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Exploring forestry options with Māori landowners: an economic assessment of radiata pine, rimu, and mānuka

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Abstract

Background: A quarter of New Zealand's land area is currently covered in indigenous forest although only indigenous forests on private land can be harvested. In addition, planted exotic forests (~90% *Pinus radiata* D.Don) cover a further 7% of the land, and these form the main basis of New Zealand's forestry industry. However, some landowners are seeking to plant a more diverse range of species (including New Zealand indigenous species) that can be managed in different ways to produce a range of products.

Methods: A "cradle-to-gate" life cycle-based economic assessment of three forestry scenarios was undertaken in collaboration with members of Ngāti Porou, an indigenous Māori tribe. The three scenarios were: (1) "business as usual" (i.e. intensive management of radiata pine); (2) continuous-cover forestry management of the indigenous coniferous tree species rimu (*Dacrydium cupressinum* Lamb.); and (3) intensive production-scale forestry of the indigenous scrub species mānuka (*Leptospermum scoparium* J.R.Forst. & G.Forst.). Using a 120-year timeframe, discount rates and opportunity costs were applied and a flat- and steep-land comparative analysis was performed (for radiata pine and rimu).

Results: The Net Present Value (NPV) was calculated for each scenario and showed that, on flat land, only the mānuka scenario is profitable. However, applications of discount rates can result in a negative NPV, as is the case with the radiata pine and rimu scenarios. On steep land, both the radiata pine and rimu steep-land scenarios have improved NPV returns due to a lower opportunity cost. On steep land, radiata pine is generally profitable with a discount rate of 6% or lower and a stumpage rate of over \$100 m^{-3} and rimu is generally profitable with a discount rate of 2% or lower and a stumpage rate of over \$650 m^{-3}.

Conclusions: This analysis demonstrates the importance of strategically considering what tree species to plant, what slope of land to plant them on, and what forest management technique to utilise. Furthermore, this analysis highlights the importance of choosing appropriate discount rates and the effect of other inherent assumptions, such as opportunity cost.

Keywords: *Dacrydium cupressinum*, discount rate, life cycle-based economic assessment, forestry scenarios, *Leptospermum scoparium*, NPV, *Pinus radiata*

Introduction

New Zealand's natural indigenous forests cover 6.8 million hectares (26% of the land area) while planted exotic forests cover an additional 1.71 million hectares (net stocked) (7% of the land area) (Ministry for Primary Industries 2017c). Natural indigenous forests contain a wide variety of native hardwood and softwood species, while planted forests predominantly contain the exotic softwood species radiata pine (*Pinus radiata* D.Don) (Ministry for Primary Industries 2017c). Natural indigenous forests are widely perceived to provide more forest-based biodiversity and recreational values while planted exotic forests are generally managed to maximise economic returns through provision of wood and fibre (Maclaren et al. 2001). However, evidence suggests that such benefits can apply to both types of forest. For instance, natural indigenous forests are known to provide valuable timber (subject to the harvesting provisions detailed in New Zealand's *Forests Act 1993;* Allen et al. 2013) and planted exotic forests have been shown to provide several recreational opportunities (Yao et al. 2013).

Two major surveys of planted indigenous forests have been undertaken. The first occurred in the mid-1980s (Pardy et al. 1992), followed by a further survey from 2005 to 2015 (Tane's Tree Trust 2011). These followed a synopsis of the extensive kauri (*Agathis australis* (D. Don) Lindl.) plantings established by the New Zealand Forest Service (Halkett 1983). These surveys found over thirty individual species that had been planted both privately and by governmental agencies for a range of purposes (including production). The majority of the plantings were composed of the major indigenous conifer species either intermixed with an indigenous nurse crop or as single species stands. Most planted stands were less than one hectare in size, and the total area of planted indigenous forest, including the extensive kauri plantings, was estimated to be less than 5,000 hectares (Halkett 1983). Although indigenous forests have harvesting restrictions (i.e. no more than 10% of the standing indigenous timber may be harvested on the area of land specified in the sustainable forest management permit), the Forests Amendment Act 1993 stipulates that *planted* indigenous forests are not subject to the same harvesting requirements. Thus, planted indigenous forests are an additional forestry option alongside planted exotic forests in New Zealand. However, such indigenous forests will only be planted if there is sufficient benefit in doing so (economic benefit or otherwise).

The objectives of this study were to compare three forestry scenarios in a catchment in New Zealand's North Island using a "cradle-to-gate" life cycle-based economic assessment, in collaboration with members of indigenous Māori tribe Ngāti Porou. The three scenarios were: (1) intensive management of radiata pine; (2) continuous-cover forestry management of the indigenous coniferous tree rimu (*Dacrydium cupressinum* Lamb.); and (3) intensive production-scale forestry of the indigenous scrub species mānuka (*Leptospermum scoparium* J.R.Forst. & G.Forst.).

Case study with Ngāti Porou

Reforestation considerations are relevant in the Waiapu catchment in the eastern Gisborne region of New Zealand's North Island (Figure 1), and is home to the Ngāti Porou tribe (iwi). Extensive erosion is an ongoing problem in the catchment as a result of deforestation and pastoral farming on relatively young geological soils over a number of decades. This erosion has resulted in the Waiapu river basin containing extremely high sediment yield rates (approximately 35 Mt year^{-1} or 20,520 t km^{-2} year^{-1}) (Hicks et al. 2000). Previous work by Scion for the Ministry for Primary Industries has shown that much of the Waiapu catchment has considerable potential for forestry (Ministry for Primary Industries 2012). Initiatives within the catchment (e.g. East Coast Forestry Project[i] (ECFP)) have resulted in reforestation but these plantings have predominantly consisted of radiata pine (Bayfield & Meister 2005).

Radiata pine forestry provides economic benefits such as employment but local people are also interested in developing planted indigenous forests. Information exists on the growth potential of certain indigenous species (e.g. Pardy et al. 1992; Trotter et al. 2005; Tane's Tree Trust 2011; Bergin & Kimberley 2012) but there is a general lack of knowledge regarding the economics of planting indigenous forests for timber production or non-timber forest products. A participatory research project was developed with three members of Ngāti Porou from the Waiapu catchment to address this knowledge gap. The three Ngāti Porou members were already working with Scion (the primary institution involved in this research) on a larger collaborative project (Warmenhoven et al. 2014) and were each interested to contribute to further research efforts in their Waiapu catchment. All three were considered to be leaders within their community, and have collective expertise in sustainable-resource planning and management, commercial investments, environmental restoration, and community development as viewed through an indigenous peoples' lens.

Three forestry scenarios were developed following extensive deliberation and included: (1) intensive management of radiata pine; (2) continuous-cover forest management of rimu; and (3) intensive management of mānuka for essential-oil production. It is important to note that radiata pine is currently cultivated in the Waiapu region and so represents the "business as usual" forestry option. Rimu is an indigenous softwood species that, compared to radiata pine, is slower-growing and longer-lived. However, it has potential as a long-term forestry resource utilising less intensive forest-management techniques (i.e. an alternative to the option of clearfelling) probably managed by more than one generation of foresters. Mānuka is a relatively fast-growing but short-lived (30 to 50 years) small indigenous tree that contains a valuable essential oil which can be harvested annually, and so this forestry option can be managed for short-term financial gain. Indeed, each of these species have large areas of suitability within the 173,400-ha Waiapu catchment region. With an elevation limit of 700 m, radiata pine could potentially thrive across 90% of the Waiapu catchment (i.e. 156,000 hectares) (Leath-

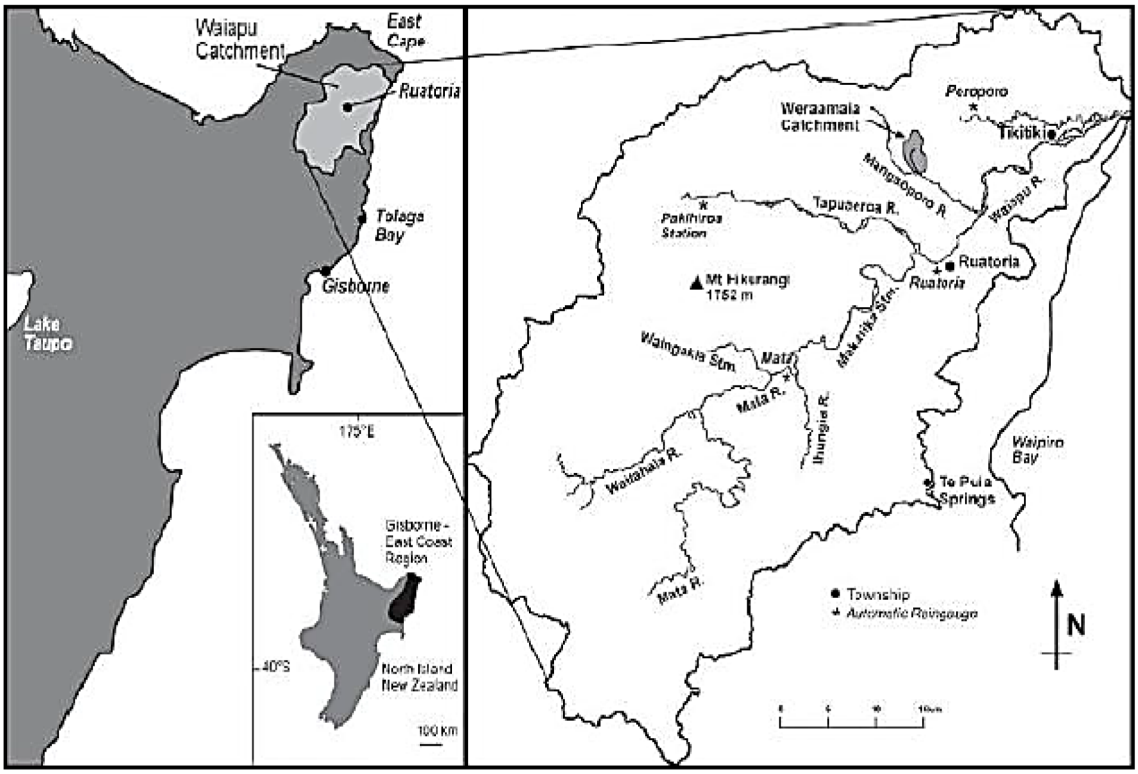

FIGURE 1: The Waiapu catchment case study site on the east coast of the North Island (reproduced from Parkner et al. 2007).

wick et al. 1995). Rimu, with an elevation limit of 800 m, could potentially thrive across nearly 95% of the catchment (i.e. 164,700 hectares) (Leathwick et al. 1995). Mānuka, constrained in this research's scenario by a need to be situated on flat land for subsequent mechanical trimming, could potentially thrive across 10% of the catchment (i.e. 17,300 hectares) (Leathwick et al. 1995).

This research was based on a larger research project that investigated the life cycle-based sustainability impacts of radiata pine, rimu and mānuka (Pizzirani 2016), by calculating the environmental, social, and cultural impacts of each scenario. This paper covers the potential economic impacts associated with the three proposed forestry options using the standard forestry investment analysis of discounted cash flow are presented and discussed. Following guidance from life cycle assessment methodologies (Weidema et al. 2004), the unit of analysis for this study is defined as "one hectare of unmanaged land". This was regarded as the most appropriate unit given that the case study participants (and intended audience of the results) are most familiar and engaged with land-based activities, and so a "hectare" is an easily understandable unit with which to communicate the results. A summary of information and assumptions relevant to the present analysis is provided in Table 1 followed by a summary of each species.

Radiata pine comprises 90% of New Zealand's planted forest area (Ministry for Primary Industries 2017c) and contributes in excess of 90% of the annual volume of wood harvested. A typical regime (direct sawlog) is to plant 833 stems per hectare, with thinning (to waste) resulting in a final stocking of 400 stems per hectare at age 7 years, with clear fell harvest at age 28 (Maclaren 1993; New Zealand Institute of Forestry 2005; Mead 2013). Radiata pine also responds well to pruning, and this is also a common approach where clear knot-free timber is desired.

Rimu is an endemic coniferous species and a member of the Podocarpaceae family, of which there are fourteen species native to New Zealand (J. Wardle 2011). Rimu grows throughout the country from coastal forests to elevations above 700 m and was once prevalent in lowland forested areas (Norton et al. 1988). The majority of the land that is higher than 700 m elevation in the Waiapu catchment is in the conservation estate forested with a significant component of *Nothofagus* species. Privately owned land above 700 m in the Hikurangi/Wharekia mountain areas has been tested for the suitability of planting Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) seedlings. Naturally durable heartwood timber was extracted from old-growth trees until the 1990s when the conversion of natural forests to agriculture or exotic forests ceased. There are currently only small areas of rimu on private land managed for timber under sustainable forest management plans approved by the Ministry for Primary Industries. In comparison to radiata pine, rimu timber is more expensive due to the scarcity of high-quality heartwood rimu trees available for harvesting and its versatility as an excellent finishing/appearance grade timber.

Mānuka (a member of the Myrtaceae family) is an environmentally-tolerant species found in both New Zealand and in forests along the east coast of Australia (Ronghua et al. 1984; P. Wardle 1991; Stephens et al. 2005;

TABLE 1. Summary of background information and case study assumptions for each of the three scenarios and associated tree species.

Background information	**Radiata pine**	**Rimu**	**Mānuka**
Annual volume of timber currently produced in New Zealand (m^3 yr^{-1})	28M–29M (MPI 2017d)	4,500 (MPI 2017d) 16,000 total indigenous, (MPI 2017c)	n/a
Geographic range	All regions of New Zealand but wood quality (i.e. stiffness, straightness, and density) is lower in the south	All regions of New Zealand from sea level to 700-800 m elevation	All regions of New Zealand from lowland to sub alpine areas, common on the drier east coasts of the North and South Islands
Primary products	Structural & appearance lumber, packaging lumber, plywood, laminated-veneer lumber (LVL), medium-density fibreboard (MDF), particle board and a variety of pulp & paper products.	High-value furniture, interior joinery, and panelling	Foliage: honey, essential oil, Māori traditional uses Wood: tool handles, sawdust for smoking meats/fish
Case study assumptions	**Scenario 1: Radiata pine**	**Scenario 2: Rimu**	**Scenario 3: Mānuka**
Management style	Intensive, clear-fell harvesting	Continuous cover forestry, 20% selective harvest of total standing volume each decade (starting at year 80 and ending at year 120).	Intensive, whole tree removal at year 15
Rotation length	28 years	120 years	15 years
Life-cycle processes	1) nursery; 2) site preparation; 3) planting; 4) tending; 5) thin (to waste); 6) clear felling; 7) extraction; 8) landing site operations; and 9) timber transport.	1) nursery; 2) site preparation; 3) planting; 4) tending; 5) form pruning; 6) selective felling; 7) helicopter extraction; 8) landing site operations; and 9) timber transport.	1) nursery; 2) site preparation; 3) planting; 4) tending; 5) harvesting of branches; and 6) distillation.
Slope	Flat land (<7°); Steep land (>18°)	Flat land (<7°); Steep land (>18°)	Flat land (<7°) Steep land (>18°)
Stand density (initial planting)	833	1,100	15,000
Blanking (seedling replacement)	None	55 seedlings at year 1, and repeated after each selective felling (years 81, 91, 101, 111, 121, 131, 141, 151, 161, and 171)	1,500 seedlings (year 1), 1,050 seedlings (year 2), 750 seedlings (year 3–13); assumed high degree of on-site mortality every year due to damage caused during planting and/or trimming
Stand management	Thinning at year 10 to final stocking density of 450 stems ha^{-1}	Three form prunings at years 8, 18, and 28.	Trimming of trees (two thirds of each tree from years 2–14); branches used in distillation process
Total standing volume (m^3 ha^{-1} at time of felling)	760	400 (at year 80)	n/a
Total recoverable volume (m^3 ha^{-1} delivered to sawmill)	650	70 (after each selective harvest)	n/a
Total foliage (branches and brush) produced (tonnes ha^{-1})	n/a	n/a	544
Total essential oil produced per ha	n/a	n/a	1,904 kg (assuming 3.5 kg essential oil produced per tonne of mānuka material)

J. Wardle 2011). Mānuka grows in naturally and artificially disturbed sites and forest margins. Mānuka acts as a nurse crop in establishing New Zealand native forests (Burrows 1973). A number of longer-lived species germinate and grow beneath its canopy before eventually overtopping. Mānuka was chosen for this study because oil distilled from various parts of the plant has valuable medicinal (anti-bacterial, anti-fungal, anti-viral) properties (Porter & Wilkins 1998). Also, honey produced from mānuka flowers contains unique antimicrobial compounds that make mānuka honey considerably more valuable than other floral honey products (McPherson 2016). Mānuka plants from various parts of New Zealand differ in their chemical composition. A chemotype found growing naturally in the Gisborne and East Cape regions of the North Island contains high levels of β-triketones that are correlated with antimicrobial activity (Douglas et al. 2004) so this chemotype is particularly valuable as a crop.

Methods

Forestry scenarios

The three scenarios investigated here were:

A. Radiata pine, involving production forestry procedures including intensive ground preparation and clearfelling

Radiata pine forestry is the most common commercial forestry in New Zealand and, as such, it represents the "business as usual" option. Radiata pine was included as a scenario as it was recognised by the participants as a forestry option that provides a range of economic benefits (employment, profit, infrastructure) and also the environmental benefit of mitigating soil erosion while the trees are growing).

For this study, the total standing volume (TSV) at time of felling was assumed to be 760 m^3 per hectare (based on a growth rate (Mean annual increment) of 23 m^3 per annum), and total recoverable volume (TRV) delivered to the sawmill was 650 m^3 per hectare[ii].

One cubic metre of radiata pine is approximately equivalent to one tonne of radiata pine (New Zealand Institute of Forestry 2005). The transport distance from the harvesting site to the sawmill gate (one-way) was assumed to be 86 km (NZ FOA Transport Authority 2007). Although a given radiata pine stem consists of both sawlog and pulp wood, it was assumed that all of the wood was transported to the same sawmill. A value of \$94 m^{-3} is assumed at the sawmill gate (based on forest market prices (AgriHQ 2015)) and is based on the weighted value of various proportions of merchantable radiata pine grade volumes (as derived from the radiata pine calculator (Kimberley 2005)).

B. Rimu, involving continuous cover forestry including minimal chemical use and select group felling

The rimu scenario was developed to represent a continuous-cover forestry-management technique as described by Barton (2006, 2008) where the first selective group felling (20% of the TSV per hectare) occurs at year 80 and is repeated each decade until year 120 (i.e. when 100% of the originally planted hectare has been selectively harvested). All impacts from the full 120 years of forest management were included in this economics assessment.

The TSV (100% of the hectare) at time of the first selective group felling was approximately 400 m^3 per hectare (with a growth rate after harvest (Mean annual increment) of 8 m^3 per annum), and thus 20% selective harvesting of the TSV at 80 years would result in 80 m^3 felled. Due to natural and artificial regeneration, subsequent selective harvesting also result in 80 m^3 felled each decade (year 90 to year 120) and total 800 m^3.

A pre-existing growth and yield model was not available for planted rimu under continuous-cover management, thus growth and yield rates were modelled using a two-step modelling process with the Mitscherlich growth function fitted to outputs from the Random Forests machine learning algorithm (Liaw & Wiener 2002). The algorithm was fitted to data for indigenous New Zealand podocarp species from the Scion permanent sample plot (PSP) database (Hayes & Andersen 2007) based on age, stocking, latitude and species. The model was fitted to data for a range of indigenous podocarp forest species, including tōtara (*Podocarpus totara* G.Benn) and kauri (*Agathis australis* (D.Don) Lindl.) for which growth models have been established (Bergin & Kimberley 2003; Steward et al. 2014) . The input data were dominated by naturally regenerated pure species stands with limited forest management intervention. Comparisons against established models for planted managed stands of tōtara and kauri indicated under prediction of volume by 50%. A model-predicted volume at year 80 of 264 m^3 ha^{-1} indicates 400 m^3 ha^{-1} is a reasonable estimation for total standing volume under intensive sustainable continuous cover forest management on the East Cape of the North Island of New Zealand. This result was referenced against: (a) a planted rimu stand from Cornwall Park in Auckland where diameter and height measurements have been recorded; and (b) from diameter and height estimates of rimu (Pardy et al. 1992; Tane's Tree Trust 2011) converted to volume using volume tables generated for rimu (Ellis 1979). Both reference methods generated a predicted volume of 700 m^3 ha^{-1} at age 60 years, which shows that the estimate of 400 m^3 ha^{-1} used in the current analysis is well within the range of rimu productivity, and that planted rimu stands can achieve substantial increases in growth rate compared with natural stands if located at suitable sites and managed appropriately.

The TRV delivered to the sawmill was set at 70 m^3 per hectare at year 80[iii]. Similar to the radiata pine scenario, one cubic metre of rimu was approximately equivalent to one tonne of rimu (New Zealand Institute of Forestry 2005), the transport distance from the harvesting site to the sawmill gate (one-way) was assumed to be 86 km (NZ FOA Transport Authority 2007), and all of the wood was transported to the same sawmill. A value of \$358 m^{-3} (KPMG 2013) is assumed at the sawmill gate for the first selective harvest at year 80. The value is assumed to increase by 10% with subsequent selective harvestings each decade as the remaining stand volume matures and becomes more valuable. Thus, the value is assumed to be \$394 m^{-3} at year 90, \$433 m^{-3} at year 100, \$476 m^{-3} at year 110, and \$524 m^{-3} at year 120.

C. Mānuka (for essential oil production), involving intensive forest plantation operations and a substantial number of seedlings planted

The mānuka scenario assumed the species would be planted, maintained, and harvested for the purpose of attaining high amounts of foliage (branches and brush) material to produce mānuka essential oil.

It was assumed that 1.5–2.5 kg of branches sustainably removed from each mānuka plant in each of the first four years, increasing to 3 kg after that) (P. Caskey, unpublished data, 2 February 2015). Therefore, the total yield (over the 15-year rotation) from one hectare of intensively managed mānuka was 544 tonnes of branches and brush material (i.e. an average of 36 tonnes per hectare per annum).

The mānuka stem and leaf material was assumed to be steam distilled to produce mānuka essential oil with approximately 3.5 kg of essential oil produced for every tonne of mānuka distilled. Therefore, if 544 tonnes of mānuka branch material are produced then 1,904 kg of essential oil will be generated during the distillation process (i.e. 126–127 kg of essential oil per hectare per annum). The value is assumed to be \$325 kg^{-1} of essential oil (P. Caskey, unpublished data, 2 February 2015). A sensitivity analysis was conducted to assess the effect of price on the profitability of each scenario.

Economic assessment

The NPV was the key financial metric generated by the discounted cash flow (Eq. 1) and this was used to assess and contrast the feasibility of the three scenarios. It was assumed that the practices adopted in the first rotation, along with their revenues and costs, would be repeated over time for eight and four rotations for mānuka and radiata pine, respectively (Figure 2). This was done to compare all options on an equal basis, including the long 120-year rotation for rimu.

$$NPV = -E + \sum_{t=1}^{R-1} \frac{I_t}{(1+r)^t} + \frac{A[(1+r)^R - 1]}{r(1+r)^R} + \frac{\sum_{p=1}^{n} P_p * Y_{p,R} - C_h}{(1+r)^R} \quad (1)$$

where t represents time, R is the rotation length, r is the discount rate, p represents the various products obtained from a crop, h the various silvicultural regimes, E the establishment costs (e.g. site preparation, planting, etc), I the intermediate and intermittent costs and revenues (e.g. thinning, pruning, etc.), A the annual and constant costs and revenues (e.g. management fees, etc.), P the product prices, and C the costs of silvicultural practices. Details of the costs assumed for the various scenarios are given in Table 2.

Data collection process

Data collection involved sourcing current and region-specific (i.e. Waiapu catchment) primary data from industry experts. Secondary data sources included modelled data, reports, publications, and the life cycle-based Ecoinvent database v3.1. Detailed data (including sources, assumptions, and quality) can be found in Additional File 1. The majority of the data are representative of values from 2013 and 2014. All values are expressed in New Zealand dollars.

Data collection assumptions

Several assumptions were made during the data collection process to assist with: (1) defining supply chain ownership structure; (2) representing the costs of ensuring cultural compliance; (3) signifying an opportunity cost; (4) selecting appropriate discount rates; (5) projecting forest growth rates for the rimu and mānuka scenarios; and (6) assessing the economic differences between flat-land and steep-land forestry. These assumptions are discussed in more detail below.

1. Supply chain ownership structure

In order to calculate profit, it was necessary to define ownership structures for each scenario. The supply chains

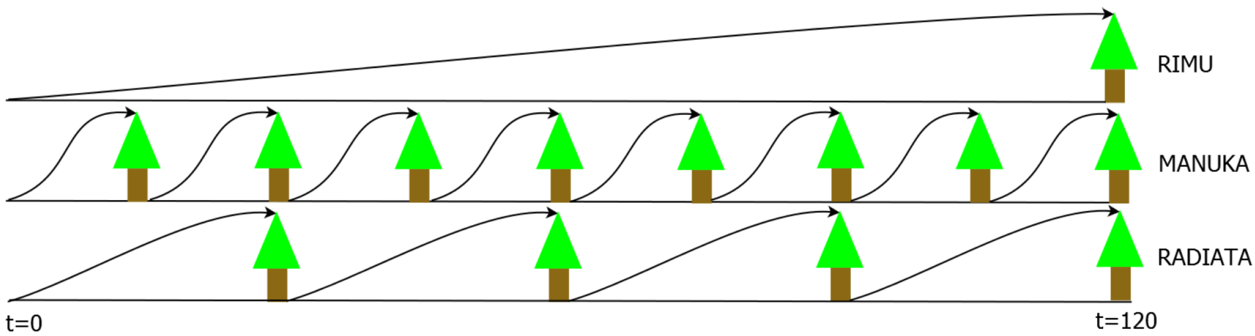

FIGURE 2: Varying rotations across a relatively similar time horizon for the various native forestry alternatives considered.

TABLE 2. Summary of forest activity cost data per rotation for each of the three scenarios.

Undiscounted costs (NZ$) per hectare, per rotation	Scenario species, rotation length and land slope				
	Radiata pine, 28-year rotation		Rimu, 120-year rotation		Mānuka, 15-year rotation
	Flat	Steep	Flat	Steep	Flat
Nursery	584	584	1,927	2,620	28,081
Site preparation	183	213	423	635	310
Planting	324	405	719	1,078	5,832
Tending	7,218[a]	9,071[a]	14,414[a]	15,456[a]	9,628
Opportunity cost (i.e. rate of land rental)	29,120	5,824	124,800	24,960	15,600
Pruning	n/a	n/a	4,845	5,023	n/a
Thinning	320	480	n/a	n/a	n/a
Felling	4,297	1,359	20,800	23,400	30,000[b]
Extraction	4,413	6,727	49,724	55,295	n/a
Skid site	6,342	13,234	9,490	10,725	n/a
Transport	12,829	12,237	6,908	6,217	n/a
Distillation	n/a	n/a	n/a	n/a	496,813

[a] The 'tending' activity for the radiata pine and rimu scenarios includes roading and skid-site landing construction. After the first installation of this infrastructure it was assumed only maintenance would be needed (at a lower cost) throughout subsequent rotations of radiata pine and selective harvestings of rimu.
[b] The 'felling' activity for the Mānuka scenario is inclusive of both branch trimming and transport.

were assumed to be owned and operated by one "entity" (i.e. the participants and the Ngāti Porou iwi), and were inclusive of the nursery through to entry at the sawmill gate (radiata pine, rimu) or through the distillation process (mānuka). This assumption was based on the participants' desire to own and operate as much of each supply chain as possible. The proposed processes from each scenario that were defined as being under one entity represent a viable, albeit ambitious, segment of each supply chain which could potentially be owned and operated by Ngāti Porou. However, output materials from certain processes were input materials into other processes (e.g. seedlings output used as planting input). With internal material flow occurring under one owner/operator entity, the dominant implication was that profit did not transpire until the final process controlled by said entity (i.e. transport and log delivery (radiata pine, rimu) and distillation (mānuka)) were completed. In addition, no cost was included for payments towards land rental or land owner royalties.

2. The cost of cultural compliance

During the development of the three case studies, the participants identified the need to formally include a "cultural compliance" process within various stages of the three respective forestry life cycles. Cultural compliance (i.e. the observation and respect of culturally-related expectations and regulations) was generally only assumed to occur during forestry operations in New Zealand. However, including cultural compliance (and the associated data) clearly and transparently within each life cycle would offer standardised evidence that forestry operations were undertaken in an ethical and culturally appropriate manner. Therefore, costs for cultural compliance were included in ground preparation, planting, and harvesting processes which required additional activities to ensure that all cultural and ethical standards are maintained. Cultural compliance included six main facets: (1) the identification of wahi tapu (sacred sites); (2) providing a cultural monitor to be onsite during all forestry operations; (3) ensuring a kaumātua (elder) performs karakia (prayers, blessings) when needed (e.g. after an accident); (4) maintenance of kaitiakitanga (environmental guardianship); (5) marketing of products from a Māori-owned enterprise; and (6) provision of benefits to landowners. Further details of the cultural compliance process can be found in Pizzirani et al. (2016).

3. Opportunity cost

An opportunity cost was included in the economic analysis of each scenario. An opportunity cost may be viewed as an internal economic check; when one option is chosen over another the forfeited economic gain from the option not pursued was included within the chosen option. It is an economic method commonly used to ensure that decisions (e.g. in this case study, regarding forestry land use options) are made which account for other options. Opportunity costs are used in other forestry-related research (e.g. Golub et al. 2009; Fisher et al. 2011; Barry et al. 2014; Monge et al. 2016a), natural resource management (e.g. Pearce & Markandya 1987), and conservation studies (e.g. Chomitz 1999).

The opportunity cost in this research was based on an alternative land option (i.e. besides forestry) of land rental as this is often a reasonable proxy for opportunity cost (Prokofieva & Thorsen 2011). The determination of this opportunity cost was done through the evaluation of current flat and steep land for sale in the case study region, and taking 4% per annum of the average land values; 4% may be considered a minimum return on investment amount. This value roughly represents the potential profitability from alternative land uses in the same type of land. For example, flat land is prime land for the most profitable land uses in New Zealand such as dairy and horticulture. Hence, its value is higher than steep land since fewer land-use alternatives can be established in such type of land, such as sheep and beef or forestry.

4. Discount rates

Discount rates are used to assess the NPV of costs and benefits over time, and allow for economic comparisons between alternative scenarios. Therefore, a sensitivity analysis was performed on each forestry scenario using a range of discount rates (2%, 4%, 6%, and 8%)[iv]. Low discount rates could be justified on two grounds: (1) the intergenerational aspirations expressed by the iwi (tribe) and (2) the lack of alternative land values in highly erodible steep land[v].

5. Forest growth rates

Radiata pine is extremely well-researched and therefore the assumptions about growth rates and timber quality in this study are very accurate. However, the rimu and mānuka scenarios relied on expert opinions and/or limited research; while this in itself does not render the results invalid it may make them less reliable.

This study used an estimation for rimu growth and yield rates of 400 m^3 ha^{-1} at year 80 with a potential growth rate after harvest of 8 m^3 ha^{-1} yr^{-1}. This estimation may prove to be conservative since the growth of a number of indigenous conifer species, including rimu, have been shown to have growth and productivity rates in plantations well in excess of those seen in natural forests even in stands where after planting care and management has been minimal or even absent (e.g. Pardy et al. 1992; Bergin & Kimberley 2003; Steward et al. 2014).

Furthermore, while continuous cover forestry regimes will require careful extraction of felled stems to avoid damage to retained trees, some form of disturbance to soil and opening of the canopy will be necessary to assist establishment and development of natural regeneration in the second and subsequent rotations. Once established some manipulation of the canopy and regeneration of target species will be required to maintain and encourage growth and tree form. In this study, for example, the rimu scenario included an ongoing blanking (i.e. seedling replacement) after every selective harvest. Rimu regeneration may also be sporadic and cyclical (Smale & Beveridge 2007) therefore some ongoing assessment of rimu regeneration, both in quantity and quality may be needed, with some thought to supplementation by planting where necessary. Whether planted stands of rimu begin to function like a natural stand beyond the first rotation is at present unknown and will require further investigation.

The mānuka scenario (intensive management for essential oil production) represents a relatively new approach to mānuka as a land use in New Zealand, and precise estimations of branch and brush output per hectare are not currently available. The estimations of both the yield of mānuka branch material and distilled mānuka oil used were based on current industry knowledge from New Zealand Mānuka Ltd (the leading producer of mānuka essential oil in New Zealand and one of the few companies who have begun planting mānuka with such high stocking rates). However, the yield of mānuka branch material is primarily based on figures attained from harvesting naturally growing mānuka, not planted and intensively managed mānuka. The branch and brush yields used in this paper (i.e. average of 36 tonnes per hectare per annum) may reflect a "high-yield" scenario, while a "low-yield" scenario may only produce 16 tonnes per hectare per annum. There were also assumptions made regarding mānuka's mortality rates, tree and brush quality, fertiliser requirements, and soil and water needs. It is also important to note that the scenarios presented for the establishment and management of mānuka on the East Cape of New Zealand for the extraction of essential oils were made before the discovery, in early 2017, of myrtle rust (*Austropuccinia psidii* (G. Winter) Beenken in New Zealand (Ministry for Primary Industries 2017a)). Although widespread public engagement and education is proving effective in the management of this fungus, it remains unknown how significantly myrtle rust will affect both wild populations and plantations of mānuka.

6. Slope

The baseline assumption for all three forestry scenarios was that all forestry activities took place on flat land (<7° slope). Some forestry can be undertaken on steep land (defined as terrain >18°) but has a considerable effect on forestry costs, efficiency, and safety (Forest Industries Training 2000). The Waiapu case study region has a substantial amount (~100,600 hectares) of steep land, ~35,750 hectares of "rolling" land (7°–18°) and ~21,800 hectares of flat land (Figure 3). A sensitivity analysis comparing flat and steep land was made for the radiata pine and rimu scenarios but not for the mānuka scenario. The latter was excluded as it was assumed to be uneconomic due to the intensive annual trimming requirements. The flat land has an assumed land rental opportunity cost of $1,040 per annum while the steep land's opportunity cost is $208 per annum due to the innate challenges and limitations that steep land poses for financially viable land use options.

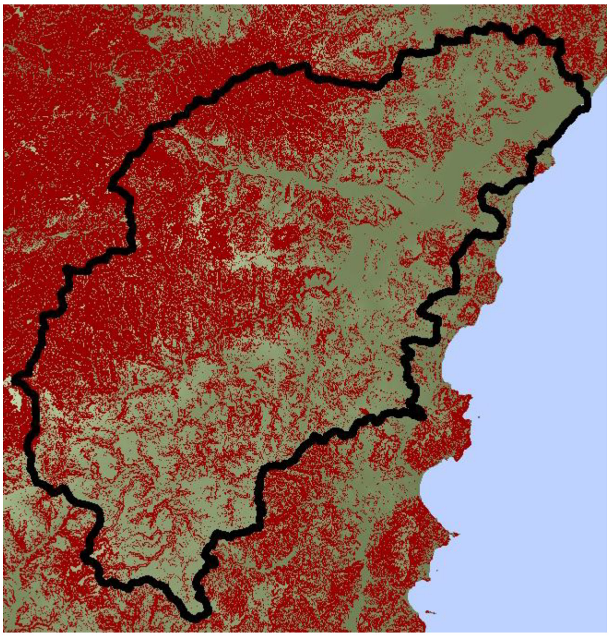

FIGURE 3. The Waiapu catchment case study site (outlined in black) with the areas of steep terrain (18° or more) indicated in red.

Results

Discounted Cash Flow

All applications of discount rates resulted in a substantially negative NPV for the rimu scenario as it is based on a continuous cover forestry regime, which has inherently long-term tree growth and management. Similarly, the radiata pine scenario showed a consistently negative NPV irrespective of discount rate. The steep-land scenario for radiata pine and for rimu had an improved NPV return compared with the corresponding flat-land option. To assist with interpretation of the results, the NPV of the three tree species for different slopes using an 8% discount rate has also been converted into annuities (Figure 4).

Sensitivity Analysis

The sensitivity analyses determined the threshold at which the NPVs become positive either by increasing product prices or by decreasing the discount rate.

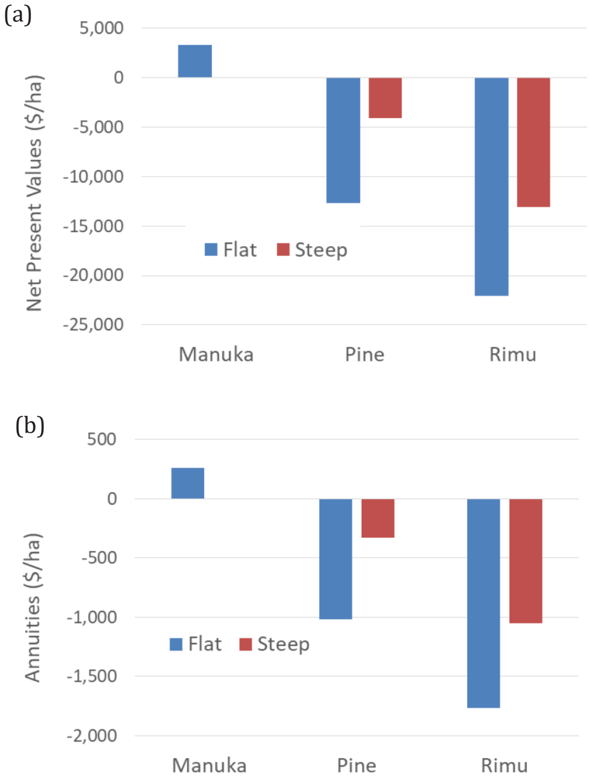

FIGURE 4. Net Present Values (a) and annuities (b) of the three tree species for different slopes using an 8% discount rate.

There is still uncertainty over the possible price for the products obtained from mānuka and rimu but these are expected to be quite high although the potential demands (domestic and international) remain unclear. A range of prices was examined for each scenario (Figures 5, 6, and 7).

Negative NPVs were obtained for radiata pine and rimu on flat land across various stumpages and discount rates (data not shown). Radiata pine on steep land generally starts becoming profitable at discount rates lower than 6% and stumpages higher than $100 m^{-3}, Figure 5.

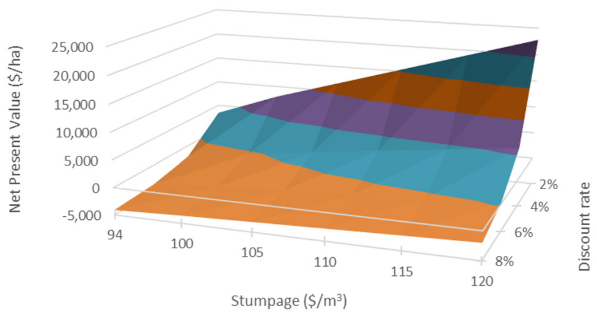

FIGURE 5. NPVs for different discount rates and stumpages for radiata pine grown on a representative hectare of steep land.

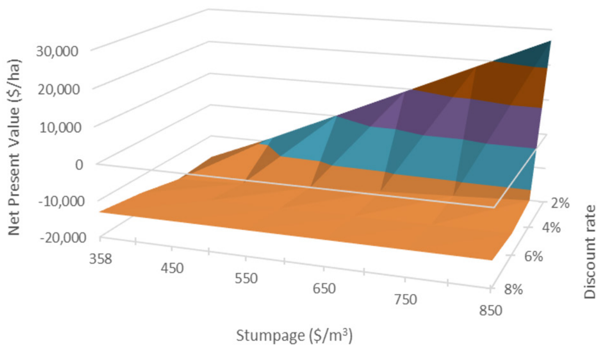

FIGURE 6. NPVs for different discount rates and stumpages for rimu grown on a representative hectare of steep land.

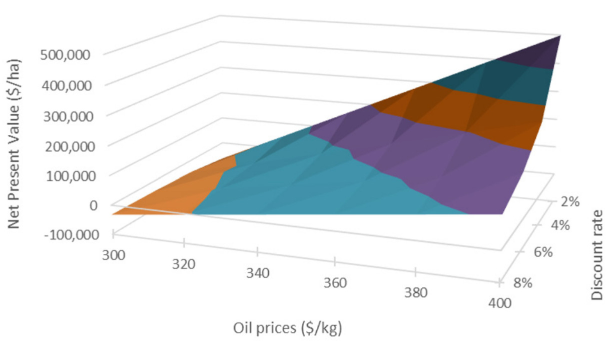

FIGURE 7. NPVs for different discount rates and prices for oil distilled from mānuka grown on a representative hectare of flat land.

Rimu on steep land starts becoming profitable at discount rates lower than 2% and initial stumpages of $650 m^{-3} in year 80 increasing by 10% in subsequent years, Figure 6.

The prices and discount rates at which mānuka becomes profitable are shown in Figure 7. Since we have assumed an expected price of $325 kg^{-1}, prices below $320 kg^{-1} start making the mānuka alternative unprofitable. At a price of $300 kg^{-1}, mānuka becomes unprofitable even at low discount rates.

Discussion

Our economic analysis of three forestry scenarios (radiata pine, rimu, and mānuka) in the Waiapu catchment considered differences in rotation length, management intensity, and harvesting technique. On flat land, the mānuka scenario had the highest NPV return per hectare, regardless of discount rate. The radiata pine scenario had negative NPV per hectare at almost all combinations of discount rates and stumpage prices examined, while rimu had negative NPV per hectare at all variations of discount rates and stumpage prices tested due to the high current cost of flat land. On steep land, both the radiata pine and rimu scenarios had improved NPV returns, largely due to the lower opportunity cost included in the steep-land assumptions as compared to the flat land (i.e. opportunity costs of $208 and $1,040, respectively). On steep land, radiata pine is generally profitable with a discount rate of 6% or lower and a stumpage rate of over $100 m^{-3} and rimu is generally profitable with a discount rate of 2% or lower and a stumpage rate of over $650 m^{-3}.

The analysis could be improved by assessing the ability of landowners to get credits from banks through the development of capital budgets using the three most important pro-forma statements: balance sheet, income and cash flow statements (Monge et al. 2014). These statements would give landowners a better idea of the profitability, liquidity and solvency of the various alternatives considered in this study conditioned on the landowners' initial capital situation.

There are, however, additional considerations regarding this economic analysis. In particular, five such considerations are discussed further below and include: (1) the provision of ecosystem services, (2) forest growth rates, (3) discount rates, (4) spatial variability and economies of scale, and (5) future markets and development.

Economic benefit for provision of other ecosystem services

There is evidence (e.g. Barry et al. 2014) confirming that flat land is currently so expensive that even growing the most established commercial forestry species in New Zealand (radiata pine) would not be profitable at present. Valuing other aspects of these forest ecosystems (environmental, recreational, etc.) and requiring payment for them could make radiata pine plantations profitable on the east coast of the North Island, however.

None of the scenarios included any economic benefit for sequestering carbon or nitrogen. In New Zealand, carbon payments are made in return for carbon sequestration through the Emissions Trading Scheme (ETS) and current carbon payments are approximately $19 t$CO_2$eq (OMF 2017). Nitrogen removal payments are also being trialled in New Zealand due to the National Policy Statement for Freshwater Management (NPS-FM), which aims to improve freshwater quality. The payment for nitrogen permanently removed from the environment was around $300 kgN in 2012 (Kerr et al. 2015). Therefore, inclusion of ETS and NPS-FM payments could add significant income to the profit margins of forestry, as demonstrated in a recent study by Monge et al. (2016b).

Also not included in this analysis is funding of $1,500 per hectare for erosion control that is available for the Gisborne region of New Zealand (which contains the Waiapu catchment-based case study location) (Ministry for Primary Industries 2017b). Future Life Cycle Sustainability Assessments (LCSA) and forestry research should endeavour to include these identified benefits and challenges – doing so will help to comprehensively account for the full range of impacts associated with forestry.

The effects of time

In the sensitivity analysis, the discount rate had a significant effect on the representation of costs and profits – especially for the long-term rimu forestry scenario. With its relatively short-rotation of 15 years and its potential to annually create essential oil product, mānuka was less affected by the discount rate sensitivity analysis.

It is important to acknowledge the indigenous world-view of sustainable inter-generational equity and its often conflicting relationship with discount rates (Clarkson et al. 1992). Many indigenous cultures have decision making and governance processes that embody the "seventh generation principle" whereby the decisions of today should be mindful of and minimise the associated impacts seven generations into the future (i.e. 140 years into the future, assuming each generation is 20 years) (Lyons 1980). Axelrod (2017, p. 13) suggests a discount rate of "no more than 0.5% to express the intertemporal preferences of the "seventh generation" principle" and thereby more appropriately recognising intergenerational sustainability.

The concept of using low discount rates over long time horizons (i.e. intergenerational discounting) is becoming increasingly discussed amongst economists (e.g. Sumaila & Walters 2005; Freeman 2010; Arrow et al. 2013; Knoke et al. 2017). Further, the use of low discount rates in forest investment decision making has been explored and justified in other case studies involving Māori communities in New Zealand (e.g. Monge et al. 2018). Many of these discussions and studies support the rationale for using a low discount rate (2%) for the long-rotation forestry option (rimu) presented in this research; that is, pursuing long-term forestry opportunities may be considered an intergenerational investment for indigenous communities which includes metrics beyond profitability such as the non-market values of job creation, environmental benefit, and cultural prosperity.

Economic effects of spatial variability and the 'economies of scale'

This research was not based on a particular, site-specific, hectare of land with defined biophysical characteristics. The case study parameters were described with the Waiapu catchment as the underlying setting, and, where possible, attempts were made to reflect the effects of this location (e.g. the radiata pine growth rate used in this research was indicative of the Waiapu catchment and surrounding region). However, processes such as tree harvesting and transport are obviously sensitive to spatial variability and may subsequently have a significant impact on indicator results.

The commercial viability or success of any forest harvesting operation can be dictated by a number of factors, one of which is scale or size of the available or planned resource to allow for continuous harvest over the period of resource maturity. In a recent study involving a range of exotic and indigenous species that included radiata pine and mānuka, both the size (scale) of planted resources and their proximity to processing and or export facilities were found to be amongst the greatest contributors to profitability (Holt et al. 2014; Monge & Wakelin 2019). For the current study, scale will be different for each species. For instance, for the mānuka oil industry there are reports of 1 to 5 tonnes of raw material harvested per hectare per day depending on the size of the processing facilities and whether mechanical harvesting was undertaken. Assuming three kilograms of brush material is harvested from each mānuka tree every year and an average harvest rate of three tonnes per day, a 6-month harvesting season would require a resource of an estimated 13,000 plants per hectare. For a 12-month harvesting season the resource would need to be at least double.

A market for indigenous timbers already exists within New Zealand, supplied predominantly from salvaged windthrown mature trees. Currently the industry supplies an estimated 4,500 m^3 of rimu annually (S. Rolls, personal communication, Ministry for Primary Industries, 4 December 2016). To supply that current market with rimu from planted stands would require a plantation resource of an estimated 56 hectares available every year, when delivering 80 m^3 ha^{-1} once every 10-year cycle. Therefore, a total resource of 560 hectares would be required to maintain the same volume on an annual basis.

Finally, scale is also likely to have an impact on discount rates. A recent review by Manley (2019) of implied discount rates (IDR) for forest valuations in New Zealand found that IDR have reduced over a 20-year period (1997–2017). This trend is most pronounced in large-scale (>10,000 ha) forest areas.

Future markets and development

The results presented have assumed values for profit based on current market prices for the proposed products in each study. The radiata pine market is a well-established industry in New Zealand with generally consistent consumer demand, especially internationally. However, the less-established rimu and mānuka options may be considered vulnerable as their resultant products currently have less market exposure; they are susceptible to the effects of unknown market behaviour and the associated impacts on product prices.

In an analysis of new product performance, Henard and Szymanski (2001, p. 364) identify four critical areas which can greatly affect the success of a new product: (1) product characteristics (price, meeting customer needs, degree of innovation, advantage and/or differentiation over competing products); (2) strategy characteristics (the product developer's ability to appropriately time entry into the market and build on pre-existing market synergies, dedicated R&D resources); (3) process characteristics (proficient management of the product's development, performance, and marketing); and (4) marketplace characteristics (likelihood and intensity of competitive response to a new product, market potential/consumer demand).

Therefore, further research and investment is needed to increase the long-term market strength of both the rimu and mānuka forestry options. In particular, research and investment should be mindful of fulfilling a current identified customer demand (i.e. responsive market orientation) but also aim to discover ways of meeting latent needs of the customer, needs of which they are unaware (i.e. proactive market orientation) (Narver et al. 2004).

Conclusions

This study assessed the economic benefits and challenges associated with three forestry scenarios comparing one exotic (radiata pine) and two native (rimu and mānuka) species. The Ngāti Porou participants chose these species to explore potential alternatives (rimu and mānuka) to their current business-as-usual forestry option (radiata pine). It is not possible to draw concrete conclusions on the basis of the presented NPV calculations; however, the results of this conceptual case study have shown the economic viability of the selected tree species under specific conditions. The best economic returns may be achieved through the combined use of all three scenarios. Short-term financial benefits could be obtained with the mānuka option, medium-term benefits with the radiata pine option, and long-term benefits with the rimu option (even though the benefits of rimu, especially on steep land, may be more in the form of avoided erosion, carbon sequestration, and biodiversity and cultural enhancement). Further calculations should be carried out to provide specific organisational and financial options for these forestry alternatives.

This analysis clearly demonstrates the importance of strategically considering what forest tree species to plant, on what slope of land to plant them, and what forest management technique to utilize. Furthermore, this analysis highlights the complexity of choosing appropriate discount rates and assessing the effects of other inherent assumptions, such as opportunity cost. Future research, particularly with planted rimu and mānuka forestry options, should include undertaking trials to determine the "cause and effect" of various parameters on their overall growth and quality.

Ethics approval and consent to participate

This research involved engagement with three Māori (Ngāti Porou) participants. A full human ethics application was submitted to and approved by the Massey University Human Ethics Committee (Southern B application, 13-58).

Consent for publication

All authors consent for the publication of this manuscript and its content.

Availability of data and materials

The datasets supporting the conclusions of this article are included within the article and its additional file.

Additional files

Additional file 1: Economic life cycle inventory data.

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

SP developed the case study, collected and analysed data, derived the associated results, and wrote the majority of the paper. JM provided significant economic expertise and guidance for all three scenarios. PH provided significant guidance and data regarding the radiata pine processes, and wrote the introductory section on radiata pine. GS provided significant guidance and data regarding the rimu processes, and wrote the introductory section on rimu. LD provided significant modelling expertise regarding the rimu scenario and wrote the section concerning rimu growth modelling. PC provided significant guidance and data regarding the mānuka processes, and wrote the introductory section on mānuka. SMcL provided significant Life Cycle Sustainability Assessment (LCSA) expertise, assisted with all data analysis and generation of results, and edited this paper.

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Endnotes

[i] The East Coast Forestry Project rebranded in 2014 and changed its name to the Erosion Control Funding Programme.

[ii] The difference in volume between TSV and TRV is due to the estimations that around 12% of the original TSV (broken tree tops) is left on-site during felling and extraction operations (Ministry for Primary Industries 2014), and that a further 3 to 4% of the original volume deposited at the landing site is left on-site (due to volume lost during log making) (Hall 1994, 1996, 1998, 2000).

[iii] The difference in volume between TSV and TRV was attributed to an estimated 9% loss in TSV due to broken tree tops left on-site during felling and extraction operations (Ministry for Primary Industries 2017d) and an additional 3 to 4% loss of the original volume deposited at the landing site was left on-site (due to volume lost during log making). The difference between TSV and TRV for rimu was based on the figures for radiata pine due to a lack of published data for rimu. However, the volume lost for rimu was adjusted and assumed to be slightly less than for radiata pine because stem breakage and other damage is likely to be minimal for rimu logs as they would be selectively harvested by chainsaw and extracted by helicopter.

[iv] Gluch and Baumann (2004) state that when a "discount rate is set to 0% this means that the timing does not matter; the higher the discount rate the more importance is given to the near-present" (p. 575). Furthermore, a high discount rate will favour "short-term low capital cost options" while a low discount rate will favour "future cost savings" (Sterner 2000, p. 388). However, Barry et al. (2014) argued that forestry discount rates can range from 4% (for net public benefits) to 8% (for net private benefits).

[v] Opportunity cost is considered in both the estimation of the discount rate and land rents. The former partly represents the opportunity cost of the seed capital (or initial investment) whereas the latter represents the opportunity cost of the land.

Additional File 1: Economic life cycle inventory data

Exploring forestry options with Māori landowners: an economic assessment of radiata pine, rimu, and mānuka

Stefania Pizzirani

This additional file details the economic data assumptions, estimations, and sources pertaining to the rotation cycles of the three forestry scenarios (radiata pine, rimu, and mānuka). The additional file presents: 1) the data specific to each forestry scenario, 2) the data assumptions and exclusions, 3) the use of an opportunity cost within the life cycle dataset, and 4) the data regarding the Cultural Compliance process (i.e. a process which includes the identification of wahi tapu (sacred sites), providing a cultural monitor to be onsite, kaitiakitanga (environmental guardianship), and provision of benefits to landowners). The data are inclusive of processes from "cradle-to-gate" (i.e. from the nursery to the sawmill gate for radiata pine and rimu, and from the nursery through distillation for mānuka). Unless otherwise noted, all processes (and associated costs) are assumed to occur and be repeated throughout subsequent rotations (for radiata pine and mānuka) and selective harvestings (for rimu).

Radiata pine scenario – flat land

- ***Nursery***
    - Nursery details:
        - The nursery process is assumed to be a small- to medium-scale enterprise producing roughly 480,000 radiata pine seedlings per year (K. Te Kani, pers. comm., 8 October 2014). The number of pine seedlings required for one hectare of land is 833 seedlings (P. Hall, pers. comm., 18 August 2014). The nursery data includes both capital expenditure and operational costs. The life of the nursery is assumed to be 50 years and so all figures are divided by and associated to the total number of seedlings produced over 50 years (i.e. 50 years x 480,000 seedlings per year = 24,000,000 seedlings).
    - Costs and profit, and employment:
        - Total capital costs are estimated to be $492,195 (or $9,844 per year), and total running costs are estimated to be $326,451 per year. Total cost per seedling (inclusive of materials and labour) is $0.70 (K. Te Kani, pers. comm., 8 October 2014).
        - Employment and wages are inclusive of a full-time nursery manager ($60,000/year salary), full-time nursery technician ($40,000/year salary), one additional full-time staff (for manual tasks; $14.25/hour wage), and four part-time seasonal casual staff ($14/hour wage; 180 days each per year) (K. Te Kani, pers. comm., 8 October 2014).

- ***Site preparation***
    - Site preparation details:
        - Site preparation involves spraying the land via helicopter with an herbicide to desiccate the existing grasses and shrubs.
        - Fertiliser, which can be applied on the site before planting, was assumed to not be required.
        - The mechanical soil preparation is assumed to be required (on average) on 8% of the area being established (P. Hall, pers. comm., 15 March 2014).

        - The helicopter pilot can spray 52 hectares of flat land per hour (Anonymous industry expert, pers. comm., 10 March 2014).
    - Costs and profit, and employment:
        - Employment and wages are inclusive of a helicopter pilot ($175/hour wage), a support technician to mix the herbicide chemicals ($35/hour wage), and an excavator operator ($18/hour wage) (Anonymous industry expert, pers. comm., 10 March 2014).
        - The site preparation cost per hectare associated with the Cultural Compliance process (Section 5.4.2) is $1.65.
        - The site preparation employment per hectare associated with the Cultural Compliance process is 0.02 hours.

- ***Planting***
    - Planting details:
        - The planting process includes only the labour cost of planting 833 stems per hectare. The cost of the seedlings was accounted for during the nursery process so, to avoid double counting, the seedling cost is not also included during the planting process.
    - Costs and profit, and employment:
        - It takes an employee 8 hours ($20/hour wage) to plant one hectare with 833 stems of radiata pine (P. Hall, pers. comm., 15 March 2014).
        - The planting cost per hectare associated with the Cultural Compliance process is $1.47.
        - The planting employment per hectare associated with the Cultural Compliance process is 0.02 hours.

- ***Tending***
    - Tending details:
        - The tending process includes weed control (aka – "releasing") using herbicides via helicopter, disease control of both Red Needle Cast (*Phytophthora pluvialis* (Reeser et al. 2013)) and Dothistroma needle blight (*Dothistroma septosporum* (Dorog.) M. Morelet) via helicopter spraying, inventory assessment, and the annual activities of forest management, rates and fire insurance, fence and track maintenance, and animal (pest) control.
        - Forest management includes such aspects as forest planning, protection (security, recreation, hunting, tourism, fire), research, inventory, roading, and engineering.
        - Included in the tending activities are the processes of landing and roading (in the forest) construction. These activities occur towards the end of the forest growth cycle at year 26 in preparation for harvesting activities. Generally, landing and roading construction are not considered to be 'tending' activities but they have been grouped under this heading to simplify the life cycle analysis.
        - Roading external to the forest was excluded as it was assumed that no additional infrastructure was required.
    - Costs and profit, and employment:
        - Wages for aerial spraying are inclusive of a helicopter pilot ($175/hour wage) and a support technician to mix the herbicide chemicals ($35/hour wage) (L. Bulman, pers. comm., 3 March 2014).

- An overall salary for a forest manager to manage a forest is $80,000 per year (based on a forest estate size of 5,000 hectare) (P. Hall, pers. comm., 15 March 2014).
- Forest management is estimated to account for two hours of employment per hectare per year (P. Hall, pers. comm., 15 March 2014).
- Employment related to rates (i.e. land value tax) and fire insurance are excluded due to its minimal impact on the life cycle indicators.
- Both a) fence and track maintenance and b) animal (pest) control are assumed to employ workers with an hourly wage of $18, and require approximately nine minutes per hectare per year and three minutes per hectare per year respectively (P. Hall, pers. comm., 15 March, 2014).
- The inventory process involves sampling forest sites within a stand to determine its quality and projected value. This process is estimated to take one worker ($20/hour wage) 30 minutes per hectare to survey (P. Hall, pers. comm., 15 March 2014).
- The in-forest workers ($30/hour wage) install 40 metres of roading per hectare in 6.33 hours (S. Hill, pers. comm., March 12 2014). Subsequent rotations assume that only roading maintenance, not installation, is required. Roading maintenance is assumed to occur 2 years before harvesting and involves half the cost and time as installation.
- The in-forest landing site workers ($30/hour wage) require nearly 66 hours to complete one landing site, or 7.67 hours per hectare (S. Hill, pers. comm., March 12 2014). Subsequent rotations assume that only landing maintenance, not installation, is required. Landing maintenance is assumed to occur 2 years before harvesting and involves half the cost and time as installation.
- The tending cost per hectare associated with the Cultural Compliance process is $54.13, and represents the annual cost of protecting the environment through Kaitiakitanga.
- The tending employment per hectare associated with the Cultural Compliance process is 0.28 hours, and represents the annual employment needed for protecting the environment through Kaitiakitanga.
- An opportunity cost of $1,040 per hectare per year was applied based on current average flat land valuations in the case study region of Gisborne.

- ***Thinning (to waste)***
  - Thinning (to waste) details:
    - The thinning process is assumed to reduce the total number of planted stems per hectare from 833 to 450 at year 10.
    - The thinnings are left on-site to decompose.
  - Costs and profit, and employment:
    - It is estimated that a worker ($20/hour wage) requires 7.6 hours per hectare to thin (to waste) (P. Hall, pers. comm., 15 March 2014).

- ***Clear felling***
  - Clear felling details:
    - The clear felling process involves the cutting of the entire forest stand.
    - Felling occurs at year 28 and the total standing volume at the time of felling is estimated at 760.5 m^3 per hectare (MacLaren & Knowles 2005), where 1 m^3 is assumed to be harvested softwood under bark.
  - Costs and profit, and employment:

        - One "feller-delimber-buncher" (FDB) operator ($22/hour wage) is required for this process (P. Hall, pers. comm., 15 March 2014).
        - It is estimated that one m^3 takes approximately 43 seconds to fell; therefore, one hectare takes 9.13 hours to clear fell (P. Hall, pers. comm., 15 March, 2014).
        - The clear felling cost per hectare associated with the Cultural Compliance process is $9.28.
        - The clear felling employment per hectare associated with the Cultural Compliance process is 0.16 hours.

- ***Extraction***
    - Extraction details:
        - The extraction process involves removing the felled stems from the site and depositing them at the landing site for further handling.
        - It is estimated that 11% of the original total standing volume (760.5 m^3 per hectare) is left on-site during extraction and landing site operations (P. Hall, pers. comm., 15 March 2014). This amounts to a volume loss of approximately 84 m^3 per hectare.
        - Volume left on-site includes material from the tree tops and branches.
    - Costs and profit, and employment:
        - Two extraction operators ($22/hour wage) are required for this process (P. Hall, pers. comm., 15 March 2014).
        - It is estimated that one m^3 takes 1.44 minutes to extract; therefore, one hectare of felled material takes 16.24 hours to extract (P. Hall, pers. comm., 15 March 2014).

- ***Landing site***
    - Landing site details:
        - Landing site operations primarily include log making (i.e. cutting the stems into pre-determined log lengths) and loading (i.e. placing the logs onto the logging trucks for timber transport).
        - It is estimated that 4% of the original volume deposited at the landing site (676.84 m^3) is left on-site, thus amounting to 27.07 m^3 left at the landing site (P. Hall, pers. comm., 15 March 2014).
        - This loss of volume is attributed to the log making process and any stem breakage that may occur during handling.
    - Costs and profit, and employment:
        - Six log making operators ($18.50/hour wage) and three loading operators ($18.50/hour wage) are required for this process (P. Hall, pers. comm., 15 March 2014).
        - It is estimated that for one m^3 log making takes 4.32 minutes to process and loading takes 2.16 minutes; therefore, one hectare of felled material takes 73.1 hours to process through the landing site (P. Hall, pers. comm., 15 March 2014).

- ***Timber transport***
    - Timber transport details:
        - The logs are transported to a sawmill.
        - The volume transported per hectare is 650 m^3 (i.e. the remaining volume after harvesting and landing site operations).

        - Although a given radiata pine stem consists of both sawlog and pulp wood, it is assumed that all of the wood is transferred to the same sawmill.
        - Subsequent processing of the logs in the sawmill yard is excluded from the assessment due to its anticipated insignificant contribution to the indicator results.
        - One m^3 of radiata pine is approximately equivalent to one tonne of radiata pine (New Zealand Institute of Forestry 2005).
        - The transport distance (one-way) is assumed to be 86 km (NZ FOA Transport Authority 2007).
        - The logging truck is assumed to be a 6x4 truck with a 4-axle trailer. The unloaded weight is 14.5 tonnes and a log payload weight of 29.5 tonnes, thus the total logging truck weight is 44 tonnes (P. Hall, pers. comm., 15 March 2014).
    - Costs and profit, and employment:
        - The timber truck driver ($30/hour wage) requires 7.2 minutes per m^3 (3.54 hours per loaded truck) to travel from the landing site to the sawmill gate (P. Hall, pers. comm., 15 March 2014).

Rimu scenario – flat land

- ***Nursery***
    - Nursery details:
        - Rimu seedlings are produced in a nursery and take 12 months to grow from a seed to seedlings ready for planting.
        - Nurseries primarily use fungicides and pesticides, electricity for heating the greenhouse, and diesel for operating the tractors on-site.
        - The amount of rimu seedlings required for one hectare of land is 1,100 seedlings (G. Steward, pers. comm., November 19 2014).
        - The nursery process is assumed to be a small- to medium-scale enterprise producing roughly 240,000 rimu seedlings per year (K. Te Kani, pers. comm., October 8 2014).
        - The nursery data includes both capital expenditure and operational costs.
        - The life of the nursery is assumed to be 50 years and so all figures are divided by and associated to the total number of seedlings produced over 50 years (i.e. 50 years x 240,000 seedlings per year = 12,000,000 seedlings).
    - Costs and profit, and employment:
        - Total capital costs are estimated to be $492,195 (or $9,844 per year), and total running costs are estimated to be $326,451 per year (K. Te Kani, pers. comm., October 8 2014).
        - Total cost per seedling (inclusive of materials and labour) is $1.40 (K. Te Kani, pers. comm., October 8 2014).
        - Employment and wages are inclusive of a full-time nursery manager ($60,000/year salary), full-time nursery technician ($40,000/year salary), one additional full-time staff (for manual tasks; $14.25/hour wage), and four part-time seasonal casual staff ($14/hour wage; 180 days each per year) (K. Te Kani, pers. comm., October 8 2014).

- ***Site preparation***
    - Site preparation details:

        - In the rimu scenario, site preparation process was assumed to utilise minimal intensive techniques. Thus, rimu site preparation involved initially hand spraying the land with an herbicide to desiccate the existing grasses and shrubs.
        - Mechanical preparation of the soil was avoided in favour of the less mechanically intensive (albeit more labour intensive) process of 'screefing' (i.e. "removal of the surface vegetation with a spade or grubber to expose the soil" (Douglas et al. 2007, p. 146).
        - In this scenario, it was assumed that fertiliser was not required.
    - Costs and profit, and employment:
        - Herbicides are estimated to cost $20 per hectare (G. Steward, pers. comm., November 19 2014).
        - Hand spraying of herbicides requiring 3.5 hours per hectare ($18/hour wage) (G. Steward, pers. comm., November 19 2014).
        - Screefing and mulching (of removed surface vegetation) requires 7.7 hours per hectare ($18/hour wage) (G. Steward, pers. comm., November 19 2014).
        - The site preparation cost per hectare associated with the Cultural Compliance process is $1.65.
        - The site preparation employment per hectare associated with the Cultural Compliance process is 0.02 hours.

- ***Planting***
    - Planting details:
        - The planting process includes only the labour cost of planting 1,100 stems per hectare.
        - The cost of the seedlings was accounted for during the nursery process so, to avoid double counting, the seedling cost is not also included during the planting process.
    - Costs and profit, and employment:
        - It takes an employee approximately one minute to plant one rimu seedling ($20/hour wage), or 17.97 hours to plant 1,100 rimu seedlings per hectare.
        - The planting cost per hectare associated with the Cultural Compliance process is $1.47.
        - The planting employment per hectare associated with the Cultural Compliance process is 0.02 hours,

- ***Tending***
    - Tending details:
        - The tending process involves the management, protection, and maintenance of the forest throughout its 120-year growth.
        - Rimu tending was assumed to include weed control (via hand weeding) only during the first three years after the initial planting, tree inventory assessment (i.e. determining the value of the standing forest) two years before a selective harvest, and the annual activities of forest management, rates (land tax) and fire insurance, fence and track maintenance, and animal (pest) control that occur throughout the 120-year rimu "rotation".
        - The tending activities included the processes of installation of in-forest roading and landing sites (i.e. cleared areas where felled trees are processed and prepared for transport). These activities occur before the first selective harvesting process at year 78 in preparation for the first selective harvesting activities. Maintenance of roading and landing sites occurs two years before subsequent selective harvestings.

    - Roading external to the forest was excluded as it was assumed that no additional infrastructure was required.
    - Hand weeding occurs twice a year in years 1, 2, and 3 after planting, and incurs only labour-related costs.
    - Replacement of dead seedlings ("blanking") occurs once in year 1 after planting. Mortality is assumed to be 5% of the initial 1,100 seedlings planted per hectare, or 55 seedlings. It is assumed that no further mortality occurs (G. Steward, pers. comm., November 19 2014). In order to bolster natural regeneration, this planting activity of 55 seedlings is also assumed to occur in the first year after selective harvestings in years 81, 91, 101, and 111.
    - There are no significant diseases currently affecting rimu; therefore, no disease management costs have been included in this process.
    - Continuous cover rimu forestry is assumed to require less in-forest roading than clearfelled radiata pine. In-forest roading costs and figures are based on the radiata pine scenario but it is estimated that rimu forestry will only require 5 metres of in-forest roading per hectare i.e. 1/8th of the roading required in radiata pine plantations (S. Hill, pers. comm., March 12 2014).
    - The landing construction process costs and figures are based on those of the radiata pine scenario but have been proportionally decreased in alignment with a lesser amount of rimu volume extracted per hectare than radiata pine. In other words, a landing site for continuous cover forestry rimu (which only fells 20% of the trees per hectare) will require a smaller landing site. Approximately 8.6 hectares of forest will be served by each landing site.
    - Quarrying for the gravel (used for in-forest roading and landing construction) has been excluded from this assessment as it is outside the system boundaries.
- Costs and profit, and employment:
    - Hand weeding time per seedling is estimated to require 1.4 minutes in year 1, 1 minute in year 2, and 0.5 minutes in year 3; as the seedling matures it is able to out-compete weeds and grasses (G. Steward, pers. comm., November 19 2014).
    - Hand weeding labour ($18/hour wage) is inclusive of mortality rates and estimated weeding times varying by year of seedling growth.
    - Weeding labour in year 1 is 48.77 hours per hectare, in year 2 is 36.67 hours per hectare, and in year 3 is 18.33 hours per hectare (G. Steward, pers. comm., November 19 2014).
    - Replacement ("blanking") labour requires 0.92 hours per hectare (G. Steward, pers. comm., November 19 2014).
    - Cost of replacement seedlings is included in the nursery process.
    - An overall salary for a forest manager to manage a forest is $80,000 per year (based on a forest estate size of 5,000 hectare) (P. Hall, pers. comm., 15 March 2014).
    - Forest management is estimated to account for two hours of employment per hectare per year (P. Hall, pers. comm., 15 March 2014).
    - Employment related to rates (i.e. land value tax) and fire insurance are excluded due to its minimal impact on the life cycle indicators.
    - Both a) fence and track maintenance and b) animal (pest) control are assumed to employ workers with an hourly wage of $18, and require approximately nine minutes per hectare per year and three minutes per hectare per year respectively (P. Hall, pers. comm., 15 March 2014).

- The inventory process involves sampling forest sites within a stand to determine its quality and projected value. This process is estimated to take one worker ($20/hour wage) 30 minutes per hectare to survey (P. Hall pers. comm., 15 March, 2014).
- The in-forest roading construction workers ($30/hour wage) install 5 metres of roading per hectare in 0.79 hours (S. Hill, pers. comm., March 12 2014). Subsequent selective harvestings assume that only roading maintenance, not installation, is required. Roading maintenance is assumed to occur 2 years before selective harvesting and involves half the cost and time as installation.
- The landing site construction workers involved ($30/hour wage) require nearly 12.54 hours to complete one landing site, or 1.46 hours per hectare. Subsequent selective harvestings assume that only landing maintenance, not installation, is required. Landing maintenance is assumed to occur 2 years before selective harvesting and involves half the cost and time as installation.
- The rimu landing site is estimated to cost approximately 19% of the radiata pine landing site i.e. $285 per hectare (S. Hill, pers. comm., March 12 2014).
- An opportunity cost of $1,040 per hectare per year was applied based on current average flat land valuations in the case study region of Gisborne.
- The tending cost per hectare associated with the Cultural Compliance process is $232, and represents the annual cost of protecting the environment through Kaitiakitanga.
- The tending employment per hectare associated with the Cultural Compliance process is 1.20 hours, and represents the annual cost of protecting the environment through Kaitiakitanga.

- ***Form pruning***
  - Form pruning details:
    - The form pruning process ensures that each tree grows with a single, straight stem and removes any steep-angled branches which may impact upon timber quality as the tree matures.
    - Form pruning occurs three times during the initial growth phase of planted rimu: at year 8 to remove steep-angled branches and double leaders (i.e. one tree growing two stems), and at years 18 and 28 to raise branch height (G. Steward, pers. comm., November 19 2014). It is not assumed to occur after subsequent selective harvesting with the naturally regenerating trees.
  - Costs and profit, and employment:
    - It is estimated that a worker ($18/hour wage) requires approximately 7.34 minutes to form prune each tree, or 134.59 to form prune one hectare of planted rimu (G. Steward, pers. comm., November 19 2014).

- ***Selective felling***
  - Selective felling details:
    - The selective felling process involves the partial harvesting of a rimu stand (i.e. 20% per hectare).
    - The total standing volume at the time of the first selective felling at year 80 is estimated at 400 m^3 per hectare (G. Steward, pers. comm., November 19 2014), thus 80 m^3 was selectively felled at year 80. Subsequent selective harvestings at years 90, 100, 110, and 120 each fell 80 m^3.

        - Selective felling involves three activities: surveying the stand before felling and marking the trees to be felled, felling the marked trees with a chainsaw, and cutting the felled trees into suitable logs for subsequent helicopter removal. 1 m^3 is assumed to be harvested softwood under bark.
    - Costs and profit, and employment:
        - Surveying the stand and marking which trees are to be felled takes two workers ($22/hour wage) one hour per hectare.
        - Felling each marked tree and cutting it to allow for helicopter extraction are both done with a chainsaw. Each of these activities require 0.04 hours per m^3, or 0.08 hours per m^3 in total (J. Dronfield, pers. comm., March 18 2014). Over 120 years, the total felled per hectare is 400 m^3. Therefore, the total employment per hectare from felling is 31.37 hours.
        - The Cultural Compliance cost per 400 m^3 of rimu timber is $9.28.
        - The Cultural Compliance employment per 400 m^3 of rimu timber is 0.16 hours.

- ***Extraction***
    - Extraction details:
        - The extraction process involves removing the felled stems (via helicopter) from the site and depositing them at the landing site for further handling.
        - A proportion of the original felled volume (i.e. 400 m^3 per hectare over 120 years) is left on-site and may include material from the tree tops and branches.
        - It is assumed that there is less wastage with rimu harvesting than with radiata pine due to the extra care that would be taken during the felling process; minimisation of wastage increases the recoverable volume of each tree and thus increases the attainable value from each tree.
        - It is estimated that 9% (approximately 7 m^3) of the total standing volume is woody material left on-site; therefore, the amount of m^3 actually handled during extraction is 73 m^3.
    - Costs and profit, and employment:
        - Employment requires two pilots ($175/hour wage), a fuel truck driver ($22/hour wage), and an engineer ($30/hour wage) (J. Dronfield, pers. comm., March 18 2014).

- ***Landing site***
    - Landing site details:
        - During each selective felling, it is estimated that 4% of the original volume deposited at the landing site (73 m^3) is left on-site, thus amounting to 3 m^3 left at the landing site (P. Hall, pers. comm., 15 March 2014). This loss of volume is attributed to the log making process and any stem breakage that may occur during handling.
        - It is assumed that the operation of "log making" at the landing site is not required as the logs are cut to transport size in the forest for helicopter extraction. Thus, the landing site process for the rimu scenario includes only the loading operation (J. Dronfield, pers. comm., March 18 2014).
    - Costs and profit, and employment:
        - Three loading operators ($18.50/hour wage) are required for this process (P. Hall, pers. comm., 15 March 2014).

        - It is estimated that loading for one m^3 takes 2.16 minutes; therefore, the felled rimu material (73 m^3) takes approximately 2.6 hours to process through the landing site (P. Hall, pers. comm., 15 March 2014).

- ***Timber transport***
    - Timber transport details:
        - The logs are transported to a sawmill.
        - The volume transported per hectare is 70 m^3 (i.e. the remaining volume after harvesting and landing site operations).
        - Although a given rimu stem consists of both sawlog and pulp wood, it is assumed that all of the wood is transferred to the same sawmill.
        - Subsequent processing of the logs in the sawmill yard is excluded from the assessment due to its anticipated insignificant contribution to the indicator results.
        - One m^3 of rimu is approximately equivalent to one tonne of rimu (New Zealand Institute of Forestry, 2005).
        - The transport distance (one-way) is assumed to be 86 km (NZ FOA Transport Authority 2007).
        - The logging truck is assumed to be a 6x4 truck with a 4-axle trailer. The unloaded weight is 14.5 tonnes and a log payload weight of 29.5 tonnes, thus the total logging truck weight is 44 tonnes.
    - Costs and profit, and employment:
        - The timber truck driver ($30/hour wage) requires 7.2 minutes per m^3 (3.54 hours per loaded truck) to travel from the landing site to the sawmill gate.

Mānuka scenario – flat land

- ***Nursery***
    - Nursery details:
        - Mānuka seedlings are produced in a nursery and take 12 months to grow from a seed to seedlings ready for planting.
        - Nurseries primarily use fungicides and pesticides, electricity for heating the greenhouse, and diesel for operating the tractors on-site.
        - The nursery process is assumed to be a small- to medium-scale enterprise producing roughly 300,000 mānuka seedlings per year (K. Te Kani, pers. comm., October 8 2014).
        - The nursery data includes both capital expenditure and operational costs.
        - The life of the nursery is assumed to be 50 years and so all figures are divided by and associated to the total number of seedlings produced over 50 years (i.e. 50 years x 300,000 seedlings per year = 15,000,000 seedlings).
        - The amount of mānuka seedlings required for one hectare of land is 15,000 seedlings (for the initial planting) and, over the 15-year mānuka rotation, approximately 10,000 additional seedlings will be required to replace any dead seedlings (P. Caskey, unpublished data, February 2 2015).
        - Requirements for replacing dead seedlings are based on annual mortality rates that are assumed to be 10% (1,500 seedlings) in year two, 7% (1,050 seedlings) in year three, and 5% (750 seedlings) every year thereafter (P. Caskey, unpublished data, February 2 2015).
    - Costs and profit, and employment:
        - Total capital costs are estimated to be $492,195 (or $9,844 per year), and total running costs are estimated to be $326,451 per year. Total cost per seedling

(inclusive of materials and labour) is $1.12 (K. Te Kani, pers. comm., October 8 2014).
        - Employment and wages are inclusive of a full-time nursery manager ($60,000/year salary), full-time nursery technician ($40,000/year salary), one additional full-time staff (for manual tasks; $14.25/hour wage), and four part-time seasonal casual staff ($14/hour wage; 180 days each per year) (K. Te Kani, pers. comm., October 8 2014).

- ***Site preparation***
    - Site preparation details:
        - Site preparation involves spraying the land to kill existing vegetation, and mechanical preparation of the soil.
        - In this scenario, it was assumed that fertiliser was required and thus includes an initial soil analysis process and subsequent application of (urea) fertiliser.
        - Irrigation was assumed to not be required.
        - The mechanical soil preparation is assumed to be required (on average) on 8% of the area being established (P. Hall, pers. comm., 15 March 2014).
        - The helicopter pilot can spray 52 hectares of flat land per hour (Anonymous industry expert, pers. comm., 10 March 2014).
    - Costs and profit, and employment:
        - Soil analysis is estimated to cost $34 per hectare, and requires approximately 0.85 hours ($20/hour wage) (Lawrence 2013).
        - Fertiliser requirements are based on recommendations from Donaghys (2014) and include 80kg of urea per hectare at a cost of approximately $69 per hectare.
        - It is assumed that a worker requires 0.25 hours ($18/hour wage) to apply fertiliser on one hectare using a 45 kW tractor.
        - The process of herbicide application requires a helicopter pilot ($175/hour wage) and a support technician to mix the herbicide chemicals ($35/hour wage) for a combined time of 0.06 hours per hectare.
        - Assuming 8% of the hectare requires mechanical soil preparation, an excavator operator ($18/hour wage) can process one hectare in 0.19 hours (Anonymous industry expert, pers. comm., 10 March 2014).
        - The site preparation cost per hectare associated with Cultural Compliance is $1.65.
        - The site preparation employment per hectare associated with Cultural Compliance is 0.02 hours.

- ***Planting***
    - Planting details:
        - The planting process includes only the labour cost of planting the initial 15,000 seedlings per hectare.
        - The cost of the seedlings was accounted for during the nursery process so, to avoid double counting, the seedling cost is not also included during the planting process.
    - Costs and profit, and employment:
        - Planting times are based on those of radiata pine, namely that it takes 35 seconds to plant one seedling (P. Hall, pers. comm., 15 March 2014).
        - Therefore, to plant 15,000 seedling per hectare requires approximately 145 hours ($20/hour wage).
        - The planting cost per hectare associated with Cultural Compliance is $1.47.

        - The planting employment per hectare associated with Cultural Compliance is 0.02 hours.

- ***Tending***
    - Tending details:
        - The tending process includes weed control (aka – "releasing") using herbicides via helicopter, disease control of mānuka blight from the scale insect (*Eriococcus orariensis* Hoy) via hand spray, replacement of dead seedlings (aka – "blanking"), and the annual activities of fertiliser application, rates and fire insurance, fence and track maintenance, and animal (pest) control.
        - No in-forest construction for landing sites and roading infrastructure is required for the mānuka scenario.
        - Weed control ("releasing") occurs three times during years one, two, and three. The helicopter pilot can spray 52 hectares of flat land per hour for weed control purposes.
    - Costs and profit, and employment:
        - Mānuka blight spray to combat the scale insect occurs every year during the mānuka rotation. It is assumed that approximately half of the hectare will require hand spraying; therefore, it takes 1.75 hours ($18/hour wage) to hand spray one hectare (P. Caskey, unpublished data, February 2 2015).
        - An opportunity cost of $1,040 per hectare per year was applied based on current average flat land valuations in the case study region of Gisborne.
        - Further soil analysis occurs annually and is estimated to cost $34 per hectare, and requires approximately 0.85 hours ($20/hour wage) (Lawrence 2013).
        - Annual urea fertiliser treatment is assumed to be required but at half the intensity of the initial application. Thus, the materials cost is approximately $26 per hectare and it requires 0.13 hours ($18/hour wage) to apply fertiliser on one hectare using a 45 kW tractor.
        - Wages for aerial spraying are inclusive of a helicopter pilot ($175/hour wage) and a support technician to mix the herbicide chemicals ($35/hour wage) (L. Bulman, pers. comm., 3 March 2014).
        - Employment related to rates (i.e. land value tax) and fire insurance are excluded due to its minimal impact on the life cycle indicators.
        - Both a) fence and track maintenance and b) animal (pest) control are assumed to employ workers with an hourly wage of $18, and require approximately nine minutes per hectare per year and three minutes per hectare per year respectively (P. Hall, pers. comm., 15 March 2014).
        - The tending cost per hectare associated with Cultural Compliance is $29, and represents the annual cost of protecting the environment through Kaitiakitanga.
        - The tending employment per hectare associated with Cultural Compliance is 0.15 hours, and represents the annual cost of protecting the environment through Kaitiakitanga.

- ***Harvesting and transport of branches***
    - Harvesting and transport details:
        - The harvesting of branches process occurs annually after the flowers have dropped from the mānuka tree (typically in February or March).

        - Harvesting (or trimming) of each mānuka tree removes 2/3 of the total branch material.
        - Harvesting is done with the simultaneous operation of a forage harvester and a truck with trailer. The forage harvester cuts and immediately deposits material into the trailer. Therefore, the harvesting and transport processes have been combined in this scenario; there is no additional transport process required.
        - The average amount of branch material trimmed each year is 3 kg per mānuka plant, or 34 tonnes per hectare (P. Caskey, unpublished data, February 2 2015).
        - Over the 15-year rotation, 544 tonnes of branch material is harvested per hectare.
    - Costs and profit, and employment:
        - It is estimated that a worker ($25/hour wage) requires 1 hour to harvest one tonne of branch material (P. Caskey, unpublished data, February 2 2015).
        - Normally, royalties are paid to the land owner at a rate of $100 per tonne of branch material. However, in this research it is assumed that the land owner is the main "entity" (encapsulating the nursery, distillation, and packaging facilities); thus, land owner royalties were not included in this assessment.
        - The harvesting cost per hectare associated with Cultural Compliance is $9.28.
        - The harvesting employment per hectare associated with Cultural Compliance is 0.16 hours.

- ***Distillation***
    - Distillation details:
        - The distillation process involves steam distilling the mānuka branch material to produce mānuka essential oil.
        - Approximately 3.5 kg of essential oil is produced for every tonne of mānuka branch material distilled (P. Caskey, unpublished data, February 2 2015).
        - Therefore, if 544 tonnes of mānuka branch material is produced during one 15-year rotation, then 1,904 kg of essential oil is created during the distillation process.
    - Costs and profit, and employment:
        - A distillation plant has a capital cost of $100,000 and a running cost (over the 25-year life span) of approximately $363,000. The plant includes two "cooker" machines for the distillation process. One tonne of branch material can be processed in each distillation "cook" (P. Caskey, unpublished data, February 2 2015).
        - Employment is inclusive of two distillation "cooks" per day with each "cook" requiring four hours. Workers receive $25/hour wage (P. Caskey, unpublished data, February 2 2015).
        - One kg of essential oil was assumed to be worth $325 (P. Caskey, unpublished data, February 2 2015).
        - The distillation cost per hectare associated with Cultural Compliance is $4.96.
        - The distillation employment per hectare associated with Cultural Compliance is 0.06 hours.

Steep-land life cycle inventory data

A steep-land sensitivity analysis was performed on the radiata pine and rimu scenarios, and used some different data to the data noted above (which represents flat land). The forestry processes that required steep-land data for the sensitivity analysis were: site preparation (spraying, aerial spraying, mechanical preparation, screefing/mulching, land rental), planting, tending (releasing (i.e. herbicide management, hand weeding, blanking (i.e. replacement of dead seedlings), marking trees for felling), thinning (to waste), form pruning, felling, extraction, skid site (log making and loading), landing construction, and roading construction.

In most instances, the main differing factor between the flat- and steep-land data is the time it takes to perform a process. Therefore, to avoid repetition, only the pertinent differences between flat- and steep-land data are presented below.

Radiata pine scenario (steep land)

- ***Site preparation***
  - Aerial spraying can cover 40 hectares of steep land per hour (instead of 52 hectares per hour on flat land) (Anonymous industry expert, pers. comm., 10 March 2014).
  - Mechanical preparation takes 1.5 times as long as on flat land (P. Hall, pers. comm., 15 March 2014).
  - Opportunity cost on steep land is $208 (rather than $1,040 on flat) due to its significantly lower land value and limited viability for other land uses (P. Hall, pers. comm., 15 March 2014).
- ***Planting***
  - Planting takes 1.5 times as long as on flat land (P. Hall, pers. comm., 15 March 2014).
- ***Tending***
  - Releasing via helicopter can cover 40 hectares (as noted in “site preparation” above) (Anonymous industry expert, pers. comm., 10 March 2014).
- ***Thinning (to waste)***
  - Thinning is assumed to take 1.5 times as long as on flat land (P. Hall, pers. comm., 15 March 2014).
- ***Felling***
  - Total felling cost is 5.6% of total harvesting cost of $8,904 (P. Hall, pers. comm., 15 March 2014).
  - One person is required for felling with a chainsaw with an employment rate of 0.025 hours per m^3.
- ***Extraction***
  - Total extraction cost is 31.8% of total harvesting cost of $8,904 (P. Hall, pers. comm., 15 March 2014).
  - Three people are required for extraction with a cable hauler with an employment rate of 0.075 hours per m^3 (P. Hall, pers. comm., 15 March 2014).
- ***Log making at skid site***
  - Total log making cost is 28% of total harvesting cost of $8,904 (P. Hall, pers. comm., 15 March 2014).
  - Five people are required for log making with a chainsaw with an employment rate of 0.125 hours per m^3 (P. Hall, pers. comm., 15 March 2014).
- ***Loading***
  - Total loading cost is 34.6% of total harvesting cost of $8,904 (P. Hall, pers. comm., 15 March 2014).

- Six people are required for log making with excavator loaders with an employment rate of 0.15 hours per m^3 (P. Hall, pers. comm., 15 March 2014).

- ***Landing construction***
  - Landing construction is assumed to take 1.5 times as long as on flat land (S. Hill, pers. comm., March 12 2014).
- ***Roading***
  - There are various costs attributed to roading on steep land such as: machine cost = \$960 (using \$24/m for construction), gravel cost = \$1000 (assuming \$25/m3 gravel), gravel cartage cost = \$710 (assuming \$0.5/km x 60km), spread and roll machine cost = \$200 (assuming \$5/metre). The total cost of roading per hectare is \$3,656 (S. Hill, pers. comm., March 12 2014).
  - Employment is approximately 10 hours per hectare (S. Hill, pers. comm., March 12 2014).

Rimu scenario (steep land)

- ***Site preparation***
  - Hand spraying is assumed to take 1.5 times as long as on flat land (G. Steward, pers. comm., 19 November 2014).
  - Screefing/mulching is assumed to take 1.5 times as long as on flat land (G. Steward, pers. comm., 19 November 2014).
  - Opportunity cost on steep land is \$208 (rather than \$1,040 on flat) due to its significantly lower land value and limited viability for other land uses (P. Hall, pers. comm., 15 March 2014).
- ***Planting***
  - Planting takes 1.5 times as long as on flat land (G. Steward, pers. comm., 19 November 2014).
- ***Tending***
  - Hand weeding occurs in years 1, 2, and 3. Costs and employment are based on the average weeding time required per plant: 1.4 minutes in year 1, 1 minute in year 2, and 0.5 minutes in year 3 (G. Steward, pers. comm., 19 November 2014).
  - Mortality for steep land seedlings is 7% in both years 1 and 2 (G. Steward, pers. comm., 19 November 2014).
  - Blanking (replacing dead seedlings) is required in years 1 and 2, and requires 1 minute to replace each dead seedling (G. Steward, pers. comm., 19 November 2014).
- ***Form pruning***
  - Form pruning occurs 3 times over the rotation and requires 139.5 hours of employment per hectare.
- ***Marking trees for felling***
  - Marking takes 1.25 times as long as on flat land (J. Dronfield, pers. comm., 18 March 2014).
- ***Felling***
  - Felling takes 1.25 times as long as on flat land (J. Dronfield, pers. comm., 18 March 2014).
  - A chainsaw is used to fell on steep slopes.
- ***Extraction via helicopter***
  - Increased hindrance factor so slower turn times (i.e. the time it takes for the helicopter to extract timber, drop it at the skid site, and return to harvested area). Assumed 15 turns are made on steep land (instead of 19 on flat land) (J. Dronfield, pers. comm., 18 March 2014).
  - Employment required is 0.05 hours per m^3.

- ***Loading***
    - Loading takes 1.25 times as long as on flat land (J. Dronfield, pers. comm., 18 March 2014).
- ***Landing construction and Roading***
    - Same as in the radiata pine steep-land data

Data exclusions, inclusions, and other considerations

There are a number of data and assumptions that are applicable to several processes throughout each scenario; instead of repeating these data throughout the appendix they are listed below.

- General details:
    - All helicopter usage was assumed to use an Iroquois helicopter.
    - This LCSA is not site-specific so all costs and figures are based on averages for New Zealand, or, where possible, for the Gisborne case study region.
- Costs and profit, and employment:
    - Employee travel to and from their working location (e.g. forest site, sawmill, house construction site) was excluded as per the PAS 2050 guidelines (BSI 2011, p. 17).
    - All costs are presented in New Zealand dollars.
    - The social, environmental, and cultural impacts associated with creating the machinery used (e.g. excavators, helicopters, chain saws, timber trucks) in the life cycles were excluded as this was outside the system boundaries for the analysis. The exclusion of GHG emissions associated with such capital goods aligns with the PAS2050 guidelines (BSI 2011).
    - The capital (economic) costs associated to the creation of the main building structures (i.e. nursery in the radiata pine and rimu life cycles, and nursery and distillation plant in the mānuka life cycle) were included. Only these main building structures were included due to their sizable capital investment requirements, without which the LCC component of these processes would be underrepresented.
    - Capital depreciation and interest costs as well as material costs are embedded in the overall costs of each process.
    - Labour overheads are included in the overall labour cost of each process. The wage and salary figures noted in the process descriptions do not include overheads.

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