Playing the long game

An analysis into the opportunity for the commercial expansion of tōtara as a plantation forest in New Zealand

Report prepared by:

Perrin Ag Consultants Ltd

For:

New Zealand Agricultural Greenhouse Gas Research Centre

perrin ag
NEW ZEALAND AGRI-BUSINESS ADVISORS

NEW ZEALAND
AGRICULTURAL GREENHOUSE GAS
Research Centre

Prepared by Perrin Ag Consultants Ltd

Registered Farm Management Consultants

1330 Eruera Street, PO Box 596
Rotorua 3010
New Zealand

Phone: +64 7 349 1212
Email: consult@perrinag.net.nz
www.perrinag.net.nz

Date of report: 31 March 2023

This Report was prepared for the New Zealand Agricultural Greenhouse Gas Research Centre as a service.

The content of this Report is based on the information which NZAGRC have provided to Perrin Ag and other information currently available to Perrin Ag.

Unless expressly stated otherwise in this Report, Perrin Ag will have no liability whatever to any person in respect of any loss or damages arising from the information contained in this Report, or in respect of any actions taken in reliance on such information (which actions are taken at the reader's sole risk). The reader acknowledges that Perrin Ag does not proffer an opinion with respect to the nature, potential value, financial viability or suitability of any farming activity, transaction or strategy referred to or connected with this Report.

Due care has been taken by Perrin Ag in the preparation of this Report. Notwithstanding, Perrin Ag does not provide any warranty as to the accuracy, reliability, or suitability for any purpose of the information and advice contained in the Report, whether to the reader or to any other person.

To the fullest extent permitted by law Perrin Ag will not be responsible for any errors or misstatements in this Report, or be liable - whether in contract, tort (including negligence) or otherwise - for any loss or damage the reader may incur as the result of any such errors or misstatements (including direct, indirect, consequential or special loss, or any loss of profits).

Document Quality Assurance

Written by:	Rachael Mitchell, CNMA, MNZIPIM Senior Consultant Abbey Dowd BAgSc (Hons) Consultant Michael Matthews BMS, CPIM Consultant
Reviewed by:	Lee Matheson BApplSc (Hons), FNZIPIM (Reg.) ASNM Principal Consultant
Approved for release:	Lee Matheson Managing Director
Status:	Final

Bibliographic reference for citation:

Mitchell, R., Dowd, A., Matthews, M. 2023: Playing the long game. *An analysis into the opportunity for commercial expansion of tōtara as a plantation forest in New Zealand*. Final report on alternative land use analysis 5: Tōtara. A report prepared for the New Zealand Agricultural Greenhouse Gas Research Centre. 54 pages.

perrin ag

Executive Summary

"Playing the long game" is the fifth in a series of reports prepared for the New Zealand Agricultural Greenhouse Gas Research Centre (NZAGRC). These reports examine potentially viable diverse land uses in New Zealand that could provide alternatives to the largely monoculture and ruminant-dominated pastoral agriculture systems across our landscapes at a more expansive farm systems perspective.

This research evaluated the potential for a plantation-tōtara industry in New Zealand as a sustainable land use change to assist in reducing methane emissions. Due to the limited opportunities for sustainable land use change on hill country, focus for this project was on land currently used for sheep and beef farming, on hilly country. Evaluation of the potential production system, including plantation establishment, management and harvesting was investigated.

Financial feasibility is one of the key factors determining whether a plantation-tōtara industry would be viable. With access to funds such as the Climate Emergency Response Fund, implementing land use change on a large scale, through the creation of a new industry, will be more achievable.

To ensure a sustainable approach is taken when considering land use change, forest conditions and harvest techniques which create a system that enhances and considers non-timber values have been focussed on. Legally, plantation-tōtara may be clear felled, but we have concluded that sustainable harvest techniques should be used in plantation-tōtara. This may include coupe-harvesting, or single-tree harvesting that maintains continuous-forest cover. In doing so, the forest retains values such as provision of habitat, aesthetic values and biodiversity values.

The planting of the forest utilising a native nurse crop, such as mānuka and/or kānuka has been investigated, providing more biodiversity benefits and improved tree form. An industry based around 500,000 ha of plantation-tōtara was evaluated, allowing the issues of scale to be considered and represents 10% of the current pastoral area of NZ that may be required to move away from farming systems which create methane emissions.

From the processing perspective, a de-centralised hub approach was the preference, keeping transport distances to a minimum and utilising 15 existing rural supply centres. Investigation into the practicality of these hubs covers all aspects of the support for the plantation-tōtara, from the nurseries growing the plants to milling, further treatments and storage.

The implications for reducing greenhouse gas emissions were evaluated compared to both the upper and lower methane reduction targets. Due to the novelty of a commercial plantation-tōtara industry and the issues of extended timeframes, the requirement for further research was also highlighted. It was identified that 500,000 ha of plantation-tōtara would likely remove between 2.2% and 4.2% of the methane reductions required in 2050.

Upon analysis of the potential for developing this industry, several opportunities were found. The forest can provide multi-generational benefits such as biodiversity, recreational, aesthetic, and cultural values. The development of the industry, including the required resources, will create job opportunities for rural areas. There is also good potential to gain secondary income streams from the forest such as utilising nurse crops and gaining carbon and biodiversity credits. Furthermore, there is a potential opportunity for tōtara to provide a land use change option to hill country land, a land class that traditionally lacks viable and sustainable options for alternative land use.

Throughout this analysis, several key risks were also identified in creating a commercial expansion of the plantation-tōtara industry. With the creation of a new industry, there will be a requirement for skilled labour which may not be surplus in other areas, or even available. Expertise in native forest

management and harvest will be required, at a commercial scale this may be challenging to source. Training for most aspects of the production and harvest cycle will be required to up-skill employees. There is also a lack of knowledge on the dynamics of a mature plantation-tōtara stand and more research will be required to fully understand these systems. This research would by necessity occur alongside the maturing forests over extended timeframes.

The sourcing of suitable land for plantation-tōtara is also likely to be a risk. Competition from other alternative land uses that provide earlier return on investment, with more known outcomes may be favoured. Due to limited opportunities for hill country alternative land uses, the land required for this research is deemed to be predominantly hill country. Conversion of this land type will not provide the greatest reduction in methane emissions per hectare due to its lower farming intensity.

This report determined a phased planting regime is likely to be the most viable option, over an eighty-year planting period. If animals are removed years ahead of tōtara establishment to reduce methane emissions, further exploration of interim land use for the land will be required.

Tōtara is likely to be used as a specialty product for uses such as interior (decorative) panelling Proposed harvest volumes within this project suggest after substitution of specialty import products, there will be surplus product. This will likely require export, further exploration into the market opportunities is required. With very limited native timber harvest at this time, there is no export market to evaluate.

The initial cost in establishing a plantation-tōtara forest is the most likely deterrent to landowners converting to this low methane option. Due to the high costs involved in planting plantation-tōtara (between $15,625 and $32,690/ha) and the 80-year delay before initial log harvest, some method of supporting the farmers with the costs of establishment, and reducing initial outlay, will likely be required for the successful establishment of this industry.

If the industry can overcome and mitigate these risks, particularly the high initial investment and resource requirements, the ability for commercial expansion may be viable. The likely contribution to methane reduction targets by 2050 are relatively low. This potential industry may not be a large driver in meeting methane reduction targets but may contribute to these whilst also utilising and enhancing New Zealand’s environment.

PERRIN AG CONSULTANTS LTD

March 2023

CONTENTS

Tables

Figures

Appendix

1 Introduction

The New Zealand Agricultural Greenhouse Gas Research Centre (NZAGRC) has initiated and funded a Future Farm Systems Research Programme. It has two key parts – the first looking at case studies and co-designed solutions for the primary sector transitioning to a low emissions future [Part 1] and a second part envisioning what that low emissions future might look like [Part 2].

"Playing the long game" is the fifth in a series of reports prepared for the NZAGRC. These reports examine potentially viable diverse land uses in New Zealand that could provide alternatives to the largely monoculture and ruminant-dominated pastoral agriculture systems across our landscapes at a more expansive farm systems perspective.

This report builds on the recommendations derived from earlier work on the potential for expanding the commercial expansion of tōtara as a plantation forest option, which identified several potential supply chain challenges to this occurring.

The earlier summary report identified the base production and supply chain parameters of interest for tōtara as a production forest as:

- 80 years to maturity
- Sourcing suitable land for a plantation
- Environment and carbon benefits
- Specialty hubs deigned for tōtara processing
- Sourcing labour for specialty harvest
- Suitability of timber for building products
- Added value processing in New Zealand

Financial feasibility is one of the key factors determining whether a plantation-tōtara industry would be viable. With access to funds such as the Climate Emergency Response Fund, implementing land use change on a large scale, through the creation of a new industry, will be more achievable.

There has been little work historically or currently being undertaken into the expansion of the tōtara industry beyond the Tōtara Industry Pilot Programme (2020), focussed largely on sustainable logging of regenerating pockets of tōtara in Northland. This work has identified that there may be a place for plantation production of tōtara but has remained focussed on farm-tōtara[1] (timber extracted from the regenerating on-farm tōtara).

Tōtara does appear to have the greatest potential of New Zealand's native species as a plantation timber crop:

- It is widespread distribution across New Zealand
- A small but existing supply chain
- An expected commercial rotation length akin to the long-rotation exotic species growing in New Zealand.

[1] Farm-tōtara is the term given to trees harvested from naturally regenerating tōtara stands on farmland. This product will be almost identical to plantation-tōtara, however the latter is likely to have more uniformity, as the trees will be grown at pre-determined spacings and given the best opportunity to grown straight and true.

Currently modelling is using a rotation length of 80 years, but a shorter rotation of 60-65 years is possible with selective breeding (E. Dunningham, personal communication, March 2023). Long rotation lengths present considerable barriers to large scale planting of novel tree species. Considering the steps needed to create a supply chain of necessary scale for a crop that will not be ready to harvest for 80 years is critical to it being considered a viable land use. Potential market demand is also critical to this and the use of tōtara as for a product within domestic construction seems logical. The process for getting a product approved for use in the New Zealand building code can be complex but pathways already exist for tōtara timber to be used in buildings (Section 5.3). Investigating the opportunity for tōtara to be approved for general use in this way would provide useful insight and complement any analysis of the required supply chain to deliver a sustainable source of native construction timber.

The biodiversity co-benefits that might be associated with plantation-tōtara have not been quantified and may be limited in the early years, with only two to three species planted as a nurse crop. However, with the likelihood of a variety of regenerating natives self-seeding under the shelter of the canopy, and longer rotation with selective logging, not clear-fell, an increase in biodiversity relative to pasture or alternative exotic forests will occur.

It is proposed that an analysis of plantation-tōtara as a viable land use, that will help the agricultural sector reduce emissions, focusses on two primary areas:

- the production system (establishment through to harvesting) that maximises environmental co-benefits; and
- how the existing supply chain for farm-tōtara scales up to support plantation tōtara (over the 80-year rotation) for use in the domestic construction industry.

In assessing the viability and scale implication of a plantation-tōtara industry a nominal area of 500,000 ha has been used.

In 2018, 10,630,980 ha was classified as exotic grassland in New Zealand (Stats NZ, 2021). Assuming much of this was used for pastoral farming, in the absence of other methanogenic inhibitors (e.g., vaccines), a 47% reduction in methane emissions could be interpreted as a 47% reduction in area of exotic grassland used for grazing. This could imply that by 2050, as much as 5 million ha of exotic grasslands might require a change in land use A nominal area of plantation-tōtara scale of 500,000 ha represents a significant component of this potential land use change (10%).

2 Sustainable production system

2.1 Production cycle

Plantation-tōtara has been shown to grow faster and have larger diameters when compared to natural stands (Bergin, 2003). This suggests that planted tōtara stands provide the greatest opportunity for rapid development of a tōtara timber industry. Whilst opportunity exists to manage and harvest from naturally occurring stands, this resource alone will not support sustained harvest volumes. The establishment of plantation-tōtara forestry will provide opportunity to maximise yields through good management and fertile sites (Bergin, 2003).

2.1.1 Land type for conversion

When evaluating potential options for sustainable land use change, which facilitate a reduction in methane emissions, there are limited options on the more contoured land in New Zealand. Plantation-tōtara offers a real possibility for conversion to a nil methane option.

2.1.2 Establishment

Tōtara (*Podocarpus tōtara*) is a coniferous tree, endemic to New Zealand. It is widely distributed throughout both main islands and found from sea level up to 600 metres in the North Island and up to 500 metres in the South Island (Bergin, 2003). The species is tolerant of a wide range of climates and conditions and found on a variety of sites throughout the country. The most productive trees are located at sites with well-drained lowland alluvial soils, but trees grow well in a variety of conditions (Esler, 1978). The tolerance to a range of conditions means establishment of plantation-tōtara on different sites throughout the country is viable.

Seeds can be collected and germinated into seedlings in large numbers at a reasonable cost. They are then raised in open beds as bare-rooted stock or in containers, reaching a planting height of 50-80 cm within three to five years in cool upland sites, with this time reduced in warmer lowland sites (Beveridge & Van Dorsser, 1980). The cost for a one litre 3-year-old tōtara is currently $7.50 (Treeline Native Nursery Rotorua, personal communication, March 2023).

Figure 1: Tōtara seedlings
Source: Matuku Link, n.d.

When sourcing seedlings, consideration is required surrounding the origin of the seed. Seeds from different areas are known to produce trees with varying characteristics. Usually eco-sourcing (collecting seed from the immediate environment) is recommended. However, as some forms of tōtara are more prone to multiple stems and lots of branches, obtaining a national inventory of tōtara styles, and their growing environments may be required. Mātauranga Māori associated with varying sub-species and their suited environment should be acknowledged and utilised during this process.

Tōtara seeds are dispersed by birds eating the seeds. However, with access to fruiting trees and good timing, they can be collected from the forest floor. A complicating factor is that the tōtara seeds take over a year to mature, but may ripen over a wide timeframe, creating further issues with the timing of seed collection.

Due to some challenges with obtaining tōtara seeds, especially in significant quantities, cuttings may be another way to augment the supply of tōtara seedlings. Younger trees may be more accessible, but careful consideration of the form of the mature tree will be needed. Additionally, repeatedly 'harvesting' cuttings from suitable tōtara is likely to have a negative impact on these trees.

Planting pattern and density varies dependant on site and individual desires for the plantation. Tōtara is a very light-demanding species. Stem form and branch development are affected by spacing. Trees growing within dense forest growing in canopy gaps with side shading, are often tall and straight with single leaders and small crowns (Bergin, 2003). Using mānuka and/or kānuka as a nurse crop to force this habitat is already practised. Different planting and establishment designs have been outlined below in Table 1, based off a practical guide prepared by Quinlan (2022b) for Tāne's Tree Trust. For most of this analysis, we have focussed on the 2,500 plants per hectare option, with 50% of the trees being tōtara.

Table 1: Different planting designs for tōtara plantations including nurse crops

Planting design	Total stocking (stems per ha)	Tōtara/Nurse ratio (stems per ha)	Spacing
Medium/low density (a)	2,500	1,250/1,250	2 metres
Medium/low density (b)	2,500	625/1,875	2 metres
Low density	1,110	555/555	3 metres
High density	4,444	4,444/0	1.5 metres

Source: Quinlan, 2022b

Drier sites will better suit kānuka, while wetter sites will better suit mānuka. In other sites a combination may work best. However, kānuka grows taller, faster and will shade out tōtara faster. This will initially slow the growth of the tōtara, perhaps by up to 20 years (i.e., 100-year initial harvest) but multi-branching will be less of an issue and form pruning costs likely greatly reduced (P. Quinlan personal communication, 2023)

Increased costs and labour requirements associated with native tree planting needs to be considered. Elizabeth Dunningham estimated that around 300-400 native trees can be planted per day (personal communication, March 2023), much less than *P. radiata*. Extra skill and care are required with native seedlings when planting to ensure maximum survival rates are achieved. The skill and planting rate both contribute to the increased labour costs.

An estimate of costs for planting a tōtara plantation at 1,250 stems/ha and the same quantity of mānuka/kānuka is demonstrated in Table 2. This identifies a significant cost differential to planting *P. radiata*. The cost range for establishing plantation-tōtara including a nurse crop is $15,625 to $32,690 per ha versus $2,548 per ha for *P. radiata*.

The range supplied for plantation-tōtara is what we believe to be reasonable and possible for sourcing and planting a plantation-tōtara forest at this time. Planting of a tōtara and mānuka/kānuka mix is in its infancy, but there are some forests being established now in the 2020's. However, it is a very new industry and there is extremely limited information and resources around what the industry may look like at scale (500,000 ha) and at full production (160 years' time).

Table 2: Comparative costs for plantation-tōtara establishment vs. *P. radiata*

		Cost/plant		Plants/ha	Range in Cost/ha ($NZD)
		Low	High		
Tōtara	Plants	$7.50	$12.00	1,250	$9,375 - $15,000
	Planting	$3.00	$6.00		$3,750 - $7,500
Mānuka/Kānuka	Plants	$1.00	$4.65	1,250	$1250 - $5,800
	Planting	$1.00	$3.50		$1,250 - $4.375
					$15,625 - $32,690
P.radiata	Plants	$0.70		1,200	$846.14
	Planting	$1.42			$1,702
					$2,548

Figure 2: Plantation tōtara stand as part of Tāne's Tree Trust.

Source: Palmer & Bergin, 2017

2.1.3 Forest management

Plantation density and forest form will determine if any pruning and thinning will be necessary. Higher stocked forests (>4,000 stems/ha) with increased side-shading may need less pruning than open forests. A 90-year-old stand with 1.2 to 1.5 metre spacing (approximately 5,500 stems/ha) was found to have desirable stem form, with many trees having 5 to 10 metre diameter clear boles and lightly branched crowns (Pardy et al., 1992). Whereas a 70-year-old stand planted 4 to 6 metres apart had short stems, multiple leaders, and large branches down to ground level. These two documented examples demonstrate the importance of initial stocking rate and form pruning.

Average stand diameter decreases as stocking rate increases. Therefore, there is an optimum stocking rate allowing for the right level of trade-off between plant diameter and tree form. This optimum rate will need further investigation and may vary for different sites. With a significantly higher planting cost than *P. radiata*, thinning will be costly and should be completed when the trees are of sufficient size to be utilised. Where thinning of trees occurs, it results in larger diameter logs, but this incurs extra costs. The labour cost of increased pruning and maintenance in lower stocked stands should also be considered.

Tōtara is intolerant of over-topping, if vegetation dominates and covers the tōtara, heavy shading will result in major growth reductions. Removal of vegetation overtopping the tree is required for 2-5 years following planting. Using mānuka/kānuka as a companion plant should avoid this issue. Exclusion of stock and pest management measures will need to be considered when managing tōtara stands. Tōtara should be managed as a plantation business, and in many cases will be part of a landowner's strategy to reduce greenhouse gas (GHG) emissions. If livestock are allowed access to plantations, the risks of trampling and browsing when livestock are present need to be mitigated to ensure maximum survival rates. Fencing around stands where livestock may be present is vital. Pest and weed management will also be crucial, particularly for younger trees and if natural regeneration of the stand is relied on after the first harvest. Due to the prickly nature of tōtara and the relative unpalatability of mānuka and kānuka, pests should be less of a problem than for some more palatable species of natives. However, rabbits especially need to be kept under control as they dig away at the roots of new plants, damaging the below ground part of the plant. Wild goats could also be an issue in areas with problem populations; there is little they won't eat, especially if the area was historically pasture, and frequented by goats.

With tōtara's intolerance for over-topping yet still requiring side shading to create a clean and true trunk, tōtara may require planting several years after the mānuka/kānuka has established.

It will be important to understand whether certain sub-species of tōtara have greater tendency to grow one main leader versus multiple leaders. Evidence to date is that however closely tōtara are planted they will require form pruning throughout their younger years – twice in the first 10-12 years and at least once a decade for the next 20 years. Frequency of form pruning will depend on growth rates, the faster the trees grow, the more form pruning they will require (P. Quinlan, personal communication, March 2023).

Extensive research has been undertaken on sprays and pest control for *P. radiata*. The concepts that apply to *P. radiata* may not be applicable to tōtara. More research is required based on effective and efficient control measures for tōtara plantations at scale.

2.1.4 Growth and harvest size

Plantation-tōtara has greater growth rates compared to naturally regenerating trees. However, these rates are lower than widely used exotic plantation species such as *P. radiata*, Douglas fir and cypress. A growth model based on data from eight stands at 1,000 stems/ha suggest that a mean volume of 800 m^3/ha may be expected at age 80 years and 470 m^3/ha at age 60 years for planted tōtara, much lower than the expected 400-900 m^3/ha expected for 25- to 30-year-old *P. radiata* (Bergin, 2003).

The growth rate of 20- to 80-year-old plantation-tōtara growing on fertile lowland sites was reported to be around 8 mm annual diameter growth and 25 cm mean annual height growth (Pardy et al., 1992). Elizabeth Dunningham reported a range of 3.1 mm to 12.3 mm mean annual diameter increment (MAI) from both planted and regenerating forests (personal communication, March 2023). Similar results within this range have been reported in Bergin (2001) and Bergin (2003). Tōtara plantation on open fertile sites have reported mean annual height growth rates of 55 cm and an annual mean diameter increase of 10 mm (Bergin, 2003).

The average age of harvest in the Tōtara Industry Pilot (TIP) project was 83 years, with a range of 50 to 150 years (Dunningham et al., 2020). This may indicate a potential harvest age for plantation-tōtara. However, it is important to note that plantation stands will grow and form differently to wild trees. Other factors that may influence this will include planting design/stems per ha and management regimes such as pruning and thinning. Different harvest techniques may also selectively harvest trees that may be of different ages.

For all tōtara, stem growth is slow to start, with values of 0.6 m^3/ha/year and 3.7 m^3/ha/year annual volume increment having been reported at 10 and 20 years respectively (Bergin, 2001). Growth later increases, particularly after 50 years. At age 30 annual volume increments can be from 7 m^3/ha/year increasing to 14 m^3/ha/year at age 60 (Bergin, 2001). Therefore, while it may be tempting to harvest trees early and reduce the harvest age, greatest gains are made towards the end of the rotation. An analysis into potential benefits gained from harvesting trees earlier at smaller harvest volumes may be of interest. Harvesting trees at an earlier date may provide greater incentive for people to investigate plantation-tōtara. However, the financial viability of this needs to be determined. The quality of the wood at an earlier stage is also an important consideration. Even at 80 years of age, heartwood is variable and sap wood (which has poorer qualities but is still useable) is more prevalent. Bergin (2001) reported harvest ages exceeding 100 years of age are likely to allow for development of adequate proportions of heartwood.

There is limited research on factors influencing heartwood formation in tōtara. Difficulty observing the sapwood/heartwood boundary in tōtara has lessened the ability to make accurate estimations. Basal areas of heartwood generally increase with increasing disc diameters. However, there is substantial variation between trees within stands. Bergin (2001) reported no significant correlation between tree size and heartwood development. Further research investigating heartwood formation in plantation-tōtara including silvicultural management, growth rates, genetic influences and site differences will be of benefit. This will likely influence rotation lengths, regarding acquiring desired heartwood proportions.

2.1.5 Partnership with Iwi

Tōtara is a taonga to Māori with divine status, engrained throughout Māori history and culture (Best, 1977). It is used as a building material, historically for carving waka, and is still used in houses, for tools, and other objects, such as carvings (Manaaki Whenua, 2020). Partnership with local iwi is likely to be of utmost importance to ensure the mana of tōtara is maintained.

Ensuring the perspective of Māori are considered throughout this alternative land use is important. Involving iwi will be necessary to understand if they need full or partial guardianship from seed sourcing to harvesting. Ensuring the tree is respected by maximising utilisation may also be an important consideration.

Mātauranga Māori exists for different subspecies of tōtara, and with certain trees their whakapapa will need to be acknowledged and utilised (E. Dunningham, personal communication, March 2023). Rights of ownership of specific trees and their seeds may already be vested with iwi who want to decide how to appropriately utilise the resource. This may result in partnership with iwi and Māori-owned or Māori-led nurseries, as per the report on the Wai 262 Claim which recommends reviews of laws, policies or practices relating to indigenous flora and fauna, amongst other things (Waitangi Tribunal, 2011).

As part of partnership, iwi may be gifted logs that are suitable for carving and building. Harvest plans can be created including the ability to grow nominated trees to an old age that may then even be suitable for carving waka.

Harvesting of native timber may not be viewed positively by some New Zealanders. However, some may view a sustainable native timber industry as a way of promoting the planting and management of native forest into our primary production landscapes (Quinlan, 2022a). It is important to recognise that moving forward sustainable harvesting will need to closely align with conservation and cultural values.

2.1.6 Other considerations

Variation present within different tōtara trees throughout New Zealand has also highlighted the potential for genetic selection and breeding for desirable characteristics. This may provide potential to increase growth rates and form. The progress that has been observed in *P. radiata* may be an indicator that there are potential production gains that could be made through management and breeding programmes. Dunningham suggested there may be the possibility with selective breeding, to decrease the age at which tōtara are first suitable for harvest to around 60-65 years (personal communication, March 2023).

When designing tōtara plantations, consideration should be given to the ease of access to harvest sites. Interconnecting forestry roads allowing equipment to travel through the forest should be implemented, making selective harvest easier and less damaging to the remaining trees. These roads will not only allow productivity gains such as efficient and easier harvesting, but the recreational value and aesthetic potential of the areas should be considered. Utilising the forestry roads as walking or biking tracks when they are not in use increases the value of these forests in the area. Harvesting is only likely to occur for a period of a few weeks each year, having little impact on the recreational activities.

The type of land to be utilised for tōtara plantations is likely to be higher slope land, traditionally used for sheep and beef farming. After cyclone Gabrielle, there is likely to be more land that has become degraded and eroded, requiring retirement from pastoral farming. Tōtara, mānuka and kānuka all establish well on poor soils, and would be suitable for this type of remediation. Predominantly flat land is more suited and profitable for continuing to farm livestock or growing alternative proteins. Decisions around the type of land used will determine and affect vital aspects of the production cycle such as the viability of nursery crops and harvest techniques. With plantations likely planted on hill country, access tracks within the forest and farm tracks to bring the timber out will need to be pre-planned and built at planting time. This will also allow planting and pruning crews easier access to the plantations.

Under the New Zealand Emission Trading Scheme (ETS), post-1989 plantation-tōtara is eligible to earn units. Tōtara is currently suggested as a viable income source across farm succession plans and generational land (Dunningham et al., 2020). If continuous cover forest management is adopted this will enable harvesting of timber without the risk of liability in carbon credits. This includes the maintenance of 30% crown cover and being replanted or naturally seeded within four years of harvest.

3 Sustainable harvest systems

Currently, under the Forest Act 1949, sustainable harvest requirements do not apply to planted tōtara for production forestry. These requirements apply only to naturally regenerating and remnant forests. This opens the door for clear felling of planted tōtara, if desired. However, value may be added to the industry if sustainable harvest techniques are considered. It is important to note that there are still obligations for record keeping as part of the Forest Act, ensuring the timber is legally milled, so that it can be legally sold. To avoid the issues seen on the east coast of the North Island after cyclone Gabrielle, there may be changes to acceptable harvest practices such that clear felling its current form may not be a viable option in 80 years' time. Legislation and social licence to operate will both play a role in this.

Under conventional economic analysis i.e., discounted cash flow (DCF) analysis, native plantations struggle to compete with P. *radiata* plantations as regards financial returns. A DCF including carbon income prepared by Dooley & Dowling (2021) demonstrated a net present value (NPV) on investment per ha of a P. *radiata* plantation at $2,126. The NPV for a native and rimu (*Dacrydium cupressinum*) plantation, with rimu harvested after 55 years was -$3,887. Based on this, and current tōtara timber values, the NPV for plantation tōtara is expected to be similar. Furthermore, with an extended period to harvest associated with plantation-tōtara (around 80 years), this NPV could be expected to be even lower.

Even with current values for stumpage in the range of $200-$400 per tree and that from 80 years onwards this will be an annual income source. Non-timber benefits may need to be accounted for to fully evaluate the potential value of this industry. It is important to note that when considering a tōtara industry, the values present in 80-100 years' time are extremely important. The potential inter-generational benefits and multi-purpose forest aspects should be accounted for, which conventional financial evaluation struggles to do unless ecosystems services are monetised, and low discount factors are utilised.

To acknowledge the non-timber values of tōtara stands different harvest methods could be considered. These methods can retain values such as continuous cover, ecosystem values, cultural importance, and maintaining close to natural character while producing wood (Bergin, 2003). Any decisions will need to factor in learnings from the past, such as issues with forestry slash and erosion caused by clear felling, whilst considering present and future generations. These techniques and an ecosystems management approach may allow demonstration of respect for natural life but also restraint. These principles apply to the landscape, the site and right down to individual tree level (Quinlan, 2022a).

3.1 Selective harvesting

There are a range of harvest options that can be considered. These range from single tree harvesting to clear felling methods. The technique used will depend on the end goals for the forest and the weighting on values provided by the forest.

A mixed-age forest system allowing for continuous cover with low impact harvesting can be applied to plantation-tōtara. This technique involves minimal disruption to the forest structure by selectively harvesting small numbers of trees throughout the forest as they reach appropriate harvest age. For continuous cover management to work, a population profile of all age classes must be maintained to allow groups of trees to continuously move up and replace harvested trees. Initially this will mean that the trees will be of around 80 years of age, but if a continuous, regenerating cover is maintained, after a further 80 years the average age of extracted tōtara will be 120 years. This will impact both tree size and quality. Harvesting regimes and capabilities will need to evolve to reflect increasing tree size.

To create longevity of the plantation-tōtara, high-quality trees may need to be retained in perpetuity. Harvesting and removing top trees and leaving only poorer quality trees will have detrimental effects on the future forest and harvests. To maintain habitat and increase aesthetic values, a small selection of older trees may be deliberately left to grow to maturity.

Remaining aware of the growth rates of the forest will help determine sustainable harvest rates each year. An annual harvest allowance set at lower than annual net growth increment ensures harvested forest is replaced at least at the same rate.

When considering selective harvesting, a major factor is the need to allow for the light demanding characteristics of the species (Bergin, 2003). For selective harvesting to work, there must be large canopy gaps allowing sufficient light to enter the floor to allow for germination and/or growth of younger replacement tree stock. Specialist advice and experience will be required for sustainable harvesting techniques. Anecdotal evidence from the TIP is that regeneration is not occurring in the space left by single tōtara extraction after five years. The forest canopy has closed in too quickly and with no light, tōtara will not germinate. It may be viable for a mature seedling (3 years) to be planted in this space; however, the growth of this tree may still be compromised.

An industry-type training programme to upskill personnel to assess and advise crews/forest owners as to when various trees are ready for harvest will be required. The ability to accurately identify suitable trees and plan harvesting regimes will be key to maintaining and obtaining full ecosystem benefits. Furthermore, existing forestry contractors (of *P. radiata* forests) are not well-equipped or trained for low-impact, low-volume harvesting, likely required for plantation-tōtara.

3.1.1 Selective harvesting equipment

Sustainable harvesting requires more frequent harvesting of smaller volumes, with low-impact equipment, often spread over varying locations. Techniques undertaken on remnant forests (farm-tōtara) have often used a modified agricultural tractor with a logging winch for harvesting. A small forestry skidder may also be used. Limited research has been completed on the viability of using this equipment for selective harvesting on plantation-tōtara. However, use of such systems is common in European forests (Quinlan, 2022a).

Continuous-cover forest management practices in the TIP harvested single stems or small groups (three to five stems). Harvesting costs during this project ranged from \$160 to \$180 per m^3 logs using a one-off contracting approach (Dunningham et al., 2020). It was acknowledged this amount could be reduced once larger volumes of trees are being harvested, and a crew can be employed rather than contracted. It is also important to note that transport costs of specialist equipment, from site to site, may be expensive. For oversize equipment this could be up to \$2,000 to and from site, which could occur as often as daily if sites are scattered (Quinlan, 2022a).

To reduce the risk of erosion, steeper, less productive pasture faces may be an increasing option for areas where tōtara stands may be planted. In these areas, harvesting of tōtara may not be appropriate with typical selective harvesting machinery. A solution to this may be harvesting using heavy lift helicopters. This technique is well suited to the selective harvest of tōtara. However, this harvest method is expensive, contributing to the increased harvest costs of tōtara stands. Quinlan (2022a) reported the cost of helicopter harvesting was around 60% more expensive than quotes for ground-based extraction. Estimated ground crew costs for harvesting *P. radiata* are \$40-48 per tonne (G. Bell, personal communication, March 2023), and these crews would be needed in addition to the helicopter.

Heavy lift helicopters are already operating in NZ, capable of extracting 80-year-old tōtara. Kāhu NZ and Heli Harvesting Ltd. have heavy lift helicopters and specialise in heli-harvesting (Helicopter services Ltd, 2019). The maximum load on the Kāhu Black Hawk is 3 tonnes (Kāhu NZ, 2022). Mark Law from Kāhu NZ provided an estimate of around $5,000 per hour for a capable helicopter travelling at 22 metres per second (personal communication, March 2023).

This means 80-year-old trees weighing around 1 tonne can easily be heli-harvested. If a tōtara is left to grow to 160 years, it may reach 2 to 3 tonnes, a weight still possible to extract by helicopter but at a greater expense.

3.1.2 Replacement trees

An important consideration is whether to allow trees to naturally regenerate or to plant replacement trees once harvesting has occurred. Allowing for natural regeneration may provide inconsistency in timings of future harvest and risks of failure to germinate. However, natural regeneration removes the need for extra labour and the cost of sourcing seedlings.

When large tōtara trees are available, seedlings can establish without tending. The extent of light reaching the floor plays an important role in the extent of natural regeneration (Bergin, 2003). Podocarp regeneration is considered less likely under dense vegetation, but commonly occurs below a gradually opening canopy. Tōtara has been reported to regenerate readily through pasture and scrub such as gorse-covered river terraces (Miller & Wells, 2003). Natural regeneration can allow for management of stands with minimal input. Trees with poor form may be removed to allow for growth of final trees to increase.

Gaps that are left by harvest trees may require active management if they get covered in weeds or the tōtara seedlings establish too thickly. Clearing these areas to allow appropriate regeneration or planted tree growth is vital for continuous cover management.

A possible limitation with relying on regeneration to maintain continuous cover is ensuring the trees regenerate in a way that enables forest quality to be retained. If a group of trees are harvested leaving an open space, it is important that enough trees regenerate in this area to not only maintain the number of trees in the forest but to ensure tree form and quality. If larger open spaces are left with only 1-2 trees regenerating these trees may adapt poor form. Whether naturally regenerated or planted, plots where juvenile trees are growing will need to be monitored and managed to ensure that the correct number of plants and spacing are maintained.

Over time as the forest matures, despite tōtara being planted in the harvested spaces, the mix of tree within the plantation is likely to change. While tōtara are light loving, trees such as rimu prefer shade to grow in (P. Quinlan, personal communication, March 2023), but will join the race to the light when mature trees are removed. Natural regeneration is expected in these forests, which may lead to different species being available for harvest, albeit they may be captured by the current limits on harvesting regenerating trees in native bush. However, these trees should be available to be harvested in addition to the planted tōtara.

3.2 Harvest techniques

3.2.1 Selective single tree harvesting

Single tree harvesting involves selecting one tree at a time for harvest. This method may not be viable due to the lack of light able to penetrate through the canopy to reach younger trees. Single tree harvesting may be a viable method for older specialty trees that may have been purposely left. These larger trees once removed, may provide sufficient gaps in the canopy to allow for regeneration and growth.

One of the largest costs found in the TIP was the transportation of specialty equipment. On a large commercial scale, single tree harvesting will not be the favoured technique. This will increase harvesting costs as equipment will need to be transported more frequently, between sites and individual trees.

3.2.2 Selective coupe harvesting

Coupe felling involves harvesting small groups of trees all at one time. The TIP used this technique, harvesting two to three trees at a time. Figure 3 demonstrates the potential resulting forest appearance utilising coupe (group) or single tree harvesting.

Using groups as large as six to ten trees may work well as more light is able to get into the forest floor (E. Dunningham, personal communication, March 2023). Using larger groups of trees will increase the economic efficiency of harvesting as equipment will need to be moved less often.

The ability to source groups of trees that are suitable for harvesting in proximity to each other will be a limitation. Even if trees are planted simultaneously, some may reach harvest quality at different ages, due to factors such as competition. Again, due to the light-demanding nature of the species, ensuring sufficient light can enter the forest floor is vital. Therefore, groups that are harvested will need to come from one area and not spread throughout the plantation. Management of forests should allow for slight manipulation to encourage groups of trees to reach harvest age at a similar time.

A combination of coupe harvesting, and single tree harvesting could be implemented. Selecting high-value trees and clearing competing trees around it, increases the value of the selected tree and produces marketable timber. The high-value trees can then be left to grow into exceptional timber, which may then even be used for carving or waka.

Another situation may be that there is a group of trees present, where none have the potential to be exceptional timber trees. Then, it may be suitable to harvest the group as a whole and allow new trees to come through which may have greater potential. Different harvest techniques for different personal/community values, end-products and situations will need to be evaluated.

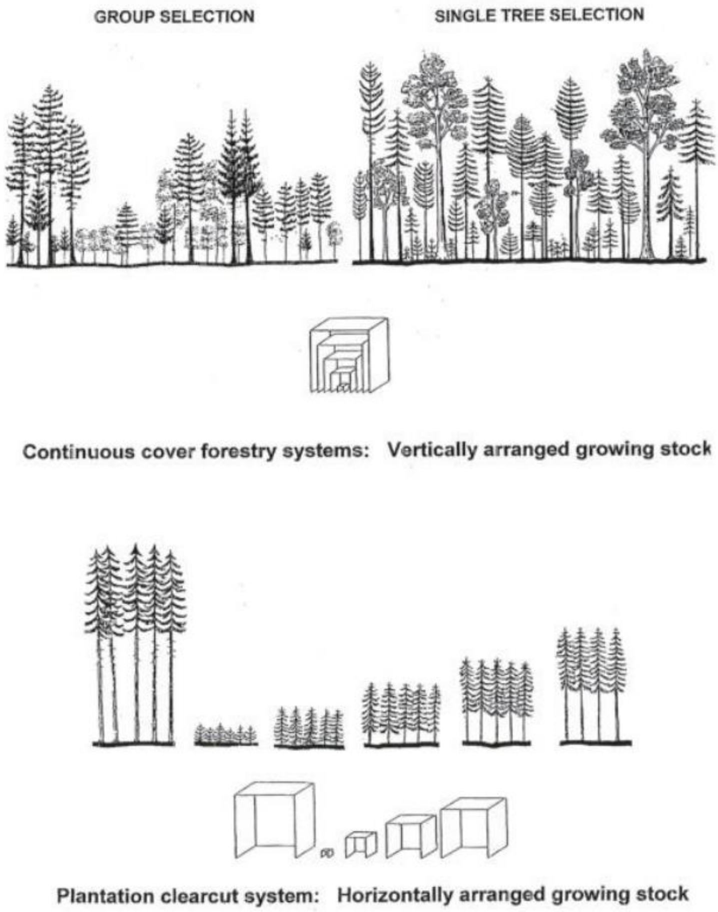

Figure 3: Diagrammatic demonstration of how plantations under different harvesting and management regimes may appear.
Source: Barton, 2008

3.2.3 Coupe harvesting whilst maintain continuous cover

Current net stumpage rates for tōtara are between $200-$400 per tree (at an average of $1 m^3 per tree; E. Dunningham, personal communication, March 2023). While this is a twentyfold price increase on *P. radiata* harvest values, assuming clear-fell is not undertaken, income will be significant less than for *P. radiata*. Taking the current legal harvest volumes for regenerating forest of 0.5 m^3/ha/annum, yields only one eighty-year-old tree per two hectares. As discussed earlier, a volumetric MAI of between 7 and 14 m^3 per/ha is more realistic, with managed 'plantation- tōtara' most likely to achieve the higher of these two values. Taking a median value of 10 m^3 volumetric MAI as achievable for plantation-tōtara and considering regulations regenerating, then 5 m^3/ha/year could be harvested, equating to approximately five trees or $1,000 to $2,000 per hectare operating profit.

However, we need to consider a forest which can be harvested in perpetuity. Initial losses from planting can be as high as 20% but with on-going management, and in-fill planting where required, a loss rate of 15% should be achievable. Additionally, 5% of trees could be left to fully mature, with occasional ones used for cultural purposes (waka/marae, etc). Recommendations for a diameter at breast height (DBH) of 60cm at harvesting is a stem/ha rate of 200 trees (thinning over 1,000 trees from the original planting; Quinlan, 2022). To enable an on-going 80-year rotation under this system would allow only 2 trees per hectare/year to be harvested and replanted to give a continuous harvesting option. This would equate to $400 to $800 per hectare operating profit (as per above). The upper range of 400 tōtara/ha at planting provides for up to four trees per hectare to be harvested.

3.2.4 Selective block harvesting

Block harvesting is another technique that could be used. Small blocks may be selected that are then harvested. Blocks may be small areas which are then felled together. Block harvesting may be considered a down-scale of clear felling. It will not leave large areas of bare land to the extent that clear felling does, however, there will still be cleared land. A general rule may suggest areas no larger than two tree heights are used, this may mean areas of no larger than 0.25 ha are harvested at one time (Barton, 2008).

Areas cleared by block harvesting will likely require re-planting as regeneration may not be sufficient to cover the block in a suitable time frame. An advantage of block harvesting is that movement of equipment will be reduced, and less labour will be required for specific tree selection.

However, the biodiversity that has been built within the block will be compromised when it is harvested. However, this will be less detrimental than clear felling large blocks of *P. radiata*, due to the smaller block size and residual adjoining habitat, ecosystem recovery should be much faster.

3.2.5 Clear felling

The New Zealand traditional approach of clear-felling plantation forestry is an option for harvesting plantation tōtara. This technique means limited additional training will be required for forestry crews. Equipment used in clear felled exotic plantations are likely to be suitable for clear-felling tōtara or will only require minor adaptions.

One of the major limitations of clear felling is the slash and material potentially left behind. With no other cover present on the land following clear-felling, this debris, if not removed, is then susceptible to being washed away and deposited in surrounding areas. It is also beneficial for the health of the future forest that the slash is cut up and ground or otherwise removed, to avoid affecting the growth of future forests (Quinlan, 2022a). If clear-felling techniques are adopted, strict regulation regarding clearing the harvested area should be considered.

Another limitation of clear-felling is that in parts of the plantation whole areas of habitat may be removed within a short period. The biodiversity and ecosystem services that have been built up through the forest will be severely compromised when large areas are clear felled. This raises the question regarding whether full ecosystem benefits can be achieved when tōtara is harvested in the same way as traditional forestry. In a native plantation, especially one of some age, there are likely to be native flora and fauna which have colonised the area which it may not be socially acceptable to disturb, i.e., kiwi, kaka. These possibilities need to be evaluated during the 80+ year lead in.

Outside of New Zealand, clear-felling plantation forestry is not a common occurrence (E. Dunningham, personal communication, March 2023). Selective harvest techniques are predominately used in places such as America and Europe (Bont et al., 2002). Increasingly negative public perceptions and greater awareness of adverse environmental consequences seems likely to render the technique unfavourable.

3.3 Other important aspects

3.3.1 Deliberate planned phasing

One concept that allows for maintenance of forestry canopy, as well as sustainable harvesting is planned phasing. This involves the implementation of a phased planting programme allowing for portions of the forest to mature and be ready for harvest at differing times. If the round length is considered as 80 years, an associated planting length of 80 years could be implemented.

An obvious limitation of this technique is the length of the planting period. Yields at the first harvest will be low, as only a small section of the forest would be harvested. As the harvest age is prolonged by using tōtara, relative to exotic plantation species, the extra time waiting to achieve the first full forest harvest will be limiting in terms of financial viability.

Assuming a staggered planting of $1/80^{th}$ of the area per year, there is clearly a long period of time for complete land use change under a plantation tōtara forest. If there was a methane-driven requirement to reduce stocking rate at a greater pace than that allowed by phased planting, alternative uses of the land might need to be considered. Planting *P. radiata* may still be a viable option, creating income while implementing phased planting of tōtara. Once *P. radiata* is harvested, sections can then be planted in tōtara. However, viable harvesting regimes for these crops may not align with the values outlined throughout this report.

Further possible options for this land use will need further investigation and consideration of how it could integrate within a phased planted tōtara stand.

Another possible limitation may be that as the acidity levels in the soils change under the forest (Jobbágy & Jackson, 2003), trees may have differing growth rate and forms. Therefore, trees may not be ready in the typical expected timeframe, disrupting the planned phasing harvest.

3.3.2 Whole tree utilisation

The implication of post-harvest field conditions has not always been fully considered in the New Zealand forestry industry (Nash & Parker, 2023). The development of a plantation-tōtara industry holds the potential to illustrate the best practice management of these conditions. Whole-tree utilisation is an important concept when developing a plantation and planning its management and harvest. As tōtara are considered taonga by Māori, this further supports the value of utilising the whole tree.

With plantation-tōtara, whole-tree utilisation may include leaving some smaller branches on the forest floor to breakdown, however all logs should be removed and utilised. Relationships and partnerships with local iwi may result in the gifting of logs that are cut but not suitable for processing. As tōtara is highly valued, off-cuts need to be treated as part of the product. Limbs and larger branches may be able to be utilised in the local carving trade for local or tourist trade. Smaller branches that are pruned may remain on the forest floor; these will serve a purpose as they will provide ecosystem services, e.g., habitat to insects and therefore birds, plus a food source for fungi. The quantity and size of branches left will need to be monitored as too many may impede harvest conditions, further regeneration, new sapling growth and potentially induce pest issues. At felling or tree-pruning, the branches left behind may be trimmed down which would increase surface area and reduce the amount of time required to break down.

Utilising other parts of the tree collected both pre- and post-harvest could also potentially provide alternative income streams. Fruit and seeds can be harvested during the trees' life and bark retained as its own value stream once the trees are harvested. Products such as bio-extracts and essential oils would need further exploration.

3.3.3 Harvest condition considerations

The Tōtara Industry Pilot project identified key constraints to successfully completing sustainable harvest techniques as soil moisture conditions, vehicle access and topography (Dunningham et al., 2020). The harvest period would likely be from November through to April, so maximising this harvest window will be important. Harvesting by heavy lift helicopter may increase this window, where extraction would be limited more by atmospheric conditions than those on the ground.

Maximising the harvest window will depend on factors such as climatic conditions and access to suitable equipment. Harvesting in suboptimal conditions can have adverse environmental consequences, including heightened risk of runoff and erosion (Marden et al., 2007).

When designing the forest, roads and inter-connections that allow access to harvest areas will be important. An effective network of forestry tracks may comprise 6-8% of the total forest area (Barton, 2008). Heli-harvesting is likely too expensive for all terrains. Therefore, access tracks facilitating ground-based harvesting will be necessary. Tractor mounted forestry winches have a reach of around 35 to 50 metres, and skidding tracks should aim to be around 70 to 100 metres apart (Quinlan, 2022b). In steep areas where access roads are not viable, helicopter harvesting may provide the opportunity to extend harvest windows, dependant on flying conditions.

3.3.4 Environmental considerations

Native plants may often be established for more than one reason. Native species plantation establishment may not be supported by financial value alone. However, when environmental considerations are included and non-market benefits are included, the economic value improves (Bergin et al., 2003). A full ecosystem management approach of plantations that ensures these non-market benefits, such as harvesting techniques and maximising co-benefits should be forefront to achieve premium prices and avoid issues relating to monoculture exotic plantations.

3.3.5 Monoculture system

One option when setting up plantation-tōtara is to follow *P. radiata* plantation techniques where monoculture stands are used. Side-shading to achieve good tree form can be achieved by densely planting tōtara instead of using nursery crops. Increased numbers of tōtara will be able to be harvested through a monoculture plantation, however the potential benefits gained by planting native species as a nurse crop may not be fully realised. Tōtara plants are also considerably more expensive than nurse crop species, therefore, extra costs are associated with a highly stocked monoculture plantation.

A monoculture plantation does not provide the same ecosystem services that a plantation with two or three species may provide. A planting design incorporating multiple species, that is more reflective of the natural state of a native, regenerating forest is likely to provide greater ecological services. Mānuka and kānuka will naturally allow for regeneration of other forest species over decades.

3.3.6 Maximising co-benefits

To obtain maximum ecosystem and environmental benefits from the implementation of plantation tōtara, the inclusion of various nursery crops may be considered. Incorporation of various species may provide mitigation strategies to the limitations and concerns of a monoculture tōtara plantation that are mentioned above.

In the absence of side shelter, tree form is likely to be compromised. To avoid this, a low-cost cover crop shrub can be planted with 1.5 to 3.0 metre spacing, providing quicker canopy closure, weed control, and providing shelter. Tōtara is then interplanted planted three to five years later (Bergin, 2003; Palmer & Bergin, 2017).

Many benefits can be gained from interplanting various species alongside/in between tōtara. These include benefits from both an environmental and production perspective and include:

i. Increased habitat and shelter for various native species.
ii. Increased ground cover, resulting in reduced soil erosion risks.
iii. Straighter trees, potentially with fewer supplementary lower limbs.
iv. Higher seedling survival and growth rates.
v. Reduced risk of frost damage.

The two most likely species for interplanting at the outset are mānuka and kānuka due to their upright form, similar growth speed to tōtara and cost. Most of the native regenerative species which would establish on bare ground are more inclined to spread vertically to fill available space. There is more likelihood that these plants will encroach on the tōtara's space and potentially restrict growth in the early years. These other species (*Coprosma sp*., *Grislinia littoralis, Pittosporum sp., etc.)* are likely to establish in spaces amongst the kānuka or mānuka and they will establish in full shade.

Tōtara tree form is highly affected by stand density. Higher stocked trees are straighter, with less branching. Tōtara forest containing trees that are side shaded produce straighter trees with single leaders (Bergin, 2003). Whereas open-grown trees have a tendency for poor form with good diameter growth (Moodie et al., 2007). Therefore, including faster growing, lower cost species such as mānuka or kānuka can provide side shading for a lower cost. The trade-off between straight trees and diameter growth needs to be considered when interplanting tōtara with various species.

Tōtara seed dispersal is bird-dependant. Therefore, if natural regeneration is the selected method of replacing harvested trees, habitats that encourage an abundance of bird life are preferred. Incorporating or encouraging various species into the stand, may attract and retain increased bird species and numbers. Adjacent areas of existing native bush will accelerate the plant, bird, and insect biodiversity.

Plantations requiring minimal input are economically advantageous. Using nurse crops will help to reduce establishment costs, improve tree form, and provide alternative to highly stocked tōtara stands, requiring less tōtara seedlings and less intensive maintenance.

One consideration is that maintenance is required to prevent the nurse species from overtopping the tōtara, incurring additional maintenance costs. When tōtara regenerates with mānuka and gorse, within two to three decades the tōtara will over top the canopy and maintenance costs will be reduced (Bergin, 2003). This may be a feasible option, but this may also extend the time taken for the tōtara to achieve a suitable trunk diameter. It should also be noted that gorse is a noxious weed, and a legume, leaching nitrogen into the ground water at significant rates (Mason et al., 2016).

The ability for these nurse crops to provide alternative income streams while also serving the tōtara stand is a possibility. Recent findings on the nutraceutical aspects of kānuka and its wound healing properties may be of interest (Beasley, 2019). This may be of relevance as trends towards natural health products increase along with the likelihood of significant antibiotic resistance 80 years from now.

4 Treatment of the timber

From this section onwards we have assumed the following parameters for a potential plantation-tōtara supply chain:

- 500,000 ha of plantation-tōtara, planted at 6,250 ha per year
- Trees thinned to 400 stems tōtara before initial harvest at 80 years
- Log harvest to timber – reduction of 61% (drying and milling)
- Processing facilities required are at the point of full production

While tōtara is naturally resistant to wood rot when used in an interior application, there are current non-chemical treatments available which could create a hardened product, which is then able to be more widely used in flooring, or even externally.

4.1 Thermal modification

This treatment is applied to already dried timber and utilises a high temperature kiln controlling humidity and oxygen levels to create a product hardened solely by heat. It is an energy intensive process so would only be suitable (in a carbon conscious world) where power from renewable technology was available. At the time of writing a 60 m^3 kiln would cost approximately NZ$1 million (E. Dunningham, personal communication, March 2023). This would be capable of processing up to 180 m^3 of timber every day (in three loads). This technology is available down to a kiln of 3 m^3, so is very accessible to smaller enterprises.

Tōtara is very suitable for thermal modification but very limited data is available on this specific timber in this process. However, timber treated this way would be even more useful in the construction industry, but at an even higher cost than the already expensive untreated tōtara.

If there was a market for the thermally modified timber, then this would likely be limited by demand. With a likely harvesting period of five months timber would either need to be processed immediately after drying or large scale, covered storage secured. Working for five months solidly, one kiln could process around 27,000 m^3 of timber (as opposed to logs) per year. An industry with 500,000 ha of plantation-tōtara would yield around 993,000 m^3 of timber (at 61% conversion rates), requiring only about 45 kilns nationwide to process the entire annual crop. This would then be required to be dry stored as supply to any market would be annually not seasonally.

4.2 Accoya Treatment

This is another non-chemical process for hardening timber, it is a proprietary acetylation process. The company which undertakes this work (Accsys) has four reactors across Europe and North America and is generally sited within large 'chemical plants'. Timber treated with the Accoya method is guaranteed for 50 years above ground (Accoya, n.d.). This compares with above ground external H4 treated P. *radiata* that has a guaranteed lifespan of 15 years. This process is currently very expensive and due to NZ set up and distance from the rest of the world, having a plant built here is unlikely. It is a great treatment for adding value and longevity to commodity timber products. Using it on tōtara could make it prohibitively expensive, especially if the timber required export and re-import.

5 Uses within the NZ building industry

5.1 Tōtara in the NZ building code

Tōtara is currently able to be used in structural applications under NZS 3603 of the NZ building code (Standards New Zealand, 1993). This allows for timbers such as farm-tōtara, redwood, etc to be use for building, by involving an engineer in the design. The timber must be dried to 18% moisture or below. The NZ Farm Forestry association undertook the required testing (Table 3), to prove the suitability of tōtara as a structural timber (Appendix 2) The timber tested was from farm-tōtara trees of a similar age to those expected to be harvested from the plantation-tōtara forests.

Table 3: Comparison of tōtara strength to *P. radiata*

Structural testing					
	Bending Stiffness MoEj	**Bending Strength MoRj**	**Tension Strength**	**Shear Strength**	**Compression Strength**
	(GPa)	(MPa)			
	100 x 50 tōtara				
Mean	7.6	57.9	22.4	5.4	35.2
S. Dev	1.3	15.7	8.0	0.7	4.3
Count	**30**	**30**	**30**	**30**	**60**
	SG graded timber NZS 3606 A4				
P. radiata					
SG10	10.0	20.0	8.0	3.8	20.0
SG 6	6.0	16.0	4.0	3.8	16.0
	Totara Comparison to P.radiata				
SG10	Below	Above	Above	Above	Above
SG6	Above	Above	Above	Above	Above

A further methodology for verification of timber suitability is available under NZS 3622:2004 of the code. This allows for the product to be controlled through output monitoring. In this case timber is continuously tested by the producer, at the point of manufacture, with stiffness and strength assessed.

Due to the already favourable results from the 100 x 50 tōtara timber, both of these methods could remain in use. The process of having tōtara accredited and able to be used as easily as *P. radiata* for framing timber would be possible especially with an 80-year lead in. As discussed in section 5.3, it is unlikely that framing timber would be the most common use for the plantation-tōtara timber.

5.2 Timber quantity

Understanding the quantity of timber available from a national tōtara forest of 500,000 ha is an important part of understanding potential uses. As discussed in Section 3, there are two realistic sustainable harvest option, not involving clear felling of the timber, assuming a final harvest plantation density of 200 tōtara planted per hectare:

Table 4: Potential harvest volumes from 500,000 ha of tōtara plantation

Harvest rates per annum (long term)		
Trees/ha	**Total m^3 logs**	**Total m^3 timber[a]**
0.5	500,000	245,000
2.0	2,000,000	980,000

[a]Assuming 55% conversion rate to timber from logs plus 6% drying

5.3 Framing timber

Tōtara would be more than adequate for timber framing for New Zealand homes. Even young tōtara (under 200 years old) with little to no heartwood still has the necessary attributes to be used for framing timber and would not require chemical processes to ensure it remains resistant to rot. However, it is likely that the shorter time required to grow a *P. radiata* to maturity (30 years) versus tōtara (potentially 60 and up to 80 years to first harvest) will mean that from a purely financial perspective *P. radiata* is likely to remain the timber of choice for internal framing.

For those customers building bespoke homes and wanting to minimise the chemicals included in their base build (woollen carpets, non-toxic fittings, and paint, etc), Douglas fir and *Eucalyptus. sp* are among the locally grown timbers suggested as alternatives. Tōtara is not currently on this list due to harvest volumes only in the tens of cubic metres per year.

Cost is the limiting factor with using plantation-tōtara for framing timber. *P. radiata* will always out-compete on the current cost of production. While there are additional chemical treatment costs to preserve *P. radiata* timber, this is insignificant in relation to the overall establishment and harvesting costs of tōtara. The additional lead in time to first harvest will also have an impact on the value requirement of the timber from the continual harvesting regime for plantation-tōtara.

5.4 Internal finishings

Plantation-tōtara is predominantly non-heartwood, making it a softwood rather than a hardwood. There are options for treatments to harden the tōtara timber but it is already being used internally in NZ buildings for decorative finishes – wall panels or flooring.

5.4.1 Interior (decorative) panelling

Currently (2023) New Zealand imports around 65,000 to 80,000 m^3 of hard wood from around the world for use in the interiors of our homes and commercial buildings (e.g., "high spec" offices and hotels). Table 5 shows the imported volumes for the three main types of imported hardwood used in the interiors of NZ buildings:

Table 5: Import quantities and costs provided by MPI

	Mahogany		Oak		Teak		
Year	**Import quantity (m^3)**	**Import cost[2]**	**Import quantity (m^3)**	**Import cost[2]**	**Import quantity (m^3)**	**Import cost[2]**	**Total import quantity (m^3)**
2020	5,104	4,881	73,395	7,718	1,351	1,741	**79,849**
2021	7,774	8,570	9,783	13,175	1,439	2,296	**18,996**
2022	6,612	8,514	56,911	10,332	21	99	**63,545**

[2]Insurance&Freight ($NZ)

There are significant variances between volumes of timber types imported and total timber imported annually. This three-year period covered the Covid pandemic, especially 2021 when NZ was in lock down, where many projects halted, and global supply of all goods was interrupted. Discounting the 2021 value and looking only at the average of the other two, there is a little over 70,000 m^3 imported, which would account for less than one-third of the lowest predicted tōtara timber harvest and only a very small proportion of the likely harvest.

Indicative prices for this imported timber are around $2,000 per m^3 and farm-tōtara these prices (E. Dunningham, personal communication, March 2023), albeit at low volumes. Plantation-tōtara can provide product which is guaranteed sustainable and has a lower carbon footprint due to the continuous nature of the forest. Although considered by many to be a hardwood, tōtara is a member of the conifer family and is in fact a softwood, making it easy to work and carve. However, there is a genuine opportunity for imported hardwood timber for internal used to be replaced with genuinely sustainable plantation-tōtara timber from within New Zealand. The limited supply of tōtara currently available through farm-tōtara harvesting is being trialled in various internal building applications, on a small scale, e.g., re-flooring marae, panelling.

Unlike *P. radiata*, tōtara is not a uniform colour which offers challenges or opportunities for high quality finishes. Where timber is used on a 'packet' basis (as milled from the logs), there are large differences in colour. This can provide a wonderfully rich but non-homogenous visual effect to the finished product. Alternatively, the timber could either be graded for colour or heat treated to standardise colours (already an option) then a visually uniform finish can be created.

5.4.2 Flooring

Unhardened plantation-tōtara is still suitable for flooring but it dents easily. This makes it very suitable for buildings such as marae, where shoes are removed. However, any environment where constant traffic of shoes, especially high heels, is a necessity it [tōtara] would be an inappropriate choice. Thermal modification (section 4.1) would make the timber durable enough to be used in less restricted flooring areas and increase the opportunity for use.

5.4.3 Exporting timber

With large volumes of plantation-tōtara timber being harvested, it is likely that exporting would become a significant part of the market. There is almost no native timber exported from NZ at the current time, due to regulations around harvest of regenerating and existing native trees and the intrinsic value of the product to New Zealanders. With heightened awareness of true sustainability of harvested timber, being able to offer product from a perpetual forest to the international market is likely to appeal. Currently this market does not exist due to lack of supply, a future project may need to focus on identifying markets and viability.

6 Knowledge gaps

6.1 Lack of knowledge of mature plantation forest dynamics

Current plantation-tōtara stands are limited and relatively young. Less than fifty years ago native forests were still being felled for timber. Therefore, tōtara trees are mostly either large remnant giants or younger regenerating trees. For this reason, the dynamics of a planted-tōtara stand past 80 years of age are largely unknown. The ratios between the wood being laid down in the crown vs trunk are almost unknown in mature tōtara - older trees may not produce proportionally greater volumes of millable timber.

There may be some applicable Mātauranga Māori knowledge regarding tōtara species and phenotype, but scientific research to give quantifiable answers can only occur as current trees mature. In the interim plantings may have to occur with the seedlings available from whatever seed can be harvested. It is highly likely that without a co-ordinated approach, tōtara trees could be planted, at scale, with issues of multi-stemming and significant branches.

Based on annual growth increments it may be expected a 160-year-old tree may well have a DBH over two meters and may weigh between two to three tonnes. These considerations will have implications for the desired planting regime. The lack of knowledge around mature plantations and the viability of processing these larger trees may drive the need for phased planting where trees are harvested at 80-90 years rather than bulk planting where harvest ages will approach 160-years-old.

6.2 Use of bare land during phased planting regimes

As earlier alluded to in 3.3.1, utilisation of the un-planted land as part of phased planting regimes is an important consideration. If only 1/80th of the proposed plantation-tōtara land is planted annually, the use of this land prior to planting will need to be sustainably managed.

If current methane reduction targets are to be met, in the absence of widespread, market acceptable and effective technological solutions (such as a methane vaccine), significant reductions in the numbers of ruminant livestock and gains in efficiency per animal will be required. The timeframe for any such changes to ruminant numbers may not perfectly align with the phasing of a staged tōtara establishment regime i.e., from a methane reduction perspective, animals may need be removed from this land ahead of it being planted in tōtara. A suitable land-use for this 'bare' land then needs to be devised.

As mentioned earlier, the option of *P. radiata* as an interim land use may be considered. If typical *P. radiata* harvest and planting regimes are adopted, there will be risks of adversely impacting this land. Options such as crops of mānuka and kānuka may be an option. Potential income streams from these crops such as honey or medicinal uses may be gained. However, as identified in 7.2.3, relying on honey for income may not be viable; there is risk of swamping a market that is already over capacity. Using honey for nutraceuticals will require further research. This could potentially require national level structures to encourage the scientific community to investigate these pathways, knowing that more product will enter the market. However, this results in a risky proposition for those planting it.

When the tōtara require planting, due to its intolerance of over-topping, the removal or trimming of the existing plants would be required. Issues regarding habitat removal and loss of biodiversity then recur. Consideration is also required regarding the cost of planting/establishing such crops.

As part of planned planting, land use that is viable for short periods (1 to 20 years), as well as both medium (21 to 50 years) and long (51 to 80 years) periods need to be considered. Therefore, multiple different land uses may need to be implemented. Further research will be required to devise strategies that may meet these criteria.

7 Sustainable supply chain

7.1 Logistics

Plantation-tōtara will likely take 80 years to mature. Planting 1/80th of the final plantation area annually would be the best and most feasible long-term approach. This would require planting 6,250 ha in plantation-tōtara every year for 80 years and in each location where plantation-tōtara was being set up. We do not envisage the initial planting to be able to commence until at least 2030 for purely logistical and timing issues. Once the forests were in permanent rotation, the number of trees required to be planted to replace those removed would likely be in the order of magnitude of around four to five due to continuing canopy cover.

Figure 4 demonstrates that the potential harvest from planting 1.25% of the planned area per year (1/80th to ensure a perpetual 80-year rotation). From year 80, the area harvested would increase in line with the annual increase in area planted 80 years previously. By year 160 all the 500,000 ha would be in full production. With the first harvest occurring in year 80, the second harvest in year 81 would be harvesting trees that were one year older and therefore slightly larger. By the time the plantation reaches 160 years of age, the average age of the trees being harvested will be 120 years. In this example we have assumed the volume of timber harvested per hectare would probably double over the initial 80 years of harvest, but the volume may well be more than that.

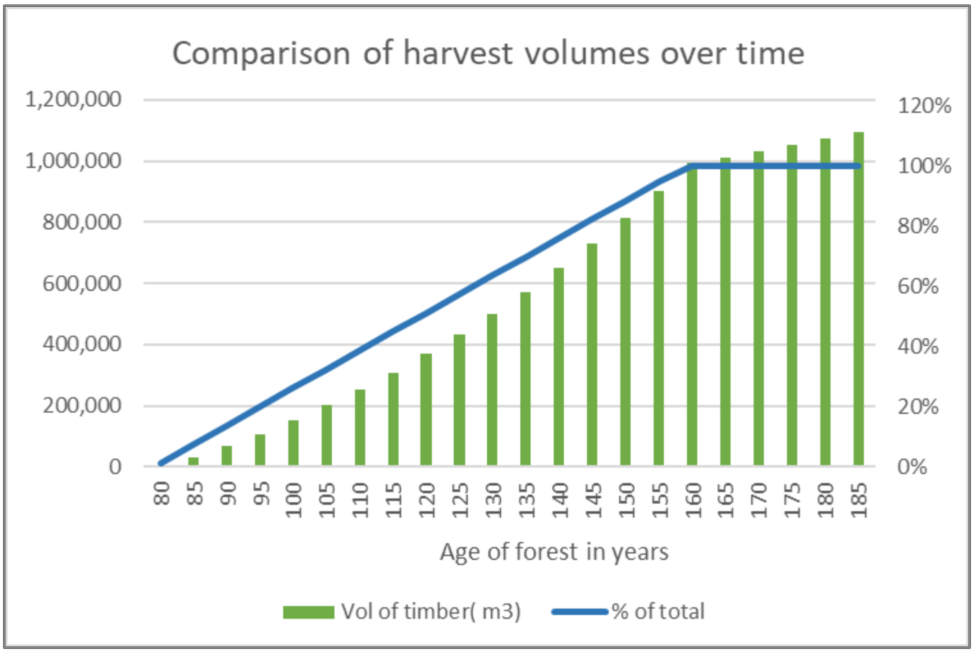

Figure 4: Comparison of nominal harvest yields over time for a phased planting regime

To plant 6,250 ha with plantation-tōtara (1.25% of the final area) with an initial 1,250 stems per hectare will require 7.8 million tōtara trees to be grown to 2-3 years of age, ready for planting out. An equal number of mānuka/ kānuka plants will be needed as well. This will require several matters to be addressed:

i. Currently a good-sized nursery can produce around 300,000 plants per annum. Most of these will be one-year-old plants, providing an annual income. To produce sufficient tōtara will probably require nurseries to be specialist in this plant and the mānuka/kānuka support plants. They will incur significant set up costs, followed by up to three years of labour, materials, utilities, and rent or mortgage payments, with limited or no income. If tōtara are planted a year after the mānuka/kānuka, then this problem may be somewhat mitigated with income from the nurse crop of mānuka/kānuka after 12-18 months of growth.
ii. Natives are not able to be planted in the same way as *P. radiata* and will require specialist crews to be trained up ready for the first year of planting. If the tōtara and mānuka/kānuka are planted a year apart to create a better nurse crop for the tōtara, planting will only be 7.8 million trees in year one.

7.2 Complementary income

7.2.1 ETS – Carbon units

With the 80-year lead in to the first year of harvest, and between $15,625 and $32,690/ha of establishment costs, any complementary income sources from the growing forest are essential to consider.

In the event plantation-tōtara was confirmed as a viable large scale land use, we would not expect planting to begin on a significant scale before 2030 at the earliest (section 7.1). We have factored in the possibility of claiming carbon credits for the period 2030-2050 when New Zealand is committed to have achieved its targeted greenhouse gas reductions. Assuming the plantation-tōtara will be planted on virgin forestry land, with plantings staggered over this period, the first hectare would be eligible for credits under the ETS for every year after planting. However, the trees planted in 2050 would have no eligibility. The average annual income from ETS units across the whole forest area planted at an even rate, continually for 20 years, has been calculated at $161.32/ha/year (Appendix 1).

7.2.2 Biodiversity credits

These are an emergent income source for retired land with a biodiversity value. Mountain Sanctuary Maungatautari, Waikato, used the services Ekos to accredit and sell biodiversity credits to APL Window Solutions. Ekos are currently piloting a biodiversity crediting approach to help unlock additional finances for community biodiversity initiatives. (J. Penelope personal communication, March 2023)

Climate Change minister, James Shaw announced in June 2020 that he would be supporting the establishment of biodiversity credits for farmers establishing native plantations. Where these native plantings are permanent, which a sustainably harvested plantation-tōtara forest would be, they will reintroduce a habitat suitable for native flora and fauna to re-establish, stabilising hills and valleys in the process.

7.2.3 Further processing of mānuka/kānuka honey

By late 2022 the New Zealand mānuka honey industry was already in a state of over-supply (The Guardian, 2022). To even suggest that, if the nurse crop mānuka has a high unique mānuka factor (UMF), it will provide a guaranteed source of income from the land would not be prudent. As identified in section 3.3.6, there is a realistic market for both mānuka and kānuka to be used in the natural medicine market. Research into the efficacy of wild produced mānuka honey versus medical grade honey concluded, amongst other things, that multi-drug resistant organisms were often more susceptible to honey treatment (Nolan et al., 2020). In research funded by Honeylab Ltd, NZ, Kānuka honey has been found to control cold sores as effectively as its 5% acyclovir cream Virban in patient trials (Beasley, 2019).

7.2.4 Grazing prior to staggered planting system

If the staggered planting method is applied, it would still be possible to use it for pastoral farming. Grazing the future planting areas with livestock in the years until they were planted, would continue to provide an income. This continued land use has been factored into the calculations in Section 7.2.1.

7.3 De-centralised hub approach

To maintain a sustainable industry, a sustainable approach should be considered when developing a supply chain. A series of de-centralised hubs approach between forests, mills, storage, kilns, and nurseries results in minimal travelling distance between the nominal areas (Figure 5).

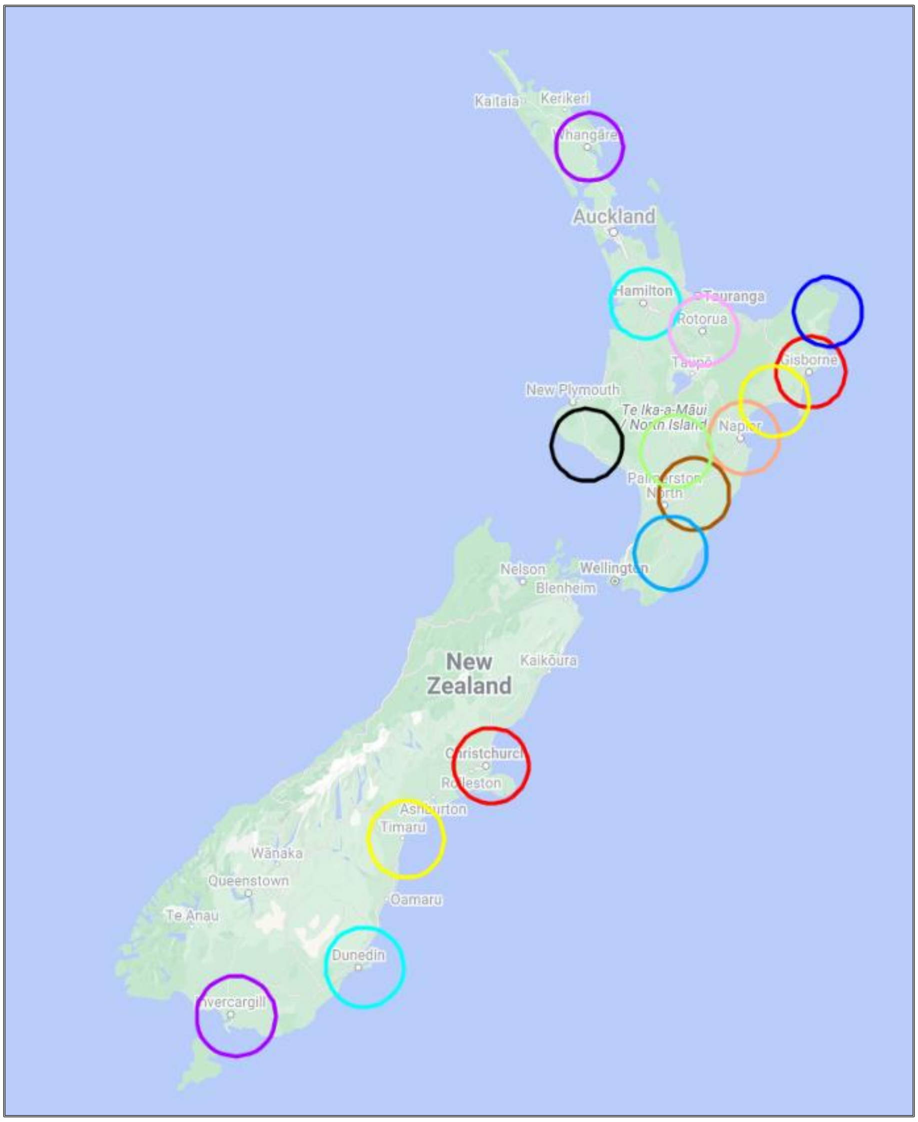

Figure 5: Map of New Zealand with potential mill sites, centred on existing rural service towns

These nominal hubs are centred around existing rural service towns. While some of these are on the coast reducing the land area within their 50 km perimeter, existing road networks should provide good transport options for harvested timber to be extracted. Additionally, using existing service towns will provide the infrastructure needed for people to be able to relocate to work within the supply chain, or undertake training. There is a heavier focus on the North Island due to:

i. unstable nature of the east coast of the North Island that might be better suited for permanent forestry systems.

ii. more extensive land use on the east coast of the South Island, providing less methane reduction per hectare retired.
iii. More transport networks in the North Island

Fifteen de-centralised hubs spread throughout New Zealand with an average 50 km radius would allow for adequate processing, storage, and resources. These would each contain, one main facility in the middle (the hub) which has a timber mill, a storage shed and drying kilns. These areas could be described as an 'industry park'. Sourcing of a suitable location for each of these areas may be difficult, as generally flat land, not susceptible to flooding will be required. In most cases, this land will be considered premium land, with a land value reflecting this.

Surrounding each hub/park would be a number of blocks of plantation-tōtara spread throughout the 50 km radius (Figure 6). The hub would also need to contain a nursery, growing both tōtara and the chosen nurse species (most likely mānuka or kānuka).

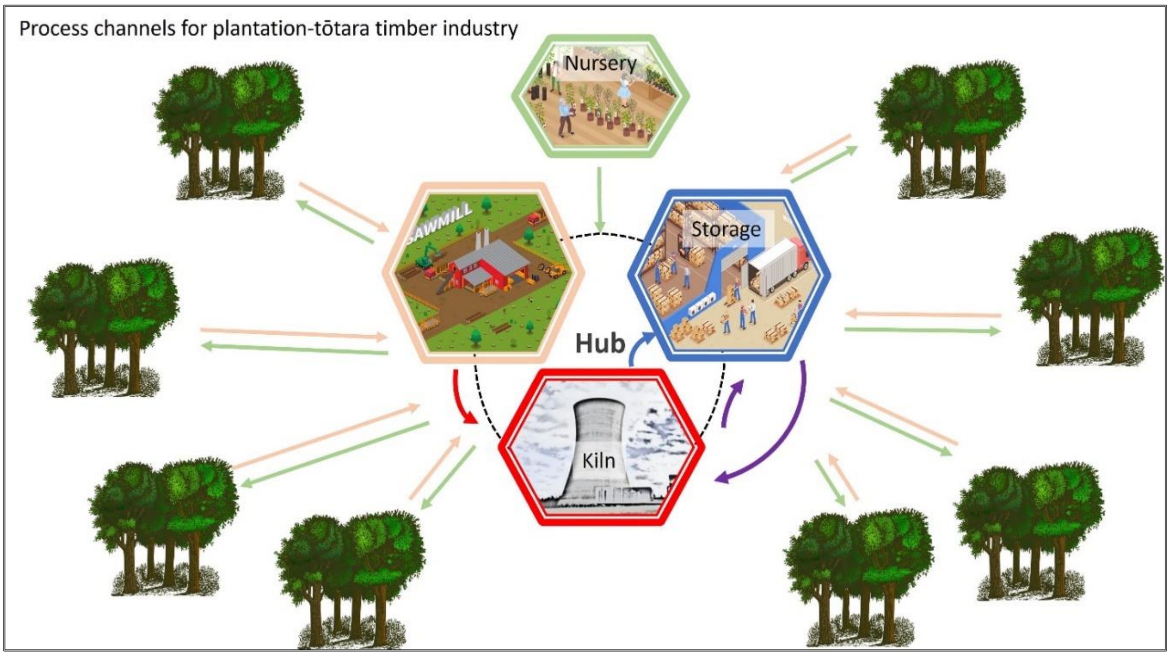

Figure 6: Process channels for plantation-tōtara industry, demonstrating de-centralised hub approach

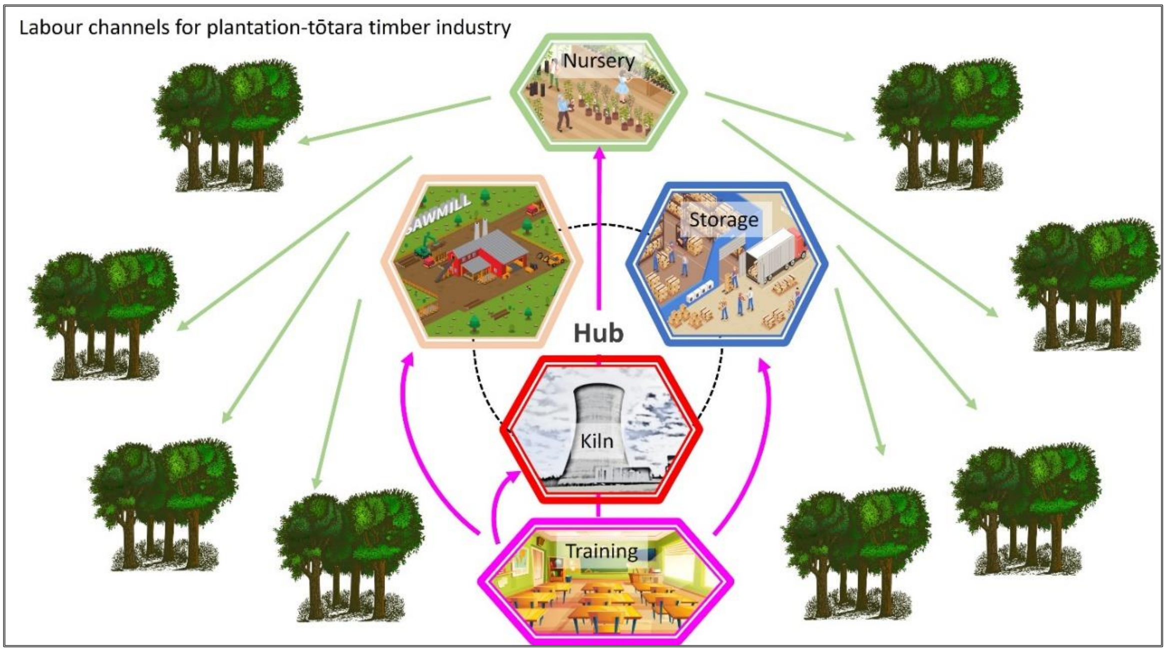

Figure 7: Labour channels for plantation-tōtara industry, demonstrating de-centralised hub approach'

Figure 6 and Figure 7 demonstrate the functions of the de-centralised hubs with regards to products and labour. In Figure 6 the purple lines indicate the transfer of products from storge back to the kilns for further processing with heat treatment. In Figure 7 the pink lines from the training centre demonstrate the transfer of skills from the institute to the working hub. Training would be on-site with the equipment that will be required once students enter the working teams. Silviculture training could occur on some or all properties, depending on proximity to the hub.

These nurseries would need to have the capacity to grow 1 million seedlings each per year, 50% tōtara and 50% of the chosen nurse crop, and have the ability to hold half of the entire crop for three years, and the kānuka and mānuka being sold as PB2's after two years. This may need to be in several separate nurseries or there may be the ability to develop one large nursery with capacity to serve both of these requirements. After 80 years, once all of the tōtara has been planted, there would be no further need for the mānuka/kānuka companion plantings and the supply required from the nursery would be halved. However, the nurseries would be set up and able to grow other natives for other projects, if required.

The option to have a training facility within the processing hub could be one option to improve utilisation of the facilities. The ebb and flow of growing, planting, harvesting, and processing the tōtara could be incorporated into the training programmes. Students could be involved with the nursery when extra labour is required and trained in the facilities during quieter processing times.

In addition to the processing for the timber at the hub, storage facilities for the dried timber would also need to be provided. Unlike *P. radiata* which has year-round supply, the seasonal nature of the tōtara timber harvest would require timber to be stored for the significant period of the year when harvest was not feasible.

Much of the timber processed over winter would need storage, even if only for a short period of time. It would be prudent to have the ability to store at least half of the dried timber in dry facilities. Allowing for fork-lift access between the stacks would require approximately 2.2 ha of covered floor space per hub assuming the timber could be stacked 3 metres high. This is in addition to the outside storage for whole logs awaiting processing.

To allow kilns to also be used for thermal modification could require even more dry storage. To reduce overall drying time for the annual timber harvest and provide the opportunity for thicker timber[2] to be dried, more kilns would be required. This would have the advantage of freeing up the kilns to be used for thermal modification, adding more overall value, but also more capital infrastructure cost to the product.

Assuming the 1/80th planting option at full-scale production with a 500,000 ha plantation-tōtara industry, approximately 993,000 m^3 of timber could be produced per annum. At a regional hub level, this would require each of the 15 hubs to process around 65,000 m^3 of timber per year, which has been harvested in a 5-month period. With kilns working almost non-stop with short periods allocated for maintenance, this would require more than 12 kilns per hub to get through annual production (Appendix 3). Overseas processing facilities have kilns as large as 120 m^3, with one site in the Netherlands having eight of this size (E. Dunningham, personal communication, March 2023). This proves scale of this size is possible and larger size kilns would probably be required. To ensure sustainability, the kilns would need to be powered by renewable energy (which could also include the tōtara chips from the milling process).

It is unlikely many of these regions would have suitable facilities already existing for the de-centralised hub approach. Therefore, in most cases significant development and initial investment will be required.

7.4 Supply chain

Figure 8 depicts the supply chain from the forest for the primary product, logs for further processing. There will be some movement of the product around the hub as it is milled, dried and potentially further processed. These activities will have minimal transport requirements.

Once the products are ready for distribution, they can be moved either by train or by truck. All of the de-centralised hubs have access (or potential access) to train lines, and this would be the preferred mode of transport. Woodchip and bark which are both secondary products.

- The woodchip can either be used to supply fuel to power the sawmill and the kilns, or further processed on site for biochar. Biochar is a very useful for use in agriculture, horticulture, and arable farming systems to aid in carbon sequestration (Ennis et al., 2011). However, its low density (80-320kg/m^3; Brewer & Levine, 2015) makes it very expensive to transport. In the case of the de-centralised hubs on flat land close to rural supply towns, it may be feasible to create biochar and transport it within a small (10km) radius. This avenue would need further investigation.
- Bark is a product that has the potential to be used in the nutraceutical industry. There is anecdotal evidence that essential oils could be extracted from it, which are likely to have anti-bacterial effects, but this would require further investigation.

---

[2] 50 mm thickness tōtara takes 15 days to dry in a kiln, as opposed to 25 mm (per con. Elizabeth Dunningham, 2023)

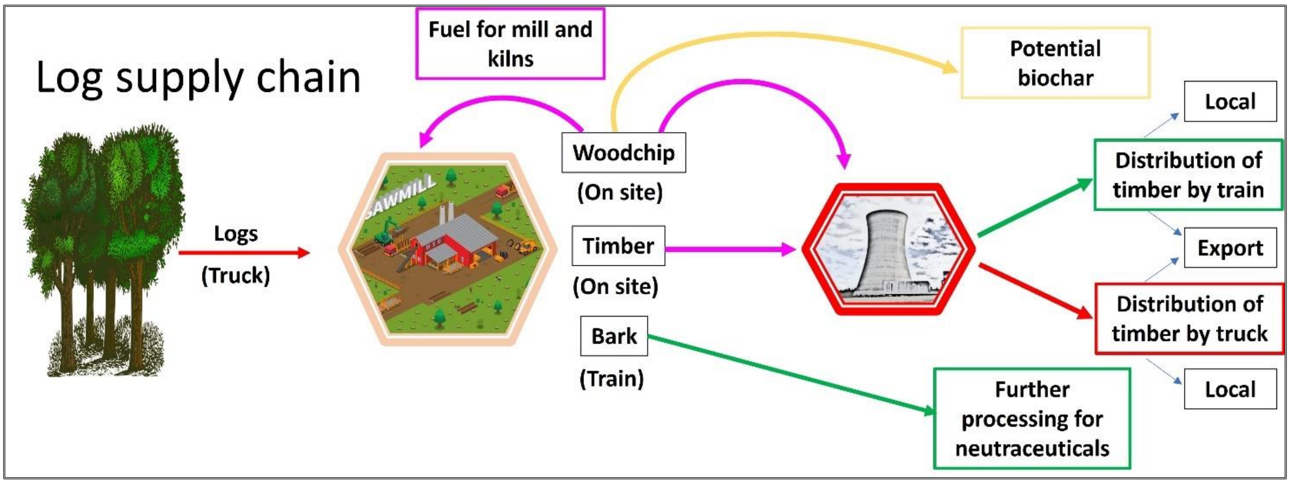

Figure 8: Log supply chain from forest

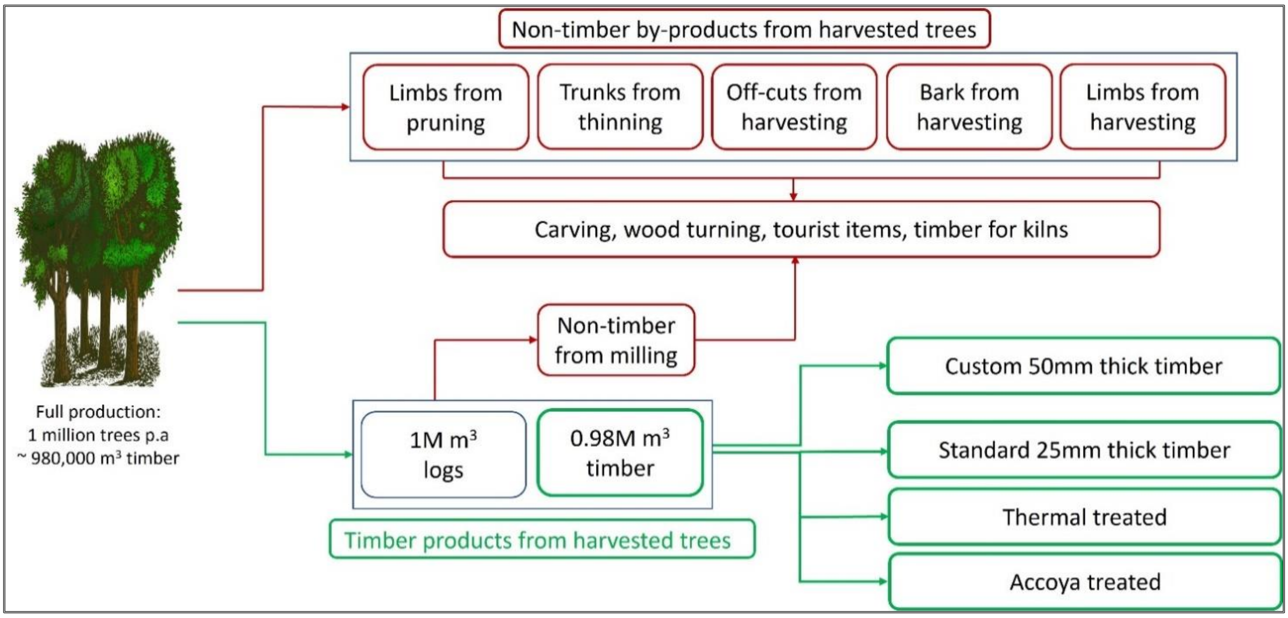

Figure 9: Timber channels for wood products from plantation-tōtara industry

Figure 10 depicts the supply chain from the forest for the main by-products (limbs and honey for neutraceuticals). Both of the by-products will vary in quantity over time.

- For the mānuka/kānuka honey, this product will only be available for the first 90-100 years, after which time the staged plantings will all have matured over 20 years of age. At this age the mānuka/kānuka stands are unlikely to be of sufficient purity to enable high quality honey to be collected. It is expected that the honey once collected can be moved by train to a nationally central processing facility.
- For the limbs, these will be produced at thinning and at final harvest. This product would currently be described as 'slash', and all left on site to rot down. For tōtara utilising as much of the tree as possible is important. The limbs will need to be extracted from the forest onto trucks and transported to the de-centralised hub for collection by wood carvers, etc.

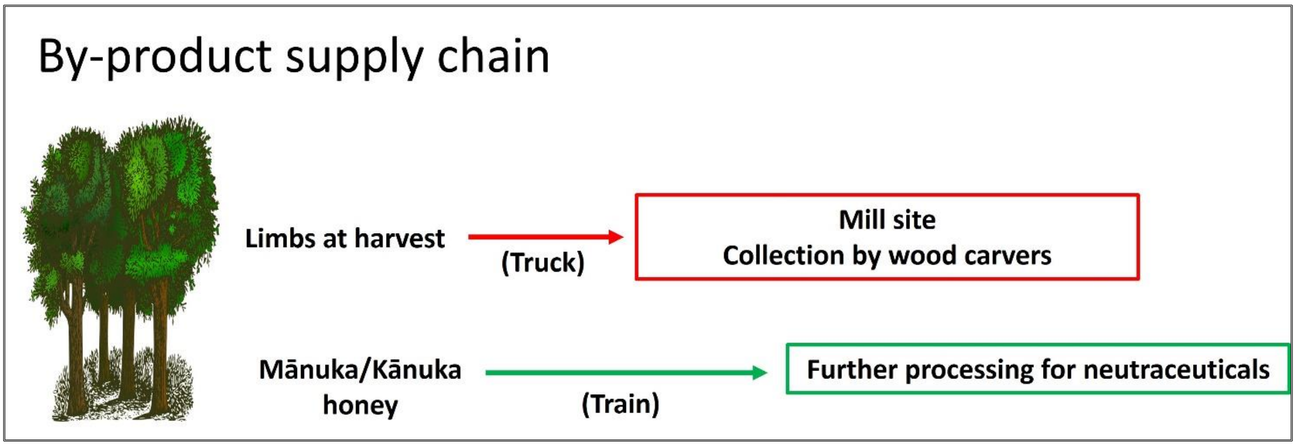

Figure 10: By-product supply chain from the forest

7.5 Government support

Development and significant landowner uptake of a plantation-tōtara industry at the scale of 500,000 ha is likely to be slow due to the large set up costs. The Climate Emergency Response Fund, set up in 2021, is an enduring, multi-year fund designed to address the long-term nature of many of the challenges presented by climate change (Te Tai Ōhanga/The Treasury). It was initially set up with $4.5 billion to be used on public investment on climate related initiatives. If funds such as this were able to be accessed by farmers wishing to convert to plantation-tōtara to support the cost of establishment, the viability of the industry would be significantly improved.

Through Primary Growth Partnerships (PGPs), NZ government has previously supported the agricultural sector. With co-funding to match participants' financial inputs, successful projects such as FarmIQ, Ballance's Mitigator and Firstlight Foods Marbled Wagyu Beef project have been undertaken over recent years. These could provide a model for supporting the livestock sector to migrate to a low/nil methane system such as plantation-tōtara. Funding levels would be significantly greater; however, funding could also be available from climate change budgets.

Without sufficient supplementary income streams and significant financial assistance, the acceleration of the development of the industry is unlikely. The viability of this land use option to landowners regarding reducing methane emissions by 2050 will depend on this. Significant establishment costs (between $15,625 and $32,690/ha) for plantation establishment and 80 years to the initial primary harvest will likely deter many landowners. Grants currently existing such as the Northland Regional Council's grant for planting erosion-prone land may help to mitigate these costs (NRC, n.d.). Widespread deliverance of grants such as these will likely accelerate and incentivise uptake of this land use option.

To be successful, the industry will need to knit together the staff training over an extended period of time and match the trained workforce with the plantation-tōtara forests as they become ready to harvest. This is an area that is likely to require co-ordination at a national level. The cost of the individual infrastructure hubs can be spread over time as the area of forest ready to harvest increases, but this will also come with a high price tag and require careful management. The nurseries will have a significant initial outlay, with delayed income with facility and wage costs to pay well in advance of initial income.

When the initial timber harvest comes online, the role of the nurseries for the plantation-tōtara set-up will reduce as forests move to small scale tree replacement at harvest. A plan for the future use of the nurseries, at a smaller scale and opportunities for the staff will be a long-term consideration. A co-operative approach may be feasible over time, but in the early years landowners will have considerable outlays in planting costs, coupled with reduced income from traditional farming opportunities.

With government support this could be a realistic avenue for making reductions to NZ's methane emissions by 2050 but it is not an industry which will be able to come together on its own. Government subsidies for land use change, at least in the form of grants for the planting costs will be essential to support farmers through the set-up phase.

8 Greenhouse gas emissions implications

8.1 Reduction in methane

If the extent of land use change to plantation- tōtara reached 500,000 ha, this is unlikely to occur before 2050. However, it could be possible for up to 125,000 ha of existing pastoral farmland to become plantation-tōtara by 2050. Using an average methane generation per ha per year of sheep and beef farms of 2.8 t CO_2e of methane, this equates to 112 kg methane/ha/yr. Table 6 provides a summary of the potential GHG reductions by 2050 for 125,000 ha of plantation-tōtara planted at 6,250 ha per year over the preceding 20-year period. Methane reductions by 2050 from a plantation-tōtara establishment programme targeted at 500,000 ha is estimated at 14,000 t CH_4/year.

Table 6: Analysis of GHG reductions for plantation-tōtara at 125,000 ha by 2050

Methane (CH_4)	**CH_4 as CO_2equiv**	**CH_4 [b]**	**Area**
	tonnes		**ha**
Average Sheep & Beef/ha/yr	2.800	0.112	
Plantation-tōtara area			125,000
Reduction in methane in 2050	350,000	14,000	
NZ Methane emissions in 2017	34,400,000	1,376,000	
24% reduction from 2017		330,240	
47% reduction from 2017		646,720	
Reduction of 14,000 tonnes of methane as portion of 2050 targets			
24% reduction		**4.2%**	
47% reduction		**2.2%**	
[b] conversion from CH_4 as CO_2equiv to CH_4 is 0.04			
Carbon Dioxide (CO_2)	**CO_2**	**5**	**Area**
	tonnes		**ha**
CO_2 Drawdown by Plantation-tōtara /ha [c]	35.935		
Maximum area under Plantation-tōtara by 2050	4,491,875		125,000
[c] Averaged across 20 years with annual planting			

Table 6 calculates the value of methane reduction over the 20-year period of the potential plantation-tōtara from 2030-2050. In 2050, with a planned 125,000 ha of land under plantation-tōtara, this would equate to a reduction 14,000 t CH_4. Compared to the lower reduction target for methane of 24% from 2017 this is 4.2% of the required reduction. For the upper reduction target for methane of 47% from 2017 numbers this is approximately 2.2% of required reduction.

Plantation-tōtara seems most likely to be planted on highly contoured land (above 20° slopes) currently farmed for drystock, as an alternative to *P. radiata*. For this reason, an average methane value of 2.8 tonnes CO_2e/ha for drystock farms was used. If the land being converted was dairy land, the impact of the plantings on emissions reduction would be far greater due to the higher methane production per hectare of the out-going land use.

While this annual methane reduction, through removal of livestock, is small relation to the national goal of between 24% and 47% decrease from 2017 levels (between approximately 2 and 4% of the total expected methane reduction required), there is also carbon sequestered as the trees grow over time, contributing to a reduction in carbon dioxide levels which would otherwise remain in the atmosphere for over 300 years. Since this plantation-tōtara forest will increase in long-term average age up until the point the final rotation is planted after 80 years, the carbon sequestered will be permanently locked up in the forest. Before the end of the planting rotation an evaluation of the carbon lost through root and limb decay, plus timber removed from harvested trees would need to be quantified to get a final value for the permanent residual carbon sequestration.

9 Conclusion

9.1 Practicalities

There is the potential for tōtara plantations to be incorporated throughout New Zealand's landscape, especially on hill country pastoral land. This would assist in meeting GHG reduction targets. Significant inclusion of non-timber values including development of amenity areas, biodiversity, aesthetic attributes, and cultural significance are all added benefits from plantation tōtara. Multi-generational benefits and future-thinking will need to be considered when designing, developing, and implementing these areas. All the co-benefits need to be considered when determining the value of the land use.

The best option going forward when considering the viability of plantation-tōtara is to consider establishment and harvest techniques that differ from traditional New Zealand forestry. It will be necessary to avoid issues associated with traditional forestry such as lack of ecosystem benefits, clear felling, bare soil, and perpetual forest cover. Harvesting forest sustainably will provide benefits for the environment and align closer with socially acceptable principles.

Planned phased planting regimes seem most appropriate for any commercial expansion. As part of an eighty-year rotation, 1/80th of the planned area needs to be planted annually. For a 500,000 ha industry this means planting 6,250 ha per year, at a rate of 2,500 stems per ha (50% tōtara and 50% nurse species). This will ensure continuous forest cover during harvest. Monitoring of tōtara growth from farm-tōtara trees up to 160 years of age should be implemented to better understand potential harvest volumes.

To maintain continuous cover forestry, two trees per hectare are then harvested annually, giving an expected average annual harvest of 993,000 m^3 (this is an average volume at full harvest production). These trees will need to be expertly selected to allow forest quality to remain stable. Selective harvest through coupe felling techniques will allow the forest to remain in a near-natural state. This maintains many of the values mentioned throughout such as habitat, biodiversity, and aesthetic considerations.

Increased associated costs with these techniques will result in the requirement for a premium price to be received for the product. The product will need to be recognised as sustainably grown and harvested, something for which consumers need to be willing to pay a premium.

Tōtara is likely to be used as a specialty product for uses such as interior (decorative) panelling. New Zealand currently imports around 65,000 to 80,000 m^3 of hard wood, for use in the interiors of its homes and commercial buildings. There is potential for plantation-tōtara to substitute these imports, assuming the building of awareness for its use as a decorative timber. However, the expected annual harvest volumes are much higher. This means there will be surplus tōtara after the market has absorbed this substitution, potentially requiring export. However, this market does not currently exist and further exploration into this market opportunity is required.

The choice to plant a slower growing native species over a faster growing exotic species will depend on a landowner's desired period for and targeted level of return on investment, costs of establishing the forest and returns from the timber (Satchell, 2021). The value of non-timber aspects such as carbon and biodiversity credits may incentivise more landowners to plant native species. Furthermore, how the landowner may value other attributes such as biodiversity, provision of habitat, aesthetic values, erosion control and water quality will have a heavy influence.

The initial start-up costs associated with this industry will be large. Creating a hub as part of the de-centralised hub approach will require significant investment. To develop this 'industry park', a large area (when considering commercial scale) of land will be required. This land will likely need to be on a flat area that is not flood prone. Finance will be required to build and develop processing sites and nurseries.

9.2 Financials

With the management regimes recommended, return on investment is not likely to be achieved for a many decades period. This may mean consideration of government funding alternatively a co-operative approach may be required for the initial start-up phase of the industry to be viable.

To achieve acceleration in uptake of this industry within landowners, it is likely some form of monetary incentive/assistance will be required. Significant establishment costs and a delayed return on investment, in the absence of supplementary income streams, creates a substantial financial gap. To achieve methane reduction targets and promote plantation-tōtara as a viable land use, financial assistance is likely to be vital.

9.3 Final summary

A viable business opportunity for land use change to plantation-tōtara based on sustainable management throughout the entire supply chain exists. However, this is subject to a significant initial investment by landowners and latter investment in the supply chain, which will likely require significant support from funds such as the one for the Climate Emergency Response. The potential opportunities and highlights are summarised below:

- Sustainable forest management allows the industry to demonstrate responsibility and create a genuinely permanent harvesting option, providing multi-generational benefits.
- Multi-generational benefits would include aesthetic, recreational, cultural, and social values.
- Potential supplementary income streams may exist during the forest establishment (honey by-products, carbon credits) or become available such as biodiversity credits and utilisation of nursery crops.
- There are limited existing suitable land use change options suited for hill country land. Plantation-tōtara could provide a viable option for this land type.
- Job opportunities in rural supply towns, including training centres, students from which can be used in the industry.
- Partnership with Iwi can allow for re-connection between forests and the land, providing options for guardianship within the industry.

There are some risks involved, requiring further investigation, these are outlined below:

- Continuous refinement and learning will be required to effectively manage plantation-tōtara, specifically as the forest ages and stages of the forest are reached that have not commonly been encountered.
- Training and research will be required to fully understand and refine the concepts surrounding sustainable forest management in a planted stand.
- Trained professionals are required to correctly select and manage the continuous cover forest management.
- Currently, lack of knowledge on the dynamics of mature plantation-tōtara stands may limit the establishment and management regimes that the industry will adopt in the initial phases.
- Significant initial investment and resource requirements are needed to up-scale the industry. Grants for landowners are likely to be necessary to accelerate land use change uptake.

- Specific labour requirements in the nurseries and for planting and harvesting will need development of training facilities. Sourcing sufficient suitable labour for this will be necessary.
- There may be a potential struggle to source suitable conversion land. Competition from other alternative land use changes which may provide earlier return on investment and have increased confidence in outcomes may reduce available land.
- The reduction in methane from converting less intensive land (mostly drystock) does not give the greatest reduction in methane per hectare. However, alternative land use conversion from other land (dairy) is more likely to be converted to other land uses such as horticulture, arable or alternative proteins.
- As part of the phased planting regime, if animals are removed years ahead of tōtara establishment, further exploration of interim land use for the land will be required. Suitable land options for different areas and timeframes will need to be further explored.
- The proposed harvest volumes and limited domestic product absorption will mean the potential to explore export market streams will be required. This market does not currently exist and research into the viability of exporting tōtara will be required.

10 Acknowledgments

Perrin Ag would like to thank the following people and organisations for their contribution to this report:

- Elizabeth Dunningham, Scion Research
- Treeline Nurseries, Rotorua
- Charlie Lea, Cambrilea Riparian
- Mark Law, Kāhu NZ
- Paul Quinlan, Tāne's Tree Trust

11 References

Ag Matters. (2022). *Dairy.* https://www.agmatters.nz/farm-types/dairy/.

Barton, I. (2008). *Continuous Cover Forestry: A Handbook for the Management of New Zealand Forests*. Tāne's Tree Trust. https://www.tanestrees.org.nz/site/assets/files/1069/continous_cover_forestry_-_web.pdf

Beasley, R (2019). *Kānuka honey heals cold sores as fast as common anti-viral creams*. Scimex. https://www.scimex.org/newsfeed/kanuka-honey-heals-cold-sores-as-fast-as-common-anti-viral-creams

Bergin, D. O. (2001). *Growth and management of planted and naturally regenerating stands of Podocarpus tōtara D. Don* [Thesis, Doctor of Philosophy (PhD), The University of Waikato]. Research Commons. https://hdl.handle.net/10289/14165

Bergin, D. (2003). *Tōtara – Establishment, Growth and Management, New Zealand Indigenous Tree Bulletin, No. 1*. New Zealand Forest Research Institute Limited.

Best, E. (1977). Bark and its Uses. In *Forest lore of the Māori* (pp. 103-108). E.C. Keating, Government Printer Wellington, New Zealand.

Beveridge, A.E., & Van Dorsser, J.C. (1980). *Raising native trees (85)*. New Zealand Forest Research Institute, What's New in Forest Research.

Blair, W.N. (1876). *The Building Materials of Otago*. Transactions and Proceedings of the New Zealand Institute, 9: 108–133.

Bont, L. G., Fraefel, M., Frutig, F., Holm, S., Ginzler, C., & Fischer, C. (2022). Improving forest management by implementing best suitable timber harvesting methods. *Journal of Environmental Management*, 302, 114099. https://doi.org/10.1016/j.jenvman.2021.114099

Brewer, C. E., & Levine, J. (2015). *Weight or Volume for Handling Biochar and Biomass?.* Biochar Journal*.* *www.biochar-journal.org/en/ct/71*

Clifton, N.C. (1990). *The Complete Guide to Exotic and Indigenous Woods*. New Zealand Timbers. Wellington, NZ: GP Publications Ltd.

Dooley, A.E., & Dowling, L. (2021). *Case Study 8: Lazy G Ranch. Integrating dairy and hill country farming with forestry for profitable and sustainable land use*. Report prepared by Perrin Ag Consultants Ltd for Te Uru Rākau. https://www.perrinag.net.nz/wp-content/uploads/2021/05/Case-Study-8_Lazy-G-Ranch_full-final_compressed.pdf

Dunningham, E., Steward, G., Quinlan, P., Firm, D., Gaunt, D., Riley, S., Lee, J., Dunningham, A., & Radford, R. (2020). *Tōtara Industry Pilot project, Final summary report, V2.1*. Tōtara Industry Pilot. https://www.tōtaraindustry.co.nz/_files/ugd/08f36a_4b5268eb869a4363ad99c61702d84da0.pdf

Ennis, C. J., Evans, A. G., Islam, M., Ralebitso-Senior, T. K., & Senior, E. (2012). Biochar: carbon sequestration, land remediation, and impacts on soil microbiology. *Critical Reviews in Environmental Science and Technology*, 42(22), 2311-2364. https://doi.org/10.1080/10643389.2011.574115

Entrican, A.R., & Reid, J.S. (1949). *The Properties and Uses of Totara (Podocarpus totara and P. hallii).* Wellington, NZ: New Zealand Forest Service.

Esler, A. E. (1978). *Botany of the Manawatu district New Zealand*. New Zealand Department of Scientific and Industrial Research. Information Series No. 127.

Ericsson, T., & Fries, A. (1999). High heritability for heartwood in north Swedish Scots pine. *Theoretical and applied genetics*, 98, 732-735. https://doi.org/10.1007/s001220051128

Helicopter Services Ltd. (2019, July 8). *Lifting & construction*. https://helicopterservices.nz/lifting-construction/

Jobbágy, E. G., & Jackson, R. B. (2003). Patterns and mechanisms of soil acidification in the conversion of grasslands to forests. *Biogeochemistry*, 64(2), 205-229.

Kāhu NZ. (2022, April 25). *Forestry helicopter services in NZ, Australia & Pacific is*. https://kahu.nz/services/forestry

Manaaki Whenua. (2020, July). *Podocarpus totara. Tōtara*. Ngā Rauropi Whakaoranga. https://rauropiwhakaoranga.landcareresearch.co.nz/names/fb454c7e-cb0c-4d98-9f97-1e9d14d3a080

Mane, S., Singer, J., Corin, A., & Semprini, A. (2018). Successful Treatment of Actinic Keratosis with Kanuka Honey. *Case Reports in Dermatological Medicine*. https://doi.org/10.1155/2018/4628971

Marden, M., Rowe, L., & Rowan, D. (2007). Slopewash erosion following plantation harvesting in pumice terrain and its contribution to stream sedimentation, Pokairoa catchment, North Island, New Zealand. *Journal of Hydrology (New Zealand)*, 73-90. https://www.jstor.org/stable/43944956

Mason, N. W. H., Mudge, P. L., Palmer, D., McLeod, M., Ausseil, A. G., & Dymond, J. (2016). Catchment-scale contribution of invasive nitrogen fixing shrubs to nitrate leaching: a scoping study. *Journal of the Royal Society of New Zealand*, 46(2), 85-102.

Matuku Link. (n.d.). *Totara trees*. https://matukulink.org.nz/product/totara/

Miller, C., & Wells, A. (2003). Cattle grazing and the regeneration of tōtara (Podocarpus tōtara var. waihoensis) on river terraces, south Westland, New Zealand. *New Zealand Journal of Ecology*, *27(1),* 37-44.

McClure, T. (2022). *New Zealand drowning in mānuka honey after a boom in beekeeping.* The Guardian. https://www.theguardian.com/world/2022/oct/05/new-zealand-drowning-in-manuka-honey-after-a-boom-in-beekeeping

Moodie, H., Quinlan, P., Bergin, D., & Kennedy, C. (2007, November). *Tōtara – Northland's farm forests of the future*. New Zealand Tree Grower. https://www.nzffa.org.nz/farm-forestry-model/resource-centre/tree-grower-articles/november-2007/tōtara-northlands-farm-forests-of-the-future/

Nash S., & Parker D. (2023, February 23). *Inquiry to investigate forestry slash and land use after cyclone.* The Beehive - the official website of the New Zealand Government. https://www.beehive.govt.nz/release/inquiry-investigate-forestry-slash-and-land-use-after-cyclone

Nolan, V. C., Harrison, J., Wright, J. E., & Cox, J. A. (2020). Clinical significance of manuka and medical-grade honey for antibiotic-resistant infections: a systematic review. *Antibiotics*, 9(11), 766. https://doi.org/10.3390/antibiotics9110766

Northland Regional Council. (n.d.). *Grants for planting on erosion-prone land*. https://www.nrc.govt.nz/your-council/work-with-us/funding-and-awards/for-landowners/grants-for-planting-on-erosion-prone-land/

Palmer, H., & Bergin, D. (2017, November). *Growing tōtara for timber*. NZ Farm Forestry. https://www.nzffa.org.nz/farm-forestry-model/resource-centre/information-leaflets/information-leaflets-2017/growing-tōtara-for-timber/

Pardy, G. F., Bergin, D. O., & Kimberley, M. O. (1992). *Survey of native tree plantations*. New Zealand Forest Research Institute, FRI Bulletin (175).

Quinlan, P. (2022a). *Harvesting Tōtara - A Practical Guide to Managing Tōtara on Private Land*. Tāne's Tree Trust. https://www.tanestrees.org.nz/site/assets/files/1234/harvesting_tōtara_-_a_practical_guide_to_managing_tōtara_on_private_land__by_paul_quinlan_2021.pdf

Quinlan, P. (2022b). *Planting and Establishing Tōtara - A Practical Guide to Managing Tōtara on Private Land*. Tāne's Tree Trust. https://www.tanestrees.org.nz/site/assets/files/1234/planting_establishing_totara_-_a_practical_guide_to_managing_totara_on_private_land__by_paul_quinlan_2022.pdf

Satchell, D. (2021). *Land Use Options and Economic returns for Marginal Hill Country in Northland.* Northland Regional Council. https://www.nrc.govt.nz/media/chij2gop/land-use-options-and-economic-returns-for-marginal-hill-country-in-northland-final.pdf

Standards New Zealand. (1993). *NZS 3603:1993*. https://www.standards.govt.nz/shop/nzs-36031993/

Stats NZ. (2021, April 15). *Exotic land cover*. https://www.stats.govt.nz/indicators/exotic-land-cover

Steward, G. (2019). To the heart of the matter–heartwood content in totara. *NZ Journal of Forestry*, *64*(2), 37.

Taylor, A.M., Gartner, B.L., & Morrell, J.J. (2002). Heartwood Formation and Natural Durability – A Review. *Wood and Fiber Science*, 34(4): 587–611.

Waitangi Tribunal. (2011, July). *Ko Aotearoa Tēnei: Report on the Wai 262 claim released*. https://waitangitribunal.govt.nz/news/ko-aotearoa-tenei-report-on-the-wai-262-claim-released/

Zobel, B., & Jett, J. (1995). *Genetics of Wood Production*. New York, NY: Springer-Verlag.

12 Appendices

Appendix 1: Average income from carbon on annually planted plantation-tōtara (out to 2050)

Yr	Age of forest	Cumulative growth	Growth	Carbon value	Plant in successive years																				
2030	0	0																							
2031	1	0.6																							
2032	2	1.2	0.6	$ 51.00	$ 51.00																				
2033	3	2.5	1.3	$ 110.50	$ 110.50	$ 51.00																			
2034	4	4.6	2.1	$ 178.50	$ 178.50	$ 110.50	$ 51.00																		
2035	5	7.8	3.2	$ 272.00	$ 272.00	$ 178.50	$ 110.50	$ 51.00																	
2036	6	12.0	4.2	$ 357.00	$ 357.00	$ 272.00	$ 178.50	$ 110.50	$ 51.00																
2037	7	18.0	6.0	$ 510.00	$ 510.00	$ 357.00	$ 272.00	$ 178.50	$ 110.50	$ 51.00															
2038	8	24.0	6.0	$ 510.00	$ 510.00	$ 510.00	$ 357.00	$ 272.00	$ 178.50	$ 110.50	$ 51.00														
2039	9	32.0	8.0	$ 680.00	$ 680.00	$ 510.00	$ 510.00	$ 357.00	$ 272.00	$ 178.50	$ 110.50	$ 51.00													
2040	10	33.0	1.0	$ 85.00	$ 85.00	$ 680.00	$ 510.00	$ 510.00	$ 357.00	$ 272.00	$ 178.50	$ 110.50	$ 51.00												
2041	11	36.0	3.0	$ 255.00	$ 255.00	$ 85.00	$ 680.00	$ 510.00	$ 510.00	$ 357.00	$ 272.00	$ 178.50	$ 110.50	$ 51.00											
2042	12	39.0	3.0	$ 255.00	$ 255.00	$ 255.00	$ 85.00	$ 680.00	$ 510.00	$ 510.00	$ 357.00	$ 272.00	$ 178.50	$ 110.50	$ 51.00										
2043	13	43.0	4.0	$ 340.00	$ 340.00	$ 255.00	$ 255.00	$ 85.00	$ 680.00	$ 510.00	$ 510.00	$ 357.00	$ 272.00	$ 178.50	$ 110.50	$ 51.00									
2044	14	48.0	5.0	$ 425.00	$ 425.00	$ 340.00	$ 255.00	$ 255.00	$ 85.00	$ 680.00	$ 510.00	$ 510.00	$ 357.00	$ 272.00	$ 178.50	$ 110.50	$ 51.00								
2045	15	52.0	4.0	$ 340.00	$ 340.00	$ 425.00	$ 340.00	$ 255.00	$ 255.00	$ 85.00	$ 680.00	$ 510.00	$ 510.00	$ 357.00	$ 272.00	$ 178.50	$ 110.50	$ 51.00							
2046	16	57.0	5.0	$ 425.00	$ 425.00	$ 340.00	$ 425.00	$ 340.00	$ 255.00	$ 255.00	$ 85.00	$ 680.00	$ 510.00	$ 510.00	$ 357.00	$ 272.00	$ 178.50	$ 110.50	$ 51.00						
2047	17	62.0	5.0	$ 425.00	$ 425.00	$ 425.00	$ 340.00	$ 425.00	$ 340.00	$ 255.00	$ 255.00	$ 85.00	$ 680.00	$ 510.00	$ 510.00	$ 357.00	$ 272.00	$ 178.50	$ 110.50	$ 51.00					
2048	18	67.0	5.0	$ 425.00	$ 425.00	$ 425.00	$ 425.00	$ 340.00	$ 425.00	$ 340.00	$ 255.00	$ 255.00	$ 85.00	$ 680.00	$ 510.00	$ 510.00	$ 357.00	$ 272.00	$ 178.50	$ 110.50	$ 51.00				
2049	19	88.0	21.0	$ 1,785.00	$ 1,785.00	$ 425.00	$ 425.00	$ 425.00	$ 340.00	$ 425.00	$ 340.00	$ 255.00	$ 255.00	$ 85.00	$ 680.00	$ 510.00	$ 510.00	$ 357.00	$ 272.00	$ 178.50	$ 110.50	$ 51.00			
2050	20	91.0	3.0	$ 255.00	$ 255.00	$ 1,785.00	$ 425.00	$ 425.00	$ 425.00	$ 340.00	$ 425.00	$ 340.00	$ 255.00	$ 255.00	$ 85.00	$ 680.00	$ 510.00	$ 510.00	$ 357.00	$ 272.00	$ 178.50	$ 110.50	$ 51.00	$ -	
			Total	$ 7,684.00	$ 7,684.00	$ 7,429.00	$ 5,644.00	$ 5,219.00	$ 4,794.00	$ 4,369.00	$ 4,029.00	$ 3,604.00	$ 3,264.00	$ 3,009.00	$ 2,754.00	$ 2,669.00	$ 1,989.00	$ 1,479.00	$ 969.00	$ 612.00	$ 340.00	$ 161.50	$ 51.00	$ -	
																								Average /ha income/yr	$ 161.32

Appendix 2: Fax from Dean Satchell, 2013 re tōtara structural testing

Te Papa Tipu Innovation Park
49 Sala Street
Private Bag 3020
Rotorua
New Zealand
Telephone: +64 7 343 5899
DDI: +64 7 343 5718
Facsimile: +64 7 343 5507
Email: bruce.davy@scionresearch.com

SCION Next generation biomaterials

Facsimile

To:	Dean Satchell	**From:**	Bruce Davy
Organisation:	Farm Forestry Timbers Society C/- New Zealand Farm Forestry Association	**Subject:**	Totara Ingrade test results
Location:	P.O.Box 10349 the Terrace, Wellington 6143	**Date:**	20 May 2013
Fax No.:	04 4720432	**No. of Pages:**	8
Tel No.:			

Please call +64 7 343 5763 if transmission incomplete

Dean,

With reference to the 100x50 Totara timber supplied for in-grade testing.

Timber History (as supplied by Dean Satchell)
In May 2009 35 Totara trees were felled on a beef-farm near Kawakawa in Northland. The trees were all in a pastoral environment and stood as groups and individual trees. These "farm-grown" stands had presumably regenerated within the last 80-150 years, following early land-clearances and/or disturbance. As an untended resource, tree-form naturally varied from open-grown multi-stemmed trees and edge trees with heavy branching on one side, to straight-boled and relatively branch-free trees within small stands. A total of 62 logs of widely varying quality were recovered and milled on-site using a combination of a portable sawmill (Lucas) and a chainsaw-mill for slabs.

The logs were sawn into 55 mm slabs and the timber was immediately transferred to an open barn with good air flow for air-drying and air dried for two years.

Slabs were selected to represent a large cross section of logs and further processed on a woodmizer bandsaw to yield 100 x 55 boards. These were filleted and further air-dried in a warm, dry, closed in, ventilated, concrete floored half-round barn for a further year. The timber was then machined and despatched for testing at Scion, Rotorua.

The timber was visually graded to the Farm Forestry Timbers No. 1 Structural grade, as follows: http://www.nzffa.org.nz/specialty-timber-market/brand-grades/structural-grading/

Appendix E lists these visual grade rules.

Timber Testing

The timber was tested for bending strength and stiffness as a joist, Tension strength Compression Strength and Shear Strength in accordance with AS/NZS4063.1:2010.

All the testing was undertaken in our Grade 1 Baldwin Universal test machine with the exception of the tension strength testing which was done in the tension testing machine.

The strength testing was completed in the Timber Engineering laboratory of Scion, Rotorua, New Zealand.

Strength and Stiffness Test Results

The characteristic strength and stiffness properties have been calculated using the calculations and procedures set out in AS/NZS4063.2:2010.
The following Table 1 shows the characteristic strength and stiffness values for the Totara timber along with a statistical summary.
Table 2 lists the New Zealand characteristic grade stresses for the SG visual grades

Appendix's A to D list the raw test data collected.

Table 1: Bending Strength and Stiffness properties

	100 x 50 Totara				
	Bending Stiffness MoE] (GPa)	Bending Strength MoR] (MPa)	Tension Strength (MPa)	Shear Strength (MPa)	Compression Strength (MPa)
Mean	7.55	54.94	22.39	5.43	35.24
Minimum	4.73	15.10	11.99	3.70	26.44
Maximum	9.49	72.99	40.41	7.13	42.91
Range	4.76	57.89	28.42	3.43	16.47
Standard Deviation	1.25	15.66	7.97	0.73	4.29
Coefficient of Variation	16.56%	28.50%	35.61%	13.53%	12.18%
Count	30	30	30	30	60
Characteristic Strength (MPa)		20.50	10.63	4.43	30.19
Characteristic Stiffness (GPa)	7.39				
Assigned Grade	SG 6	SG 10	SG 10	SG 10	SG 10

Table 2: Characteristic stresses for SG graded timber NZS3603 A4

1. Moisture Content – Dry (m/c = 16%)					
Radiata pine and Douglas Fir	Bending Strength MPa	Compression Strength MPa	Tension Strength MPa	Bending Stiffness GPa	Lower bound Bending Stiffness GPa
SG10 (Dry)	20.0	20.0	8.0	10.0	6.7
SG8 (Dry)	14.0	18.0	6.0	8.0	5.6
SG 6 (Dry)	10.0	16.0	4.0	6.0	4.0
Verified Heartland	14	16	4.0	6.0	4.0
2. Moisture Content – Green (m/c = 25%)					
SG 10 (Wet)	15	14.0	5.0	8.0	5.6
SG 8 (Wet)	11.7	12.0	4.0	6.5	4.4
SG 6 (Wet)	7.5	11.0	3.0	4.8	3.2

Note:

- The shear strength for dry Radiata pine shall be taken as fs = 3.8 MPa.

References

1. AS/NZS4063.1:2010, Characterization of structural timber Part 1: Test methods. Standards Australia/Standards New Zealand.

2. AS/NZS4063.2:2010, Characterization of structural timber Part 1: Determination of characteristic values. Standards Australia/Standards New Zealand.

Summary

Comparing Tables 1 & 2 shows the:

- The 100 x 50 Totara timber achieving the NZ visual grade SG6 for bending stiffness, but exceeding SG10 for bending strength, compression strength. Shear strength, and tension strength.

I trust this initial information meets with your approval, please feel free to contact me if you have any queries

Bruce Davy

Appendix 3: Calculations for hub areas

Hub area calculations - per annum	
Volume of timber m ^{3}	***993,230***
No of hubs	15
Volume of timber/hub	**66,215**
Maximum area within 50 km	***785,500***
Total plantation-totara area (ha)	500,000
Area required per hub (ha)	33,333
% of maximum available	**4%**
Kiln drying 25 mm boards	
Days to dry	4
Timber/kiln (m$^{3)}$	60
Timber/kiln (m$^{3)}$	993,230
Total drying days	3,972,920
Annual capacity of 60 m^{3} kiln (m^{3})	21,900
Number of kilns for annual production	181
No of kilns per hub	**12.1**
Area needed to store 50% of timber at each site	
Timber volume (m^{3})	**66,215**
50% storage (m^{3})	33,108
Store 3 m high (m^{2} required)	11,036
Double area for vehicle access	22,072
Site size (ha)	**2.2**