but other CRIs such as Manaaki Whenua Landcare Research also have data). It should be noted that plantation or regenerating timber is typically less durable than old growth timber due to its younger age. Heartwood develops as a tree grows, depending on species and the age of maturity for that species, for species that have durable heartwood (not all wood from mature trees will be durable).

Scion applied its novel dewatering technique (Supercritical Fluid (SCF) process) to a wide range of New Zealand-grown species, including five native species, silver beech, red beech, rewarewa, tawa and tōtara (Dawson et al., 2010). This process has the potential to overcome thermal drying issues (such as cracking, splitting and collapse), but needs to be refined for each species. Modelling was recently undertaken to identify how the process works, particularly in hardwoods (Pearson et al., 2022) and red beech (paper pending). A by-product of this technique is concentrated sap collection that may contain valuable chemicals for use e.g., in nutraceuticals.

Tōtara and kauri

The majority of current wood quality research on native timber is on tōtara and kauri. Second-growth tōtara and kauri (60-70 years old) have wood density relatively stable from the pith (tree core) to the bark (Steward & McKinley, 2019). This profile means the wood is amenable to sawing and high-value furniture manufacture (c.f. radiata pine which is unstable because its inner wood is lower density than its outer wood). Regenerating tōtara and planted kauri appear to have the same pattern of heartwood development as old growth stands, although heartwood colour and potentially durability are incompletely formed (See Appendix One).

Tōtara wood properties and market performance from second growth stands was investigated by a group of partners including Scion, Taitokerau Māori Forestry Inc, Northland Inc, Tane's Tree Trust and MPI through the Tōtara Industry Pilot (Dunningham et al., 2020), including trials of drying and sawing, product testing and evaluation, and market evaluations of potential products. This Pilot study found there was sufficient tōtara growing in these regenerating stands on farmland to supply a viable regional industry. The timber was able to be milled and kiln-dried in existing mills and was suitable for a range of high-value interior products. Exterior products were largely excluded from the Pilot due to the unknown durability of the forming heartwood.

Scion has conducted a small amount of research on thermal modification of a range of New Zealand wood species, including tōtara and silver beech (Sargent & Dunningham, 2018). The aim of this technique is to improve the wood dimensional stability, decay resistance and in some cases, appearance (i.e. change colours). Although longer term durability field tests are still underway (these take 15 years), preliminary screening tests showed promising results for tōtara sapwood, indicating above-ground durability has been improved. In silver beech, shifts to a more desirable, warmer honey colour were achieved (used in a demonstration show home interior, (Abodo, 2023). If the durability performance for above-ground exterior applications is confirmed for these species, this means that products options would be expanded to exterior uses such as cladding of buildings. New Zealand already has thermal modification kilns that could be adjusted to modifying native species, which would be a much cheaper option than chemical treatment options.

Totarol has been extracted from tōtara and could be used in fine chemicals or nutraceuticals, given its antibacterial properties (Zammit et al., 2013). Extracts from mānuka are being used in the nutraceuticals industry. A quick online search conducted for mānuka oil found only essential oil retail products which had an average price of $2,500/kg (volumes 10-100 ml). For totarol one bulk product was found at $3,300 /kg and the has clearly risen over the past 7 years as a reference was found to 2016 prices being between $1350-1700/kg (Bosworth, 2016). More recently Kanuka oil products can also be found, both in retail products (Average price $1650/kg) and bulk ($190/kg). This compares to pine rosin which can be found in bulk from $25/kg.

Beech

Beech is the most commonly used indigenous wood in New Zealand by volume (KPMG, 2013). Beech is currently used in the New Zealand domestic market in a range of products including flooring, wall and ceiling panelling and furniture. The properties of beech species (silver, red, hard, black and mountain) are described in (Wardle, 1984). They have medium density of 445-660 kg/m3 compared with other hardwoods and excellent strength, although they are harder to dry compared with native softwoods and radiata pine given their moderate to high shrinkage during drying. Once dried, they are relatively stable.

Beech heartwood is durable, but sapwood is not. Some modern beech products are rated class 2 durability (where class 1 is the highest and class 4 is the lowest durability) so is suitable for above-ground exterior use. (https://www.healthbasedbuilding.com/foreverbeech/cladding)

Both indigenous timber processing and marketing industries have lost much of the experience and information they once held. There is a resultant lack of understanding of new products and resources that might become available and significant re-education is required.

Several scoping studies were conducted in the 1970s at Scion on the potential of pulping of New Zealand-grown wood species, including, tawari, beeches, kamahi, rata and rimu e.g. (Dare, 1975; Uprichard, 1976). These species were subjected to various pulping techniques, with yield and paper quality evaluated. Although, it was found that some of the indigenous species evaluated were suited to this application, they were not pursued commercially.

There is a range of sawmills that can process native timbers. In 2013, there were 167 sawmills registered to mill indigenous timber in NZ, although the number may well have dropped in recent years. The Lindsay and Dixon sawmill in the South Island appear to be the biggest Beech millers (based on volume). Some sawmills cut beech on a regular basis, others on contract. So there is some capability in NZ to cut and dry beech, although only a few sawmills do so at volume.

An example that illustrates the vastly different scales for native and exotic processing is the total volume of silver beech processed per year (25,000 m^3) which is the largest volume for a native species, compared to one radiata pine structural mill (Red Stag) who process >900,000 m^3 per year.

A KPMG report regarding the commercial viability of red beech, silver beech, rimu and tawa as wood products identified impediments including the following (KMPG 2013):

- Marketing likely required to educate the market about the new products.
- Regulatory compliance and costs present significant barriers (time, complexity, additional costs)
- Export barriers e.g., what native timber products are compliant with regulations and fit export markets
- New kiln drying capability required due to longer drying times required
- New heavy lift helicopters required (not necessary for all species, forestry winch units can also be added to tractors).

The regenerating Tōtara Pilot in Taitokerau (Dunningham et al 2020) found similar issues.

What's currently being investigated?

Scion is assessing the natural durability and possible treatability of second-growth timber for a number of indigenous species such as kōwhai (Nguyen et al., 2021), beech (Singh & Page, 2019), tōtara and kauri.

Scion is conducting a small preliminary study evaluating the supply chain logistics for tōtara in Te Taitokerau, as logistical links between where the scattered resource is harvested and possible processing hubs need to be considered and optimised. Several regional hubs for processing and manufacturing would minimise extraction and processing costs per unit, as well as increase community participation. The regional context and infrastructure such as roading, population density and skills, suitable processing, and locations of the suitable tree at volume all impact cost structure and therefore viability of any indigenous wood products enterprise.

Te Taitokerau Māori Forests Inc are currently repositioning the tōtara initiative following on from their pilot project to become a kaupapa Māori enterprise based on natural native ngahere in Te Taitokerau via a collective regional plan. This will include integrated supply and value chains to deliver benefits over the long term to local rural communities. This will provide a clearer understanding of what the ngahere, whenua, te taiao and ngā tāngata require to thrive together.

What do we need to find out or do?

Knowledge gaps with regard to research and data gaps to allow informed decision-making on native species include:

- A nationally relevant database on the properties, uses and properties of native timber is needed that summarises:
    - Documentation of the properties of native timbers and their expected performance in different product types in a centralized and ideally, collaborative, place would not only help build awareness of practitioners, but also of architects and regulators. This information is also required for timbers to be approved for utilization under the building code. This includes for timber framing and cladding, which is likely to be useful for some high-end applications.
    - Data on wood properties is lacking in relation to stocking density, growth rates and growing times for younger regenerating trees or planted stands. This includes the impact of silviculture management of trees on timber characteristics and extracts (bark, needles, branches, wood) and the application of appropriate harvesting techniques.
- Further research on the impact of management, silviculture and harvesting interventions on timber characteristics and extracts (bark, needles, branches, wood).
- The inclusion of mātauranga Māori and kaupapa Māori approaches and methodologies. This is significantly under-represented, and opportunities need to be created for Māori to lead and co-develop research on indigenous wood products.

- Market research to gain insight into market interests, demand, and potential export opportunities, while aligning wood properties and product performance with these factors.
- Consideration of native timber value chains which encompass multiple products and uses including kai for people and other organisms, rongoā, pharmaceuticals, nutraceuticals, freshwater fisheries, timber, perfumes.
- Address logistical challenges in regional supply chains, exploring smaller regional processing options and establishing manufacturing hubs. This would include identifying suitable sawmills and drying facilities, assessing existing skills and building expertise to apply to native species.
- Social and cultural Licence to Operate in the use of indigenous species for wood products is important to consider and address.

Economic modelling

Economic modelling a tool that can provide investors a framework for decision-making. It can help investors decide whether to invest in forests, and which forests to invest in. Economic modelling can include non-financial benefits as well as financial benefits. The current impression of indigenous forestry is that it is economically marginal at best (McGlone et al., 2022), even where there are clear studies that show there is real potential (e.g. Steward et al., 2018, Steward 2020a). For more indigenous forests to be planted, investors, including the government, can use economic (or financial) models to evaluate the viability of production indigenous forests. Models with immediate and longer-term management costs will also allow the realistic comparison of regenerating forests when compared with planting forests. Real quantitative data is required to make these comparisons rather than rhetoric. In addition, land use decisions are often only based on economic benefits, whereas we know from recent events that there is an urgent need to balance environmental, social, cultural and economic needs and benefits. Again, quantitative comparisons of these would greatly benefit decision-makers. (Note that the cost of planting native trees involves seed collection, propagation of plants, planting of seedlings, fencing, pest and weed control, forest management and silviculture; costs of allowing or enabling regeneration of native forests may only require pest and weed control, and fencing).

While data and models exist for some species, the data do not even approach that available for radiata pine. More native forest tree species need models and data equivalent to this, and this has been underfunded for some time. More work is needed to strengthen the models, the value chains available and quantitative data to compare regeneration with planting so that landowners and policy makers are ensuring the best outcome for their land and for NZ. In particular, where and how non-timber values and benefits can be included in the value chain, estimation of size of markets and product price points where there is a new product offering. This means that some of the results from existing studies appear to conflict with the conclusions and recommendations made.

What do we know?

Analyses of planted forests of kauri and regenerating tōtara indicate the potential for these forests to be economically viable (Bergin, 2001; Dungey et al., 2011; KPMG, 2013; Steward et al., 2014), due to the higher expected value of the timber at \$350-\$5,000/cubic metre compared with radiata pine logs sell for approximately \$90/cubic metre, and radiata pine kiln-dried clear boards sell for around \$1200/m3, with a maximum prices given for the most highly performing treated boards around \$1900-2000/m3 for H5 (marine grade):

- Current research shows that high quality kauri wood can be harvested at60 years, from unimproved and unmanaged 'wild' stock (Steward et al., 2002). This is more than double the time needed to harvest radiata (25-30 years), precluding kauri achieving similar internal rates of return (6-12% is commonly used for radiata). However, 4-8% may be possible
- The Tōtara Industry Pilot study has documented the potential value of tōtara that could be derived from a regional industry based on tōtara timber already in the landscape (Figure 10). The average harvest age proposed was 83 years (range 40-120 years). Further, the financial model showed that when a discount rate of

8% was applied, instead of the initial 15%, the economics were viable, even with lower volumes of timber (Dunningham et al., 2020).

- Social acceptability of native harvested timber will need to be understood and stories told to ensure there is a viable sustainable New Zealand market.
- The value of indigenous forests can be additive i.e. not just the value of the timber, but the additional value of biodiversity, non-timber products, protection of waterways, recreation, and others (van Noordwijk et al., 2012).

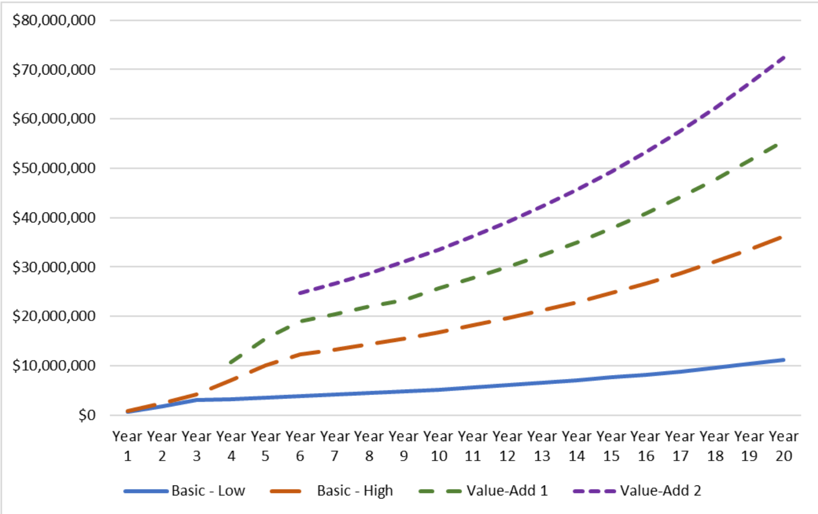

Figure 10: Predicted value of logged tōtara for New Zealand (Dunningham et al., 2020)

Key:	
Basic	Low uses the lowest weighted average for manufactured product (estimated $2200/m^3$ retail), the lowest harvest volume, no value added
Basic	High uses the higher weighted average ($3000/m^3$ retail), the higher harvest volume, no value added.
Value	Add 1 uses higher timber volume and weighted average with 50% basic strategy and 50% value-add of medium value ($6200/m^3$ retail)
Value	Add 2 uses same as Value-Add 1 but at 75% basic strategy, with 25% value-add of 5 times value per volume ($15,000/m^3$ retail, the higher of the value-added options)
Note the value-add here is around product design and market positioning	

(Pizzirani et al., 2019) assessed the economic benefits of exotic forests (radiata pine) and native forests (mānuka and rimu). Results indicated that a combination of all three species was optimal when considering the landscape as well as the short- and long-term economic benefits (timeframes). Landscape-level analysis of where to plant the species included how to gain benefit from avoided erosion, carbon sequestration, cultural enhancement, and biodiversity as well as timber production.

An earlier analysis of different forest types by (Holt et al., 2013) has shown that while radiata pine is economically the best option, harvesting native forests for wood might be viable if lower (or no) discount rates and land expectation value are considered. Depending on the portfolio of forestry options, exotic forests may help support the transition to more native forests until other value chains can be developed.

Mānuka Henare (2014) considered that the concept of Māori enterprise, and collective and communal networks and relationships that act as a collective supply chain, provide better economic returns. The Te Tai Tokerau Forestry Innovation Cluster is one example of this. Huge impact could be made if Māori landowners were released from the existing forest leasing agreements to forest owners, managers and manufacturers (see Rotorangi 2012). Rather than profits going overseas, the opportunity for New Zealand would be significant.

In 2013 a KPMG report (KPMG, 2013) identified four other species with commercial potential, with total value of $9 million and up to $24 million once converted to finished products. The following figures are estimation of total potential annual revenue streams based on utilising the maximum forest resources available by species, showing the species with the highest relative value and volume (page 5 of KPMG 2013):

- Red Beech 34% ($156 million)
- Silver Beech 51% ($237 million)
- Rimu: 10% ($45 million)
- Tawa: 5% ($22 million)

What's currently being investigated?

Taitokerau Māori Forests Inc. is continuing to attempt to build a new Māori-centred forestry initiative in Northland, building a portfolio of forest-based value chains to enhance the ngahere and the quality of the relationship with the ngahere (Henare 2014).

Scion is not aware of any other work currently being undertaken in this specific area at present.

What do we need to find out or do?

We have little data regarding market value and demand for indigenous wood-based products, so there are many assumptions in current economic modelling, especially for high value applications. We need to expand from the current detailed studies regarding harvesting, processing, and market approaches for tōtara and kauri to consider other species and other silviculture and planted forest types – from monocultures for specialist timbers, to close-to-nature plantings/reversions, including natural or assisted regeneration.

The predicted values shown in Figure 10 was only made possible through rigorous evaluation of likely harvesting and processing costs, potential price points, product options and mixes and potential of export markets.

Knowledge gaps include:

- Systematic evaluation and comparison of the economics of planted stands and regenerating natural stands by region that considers existing infrastructure and supply chains for a range of indigenous species.
- Consideration of scale and value with the positioning of indigenous species into suitable product applications suited to their mana and status as taonga (for example, these products may well be low volume and high value
- Feasibility studies of a wider range of species by region that include fit for purpose management, harvesting, processing and manufacturing as well as market intelligence.
- Carbon accounting for indigenous species needs to be realigned with true sequestration rates for these species over longer time spans, as this will hugely impact economic viability for the planting and use of some indigenous species.
- Consideration of climate change and species survival long-term in different regions would be useful to secure supply. To do this, models that include species physiology are needed.

- Support Māori-led innovative value chains based on new models of forestry. Investigate how to release the current leaseholds in order to facilitate this transition to forest ownership.

Non-market benefits of forests (biodiversity, recreation, social)

Why does this matter?

Many New Zealanders are seeking to grow native forests on their land. Non-market benefits of native forests can help to balance the economic discussion with the benefits from biodiversity, recreation, employment, avoidance of erosion among others, to the overall benefit to New Zealand.

Climate change has the potential to cause catastrophic loss of biodiversity as species and ecological complexes are rapidly pushed outside their current environmental paradigm. The recognition of non-market benefits has the potential to incentivise a change in behaviour such that at least some of the planting in New Zealand is of native forests. These forests may not be the same as current old growth forest but will provide a biological buffer for future generations.

What do we know?

When New Zealand indigenous forestry was halted on Crown land, the closure had profound effects on the communities. This includes Kaingaroa Forest, the village of Minginui and the Pureora Forest (King, 2023). Pureora Forest is certainly a national treasure, as one of the largest native forest stands in the North Island (King, 2023). The preservation of this forest has allowed development of tourism operations (The Timber Trail), and the preservation of wildlife providing both local and national benefits, but this has taken some time. At the time, halting of harvesting resulted in mass local unemployment and social conflict. The closure was a catastrophe for tangata whenua, as most of the compensation payments went to companies who lost log supply contracts.

There remains a perceived conflict between preservation of forests and harvesting and utilisation of timber. It is Scion's opinion that, with the right silviculture and harvest techniques and the right forests, harvesting of native forests can be sustainable and the forests can provide many other benefits including social and cultural ones such as providing community employment and resilience. New types of native forest for recreation and harvesting are possible. New Zealanders can help define what this approach looks like and tangata whenua must have the option to decide what they want on their land. This remains one of New Zealand's great challenges as the goal of planting 300,000 ha by 2035 lies before us (Climate Change Commission, 2021).

There are several studies investigating the options for valuing 'ecosystem services' of forests. This is a review topic in itself and a summary of key references follows.

Allen, Platt and Wiser (1995) and Allen et al., 1995a,b examined biodiversity within exotic radiata pine plantations, in support of the evidence that they are not biological deserts. Species richness was evident in some exotic forests, particularly where the forests were close to existing native forest. Plantations do not provide specific outcomes for ecological associations which make up New Zealand's natural native forests. Nor do they provide specific habitat for certain niche species such as fruit and nectar feeders. Interventions to provide this habitat would be needed if this was to be a requisite of any planted forest.

Recent analyses by Yao et al., 2021, 2019 have looked specifically at spatial economic analyses that incorporated non-timber (non-market) values (carbon sequestration, avoided nitrogen leaching and avoided erosion, Figure 11). Fourteen forest managers were interviewed, representing 60% of the planted forest area. Results from the spatial economic analysis indicated that:

- Non-market ES values can be worth more than four times the value of the timber, and up to 12 times that value in New Zealand's most erosion-prone regions.
- The value of proposed biodiversity conservation in the study at the national level can be >100 times higher than the cost of the biodiversity conservation programme.

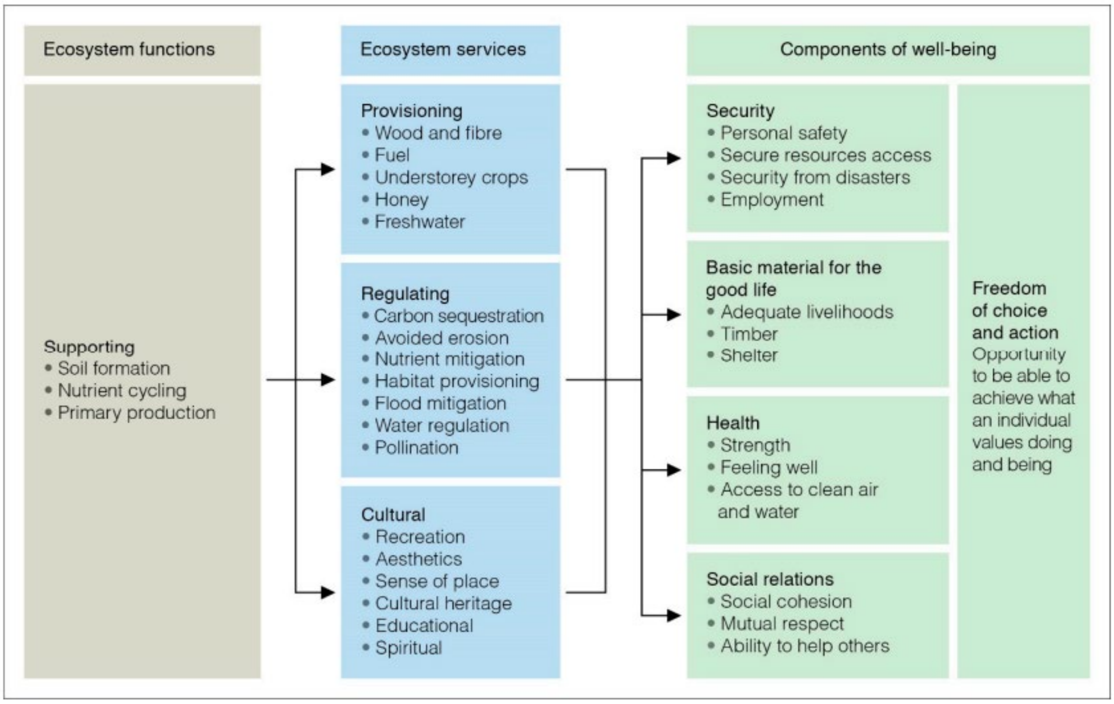

Figure 11: Ecosystem services provide by planted forests and their contributions to human well-being

What's currently being investigated?

The New Zealand government has a group considering the possibility of biodiversity credits (Newshub 2020).

Studies are continuing across New Zealand by the authors mentioned in the previous section.

What do we need to find out or do?

A review of where ecosystem services that forestry can deliver across New Zealand and in different types of landscapes is long overdue. There are clear non-economic benefits to forests other than their economic value. The information needed is:

- Across New Zealand, on a landscape scale, consider supporting various types of economic analyses (including those where the environment is at the centre rather than the economy) and compare the economic, social, cultural and environmental outcomes of different types of forests. Climate change could be included in these models. Re-imagine the value chains that could be possible. Consider this in a multi-generational framework which is relevant in the context of climate change adaptation and New Zealand's culture. Facilitate some case studies with landowners that are mobilising in this direction and wrap this with storytelling to capture the imagination of other landowners and wider New Zealand society. Consider a national think tank to undertake this analysis.
- Understand the management of biodiversity spatially in any forest type, and how any exotic planted forest can increase its biodiversity through augmenting the planted area with plants that support critical (and missing) ecological gaps. Funding case-studies on how to do this at scale would be very useful, particularly amongst agencies such as the Department of Conservation, Manaaki Whenua Landcare Research, Scion and Te Uru Rākau.
- Support the concept of biodiversity credits and other incentives that maximise biodiversity.

- Consider the impact that loss of trees/lack of trees has on landscapes, particularly on vulnerable soils and investigate with urgency how to maximise the engineering strength of roots and forests to minimise further loss of soil and infrastructure. Create resources for landowners which document the types of root structures and recommendations for planting.

Māori perspectives

Noting the dispossession of Māori lands and resources since the signing of Te Tiriti, Māori have had to both reclaim the ability to manage their lands and the resources on them. Te Ture Whenua Māori, co-governance arrangements and the Treaty of Waitangi claims process has enabled Māori to reclaim some of the ability to manage their lands, territories, and resources and to have land returned to iwi, hapū and other collectives.

Māori are significant potential economic players, with the Māori economy being estimated to be worth over $70b and owning over $4b in forestry assets. Māori land presently makes up just over 5% of total land in the country (Te Puni Kokiri, 1996). Over 500,000 hectares of Māori land is currently in plantation forestry (Holt & Bennett, 2014), approximately a third of the total plantation forestry in NZ. Of this, ~350,000ha is leased to forestry companies (and has existing planted forest estates). Te Uru Rākau (2018) and TUR (2018) cite that Māori own large areas of indigenous forest. Anecdotally we understand that there is significant interest amongst Māori landowners in native afforestation and conversion of pasture or existing exotic plantations towards native species or mixed species forests. Pohatu et al., 2020 is one example of research, with a sample of Māori trusts and incorporations in Te Tairāwhiti, that demonstrates the desire to revert to native tree species and the dynamics (such as availability of capital and capacity) and phases of decision-making needed to transition to native forest. Studies also highlight the preference for decisions to transform to native forests to be informed by mātauranga Māori (Evans, 2018; Pohatu et al., 2020).

What do we know?

Mātauranga Māori is its own knowledge system (Smith, 1999), commonly referred to as Māori knowledge (Mead, 2003). Mātauranga Māori is the understanding of everything visible and invisible (Landcare Research, 1996). Mātauranga Māori is knowledge owned by collectives (Iwi, hapū and whānau). Research that includes coded knowledge (mātauranga) is different from research that includes and is informed by Māori participation. Mātauranga is owned by the source of that knowledge – the iwi, hapū and whānau from where the knowledge originated. This affects the ability of researchers to share mātauranga without the express permission of the owner.

While integrating knowledge systems, in this case modern science and Indigenous knowledge, is challenging (Bohensky & Maru, 2011; Mercier, 2013; Wilkinson et al., 2020) argue that Indigenous knowledge working alongside Western science can bring mutual benefits to scientists, Indigenous communities, and governments. (Hikuroa, 2017; Ledgard & Dungey, 2010) points to the value of co-development and co-design across the two systems, providing a culturally responsible and respectful research pathway to considering the relationship between modern science and mātauranga Māori.

Māori perspectives in indigenous ngahere and indigenous forestry are underpinned by values including whakapapa. Māori perspectives and mātauranga are often connected to specific locations, lands, forests, trees and waters, meaning that practices and mātauranga are local and place-based and can vary between whānau, hapū and iwi. Māori have generations of observation of environments in a given place (Mazzocchi, 2006), which can manifest as and be integral to mātauranga-informed decisions and management of forests and lands (Clapcott et al., 2018; Paul-Burke et al., 2018) for specific species, ecologies, sites and locations. (Wilkinson et al., 2020) talks to how indigenous communities would "live with the environment in an intergenerationally sustainable way" based on mātauranga Māori.

For generations, modern science and research has not included Māori, or seen Māori merely as subject participants. Further, the disregard for mātauranga Māori and loss of land, has resulted in loss of access to what little ngahere remains. It is important to acknowledge that opportunities for mātauranga Māori to be acknowledged or operate alongside science have only recently arisen. These pathways have been made visible and possible by leaders of Kaupapa Māori Research methodologies advocating their value and validity. These pathways are slowly transforming to partnerships and access to genuine interactions between Māori and the research sector, including protecting and restoring of ngahere.

For some Māori collectives, forestry is recognised as a long-term option that meets broader aspirations for environmental, economic, social and cultural outcomes. Collectively, where forestry is considered a priority by Māori, a desire is being expressed for new sustainable forest systems based on both exotic and indigenous forest species, that deliver on Māori aspirations. This includes developing forestry models that are informed by mātauranga Māori and systems that include Māori perspectives. For example, Scion is currently supporting a Ngāti Hine Forestry Trust project to transition from exotic pine to a native forestry system based on Ngāti Hine kōrero tuku iho (mātauranga) relating to land and ngahere. The mātauranga that informs this project is owned by Ngāti Hine. The Tōtara Industry Pilot was a Māori-directed partnership project which is an example of Māori aspirations for productive forestry beyond existing plantation exotic paradigm, shifting conversations towards more circular, regenerative models. Further, protection and mauri restoration partnerships are also growing in areas that are typically considered biosecurity.

In a discussion of ecological economics by (Henare, 2014), the kaitiaki values (and function for all New Zealanders) towards forests, in the context of Te Tai Tokerau, includes the following considerations:

- **The importance of land protection:** Participants were strongly interested in positive ecological and cultural outcomes. Protection, appearance and visual amenities of land, effective land use, availability of taonga species, and land-use policies that fit with aspirations were priorities. This is consistent with the Māori whakataukī “toitū te whenua only the land remains". Radiata-centric forestry was perceived as “damaging the land”, and this alone was sufficient rationale for moving away from it.
- **The relative unimportance of economic factors:** Economic-related factors ranked low among the considerations for impact, contrary to expectations that jobs, and financial returns would be a primary concern for land trusts. Henare et. al. was of the view that rotation length, management expertise and past experience with low performance of economic activities may have influenced the low ranking of economic concerns. However, Māori priorities often centre on broader holistic aims that support iwi, hapū, whānau and community development, and economic considerations are only a means to achieve those holistic aims (see (Joseph et al., 2016; Smith et al., 2015).

Mātauranga has potential to be used as part of Māori community-based monitoring systems of forest health. (Lyver et al., 2017) research highlights that community-based indicators needed to be relevant and trusted by the people whom they were intended to serve. Further, it found that the ideal monitoring system or forest health was based on community reporting on impressions of biodiversity, especially compared to recollections of past ecological baselines.

Scion has a Te Tiriti framed portfolio – Restoration, Protection & Mauri o Te Waonui a Tāne, which focuses on forest health research projects that relate to trees other than for harvesting purposes. Generally, most projects relevant to the past, present and future health and knowledge of indigenous ngahere were undertaken with minimal Māori partnerships or mātauranga contributions. Various National Science Challenges, in particular the Biological Heritage Challenge, promote authentic partnerships and co-leadership with Māori. Similarly, Scion’s Te Tiriti Portfolio, has a new programme pathway that enables mātauranga and kaitiakitanga approaches to ngahere forest health protection and restoration of mauri that creates new opportunities for Māori to contribute and lead in meaningful and culturally appropriate projects.

Past, continuing and emerging programme projects in this portfolio include:

- social science human factor research
- risk assessments and responses
- remote sensing tools for ngahere management
- mauri tools for monitoring ngahere health
- biocontrol assessments and responses
    - natural enemy studies for indigenous species health
- biosecurity
    - Myrtle Rust monitoring
    - Te Reo Māori Myrtle Rust education tools for Māori
    - Kauri (Dieback) Disease
    - taonga species susceptibility to pathogens and fungal diseases
    - exotic insect prediction modelling
- wildfire predictions and prevention
- entomological studies for biodiversity
- Te Ao Māori kaitiaki approaches
- holistic ecological planning tools
- capability, capacity, mentoring and career development opportunities
- traditional knowledge, karakia, pūrākau, mahi toi
- climate planning - non-economic values.

This will build on the existing research that has been done in partnership with Māori across Aotearoa either with CRI's, local or central government or other organisations. It will support the much-needed research, science, innovation, and cultural determination of Māori rights in ngahere environmental and economic futures.

What's currently being investigated?

At this time, Scion's research regarding mātauranga Māori and indigenous ngahere is limited. Scion aspires to partner with Māori more and to enable Māori-led and Māori-centred research that holds space for mātauranga-based enquiry, while also appropriately acknowledging the origin and responsibilities towards mātauranga that whānau, hapū and iwi bring to the research.

Mātauranga Māori has been considered as a possible knowledge base for determining land-use options, and Scion is currently undertaking a project with Māori landowners to consider how this can be considered in decision-making.

In 2021, Scion established a Te Ao Māori Research Group (consisting of Kaupapa Māori Researchers, Māori scientists, research assistants, project coordinators, Partnerships Team, and interns) and advancing its Māori capability and scientist competency to engage in research that impacts on Māori and Māori interests. The spectrum of research ranges from Māori participation to Māori co-design and Māori-led research. With this capability in place, Scion is strategically positioning to support more Māori-led research and enabling a space where mātauranga can be integrated within research.

What do we need to find out or do?

Mātauranga Māori and indigenous forestry research are areas that need more significant research investment as they have been identified as priorities.

An historical account and reflection of Māori forestry will be helpful to document the journey to our current state, and potentially document elements of practices and mātauranga that Māori collectives and practitioners are willing to share.

Māori values, such as whakapapa connection to indigenous ngahere can make replanting with native species an attractive option. However, we know anecdotally that issues, such as cashflow and available investment capital, make replanting difficult. We need to find out how to support Māori landowners, Iwi and hapū in making informed decisions about land use and forest management.

Research could be conducted in models planting indigenous forests for multiple purposes. This includes research around the overlapping ideas of ngahere (forests from a Māori perspective), complex forestry, garden forests and food forests. Models, informed by Māori values and mātauranga Māori, for establishment, resilience and productive purposes and benefits would be useful to demonstrate how Māori and private landowners could sustainably adopt these models.

From a productive forestry position, research and modelling for sustainable establishment and continuous use at farm and small scale would also be useful. Indigenous forestry, particularly within a more regenerative and Māori-based approach, requires research to create and demonstrate value chains that work and can be adopted at local and regional levels. This includes testing how it can be scaled or enabled via distributed network models. Some of this may be informed by mātauranga but would also benefit from research to connect value chains and models that can be deployed across local or regional distributions. For Māori, this would also include moving Māori participation along the value chain so that Māori contribute to more than supply of resource or as labour. This then improves benefits for Māori collectives and individuals and enables self-sufficiency and self-determination that Māori collectively aspire to. This also highlights that research in this space should be led by Māori and should deliver clear impacts for Māori. These impacts must have multiple value for Māori and not just for economic or productive purposes. It must include benefits for the forests and the environment itself, as these are important from a Māori values perspective.

Where mātauranga is concerned, this should be researched with the holders and owners of that mātauranga. It should not and cannot be removed from that context. This means that any research must maintain that the mātauranga holders own that data, and benefit from its use in research. Where the research findings and models can be shared with others, this is also done with the permission of the mātauranga holders.

While we are aware that there are a number of projects in this area that have not been mentioned, particularly in other CRIs, Universities and Māori organisations. Insufficient time was given to allow for their inclusion and for contributions to be genuine.

Scale of investment in native versus exotic forestry knowledge and capability

Quantifying the funding allocated for research into indigenous forests for multiple outcomes is difficult. Competition is very strong among agencies and research providers, resulting in a difficult if not toxic working environment. A more collaborative and resourced approach to indigenous forestry would result in greater benefits for New Zealand.

Current investment in indigenous forests at Scion, represents below 5% of total research. This has increased significantly in recent times. The scale of the difference compared to exotics is therefore in magnitudes. More work is needed to determine how to better quantify and address this imbalance.

Publication trends in forestry, as a measure of research activity, have accelerated globally (

Figure 12) while they have been steady state in New Zealand for both exotic and indigenous forest topics (based on a systematic literature search, these have not been analysed as to their specific topic and publications on New Zealand forestry overseas has not yet been teased apart). FTEs in research at Scion (Figure 13), as another measure of investment in indigenous forestry knowledge, have been minimal and static for 2.5 decades.

It was not possible to quantify the scale of investment into indigenous and exotic forests.

Figure 12: Global forestry publications have increased exponentially compared to a linear increase in New Zealand they have increased steadily. Interestingly, indigenous and exotic NZ publications show similar trends.

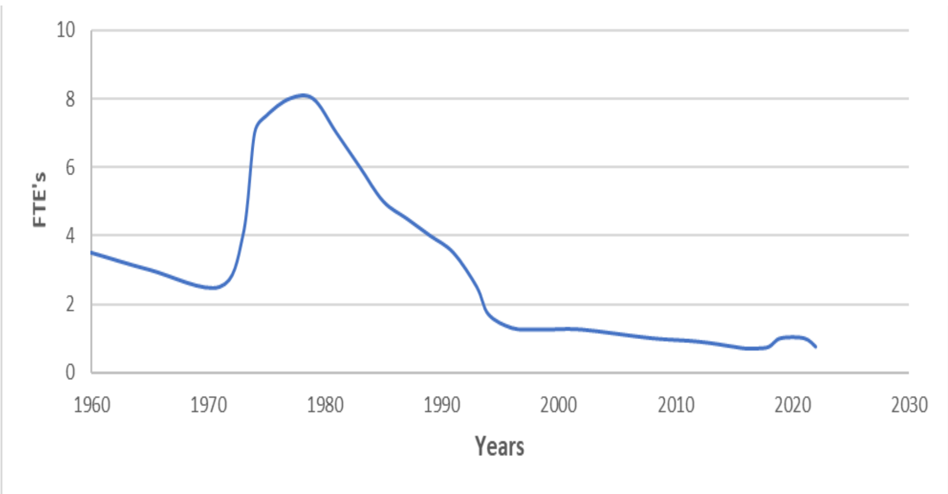

Figure 13: Estimated FTEs in indigenous forest research at Scion

Glossary and definitions

Biodiversity - The genetic variety of life forms and their ecosystems. Comprises genetic diversity (within species), species diversity (between species) and ecosystem diversity

Canopy - The uppermost level of foliage formed by the branches and leaves of a tree.

Clear-felling - The removal of all or most of the tree cover from a forested or vegetated area.

Community (**ecological**) - An ecological unit composed of a group of organisms or a population of different species occupying a particular area usually interacting with each other and their environment.

Community (**social**) - A group of people who live near each other, share common interests, needs, and sets of services.

Conifers - Evergreen trees and shrubs of the botanical group gymnosperms. These plants produce naked seeds usually in cones.

Coupe - An area of forest within a compartment that is harvested in a single operation.

Deforestation - Clearing of forested areas.

Ecosystem - Any biological community and its non-living environment, including all the plants and animals in an area together with the air, land and water with which they interact.

Exotic - An introduced species, not native to New Zealand origin.

Forester - A forester is a professional person who uses scientific principles to manage forests, engaging in a variety of activities including timber harvesting and wildlife conservation.

Forestry - Is the science and art practice of planting, managing, and caring for forests. (

Hardwood - Tree species that have hard and dense wood and include tawa. Timber from natural hardwood forests is frequently used in hardwood flooring and furniture.

Harvesting - The felling of trees, either as a group selection operation or a thinning or a clear-felling operation.

Heartwood is the inner part of the log (including the pith) which for some species contains extractives that provides decay resistance or outdoor durability for the timber in use. The heartwood is developed as the tree grows to maturity which may appear as different colours depending on the maturity, genetics and growing conditions of the tree.

Log - To cut trees into logs; to cut down trees for timber; a portion of cut tree trunk or branch.

Mātauranga Māori - Indigenous knowledge of Māori, the indigenous people of Aotearoa New Zealand (except for the Chatham Islands).

Ngahere - forest

Nurse crop is the dominant species

Old-growth forests - An old-growth forest, sometimes synonymous with primary forest, virgin forest, late seral forest, primeval forest, or first-growth forest—is a forest that has attained great age without significant disturbance, and thereby exhibits unique ecological features, and might be classified as a climax community. (Wikipedia)

Old growth forest - Forests in which the upper stratum is ecologically mature and has been subjected to negligible unnatural disturbance such as logging, road building and clearing.

Pinus radiata - One species of the genus *Pinus,* known as radiata pine. A coniferous tree, native to California. The major source of softwood timber grown in New Zealand.

Reforestation - Replanting of a forest on cleared, degraded or destroyed forest areas.

Regeneration - The process of growing new trees on areas previously forested, whether naturally or planted. In New Zealand this is often associated with reversion.

Resource - Material required or needed, where stock that can be drawn on. Anything for which there is a perceived present or future use. Can be either renewable or non-renewable

Release - To free a tree from competition with its immediate neighbours by removing the surrounding vegetation.

Restoration - Practice of restoring a forest to its previous condition in terms of ecological function and structure as it was prior to disturbance.

Reversion - The process of allowing for natural regeneration of native trees. May include weed and pest management to ensure regenerating forest species are protected.

Rotation - The number of years required to establish and grow trees to a specified size, product or condition of maturity.

Selective logging - Selected trees within an area nominated for logging are felled while other trees are retained to maintain the forest structure & wildlife habitat.

Silviculture - This is a branch of forestry that involves the use of science and art to grow and maintain trees. It involves tree establishment, growth, health and quality.

Shade-Intolerant Species - Trees that require full sunlight to thrive and cannot grow in the shade of larger trees.

Shade-Tolerant Species - Trees that have the ability to grow in the shade of other trees and in competition with them.

Stand - A group (or cluster) of upright trees.

Sapwood is the outer portion of the log nearer to the bark and does not have decay resistance or provide outdoor durability for the timber in use. The portion of heartwood and sapwood depends on the species, the age and size of the tree, and variations within tree itself.

Second-growth forests refer to regenerating trees after a wide-scale harvest has been done or the land has been disturbed. For native trees, the growing rates, situations (such as terrain, browsing by stock and inclusion of other species) and age distributions of such stands will be very different when compared to the "old-growth" virgin native forests that have been left untouched by such disturbances.

Second-growth timber is timber harvested from second-growth stands.

Tāne's Tree Trust - A not-for-profit organisation dedicated to the planting, management and harvesting of native trees.

Timber - The general term used to describe sawn wood suitable for building and other purposes.

Understorey - The layer of forest vegetation between the overstorey or canopy and the ground layer.

Recommendations and conclusions

1. The government invests in a future with more indigenous/native forests for multiple purposes. Exotic forestry has had more than 75 years of funding to create the strong industry that we have today. To create a diversified wood product industry, new forestry-understorey value-chains and resilient rural communities, investment is required to plant, research and manage these new forests as well as develop new forest-based products. Exotic forests were first established by the New Zealand Government, and it is now time to do the same for indigenous/native forests. Invest in genuine partnerships with Māori, invest in Māori-led projects and insist on collaborative research among institutes and organisations. Ensure funding is long-term and enduring. Forestry is not a short-term 3-5 year project and requires a multi-generational approach. Start with a Research and Practitioner Nursery and Establishment Cooperative, targeting the empowerment of reforestation of cyclone-affected areas. Work to develop a second research and/or practitioner institute based on the development of forest health rangers/kaitiaki throughout all Department of Conservation land as well as on and within the new planted indigenous/native forest areas.
2. Create communities similar to the Cooperative Research Model used previously at Scion and in other organisations, where research can be shared, knowledge progressed, and practitioners and researchers can collaborate. Fund these without the need for cash in-kind contributions in order to allow equitable participation.
3. Empower organisations that already exist (particularly research organisations Scion, Manaaki Whenua, as well as Tāne's Tree Trust, and empower Māori to lead) as well as any new or virtual entities created in 1) and 2) to freely share information in field days and instruction videos available on-line. Suggest that as the Forestry Research Crown Research Institute, that Scion is the lead host of a virtual indigenous forestry innovation park or institute with these research entities, based in Rotorua, Christchurch, and with the establishment of small regional 'pop-up' offices in Northland, Nelson and in the East Coast. Consider how this can work seamlessly feeding research results through to Te Uru Rakau – New Zealand Forestry Service.
4. Record knowledge and stories of the last generation of indigenous forestry workers, of Māori and communities. Use this knowledge as a baseline to begin building a sustainable harvesting regime for native forests. Ensure that the New Zealand public is on board through involving them and engaging through citizen science and other relevant mechanisms.
5. Work with Te Puia Arts and Crafts Institute to develop the arts, storytelling and interactions with native forests.
6. Work with Māori to determine how they can exert tino rangatiratanga and/or mana Motuhake in the forests that are established on their land.
7. Facilitate the re-training and career pathways for New Zealanders who wish to work in this area by providing equitable funding opportunities for young and old. Strengthen the connections to universities and embed them in any research and training opportunities. Provide funding to create co-housing opportunities and interactions.
8. Review the Forestry Act to facilitate the development of sustainable forest value-chains.

   … and finally

9. This review has been the best information that Scion could provide in the timeframe. This is only the tip of the iceberg and we therefore recommend that this piece of work is used as a basis to do a more comprehensive and collaborative review.

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Appendix One: Wood properties of native species

Table A.1.1: Wood quality data for indigenous timbers. Source: Timber information sheets

	Red beech	Rimu	Silver Beech	Tawa	Matai
Density at 12% moisture content (MC)	630kg/m^3 (ranges	519 kg/m3	592kg/m^3 (ranges	720kg/m^{3*}	610kg/m^3
Modulus of elasticity	11.6 GPa	9.65 GPa	12.0 GPa	13.2 GPa	8.5 GPa
Modulus of rupture	116 MPa	85.6 MPa	100 MPa	114 MPa	78.4MPa
Shear strength parallel to grain	13.6 MPa	10.56 MPa	12.5 MPa	12 MPa	
Compression strength parallel to grain	54 MPa	39.15 MPa	47 MPa	32 MPa	48.4 MPa
Bending Strength	116 MPa				
Side Hardness	5.4 kN	3.62 kN	4.5 kN	4.0 kN	
Tangential shrinkage - green to 12% MC	7.60%	4.40%	5.70%	6.70%	3.50%
Radial Shrinkage - green to 12% MC	2.40%	2.50%	2.60%	3.40%	1.90%

Table A1.2: Wood characteristics of indigenous timbers. Source: Timber information sheets

	Rimu	Kauri	Matai	Tawa	Red Beech	Rewarewa	Silver Beech
Characteristics	*Dacrydium cupressinum*	*Agathis australis*	*Prumnopitys taxiflora*	*Beilschmeidia tawa*	*Nothofagus fusca*	*Knightia excelsa*	*Nothofagus menziesii*
Colour	golden	silver	golden	greybrown	red		
Workability	Good	Excellent		Good-Very Good	Good	Excellent	Excellent
Side Hardness	1250 - 1500 lbs00-over 1750 lbs00 lbs	over 1750 lbs1250 - 1500 lbs0-1000 lbs		1250 - 1500 lbs	1000-121250 - 1500 lbs0 lbs	1250 - 1500 lbs	1250 - 1500 lbs00-over 1750 lbs00 lbs
Finish	Excellent	Excellent		Excellent	Excellent	Excellent	Excellent
Seasoning	Mod. Good	Mod. Difficult-Mod. Good		Mod. Difficult	Difficult	Mod. Difficult	Mod. Difficult-Mod. Good
Staining Ability	Good	Good-Very Good		Very Good	Good-Very Good		Very Good
Treatability	Very Difficult			Mod. Difficult	Difficult	Very Difficult	Mod. Difficult
Splitability	Mod. Good	Good		Mod. Good	Mod. Good	Mod. Good	Mod. Good

Table A1.3: Wood properties defined by WPMA^

Species	% Tangential shrinkage	% Radial shrinkage	Fibre saturation point	Dimensional stability Long-term movement^	Dimensional stability Short-term movement^	Modulus of Elasticity (GPa)	Bending strength (MPa)	Tension strength (MPa)	Shear strength (MPa)	Compression strength (MPa)
Radiata pine	3.9	2.1	29	2.2	2.2					
Kauri	4.1	2.3	26	3.0	2.8	7.4 (farm)	20.5 (farm)	10.6 (farm)	4.4 (farm)	30.2 (farm)
Tōtara	3.5	1.9	24							
Rimu	4.2	3.0	27	2.9	2.2					
Red beech	7.1	3.3	24	5.9	1.0					
Silver beech				4.0	1.9					
Tawa	6.7	3.4	30	4.5	3.0					
Kahikatea				2.9	2.8					
Matai				2.6	2.8					

^ Long-term movement is the percentage decrease in tangential dimension from equilibrium at 90% relative humidity to equilibrium at 60% relative humidity. Short-term movement is the tangential swelling from equilibrium at 60% humidity after 24 hours at 95% relative humidity. Data sources from WPMA (2020). WPMA = Wood Processors and Manufacturers Association.

Table A1.4: Whole stem density of wood plus bark (WSD) for native species averaged across all studies. P values for region and age are given. From Beets, P. N., et al., (2008)

Species	Mean WSD	No. regions	No. studies	No. trees	Region P-value	Age regression		
						Intercept	Slope	P-value
Cunninghamia lanceolata	310	1	1	1	.			
Libocedrus bidwillii	329	1	1	7	.			
Coprosma grandifolia	333	1	1	1	.			
Laurelia novae-zelandiae	341	2	4	31	0.4130			
Dacrycarpus dacrydioides	351	3	5	28	0.8526			
Melicytus ramiflorus	358	1	1	6	.			
Podocarpus totara	370	2	3	19	0.6108			
Pseudowintera colorata	389	1	1	1	.			
Dysoxylum spectabile	424	2	2	6	.			
Dacrydium cupressinum	433	3	9	53	0.2602			
Agathis australis	435	4	7	49	0.4367			
Nothofagus menziesii	445	8	94	1191	**<.0001**			
Elaeocarpus hookerianus	448	2	2	9	.			
Nothofagus fusca	448	8	79	1057	0.1231	446	0.1	0.6728
Litsea calicaris	454	2	5	35	**0.0021**			
Nothofagus solandri var. solandri x N. solandri var. cliffortioides	462	1	2	6	.			
Hedycarya arborea	465	1	2	24	.			
Nothofagus fusca x N. solandri var. cliffortioides	468	3	3	4	.			
Weinmannia racemosa	469	3	28	214	0.0879			
Nothofagus solandri var. cliffortioides	475	5	37	390	**0.0248**			
Prumnopitys ferruginea	482	4	6	34	0.3054			
Phyllocladus trichomanoides	489	2	2	6	.			
Prumnopitys taxifolia	499	3	5	32	0.5240			
Lagarostrobos colensoi	499	1	1	6	.			
Knightia excelsa	503	2	9	62	**0.0054**			
Beilschmiedia tawa	505	2	9	54	0.2108			
Nothofagus truncata	525	5	53	894	0.1310	518	0.1	0.6906
Elaeocarpus dentatus	526	2	2	6	.			
Beilschmiedia taraire	527	1	1	3	.			
Nothofagus solandri var. solandri	536	6	8	21	**0.0419**			
Metrosideros robusta	632	1	1	5	.			
Kunzea ericoides	635	1	1	1	.			
Metrosideros umbellata	746	1	6	39	.			
Quintinia serrata	427	1	16	112	.			
Nestegis cunninghamii	770	1	1	6	.			

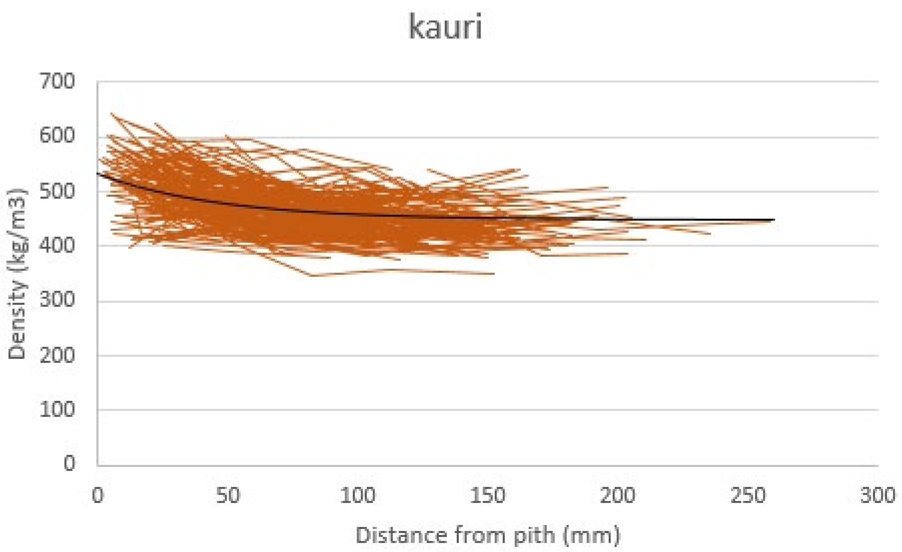

Figure A1.1: Radial wood density pattern in kauri (solid line represents the predicted density)

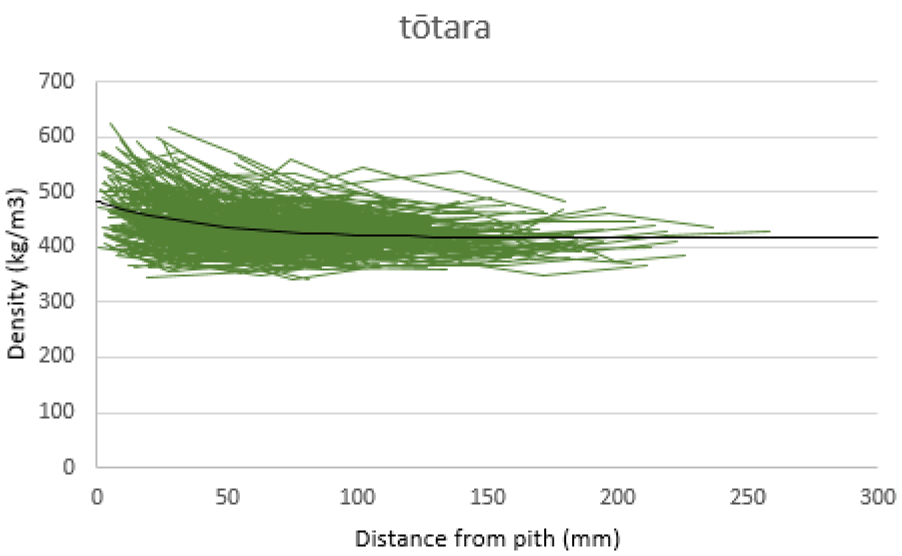

Figure A1.2: Radial wood density pattern in tōtara (solid line represents the predicted density)

Whole-core wood density and sapwood/heartwood content was in line with that seen in mature trees of two species, tōtara and kauri, and in comparatively young second-growth natural stands (Figures A1.1, A1.2, A1.3 and A1.4). The radial density patterns also suggest relatively uniform wood characteristics across the width of the stem that were likely to include both sapwood and some heartwood (Steward and McKinley 2019). This is in contrast to radiata pine, which has a distinct transition between inner wood (lower density) and outer wood (higher density) that can cause instability on drying.

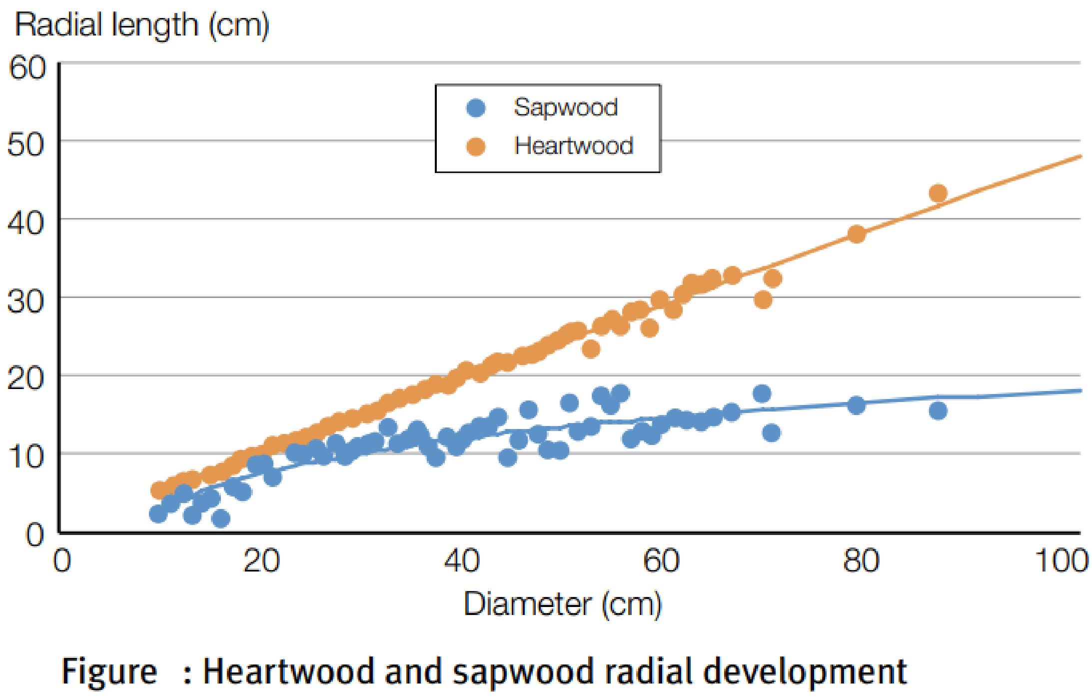

Figure A1.3: Tōtara heartwood development. Radial length is the length from the pith of the trees. Diameter represents the diameter of the log at harvest

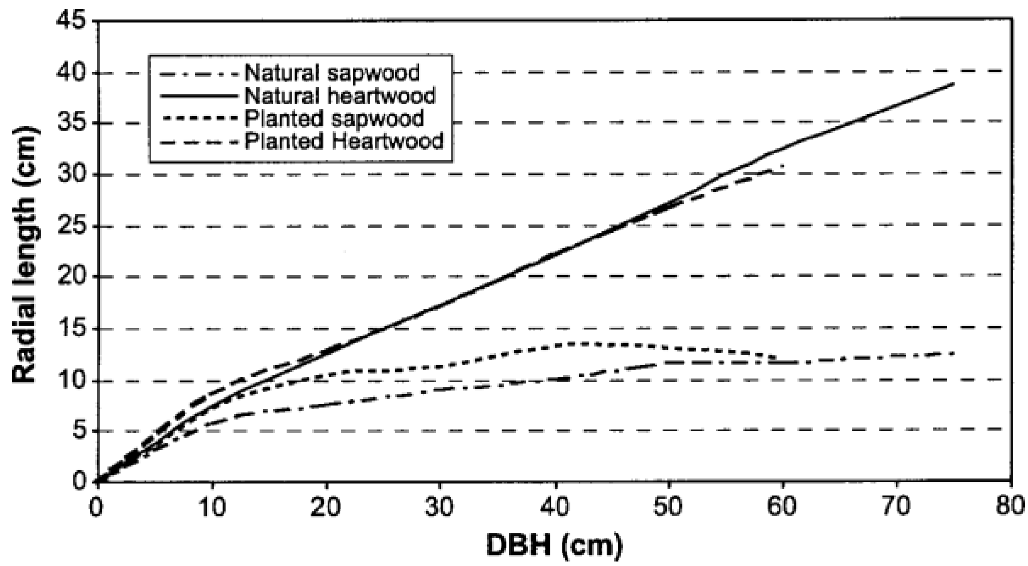

Figure A1.4: Heartwood development in planted and natural kauri stands. (From Steward and Kimberley 2002)

Appendix Two: Recommended additional reading on native forests

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