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Front cover photo: The Woodhill Long-Term Site Productivity trial at end of rotation. The trial was installed in 1986 with a range of harvest removal treatments from stem only removal through to whole tree plus forest floor removal. Photo courtesy of Loretta Garrett, Scion

Back cover photo: The Woodhill Long-Term Site Productivity trial and sampling tree biomass at end of rotation. Photo courtesy of Stephen Pearce, Scion

Long-term thinking, resilience and doing forestry differently

Adam Forbes

In forestry, today's decisions shape the future issues we will face and our ability to address them. Given our uncertain future, now is the time to challenge the status quo in Aotearoa New Zealand's forestry. What future will we choose, and which legacies will we leave?

In this August edition, the benefits of long-term forestry trials are seen in Aotearoa and the Solomon Islands. Garrett et al. report on the Puruki forestry experiment established in response to the United Nations Hydrological Decade (1965–1974). This is an exemplary paired catchment trial looking into water yield and productivity, nutrition and carbon sequestration. A productive trial, over its 50-year duration, 67 articles have been published. This work shows the enormous value of long-term investment in forestry research.

Today we are at the outset of the important UN Decade on Ecosystem Restoration (2021–2030), where the focus is on halting ecosystem degradation and restoring ecosystems to achieve global goals to benefit people and nature. Through work on global Sustainable Development Goals, scientists have identified that this decade is our last chance to prevent catastrophic climate change. We need to assess how our forestry models perform in terms of ecosystem degradation and restoration and adapt to achieve a sustainable future.

Papers in this issue demonstrate the value of longitudinal forestry studies. Forestry is key to restoring Aotearoa species and ecosystems. Diverse and resilient forests are central to addressing our biodiversity and climate crises. However, we need to understand growth and community dynamics in planted and naturally established native stands and in mixed stands of exotic and native species. Unless we invest in native forest research, as we have with exotic species, this direction will not eventuate.

Clinton et al. highlight the rarity of long-term trials in the context of the sustainability of biomass (forestry crop and/or residues) removal in forestry. Their work highlights the need for site-specific management strategies to inform the use of residues. One important application is in the context of bioenergy to reduce reliance on fossil fuels and the need to keep biomass removal research going over future rotations. They observe the preferred use of site resources, such as those contained in the forest floor, over the use of supplementary mineral fertilisers.

From Northland, Satchell presents an economic analysis of environmental outcomes and economic returns from converting steep erodible farmland to forestry. Comparing the performance of rotational radiata pine with permanent tōtara forest, he presents an alternative to rotational radiata pine where continuous cover tōtara forest, grown under a nurse crop of mānuka, provides an early income from honey harvest while the tōtara matures for a sustainable harvest. Furthermore, the forest would provide a passive income through the Emissions Trading Scheme. This approach to forestry would deliver multiple outcomes, resilience and is consistent with the direction of the current UN Decade.

In their contribution on the importance of psychosocial factors in forestry health and safety, Cawood et al. state that resilience can come from embracing the variability in human attitudes. They note that forestry and logging have the highest fatality rate across all of Aotearoa's occupational groups. Their work explores the effects of psychosocial factors on workplace behaviours in the context of unsafe actions. They suggest that variability in human attitudes and performance can be valued positively and adds resilience to safety, as opposed to seeing human variability as a liability that should be prevented as far as possible.

Lastly, from the Solomon Islands, where the Government is looking strategically at the forestry sector and where forestry makes up a large proportion of the economy, Cornelio reports on the growth performance of four commonly planted exotic timber species. Importantly, the work highlights alternatives to the status quo. He identifies options for interplanting native fast-growing hardwoods into teak stands to provide an early income after only several years, and using native rather than exotic species, polycultures rather than monocultures, plantations to facilitate natural understorey regeneration, and boosting compositional and structural diversity in plantations to enhance wildlife habitats.

Interestingly, Cornelio notes that in the Solomons native trees are seen as a risky option in forestry due to limited knowledge about species performance – a situation similar in Aotearoa. The direction given to the Government by the recent Climate Change Commission's recommendations suggest native forestry must become more prominent, but due to our focus on exotic forestry we are in a position where we lack knowledge of native forestry. We can change this if we choose to, and we must.

We need to regard forests broader than purely in an economic sense. Productivity measurements must include human and environmental wellbeing. Forest research and practice must achieve a balance between economic and environmental outcomes.

Puruki Experimental Forest – half a century of forestry research

Loretta Garrett, Steve A. Wakelin, Stephen Pearce, Steve J. Wakelin and Tim Barnard

Abstract

Puruki Experimental Forest (PEF) is a second rotation *Pinus radiata* forest located in the Central North Island, New Zealand. It has been a showcase for leading forest science for over 50 years. PEF is part of the Purukohukohu paired land use catchment study installed in 1968 by the Department of Lands and Survey, the Ministry of Works Water and Soil Division, and the New Zealand Forest Research Institute of the New Zealand Forest Service. From the outset, PEF was visionary in ambition and scope and founded on interagency collaboration and support. Since establishment, PEF has provided valuable longitudinal data sets and the importance of these has increased over time. Data from PEF has been used to build and parameterise tools and models adopted by the forest sector and government agencies, particularly associated with carbon and nutrition, productivity models, genetics, disease and growth, and hydrological modelling and water quality assessments. PEF has underpinned much of our knowledge on how to design and sustainably manage a highly productive planted forest, whilst delivering wider forest benefits and ecosystem services to society. PEF is now nearing the end of its second rotation. The next phase offers a new opportunity to extend the legacy of PEF by undertaking ambitious, ecosystem-level research for the benefit of New Zealand.

The story of Purukohukohu Basin and PEF

In 1968, the Department of Lands and Survey, the Ministry of Works Water and Soil Division, and the New Zealand Forest Research Institute (NZFRI) of the New Zealand Forest Service established a significant research programme in the Purukohukohu Basin in the Paeroa Ranges of the Central North Island. The site was established under the umbrella of the International Hydrological Decade (1965–1974), a United Nations Educational, Scientific and Cultural Organisation (UNESCO) initiative to address a global decline in freshwater resources (Nace, 1964). This collaboration led to the design and implementation of an ambitious long-term research programme that sought to understand the effects of land use change on local hydrology and volcanic soils (Beets & Brownlie, 1987; Tustin, 1987).

The Purukohukohu Basin included paired catchments comprising native forest, pasture and pine forest planted into pasture – the Puruki Experimental Forest (PEF) catchment. Each catchment was similar for slope, aspect, soils, area and climate. Native forest had been removed from PEF and paired pasture catchments in the 1920s and the land had reverted to scrub. In 1957, the pasture was restored and improved with the application of super phosphates. This investment of fertiliser was to play a significant part in the research history of the site.

The interest of the NZFRI (now Scion) focused on productivity and dry matter production in the planted pine catchment. Today, the site is managed by Scion under lease from Pāmu (Landcorp) Farms. The original research agenda can be considered visionary in ambition and scope (Tustin, 1987). Fifty years on, PEF has delivered longitudinal data sets that have grown increasingly important over time and remain very relevant to the challenges we face today. The value of PEF goes well beyond the forestry sector to others actively engaged in sustainable land management:

> *'The commendable foresight of those involved in the Puruki research site is proving invaluable to those involved in forestry, agriculture and conservation alike. Having almost 50 years of scientific data measuring the interaction of forestry and agriculture on our waterways as well as nitrogen leaching and carbon sequestration is arguably more relevant today than they were when the Puruki trial was established. Pāmu are proud to be involved and remain committed to our role in continuing the legacy of Puruki.'*
>
> Andrew Sliper, General Manager (Pers comm)

PEF site and its management history

PEF lies on pumice soil with underlying ignimbrite and is typical of much of the Central North Island (Figure 1). In 1968, the three paired land use catchments were established, of which PEF was a total of 34.4 ha (Beets & Brownlie, 1987). The original pasture was restored after significant scrub encroachment and managed as a dry stock pastoral farm. In 1973, PEF was aerially sprayed to control weeds and planted with *Pinus radiata* 'GF7' (Growth and Form 7; GF rating scale) seedlot at 2,200 stems/ha (SPH).

PEF itself is made up of three sub-catchments and these delimited a thinning treatment in the first rotation imposed over the trial, with the sub-catchments 'tahi, rua and toru' stocked to final crop stocking of 550, 180 and 60 SPH, respectively (Beets & Oliver, 2007). The site received regular spraying with copper through the rotation to control dothistroma needle blight, a foliar disease caused by the pathogen *Dothistroma septosporum*.

During the first rotation research focused on forest water use, stream water chemistry, stand volume growth, biomass and nutrient uptake and cycling, forest floor accumulation, leaf area, needle retention, foliar disease, foliar nutrient status and soil chemistry. In 1976, a meteorological station tower was erected to collect climate data (Beets & Brownlie, 1987). The first rotation was harvested in 1997 aged 24 years. Two sub-catchments (180 and 550 SPH) were harvested with ground-based operations and the third (60 SPH) using a hauler system (Oliver et al., 2004).

The second rotation forest was planted soon after logging the first rotation. The second rotation PEF was established with a focus on: (1) genetic heritability of upper mid-crown yellowing (UMCY – an expression of tree magnesium deficiency (Beets & Jokela, 1994)); (2) productivity on low and high solar radiation aspects; (3) productivity between improved genotypes; (4) a later focus on the use of LiDAR to monitor forest carbon stocks; and (5) improvement of allometrics for calculating carbon stocks.

A single post-planting herbicide spot-spraying operation was used to control weeds. The experimental trials (12.5 ha) were established with a variety of *P. radiata* stock and stocking rates, medium and high pruned, one trial thinned and the rest of the trials were un-thinned (Beets et al., 2011b). The remainder of PEF (21.9 ha) was planted at 500 SPH using a mix of genotypes, medium and high pruned (350 SPH) and left un-thinned. The site received two copper sprays at tree age seven and nine years old.

PEF – a legacy of science impact

PEF has been an experimental forest since 1973 and is a unique resource for ecosystem-level research within New Zealand. Over many decades, PEF has deepened our understanding of watershed-level hydrology as well as forest health and productivity. This makes PEF a rare and valuable resource for this country, delivering far more than its original mandate when established under the United Nations Decade of Hydrology.

Also, data from PEF has been invaluable in the development and parameterisation of carbon and nutritional models for New Zealand's planted forests. It has provided new knowledge about the role and interaction of genetics, nutrition and growth, and forest productivity, nutrient flow, carbon balances, hydrological cycles and water quality. All of this has been made possible through visionary leadership that recognised the need for long-term forestry research in New Zealand, supported by continued investment into the maintenance of trials and ongoing data collection.

As we face an uncertain future in a changing climate, the demand for more experimental forests across various ecological zones throughout New Zealand is increasing. To achieve this, collaboration and an intentional move toward partnership and long-term environmental research investment is required. This is a need highlighted by the Parliamentary Commissioner for the Environment in a review of environmental research in New Zealand in 2020 (PCE, 2020).

Figure 1: Puruki Experimental Forest 1981

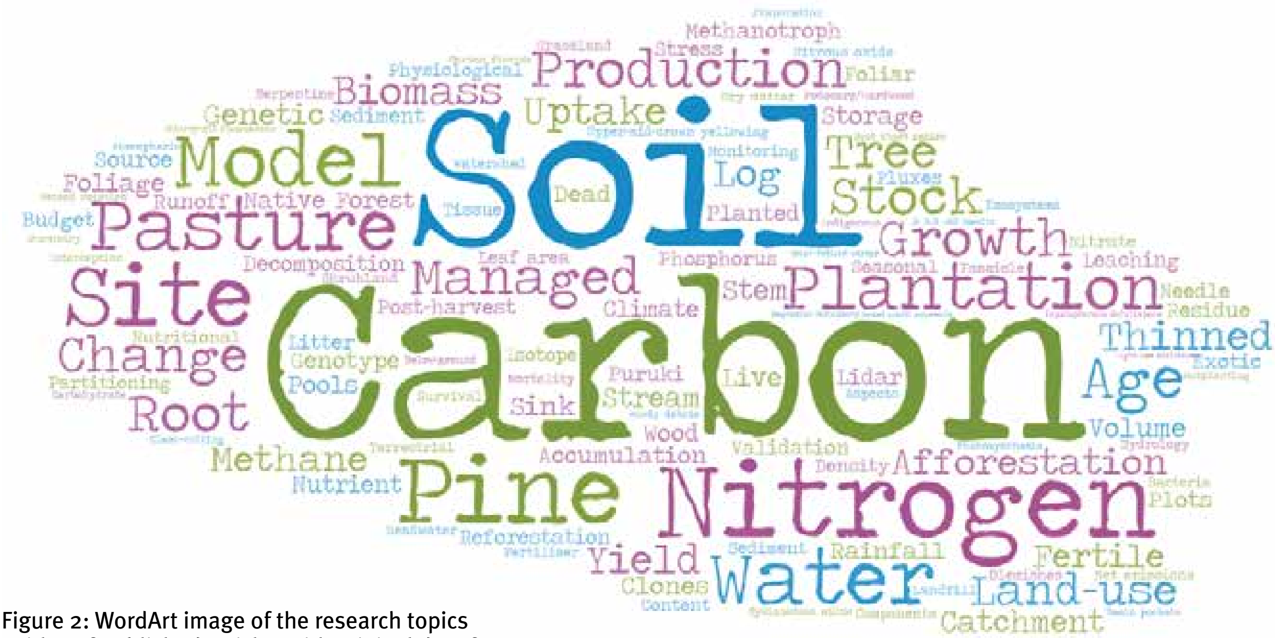

Figure 2: WordArt image of the research topics – titles of published articles with original data from PEF

PEF remains an exemplar of what can be achieved with long-term forest-level trials. However, more than that, it is a signpost toward the need for a national series of secure and appropriately funded long-term forest ecosystem experiments in New Zealand. The following sections highlight some of the major impacts of the research undertaken at PEF.

A half century of research excellence

The impacts of this work have had a profound influence on forestry research and practice in New Zealand (Figure 2). By 2021, a total of 67 articles have been published using original data from PEF. If the forest were an author in its own right, PEF would have a Google Scholar h-index of 34/Scopus h-index of 26 (data as at March 2021).

Data to support nationally important forest models

PEF data has been critical to the development of nationally important tools that underpin carbon and nutrient predictions, including C_Change, Forest Carbon Predictor (FCP) and the Nutrient Balance Model (NuBalM) (Figure 3) (Beets et al., 1999; Beets et al., 2011a; Smaill et al., 2011). PEF provided the opportunity for the early application of LiDAR for remote sensing and monitoring of forest ecosystems (Beets et al., 2011b). LiDAR data from more than a decade ago helped demonstrate the importance of aspect and tree genetic data in improving stand productivity models (Beets et al., 2011b).

Data collected from the first rotation and early second rotation was comprehensive, especially the PEF time-series tree-biomass, and supported development of the C_Change model (Beets et al., 1999) which, in turn, underpins the FCP (Beets et al., 2011a) and the NuBalM models (Smaill et al., 2011). The flow-on impacts of data collected from PEF into New Zealand's models and tools should not be underestimated. For example, C_Change predicts annual carbon stocks in forest pools, including above-ground biomass, below-ground biomass, coarse woody debris and forest floor litter. C_Change, incorporated into Forecaster, is central to planted forest carbon assessments in New Zealand.

The C_Change model provides an integrated, consistent carbon estimation and projection system. This gives confidence in predictions used by agencies such as the Ministry for the Environment (MfE) for national planted forest carbon stock reporting obligations under the United National Framework Convention on Climate Change and Paris Agreement Nationally Determined Contribution (MfE, 2021). The carbon stock and stock change data is also used for reporting against the Criteria and Indicators of the Montrèal Process, as well as the United Nation's Food and Agriculture Organisation's Forest Resource Assessment (FAO, 2015; MPI, 2015). C_Change has also been used to support the quantification of carbon ecosystem services provided by planted forests (Yao et al., 2021).

C_Change plus the 300 Index – effectively the FCP (Figure 3) – was used to develop the default Emissions Trading Scheme (ETS) Lookup Tables for radiata pine and is also used to underpin Participant-Specific Tables for the ETS Field Measurement Approach as part of governmental data analysis tools. As well as estimating current carbon stocks for reporting, it is used to develop yield tables for projections that underpin policy development, e.g. the Climate Change Commission report on the development of carbon budgets and emission reduction strategies (Climate Change Commission, 2021). At a forest management level, C_Change (within Forecaster) is used by forestry consultants and companies undertaking carbon investment analysis.

Scion's FCP model is made up of a linked suite of sub-models (Figure 3). The annual biomass pools predicted by C_Change are used as inputs for NuBalM (Figure 3), which models site-specific nutrient sustainability over multiple rotations under different harvest residue and forest floor removal methods.

There is increasing interest in the use of NuBalM to support sustainable precision nutrient management for planted forests in New Zealand. The interest is mainly from the forestry sector to support nutrient management planning for increasing sustainable productivity and from regulatory authorities to predict nitrogen leaching under various new land use scenarios that include forest establishment (Garrett et al., 2021). Moreover, NuBalM is underpinning engagement with the Overseer[FM] model, a model widely used in agricultural systems and more recently by local government regulatory bodies for decision-making related to land use management (Wheeler et al., 2003; MPI, 2020; Garrett et al., 2021).

Improved forest productivity

As an improved ex-pasture site at moderate altitude with generous rainfall, PEF supports one of the fastest-growing forests in New Zealand. PEF has demonstrated a 54% increase in forest productivity in the second rotation (Table 1) compared to the first rotation, and is 63% more productive over the second rotation compared to the national average (for all species) in

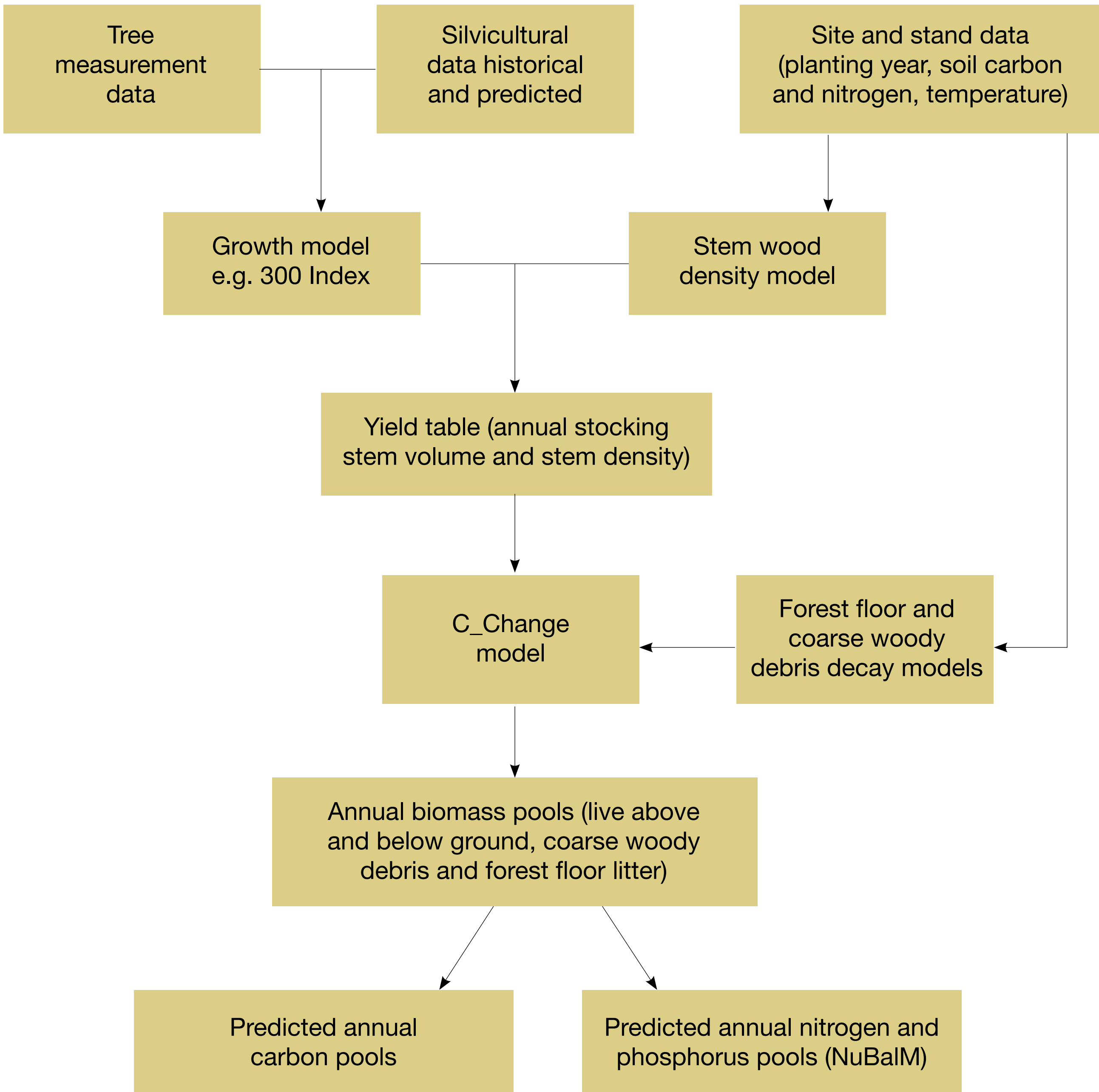

Figure 3: Flowchart outlining the FCP that models carbon stocks and includes the NuBalM to predict nitrogen and phosphorus stocks for New Zealand's planted forests. Adapted from Beets et al. (2011a). The 300 Index model is used to derive the mean annual increment corresponding to a standardised regime with a final stocking of 300 stems ha^{-1} at stand age of 30 years (Kimberley et al., 2005)

post-1989 planted forests (MfE, 2021). This high forest productivity is due to the:

- Inherent site fertility brought about by past application of fertilisers (super phosphates) (Beets et al., 2019)
- Planting of healthy trees (less prone to needle-cast fungus e.g. *Cyclaneusma minus*) and superior growing genotypes at a high stocking rate (Beets et al., 2011b)
- Likely benefit of a harvesting and site preparation for re-planting regime that left the harvest residues and nutrients they contain on-site (Oliver et al., 2004) to benefit the next forest rotation (Garrett et al., 2021).

The value of PEF can be demonstrated through the impact on the forestry sector:

> *'Puruki has shown Timberlands what is possible from a productivity standpoint and really highlighted the importance of forest nutrition. The outcomes from Puruki are helping to inform our research and development programme that is targeting a step change in forest productivity.'*
>
> Dr John Moore, Research & Development Manager (Pers comm)

During the first rotation at PEF, UMCY was a nationwide issue in some forests and stands. UMCY is expressed as a loss of foliage in the upper crown and, if severe, results in crown dieback and productivity loss (Beets & Jokela, 1994). UMCY was particularly prevalent in the 60 SPH catchment at PEF and, along with *Cyclaneusma minus*, was causing considerable foliage loss in many trees (Beets et al., 1997). These observations initiated research toward understanding the large variability in the expression of these two disorders.

Research at PEF established the importance of within site variability of environmental, soil and tree genetic factors in UMCY disease expression (Beets et al., 1997; Beets et al., 2004). Healthy individuals from PEF's first rotation, inferred as showing tolerance to both UMCY and *Cyclaneusma*, were identified and cones used as parent trees for the second rotation Puruki Control (PC) seedlot (Beets et al., 2004). This simple selection for tree health within the same genotype, and then planted at higher stocking, demonstrated productivity increases of 24% (Table 1).

Better understanding of carbon and nitrogen stocks

New Zealand's planted forests sequestered 29 million tonnes of carbon dioxide from the atmosphere in 2019 (MfE, 2021). The rate of carbon sequestration in the growing forest is directly linked to tree growth and site productivity. As PEF is highly productive, carbon sequestration rates are high; second rotation GF30 planting stock are estimated to store ~400 Mg ha^{-1} of carbon at age 26 years in the live biomass and forest floor (Figure 4a). This is in comparison to New Zealand's post-1989 planted forests with a mean total carbon amount at age 26 years of 245 Mg ha^{-1} in the live biomass and forest floor (MfE, 2021), tall natural forest total live biomass and forest floor carbon amount of 252 Mg ha^{-1} (MfE, 2021; Paul et al., 2021) and pasture biomass between 3–6 Mg ha^{-1} of carbon (MfE, 2021).

Comparing the PEF GF30 biomass and forest floor carbon amount (~400 Mg ha^{-1}) to the carbon in the soil at PEF, the soil holds about 38% of the planted forest total carbon stock, 143–164 Mg ha^{-1} of carbon to 1 m soil depth (Oliver et al., 2004). Therefore, at the end of the second rotation PEF will have about 553 Mg ha^{-1} of carbon stored on-site.

The impact of land use change and clear-cut harvesting on the soil carbon stocks has been researched at PEF. With conversion of pasture to pine, 4 Mg ha^{-1} of carbon was lost from the surface soil layer (Beets et al., 2002), but this comprised less than 1% of the total carbon at the end of the second rotation at the site.

Table 1: PEF productivity metrics for tree age 20 years from the first rotation (GF7 at final crop stocking of 500 SPH) and second rotation (range of planting stock, planted at 1,000 SPH with no thinning)

Puruki Experimental Forest age 20 years	Rotation 1	Rotation 2			
	GF7	GF30	HD	PC*	GF2
300 Index (m^3 ha^{-1} yr^{-1})	30	36	32	30	26
Site Index (m)	31	30	31	30	29
MTH (m)	32	30	30	30	29
BA live (m^2 ha^{-1})	60	89	79	72	61
SPH live (count ha^{-1})	518	693	708	676	611
Stem volume live (m^3 ha^{-1})	690	1009	875	814	661
Production stem volume net MAI (m^3 ha^{-1} yr^{-1})	33	51	44	41	33
% increase in production stem volume net MAI compared to GF7 rotation one		54	33	24	1

* GF7 selected for healthy trees; MTH – Mean Top Height; BA – Basal Area; SPH – Stems Per Hectare; MAI – Mean Annual Increment. Note that GF2 seedlings from unimproved Riverhead Forest, Puruki Control (PC) seedlings from PEF first rotation GF7 were selected for health, High Density (HD) and GF30 seedlings from a defined set of control pollinated parents with improved growth and form (Beets et al., 2011b)

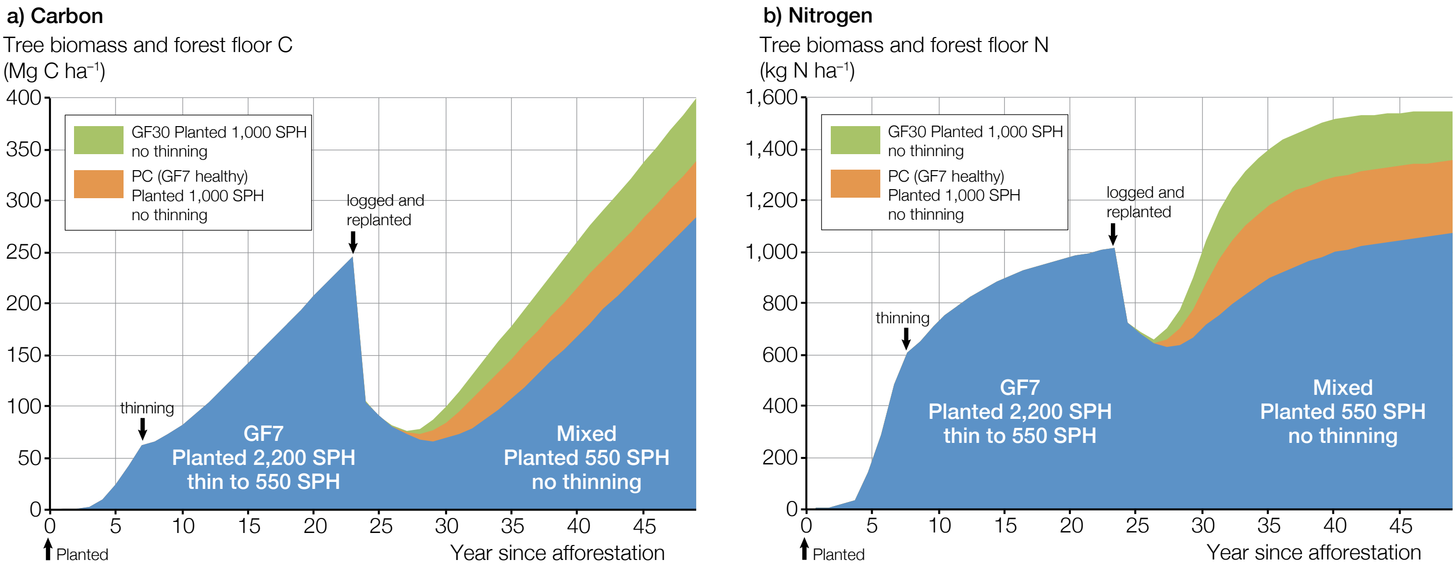

Figure 4: Modelled tree biomass and forest floor (a) carbon stocks and (b) nitrogen stocks over two rotations using the FCP and NuBalM models, respectively. Modelled inputs were the first rotation planted with *P. radiata* GF7 stock at 2,200 SPH, thinned to 550 SPH, and the second rotation planted with *P. radiata* mixed stock at 500 SPH, no thinning, and GF30 and Puruki Control (PC = GF7 selected for tree health) at 1,000 SPH, no thinning. Harvesting extracted the tree stem only, leaving tree crown and stump (slash) distributed over the site

High spatial variability in soil carbon was also found. This was attributed to the past podocarp/hardwood native forest, which was cleared from the site 100 years earlier (Beets et al., 2002), demonstrating the importance of historical and protected carbon in the soil.

Clear-cut harvesting activity of PEF first rotation forest was found to reduce surface soil carbon stocks by 3.1 Mg ha^{-1} due to mixing with sub-soil, but there was no change when the soil was measured down to 1 m depth (Oliver et al., 2004). The work on soil carbon at PEF has supported recommendations on how to sample planted forest soils that have deep-rooting trees and consideration for New Zealand's soil carbon, which can have high variability in soil carbon stocks as a result of the past native forest land cover.

The high fertility of soil at PEF, a legacy of past farming practices, means that the site can sustain highly productive forestry across multiple rotations whilst maintaining nutrients on-site. Results from NuBalM show the first rotation forest at PEF accumulated 1,011 kg of N ha^{-1} in the live and dead biomass pools (Figure 4b), using available nutrient resources only, i.e. without any further additions of fertiliser. The harvest operation extracted the stem only, exporting 150 kg of N ha^{-1} from the site and leaving 85% of the tree and forest floor nitrogen.

The nutrients held in harvest residues and forest floor were supplied to the second rotation pine that had greater potential growth (due to improved genotypes maintained at higher stocking rates), subsequently lifting the overall productive capacity of the site (site quality; Figure 4b). Supported by retaining harvest residues on-site, release of nutrients through natural soil weathering (Garrett et al., 2021) and atmospheric deposits of particularly nitrogen, PEF has demonstrated that a fertile site can sustainably supply the additional nutrients for a more productive second rotation forestry.

Better understanding of water yield and quality

The comparative assessment of the paired land uses on water yield and quality has been a key outcome of the Purukohukohu Experimental Basin trials. With the conversion of pasture to planted *P. radiata*, overall annual water yield decreases by 160–260 mm/year dependent on silvicultural regime (Beets & Oliver, 2007). However, water yield measurements derived from PEF, when compared to the adjacent pasture land, demonstrated how forest cover allowed continued stream water flows during dry summer months whilst mitigating floodwater during high rainfall events with more than a 50% decrease in peak flows (Scion, 2020). Thus, continuous monitoring has revealed that annualised water harvest data obscures key metrics associated with seasonal water supply that support ecosystem functioning and potentially other users of water downstream.

Despite PEF being a highly productive forest on a fertile site, data shows it has low nitrogen and phosphorus losses to stream flow, with levels that are comparable with native forest and much less than that from the neighbouring livestock grazed pasture (Figure 5) (Quinn, 2005).

Experimental forests that monitor long-term changes in water yield and quality are rare in New Zealand (Meason et al., 2019), making PEF and its associated long-term monitoring of particularly high value. As this country's water resources come under increasing pressure with intensification, land use change and the integration of production forestry into mosaic land use landscapes, the importance of such data will dramatically increase.

Extension forestry experiments

The second-rotation PEF included an experimental trial established using improved genotypes (Beets et al., 2004; Beets et al., 2011b). A sub-set of 10 of these genotypes were clones and subsequently planted with other *P. radiata* genotypes in a national long-term experimental trial (FR442) to investigate genotype by environment interactions (Hawkins et al., 2010). The FR442 national trial series was established at 14 sites from 2002 to 2004, with the aim to extend site-specific studies on pumice soils to a range of soil types found nationally.

Summary

PEF has had a significant impact on New Zealand forestry science with large benefits for both the forest industry and government. There is now a window of opportunity to collect data leading into and over the harvest phase of one of the fastest-growing and most productive second rotation forests in this country. This research will contribute significantly to the already valuable legacy of research into forest management and growth modelling that supports the forest industry's social licence to operate. The next phase offers a new opportunity to extend the legacy of PEF by undertaking ambitious ecosystem-level research for the benefit of New Zealand.

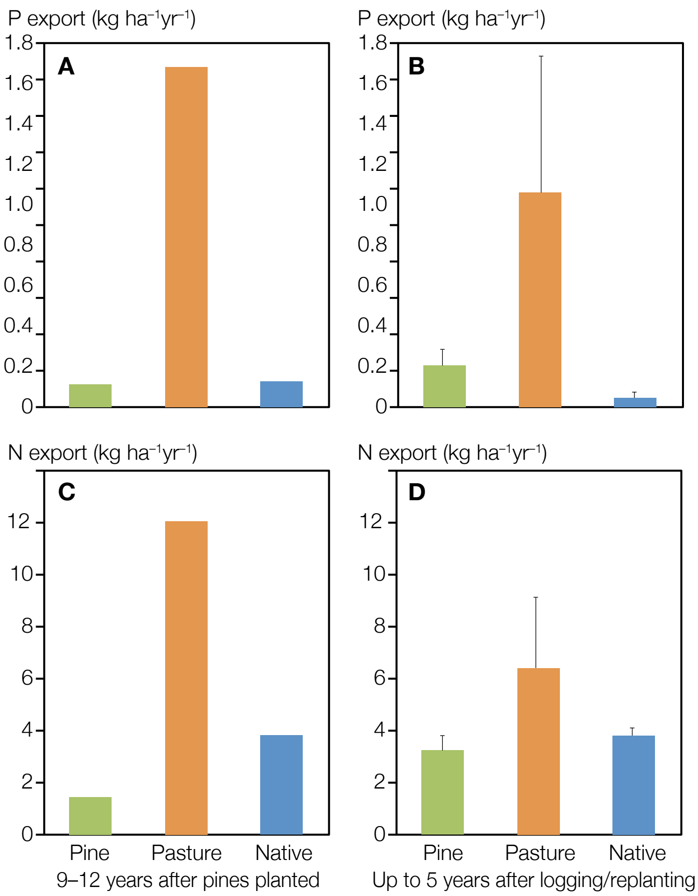

Figure 5: Land use effects on average yields of total phosphorus and nitrogen at Purukohukohu (Quinn, 2005)

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Long-term site productivity research – 30 plus years in the making

Peter Clinton, Loretta Garrett and Simeon Smaill

Abstract

Research that spans the full cycle of a stand of trees is rare. This paper summaries a series of recently published articles that provide detailed assessments of the impacts of intensive forest harvesting residue management over the life of several trials located around New Zealand. Key findings were that the impact of increasing harvest residue and forest floor removal on tree productivity was significant only on the poorer site where soil nitrogen pools were initially low, and the intensive residue removal further reduced nutrient pools. However, wood quality at the end of the rotation at the poorer site was not affected. The importance of the forest floor to nutrient storage and supply was demonstrated at the low nutrient sites. These findings demonstrate a need for site-specific management strategies if harvest residues are to be removed for use as feedstocks. The conclusions generated from this long-term research will be of benefit to the New Zealand forestry sector for many years to come. Future research needs are also described, with specific attention to the increasing proportion of planted forests that are entering their second or third or fourth rotation.

Introduction

Research findings from both a national and internationally significant long-term trial series located in New Zealand have recently been published in a series of seven papers. Several of these papers were part of a special issue focusing on long-term planted forest sustainability in the international journal *Forest Ecology and Management* (Hatten et al., 2021). These seven papers add to a legacy of more than 30 research articles from this trial series. Given that the first paper reporting on this long-term trial series was published in the *New Zealand Journal of Forestry* in 1987, it is appropriate to use this journal as a vehicle for reporting the cumulation of nearly 40 years of research at these sites, spanning three generations of researchers and forest managers (Dyck & Beets, 1987).

Sustainability of forest soil nutrient supply

The harvest of planted forests removes biomass and the nutrients they contain from the site. Early in the development of New Zealand's planted forestry estate, research questions were asked about the sustainability of biomass removal and the potential impact on the long-term ability of a site to supply the nutrients required for sustainable forest production. Initial nutrition research on New Zealand's planted forests demonstrated that reduced nutrient supply, occurring as a result of harvesting over multiple rotations (Will & Knight, 1968; Webber, 1978; Dyck & Beets, 1987), or large-scale disturbance of the forest floor and surface soils during harvesting (Ballard, 1978; Ballard & Will, 1981), did have consequences for future forest productivity. This research was subsequently identified as being relevant to assessments of the use of harvesting residues as feedstocks for bioenergy (Dyck et al., 1991).

To address questions around the sustainability of removing forest residues for bioenergy feedstocks the Long-Term Site Productivity (LTSP) trial series was initiated in the 1980s. From 1986 to 1992 six sites were installed (Woodhill, Tarawera and Kinleith in the North Island; Golden Downs, Burnham and Berwick in the South Island), providing a soil fertility gradient spanning recent volcanic soils to highly weathered greywacke gravels. The trials were designed to examine the long-term consequences of increasing levels of biomass removal at harvest, typical of a range of management practices. The intensity of the harvesting treatments varied from removing the tree stem only (SO), removing the whole tree (WT) through to removing the whole tree and the forest floor (FF) (Figure 1). This effort was part of a global initiative to install LTSP harvest removal trials. These treatments have now been repeated in many locations throughout the world (Achat et al., 2015) and represent possible biomass removal through conventional harvesting.

Findings from the New Zealand LTSP trial series indicated that the impact of increasing harvest residue and forest floor removal on tree productivity was significant only at Woodhill Forest (Table 1), where soil nitrogen pools were initially low and the intensive residue removal further reduced nutrient pools (Garrett et al., 2021b). However, this did not impact on end of rotation wood quality at Woodhill Forest (Moore et al., 2021). The end of rotation findings also showed there was limited negative long-term impact on soil nutrient supply with SO and WT removal, but at sites with low initial soil fertility the FF treatment negatively impacted soil fertility (Garrett et al., 2021b). The importance of the forest floor to nutrient storage and supply has been demonstrated for these low nutrient sites where, for example, the forest floor can make up 21% of the forest ecosystem nitrogen pool (Woodhill) compared to just 2% of the forest ecosystem nitrogen pool at more fertile sites (Berwick).

These findings demonstrate a need for site-specific management strategies if residues and forest floor are to be removed for bioenergy feedstocks (Garrett et al., 2021a). This consideration is particularly important in New Zealand, where planted forests are supported by soils with a wide range of soil fertility due to variations in soil types and legacy effects from previous land uses (e.g. fertiliser use for pastoral grazing) (Watt et al., 2008; Ross et al., 2009; Beets et al., 2019). Therefore, some sites are inherently more capable of buffering the impact of intensive harvest residue removal compared to others. Overall, the body of work published in the seven papers demonstrates the sustainability of planted forestry in New Zealand, which is essential for public acceptance of these forests and also for meeting the requirements of external agencies such as the Forest Stewardship Council.

The importance of maintaining the forest floor can been seen in Figure 1 where the Nutrient Balance Model (NuBalM) has been used to illustrate the impact of removing the forest floor at Woodhill Forest.

Assessments of soil biodiversity demonstrated the degree to which the soil microbial communities varied between sites, but regardless of these inherent differences the diversity of the soil fungal communities was consistently reduced by the FF treatment compared to the SO treatment (Addison et al., 2019). Interestingly, in contrast, the response of the soil bacterial communities showed no evidence of long-term effects indicating that soil bacteria were less sensitive to different environmental pressures created by variations in harvest removal management.

Table 1: Main treatment – forest floor removal (FF), whole tree (WT), stem only (SO) – effects on tree stocking, mean top height, stand basal area and volume 27 years after establishment at Woodhill Forest

	FF	WT	SO
Stocking (stems ha^{-1})	583	575	542
Mean top height (m)	33.4	32.2	32.1
Basal area adjusted for stocking (m^2 ha^{-1})	48.9a	55.3b	55.9b
Stem volume adjusted for stocking (m^3 ha^{-1})	540	591	601
Age when DBH=35 cm (years)	28.6a	25.6ab	25.5b

Note: Basal area and volume are shown for a standardised mean stocking of 549 stems ha^{-1} (using analysis of covariance). Also shown is the estimated age when trees achieved a quadratic mean DBH of 35 cm. Significant differences between harvesting treatments are identified by letters. Source: From Garrett et al. (2021b)

The lessons learnt from the research are globally relevant, not only for other radiata pine growing countries but for other forest plantation species. This global reach has been supported by the fact that the research has been reported in several very highly ranked international peer reviewed journals, for example, in *Soil Biology and Biochemistry* (Huang et al., 2011), which is ranked second in the field of soil science, and in *Biology and Fertility of Soils* (Smaill et al., 2010) ranked number three (top 1%) of 334 agronomy and crop science journals.

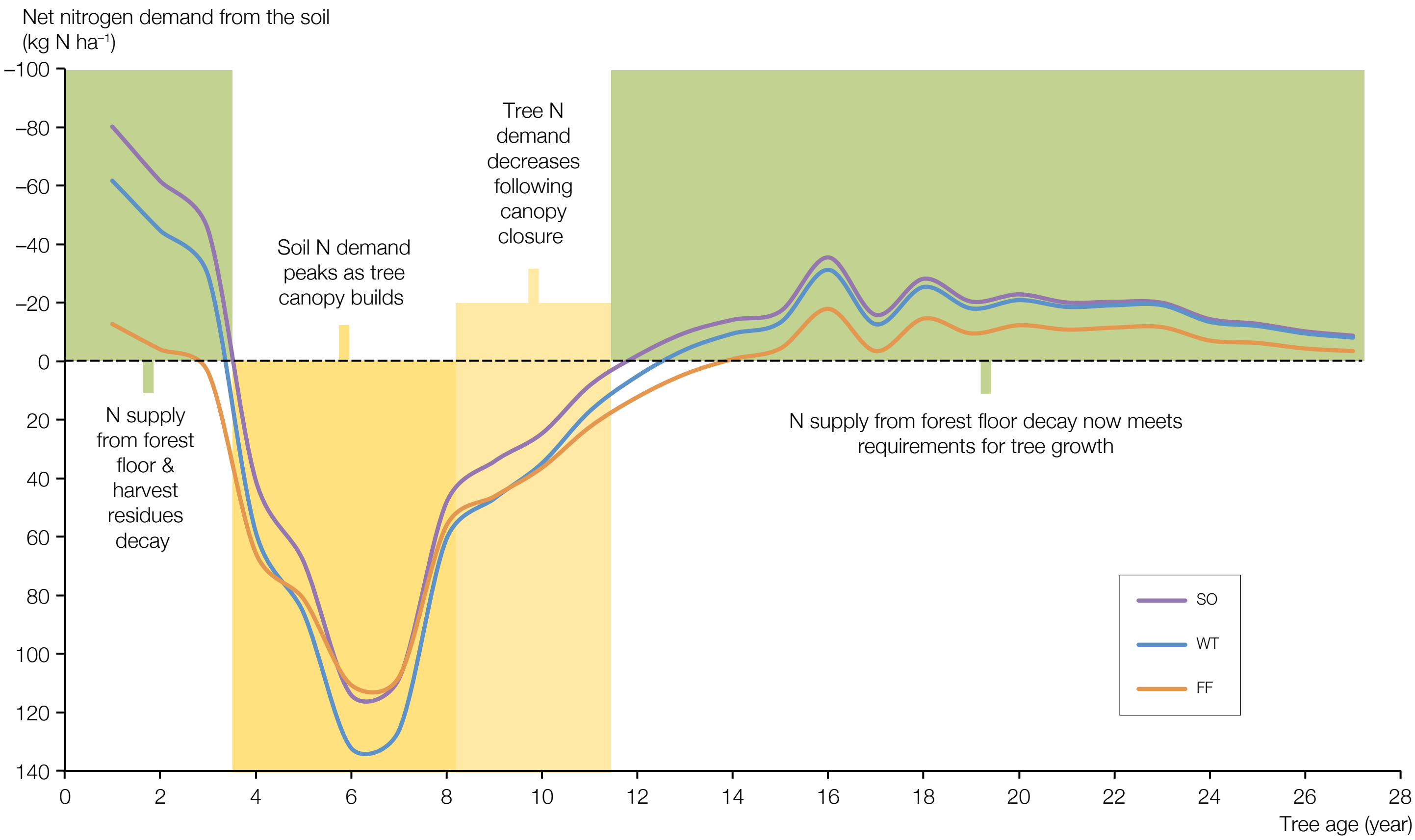

Figure 1: Tree crop nitrogen demand over a rotation for the stem only (SO), whole tree (WT) and whole tree plus forest floor removal (FF) treatments at Woodhill Forest estimated using NuBalM with thinning occurring at age seven and 15 years

Legacy of research infrastructure

The LTSP harvest residue removal trials have provided the framework in which the original objectives of the trials have been addressed, cumulating in a final assessment of tree productivity and soil and biomass nutrient stocks at the time of tree harvest (Garrett et al., 2021b). In addition, intensive timeseries measurements of forest biomass and where in the forest ecosystem nutrients are held (e.g. in the soil, forest floor and live tree) have been made.

Many new additional research projects have emerged as a result of the trial infrastructure. Examples of how this infrastructure supported new research directions is provided by the emergence of the NuBalM (Smaill et al., 2011) and the study of the forest floor and soil microbiome (Smaill et al., 2010). This work has been further built on in recent years and unearthed a greater understanding of the impacts of intensive residue management practices on soil biodiversity (Addison et al., 2019, 2021).

A variety of research findings have been reported in the numerous publications based on the research infrastructure provided by the six trials. There is not sufficient space in this paper to fairly summarise the 30 or more papers so the focus of this summary will be directed to a few key points raised in the most recent papers. Garrett et al. (2021a) provides an excellent summary of the key lessons learnt over the years and we suggest this is the best place to start any assessment of the value this trial series has provided.

Considerable effort was expended at the establishment of each of the trials to describe the preharvest tree and soil nutrient pools (Figure 2). This data now represents an important source of information describing the variation in planted forest ecosystem carbon storage, nutrient storage and site quality (Garrett et al., 2019).

The duration of the trials themselves highlight the many issues and challenges that confront long-term research projects of this nature. For example, changes in personnel, funding arrangements and pressures from land use change and the climate itself all played a part in determining outcomes across the six trial sites. These factors all came into play at one point or another for the trials, threatening both the quality of the data that could be collected and the return on the investment made in the establishment and maintenance of the sites. Some events were effectively out of context problems, with two sites being lost due to conversions of land use from forestry to pasture and the Golden Downs site (Nelson) being subjected to a catastrophic windthrow event.

Bioenergy

As was the case when the trials were established, the use of harvest residues for bioenergy feedstocks is still currently under active consideration in New Zealand (Suckling et al., 2018), as well as on the international

Figure 2: Removal of the forest floor in a trial plot at Woodhill Forest prior to harvest. Source: Photo courtesy of Bill Dyck

stage. Around the world there is much debate about the sustainability of this practice and the climate effects of bioenergy (Cowie et al., 2021). Even though these local trials examined the impact of harvesting residue removal intensity after one rotation, the question still remains as to what might happen in subsequent rotations. This issue will gain more attention in the coming years as an increasing proportion of the current planted forest estate enters into its third or fourth rotation and reductions in the use of fossil fuels increases the attractiveness of bioenergy production from forest residues. The findings generated by the LTSP trials over 30 years can be used to address issues arising around the sustainability of biomass harvesting (e.g. Vance et al., 2014) and could prove very useful in underpinning any development of local guidelines (e.g. Titus et al., 2021) to support the use of forest residues for bioenergy or feedstocks for tree-based biorefineries.

The results provide confidence that not only is the productive capacity of most sites unlikely to be impacted upon by one rotation, but wider encouragement that the future security of forest carbon pools and sequestration capacity is also maintained. This confidence also extends to issues of:

- Energy security, should local forest biomass use become important to the economy
- Regional economic growth and the supply of timber for onshore processing, to ensure it is not impacted upon
- Future exports of timber products, to ensure they are maintained
- Reducing the carbon footprint of exporters through the sustainable production of bioenergy.

Future demands on forest soils

It is important to continue this line of research because there will be an increasing area of third and fourth rotations arising in the not too distant future (Garrett et al., 2021). Consequently, it will be important to understand not just the consequences of crop and/or residue removal after one rotation, but also after two or three or four rotations (Smaill & Garrett, 2016). Increasing global demand for timber products is creating more pressure on forests and new management practices will need to be developed to buffer the soil resources against any pressures resulting from intensification (e.g. shorter rotations, higher stocked stands, more disturbance and residue removal) (Clinton, 2018) However, new technologies promise the potential to avoid some negative impacts, such as robotic harvesting systems that protect the soil surface from disturbance while improving worker safety (Parker et al., 2016). Strategies to ameliorate nutrient removals, particularly nitrogen, may include the use of nitrogen-fixing plants during periods of increased nutrient demand up until canopy closure (e.g. West et al., 1991). It is even more important to maintain and enhance productivity of our planted forests here in New Zealand given the reliance on forestry to meet the country's zero carbon emissions aspirations. Overall, the research described in this review shows that it is better to keep what you have in terms of site resources, such as those contained in the forest floor, than to rely on the use of mineral fertilisers.

What's next?

It was not anticipated at the time of the trial establishment that they would be re-established to study a subsequent third rotation. However, an evaluation of the pros and cons of continuing the trials at the existing sites following harvest, and significant issues related to the size of the plots, the pressures of prior sampling and the use of large amounts of fertiliser were identified. Consequently, no attempt was made to re-establish any of the trials for another rotation.

The new Accelerator trial series that was established to study and monitor the impacts of intensification are now providing research infrastructure to explore a number of research questions, for example, the use of drones to identify individual trees at a young age and monitor their growth (Hartley et al., 2020). The trials are examining a range of management options, including novel plant biostimulants, greater stockings, new genetics and site preparation techniques, all while capturing sufficient data to assess the sustainability of these treatments.

Although the scenario of increasing rotation numbers has been modelled, the impact of intensification of management practices through greater stocking rates, the deployment of faster-growing genotypes and shorter rotations still needs further examination across a range of soil types. These questions are likely to become the focus of new research projects in the near future.

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Emergence of psychosocial considerations for improving safety in the New Zealand forest industry

Shaun Cawood, Trevor Best and Rien Visser

Abstract

There is a growing body of evidence that psychosocial factors have a significant impact on the mental and physical health of workers through increasing stress, depression and anxiety. However, psychosocial factors may also directly influence workplace behaviours to the point where unsafe acts may result. This paper presents an overview of a contemporary understanding of psychosocial influences, by exploring their meaning and development and as they relate to New Zealand forest industry safety. Also presented is how psychosocial considerations have been integrated into health and safety laws over time. Although this paper concludes that our pragmatic understanding of psychosocial influences on workplace behaviour is a relatively recent phenomenon, it also shows that the Person Conducting a Business or Undertaking (PCBU) has legal responsibility for the health and safety impact of worker behaviours and therefore may need to concern themselves with psychosocial influences.

Introduction

As many as 95% of workplace injuries involve something an individual has done alongside technology or machine failure (Wilson & Higbee, 2012). In a risk factor analysis of fatal harvesting accidents in Turkey, Melemez (2015) found personal factors to have the highest weight followed by organisational, job-related, equipment and environmental factors. Yet, root cause analysis focuses mostly on identifying organisational or systemic failures at the root of an accident. When human factors are considered, they are often ergonomic or physiological in perspective. The underlying psychosocial causes are often left understated and in the domain of the personal and private. The prevailing perception is that if physical hazards are managed, the risk of injury is minimised as far as is practicable (Leka & Jain, 2010). Within health and safety assessment, consideration of psychosocial factors is largely absent (O'Keeffe & Tuckey, 2014). To a large extent, comprehensive safety systems focused on the use of technology and administrative controls are seen as the solution to keep people safe and accidents are the result of system failure or system inadequacy.

Many businesses in New Zealand developed comprehensive systems after the introduction of the Health and Safety in Employment Act 1992 (HSE Act 1992) and its implementation under the Regulations and accredited codes of practice by inspectors and insurers. The extrinsic control provided by systems helps achieve compliance and some peace of mind for those responsible for the workplace. In the period 2012 to 2017 there was a 53% reduction in serious harm incidents in the forest industry (Steepland Harvesting Programme, 2018). That reduction has happened alongside the introduction of the Approved Code of Practice for Safety and Health in Forest Operations in 2012 and an increase in the proportion of all harvesting operations using mechanised felling to 55% in 2016 from 23% in 2009 (Steepland Harvesting Programme, 2018). The serious harm injury rate in forestry and logging operations is now below that of industries such as construction and farming (Hutching, 2018; WorkSafe New Zealand, 2019).

Yet the fatality rate in forestry and logging is proving to be a stubborn and distressing statistic. While the increase in mechanised felling operations has removed approximately 213 manual fallers and breaker outs from the workforce (Steepland Harvesting Programme, 2018), the fatality rate is still the highest across all occupational groups in New Zealand (WorkSafe New Zealand, 2018). In addressing the high fatality rate, the Independent Forestry Safety Review (Adams, Armstrong & Cosman, 2014) recognised that no single task or single factor was responsible, and recommended doing the research required to understand both the physical and psychological characteristics of near misses or accidents in order to fully address the causes of the fatality rate. Once some action or behaviour becomes a contributing factor to an accident, understanding what may have contributed to that behaviour has passed beyond the scope of the investigation tools currently being used to define root cause.

Human behaviour is constructed in the psychosocial domain – the outcome of relations between our physical and mental capabilities and our social environments (Woodward, 2015). In this domain, the various factors do not act independent of each other or at a conscious level. Psychological, organisational and environmental factors can interact and amplify each other to create a level of resonance that predisposes the system to failure. A factor that was unlikely to directly influence behaviour in one situation may surge to directly influence behaviour in another, as happens when production pressure and fatigue impacts the assessment of risk by a manual tree faller and something critical to the safe felling of the tree gets missed. In well-developed systemised workplaces the impact of psychosocial factors on that behavioural variability can be suppressed until their influence resonates enough for an accident to happen where there are more severe consequences (low frequency, high consequence accidents).

Most often a person's unsafe behaviour is conveniently grouped under negligence and placed in the category of the individual's responsibility. Ignoring psychosocial factors makes it difficult to draw a distinction between negligence and behaviour arising naturally through the influence of those factors. Placing the responsibility on the individual comes with the expectation that people should be more careful and not break important safety rules. It ignores the potential to learn how psychosocial influences can result in positive workplace behaviours that may prevent such an occurrence. After all, there are significantly more safe behaviours in New Zealand workplaces than accident causing behaviours. Building capability and capacity for successful work and using systems that recognise the inherent variability in everyday work helps build organisational resilience and is considered the next evolution of safety thinking (Hollnagel, 2014).

Given the potential importance of psychosocial influences to safety in the New Zealand forest industry, the aim of this paper is two-fold:

1. Explore what is understood about psychosocial factors within the context of health and safety legislative development, and
2. Examine what may need to change in the way safety is viewed in the forest industry to take account of the influence of psychosocial factors.

It will do this by reviewing what is meant by safety and then what is meant by psychosocial factors within the context of safety. The place of those psychosocial factors in the New Zealand health and safety legislative framework is reviewed, and suggestions are made as to what may have to change to accommodate the role of psychosocial influences in our approach to safety.

Importance of psychosocial factors in health and safety

There is a growing body of evidence showing the negative consequences of psychosocial pressures on general mental and physical health, and that those consequences impact business through factors such as absenteeism, productivity, job satisfaction and intention to quit (Leka, Van Wassenhove & Jain, 2015). More importantly, the reduction in wellbeing due to exposure to poor psychosocial conditions has been associated with negative safety outcomes. O'Keeffe and Tuckey (2014) highlighted research showing psychosocial factors make a major contribution to musculoskeletal injuries. In an eight-year study on 10,062 Finnish forestry workers, burnout (a psychological consequence of prolonged work stress) was associated with an increase in workplace injuries (Ahola, Salminen, Toppinen-Tanner, Koskinen & Väänänen, 2013). Nahrgang, Morgeson and Hofmann (2011) reported an association between burnout and an increase in risky and dangerous behaviours. This evidence is reflected in the changing way we look at safety and in our legislative framework. However, it is largely absent from the tools we use to manage safety.

Evolving definition of safety

Safety is often defined as the absence of negative events – the absence of harm being experienced by the people engaged in the workplace. Therefore, a safety Key Performance Indicator (KPI) is often to measure the absence of something.

Safety, especially in relation to psychosocial influences, is a dynamic event. Hence it is something that must be created constantly and continuously as a capacity of both the organisation and the people within it. It is complementary to the more traditional avoidance view of safety. Effective performance requires both that people avoid the things that go wrong and ensure that things go right.

The traditional view of regulators and managers is to prevent workers from being exposed to unacceptable hazards. The people most often held responsible for the elimination or substitution of activities are not directly engaged in the actual work (e.g. harvest engineers). Therefore, their awareness is raised only when an unwanted event occurs or is predicted to occur and they do not become overly concerned when observing positive behaviours. Acting on positive events is difficult as things more often go right than wrong. Acting on everything that goes right would likely overload a system or manager.

Hollnagel (2014) suggested things happen basically in the same way, whether the outcome is positive or negative. If the focus is on avoidance, then suppressing the processes leading to things that go wrong will also suppress the processes that lead to things that go right. An unintended consequence of a system focused entirely on controlling behaviour as the means of reducing harm is that the ability of the system to adapt to variability in the psychosocial environment is reduced and the system becomes less resilient.

The differences between the traditional view of safety and this evolving view of safety that makes the psychosocial much more important are captured in Table 1.

Defining psychosocial factors

Academia has tended to define psychosocial factors as a risk, hazard, or health effect. Both the New Zealand Workplace Barometer (Bentley et al., 2019) and the World Health Organisation (Leka & Jain, 2010) use the following definition of psychosocial hazards:

> *' … those aspects of work design and the organisation and management of work, and their social and environmental contexts, which have the potential for causing psychosocial or physical harm.'*
>
> Cox, Griffiths & Randall (2003, 195)

Table 1: Comparisons of two ways of thinking about safety (modified from Hollnagel, 2014)

Two views of safety	Traditional	Focus on things that go right (Safety II)
Definition of safety	As few things as possible go wrong	As many things as possible go right
Safety management principle	Reactive, respond when something happens, or is categorised as an unacceptable risk	Proactive, continuously trying to anticipate developments and events
Explanations of accidents	Accidents are caused by failures and malfunctions. The purpose of an investigation is to identify causes and contributory factors	Things basically happen in the same way regardless of the outcome. The purpose of an investigation is to understand how things usually go right
Attitude to the human factor	Humans are predominantly seen as a liability or a hazard	Humans are seen as a resource necessary for system flexibility and resilience
Role of performance variability	Harmful, should be prevented as far as possible	Inevitable but also useful. Should be monitored and managed

Based on this definition, psychosocial hazards within the workplace have been summarised within 10 domains (Table 2).

What this definition ignores, however, is that the psychological consequences of exposure to psychosocial conditions goes with the person as they traverse the various social settings (work, family, community) they occupy within their daily lives. In a study of the psychosocial factors potentially impacting New Zealand forestry workers, Lovelock and Houghton (2017) found that many live in challenging social environments. All respondents drew attention to issues such as poverty, intergenerational drug use in the community, insufficient support for young forestry workers at home and in the community, poor housing, crowded houses and poor nutrition. Many workers engaged in forestry also have a high exposure to extreme violence in their social environment. The issues raised above will impact on their ability to be safe and healthy within their workplaces.

Place of psychosocial factors within a health and safety framework

Prior to 1992, New Zealand's approach to health and safety legislation developed in response to specific concerns and was targeted solely at the workplaces in which those issues arose. While some of those concerns did address psychosocial factors within the workplace (length of the working day and working week), they reflected organised labour's experience of the Industrial Revolution, i.e. exploitation (sweating) of labour, particularly those considered vulnerable (women and children) and the risk of economic impoverishment due to the death or maiming of the primary breadwinner. The first pieces of workplace legislation, such as the Employment of Females Act 1873, the Regulation of Mines Act 1874 and the Employers' Liability Act 1882, were an extension of the Government's responsibility to protect citizens from harm.

Early safety theorists (e.g. Greenwood & Woods, 1919) saw accidents as the result of human error. To ensure citizens did not come to harm the Government identified specific sources of harm and imposed legislation and regulations to provide rules around the activity. The Government established an inspectorate within the Department of Labour to ensure the rules were followed (e.g. the Bush Workers Act 1945 that included the establishment of Bush Inspectors). The regulatory and industry response to the psychosocial hazards and influences on health and safety remained narrow, focusing on harassment, occupational violence and work stress. Workplace records by inspectorates reveal psychosocial hazards to be a marginal area of inspectorate activity (Johnstone, Quinlan & McNamara, 2011).

In 1970, the British Government, in response to rising accident rates, concluded that the prescriptive legislative approach needed to give way to a sharing of responsibility between government, employers and workers. The belief was that only by employers and workers taking responsibility would the improvements to the social environment required to reduce accident rates be achieved. The report, headed by Lord Alfred Robens and published in 1972, laid the philosophical groundwork for occupational health and safety management throughout the Commonwealth. Its tripartite approach is an important structural principle for moderating negative influences of psychosocial factors.

Faced with accident rates that were significantly higher than both Australia and the US, despite 14 major Acts, 17 minor Acts and over 50 Regulations pertaining to occupational safety in force (Wren, 2002), New Zealand introduced the Health and Safety in Employment Bill into the House in 1991. For all intents and purposes, the new Act (HSE Act 1992) was based on the Robens Report, and was comprehensive (covering all workplaces) and an attempt to share responsibilities between government, employers and employees.

However, despite a definition of hazard within the HSE Act 1992 that included the potential of psychosocial factors to be a hazard, the focus of those with regulatory authority on 'taking all practicable steps' marginalised psychosocial influences as a source of accidents. Faced with the prospect of large fines, prosecutions targeting organisations rather than individuals and the offer of reduced levies for workplace injury compensation from the Accident Compensation Commission, employers focused on developing extensive safety systems that would ensure all practicable steps were taken. The principal assumption for system development was all accidents are preventable and therefore all accidents can be avoided. Furthermore, the emphasis on 'current state of knowledge' in the definition of 'all practicable steps' did not allow for much consideration of human or situational variability arising from influences that might sit below the level of immediate conscious awareness of either the human or the situation.

The 2002 amendment to the HSE Act 1992 incorporated extensive additional provisions for good faith cooperation between employers and employees about health and safety. In doing so the amendment sought to correct the deficiencies in the principal Act and build a more balanced tripartite approach. The amendment also strengthened the requirements around the areas of psychosocial factors by confirming that certain temporary conditions may cause a person's behaviour to be hazardous, and included provisions confirming that harm can be caused by work-related stress. That emphasis, however, translated only into concern about chronic occupational health issues and not about the potential role of psychosocial factors in accidents. In the 13 technical reports provided to the Minister of Labour by the National Occupational Health and Safety Advisory Committee between 2004 and 2009 the only mention of psychosocial factors is about health affects, with no mention of the impact on accidents.

Table 2: Psychosocial hazards summarised within 10 domains (Leka & Jain, 2010)

Job content	Lack of variety or short work cycles, fragmented or meaningless work, under-use of skills, high uncertainty, continuous exposure to people through work
Workload & work pace	Work overload or underload, machine pacing, high levels of time pressure, continually subject to deadlines
Work schedule	Shift working, night shifts, inflexible work schedules, unpredictable hours, long or unsociable hours
Control	Low participation in decision-making, lack of control over workload, pacing, etc
Environment & equipment	Inadequate equipment availability, suitability or maintenance; poor environmental conditions such as lack of space, poor lighting, excessive noise
Organisational culture & function	Poor communication, low levels of support for problem-solving and personal development, lack of definition of (or agreement on) organisational objectives
Interpersonal relationships at work	Social or physical isolation, poor relationships with superiors, interpersonal conflict, lack of social support, bullying, harassment
Role in organisation	Role ambiguity, role conflict and responsibility for people
Career development	Career stagnation and uncertainty, under-promotion or over-promotion, poor pay, job insecurity, low social value to work
Home-work interface	Conflicting demands of work and home, low support at home, dual career problems

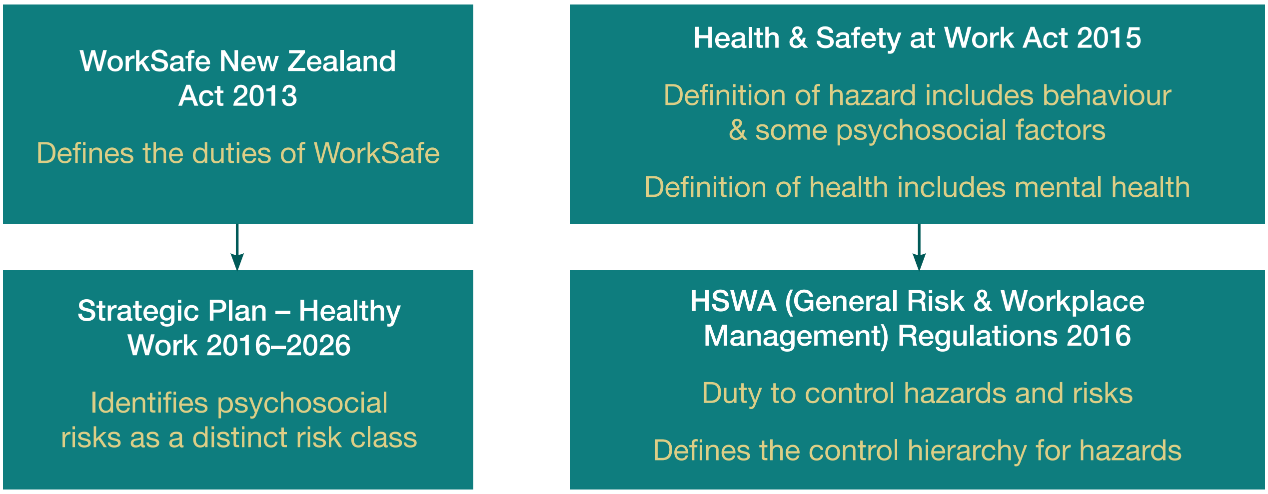

Figure 1: Current legal requirements to consider psychosocial factors

The Pike River tragedy provoked another review of the legislative framework. Both the subsequent Royal Commission in 2012 and the Independent Taskforce on Workplace Health and Safety (Jager et al., 2013) concluded that the HSE Act 1992 and the Health and Safety in Employment Amendment Act 2002 (HSEA Act 2002) represented a poor implementation of the Robens model. Specifically, they were critical of the extent to which the development of regulations, codes of practice and guidance material had involved both employers and employees and of the failure to establish a tripartite body charged with overseeing the framework's implementation. As a result, New Zealand's work health and safety system underwent its most significant reforms since the HSE 1992, with the establishment of Worksafe New Zealand and the Health and Safety at Work Act 2015 (HSWA 2015), which came into effect on 4 April 2016.

Principal changes to the framework included clarifying responsibilities through the introduction of the Person Conducting a Business or Undertaking (PCBU) having the primary duty of care, an increased level of expectation around worker involvement in the development and management of the safety system, changing the focus from hazard to risk, and defining health as meaning both physical and mental health. By specifically referencing mental health, the HSWA 2015 clarifies that psychosocial factors are principally characterised as a type of hazard. This can be confusing when developing moderators and interventions for psychosocial factors.

The current legislative framework (see Figure 1) requires those responsible to act if there is a risk of harm to the extent that is reasonably practicable. Grouping psychosocial factors under hazards and risks can be misleading to the management of those factors, as the factors are often influencers and may not directly cause significant loss but can influence this loss in unexpected and unanticipated ways. An example is stress. Stress can be a reaction rather than a predetermined state, although there are likely to be pre-determined events that lead to a significant stress reaction that could just as likely be deeply personal and originate from outside the workplace.

Recent work by Worksafe New Zealand moves the focus of psychosocial factors from a hazard to a risk on health. The report on psychosocial hazards in work environments (Lovelock, 2019) provides some guidance on approaches for managing those factors. Of relevance for the forest industry is that there are a range of upstream determinants on psychosocial factors operating in a workplace. These determinants include economic conditions and the nature of contractual arrangements impacting worker employment, as well as that the impacts of those factors experienced in the workplace can extend to other specific settings (such as home and community) and vice versa.

However, apart from noting that accidents can arise as a result of job strain and bullying, both relevant to the forest industry (Bentley et al., 2019), the focus of the report is on the impact of psychosocial factors on health. That reflects the place of psychosocial factors in Worksafe New Zealand's strategic planning where harm from accidents is covered in a shorter-term plan (Harm Reduction Action Plan), and the longer-term plan (Strategic Plan for Work-related Health 2016–2026) covers harm to health from exposures at work. The 10-year plan identifies psychosocial factors as a type of hazard, as distinct from biological, physical, chemical and ergonomic risks (see Figure 2). This separation of harm from accidents and harm to health from exposures risks hiding the relationship between psychosocial factors as an influence over the risk of accidents.

Dealing with psychosocial factors in forestry

The impact psychosocial influences have on workplace behaviours can be moderated by more rigorous engineering controls, particularly by effective isolation measures. However, where those controls are still reliant on a worker following a set of procedures (e.g. lock out or isolation through the imposition of a 'keep clear' minimum distance), they can be rendered ineffective by a combination of factors, including decision-making under conditions of psychosocial duress. In a hazardous environment, that variability can have dire consequences.

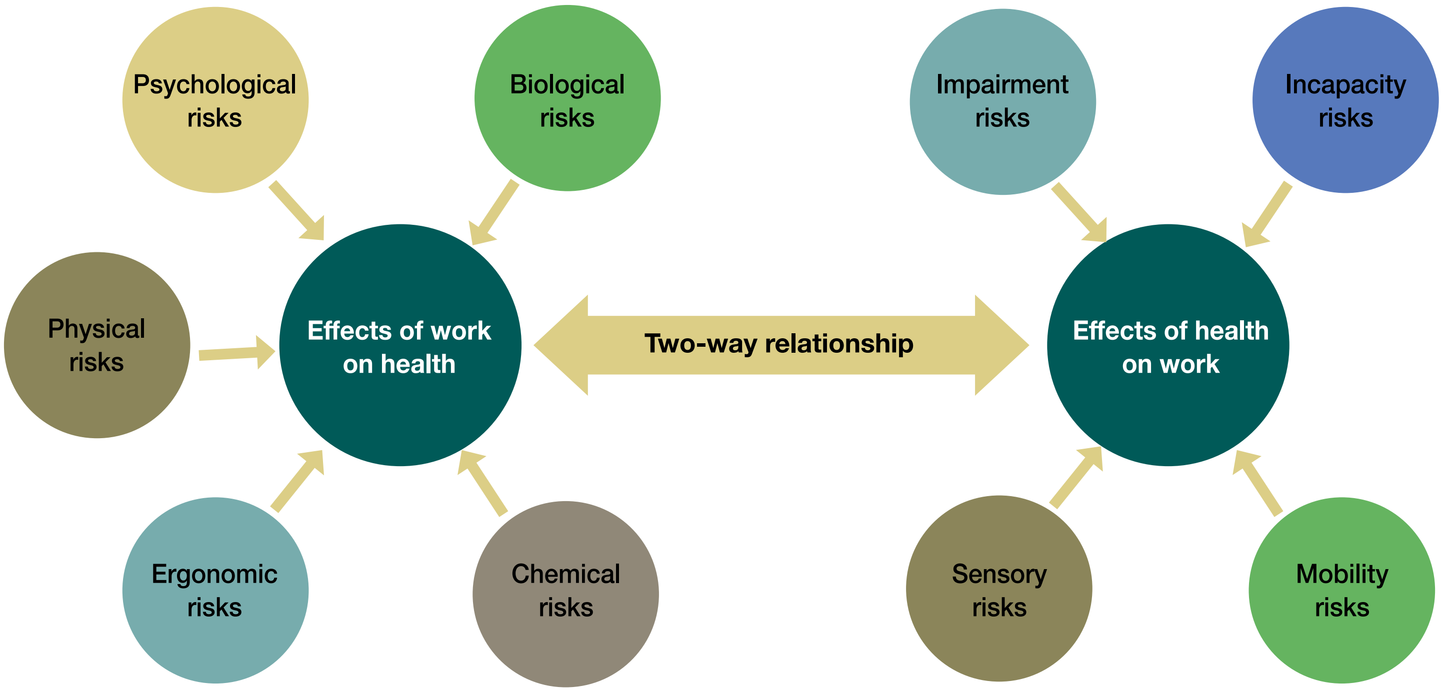

Figure 2: What Worksafe New Zealand means by work-related health and the influence of psychosocial factors. Source: WorkSafe New Zealand (2016)

The Health and Safety at Work (General Risk and Workplace Management) Regulations 2016 provide the current model of the hierarchy of control measures (see Figure 3). The hierarchy of control measures applies if it is not reasonably practicable for a PCBU to eliminate risks to health and safety:

> *'(3) The PCBU must minimise risks to health and safety, so far as is reasonably practicable, by taking one or more of the following actions that is the most appropriate and effective taking into account the nature of the risk: (a) substituting (wholly or partly) the hazard giving rise to the risk with something that gives rise to a lesser risk: (b) isolating the hazard giving rise to the risk to prevent any person coming into contact with it: (c) implementing engineering controls. (4) If a risk then remains, the PCBU must minimise the remaining risk, so far as is reasonably practicable, by implementing administrative controls. (5) If a risk then remains, the PCBU must minimise the remaining risk by ensuring the provision and use of suitable personal protective equipment.'*
>
> Health and Safety at Work (General Risk and Workplace Management) Regulations 2016, 7

The Health and Safety at Work (General Risk and Workplace Management) Regulations 2016 define the controls as distinct strategies when in reality there is a high degree of cross-over between them. The controls are often implemented in groupings of two or more strategies. An example is guarding on machinery. This engineering control isolates people from the moving parts, but administration controls are often also necessary to control who and under what conditions the guard be removed. The intervention strategies are not fully effective in another dimension and can be implemented with varying degrees of strength. For instance, in a sawmill, the isolation strategy covers everything from a padlocked electrical switch in a Motor Control Centre room to a fully interlocked fenced gate system with mechanical and electrical isolation devices.

In situations where strong isolation strategies are not considered practicable, psychosocial factors will have a greater influence on workplace behaviour. The influence of psychosocial factors on workplace behaviour is also greater when the control strategy implemented is weaker. The forest is a variable environment with multiple hazards expressed in a way that is difficult to isolate and control. Forest activities are often typically carried out in high consequence high hazard exposure

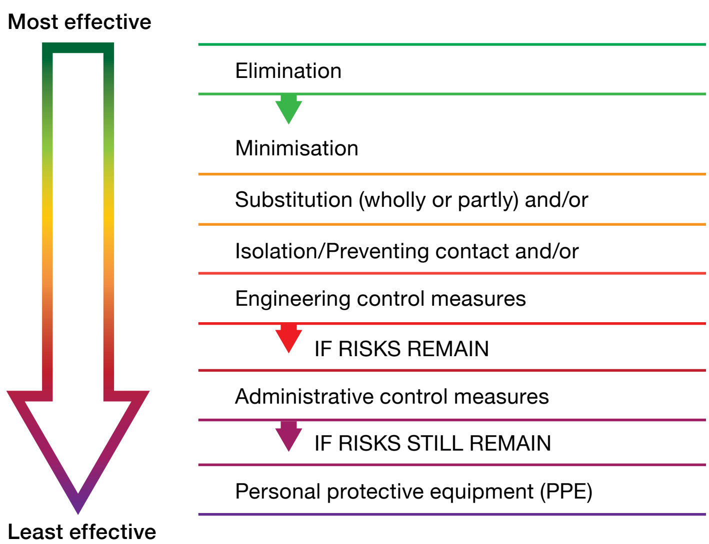

Figure 3: The cross-over of the hierarchy of controls. Source: WorkSafe New Zealand (2017)

situations. Consider simply walking underneath a near mature pine plantation with numerous dead branches suspended at height (see Figure 4). Even a slight breeze can cause branches to dislodge and fall to the ground. If these aerial hazards existed inside the limited space of a factory, the expectation is people would be fully isolated from such a hazard.

Johannesen, Sarter, Cook, Dekker and Woods (2012) believe there is a common notion that safe systems need protection from unreliable, erratic human beings (who get tired, irritable, distracted, do not communicate well, and have all kinds of problems with perception, information processing, memory and recall). Eliminating human error becomes the target of more rigid rules, tighter monitoring of other people, more automation and computer technology, all to standardise practices. Ironically, such efforts have unintended consequences that make controls more brittle and hide the sources of resilience that make systems work despite complications, gaps, bottlenecks, goal conflicts and complexity (Johannesen et al., 2012).

An example is if controls have been placed on the manual choker setting for a yarder, with escalating isolation controls for classified zones. Psychosocial influences can influence this implementation in several ways – production pressure, the extent of the team or individual involvement, who and how many are involved in the application of the control zones, risk level recognition and team culture. All these psychosocial influences can influence the extent of implementation of controls in a high consequence situation, both positively and negatively.

The nature of accidents is changing with increasing complexity in technology and social systems. An increasing number of accidents defy explanations in simple terms such as in cause-effect chains or human error. The domino theory was first proposed in 1931 (Slappendel, 1995). The original domino model had five dominos: any injury (fifth domino) is caused by an accident (fourth domino); the accident in turn is caused by unsafe acts of a person or unsafe conditions (third domino); and the conditions are preceded by the fault of a person (second domino) and ancestry and social environment (first domino) (Seo, 2005). The pioneer Heinrich also used the now widely-used terms of unsafe act and unsafe condition. Two sources of psychosocial causes were considered in the theory, being ancestry and the social environment. Unsafe acts and personal fault could also be argued to highlight human behaviour. Heinrich reported his discovery from case studies of 75,000 accident records that 88% of all industrial accidents were caused primarily by unsafe acts of persons (Seo, 2005).

Undoubtedly the most popular modern accident causation model, the Swiss Cheese model (see Figure 5), has been widely used across a wide range of industries (Underwood & Waterson, 2014). When applied retrospectively to accidents, it often highlights linear pathways from effect to root causes that do not recognise the importance of the parallel influences of psychosocial influences.

Contemporary forest industry thinking

The SafeTree Safety Culture model developed by the Forest Industry Safety Council (FISC) is an excellent example of contemporary thinking on safety in forestry in New Zealand (see Figure 6). Significant resources have been put into this model, leaning on the collective experiences of a number of forest and safety industry experts. FISC is supported by Worksafe New Zealand and is incorporated into their Injury Prevention Action Plan, which Worksafe New Zealand

Figure 4: Suspended dead branches are relatively common in some stands

has a legislative requirement to produce. The SafeTree tool has been designed to create a safe, productive and resilient workplace culture as this is important to drive positive behaviours and practices at work (Ewing, 2017). Elements identified in the SafeTree model incorporate significant psychosocial influences, specifically: work pressure; risk taking; relationships; recognition; and worker engagement. It is a workplace cultural model incorporating many of the elements identified in the Robens model, most significantly employee engagement.

The SafeTree model falls short of identifying psychosocial factors as a risk factor that needs to be accounted for during hazard mitigation. Although social factors are visible on the worksite and many crew managers have to deal with the downside consequences of them (Lovelock & Houghton, 2017), they are not mentioned in the model.

The link between psychosocial influences and behaviour is well established in academic literature, but the pathway of external social influences into the workplace is less defined. A valid working pathway theory can help understand the nature of psychosocial influences and therefore what moderators may prove effective. Without such a theory, workplace safety interventions are likely to fall short of their potential effectiveness and accidents will continue despite the significant investment in safety systems (Hollnagel, 2012).

At first glance, the Pathway model appears to be a simple structural representation (Figure 7). It helps explain how things happen, but not the why. The model tells us more than that; it is part of being human to have workplace behaviours influenced by emotional memories. Most significantly, these behaviours are driven by non-conscious as well as conscious influences. Individuals react differently to a set of workplace stimuli and they may not even be aware of why, and this has profound implications on safety in the workplace, especially for high hazard situations. Any moderating interventions that rely on the human element across a number of people will have to account for non-conscious behaviour deviation.

A significant contribution of the Pathway model is the temporal elements it identifies. Social influences may originate from an individual's past, even their childhood and experiences during their upbringing. These emotional memories remain below the observable threshold for most workplace situations, buried within the individual.

Classifying psychosocial factors as a hazard has an underlying assumption that it is practicable to identify them ahead of time. The Pathway model shows psychosocial factors are often undetected and unpredictable without the most complex of models. Environments are fluid and variation can change the way the factor influences workplace behaviours. Real effects can emerge from time-to-time through the resonance of multiple factors not fully explained through linear models.

Conclusion

This paper presents a contemporary understanding of psychosocial effects in terms of meaning for the forest industry, as well as its establishment within New Zealand's health and safety laws. However, it recognises that a well-defined process remains absent for its implementation and there remains a need for research into the human factor of psychosocial influences to incorporate these into the contemporary accident avoidance models in forestry.

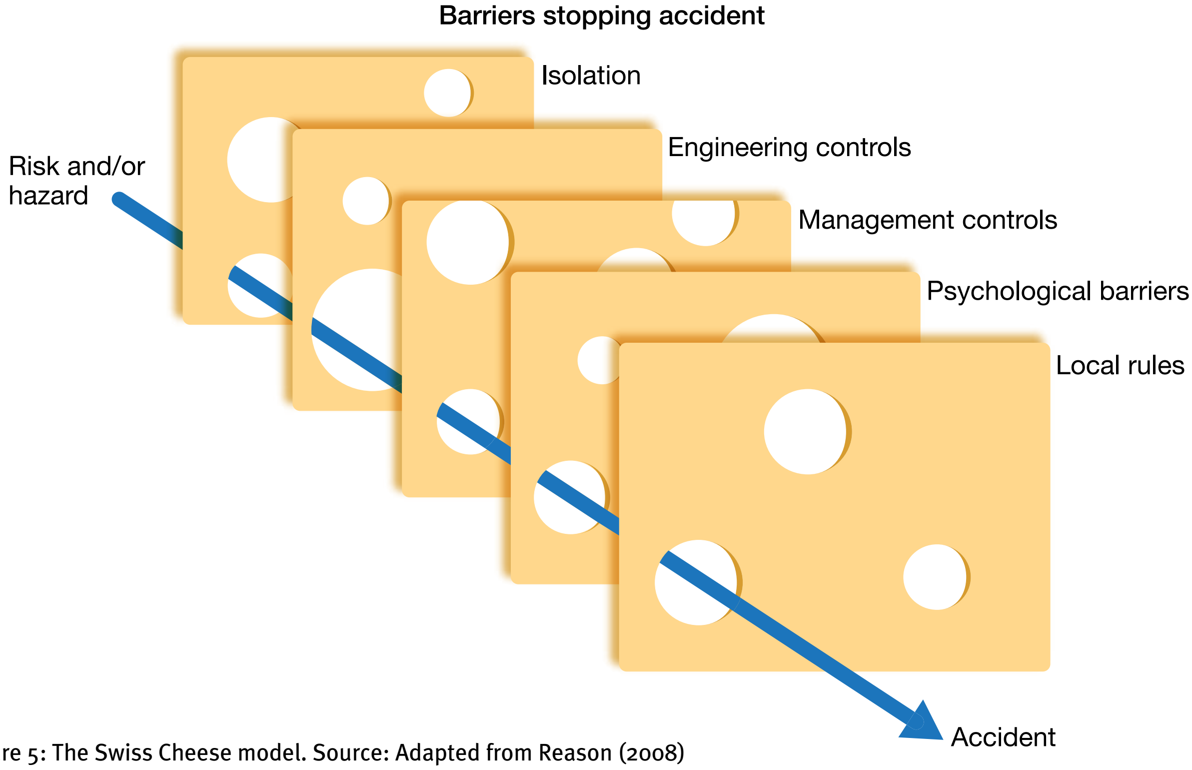

Figure 5: The Swiss Cheese model. Source: Adapted from Reason (2008)

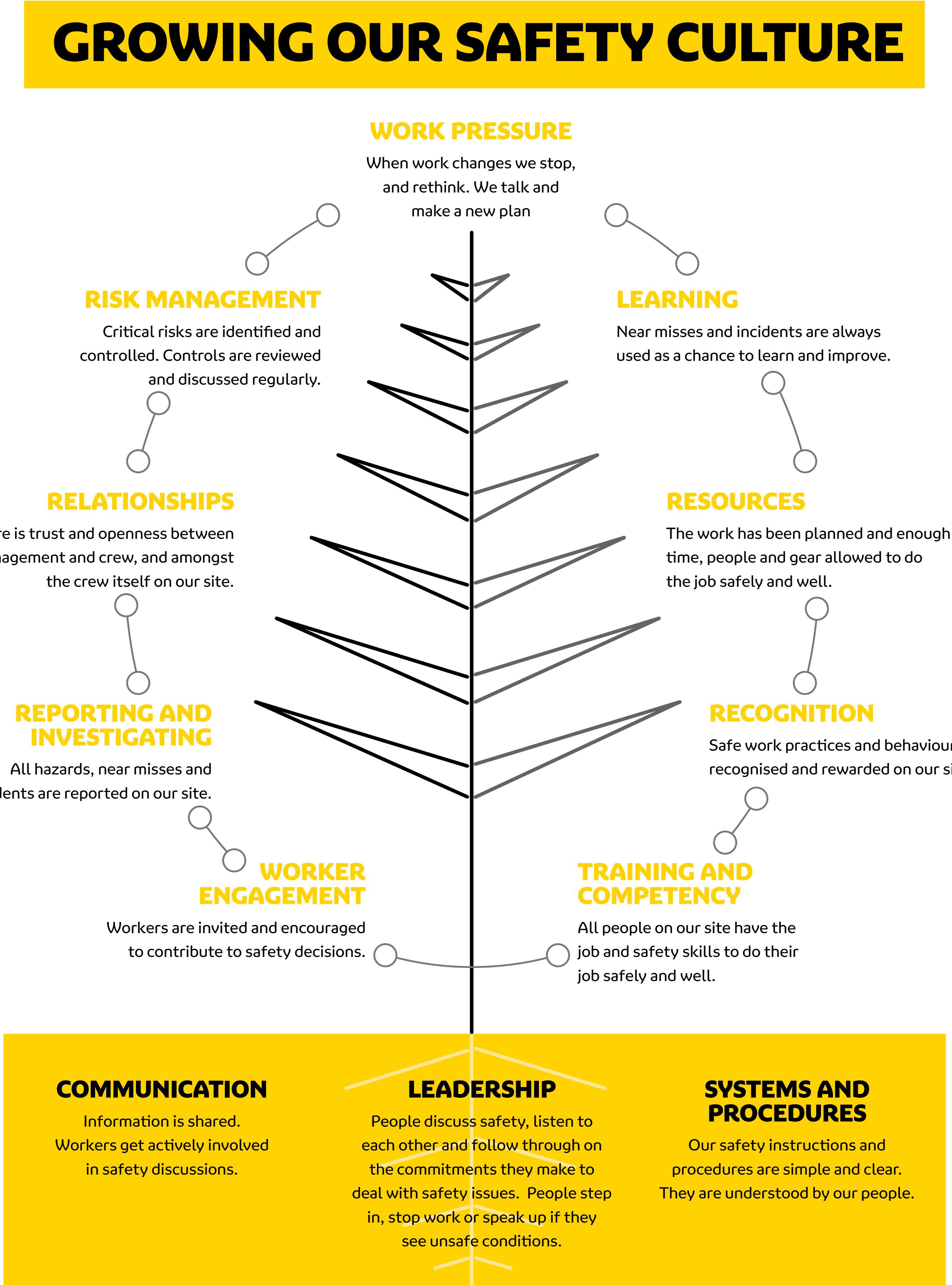

Figure 6: SafeTree's Safety Culture Framework. Source: SafeTree (2017)

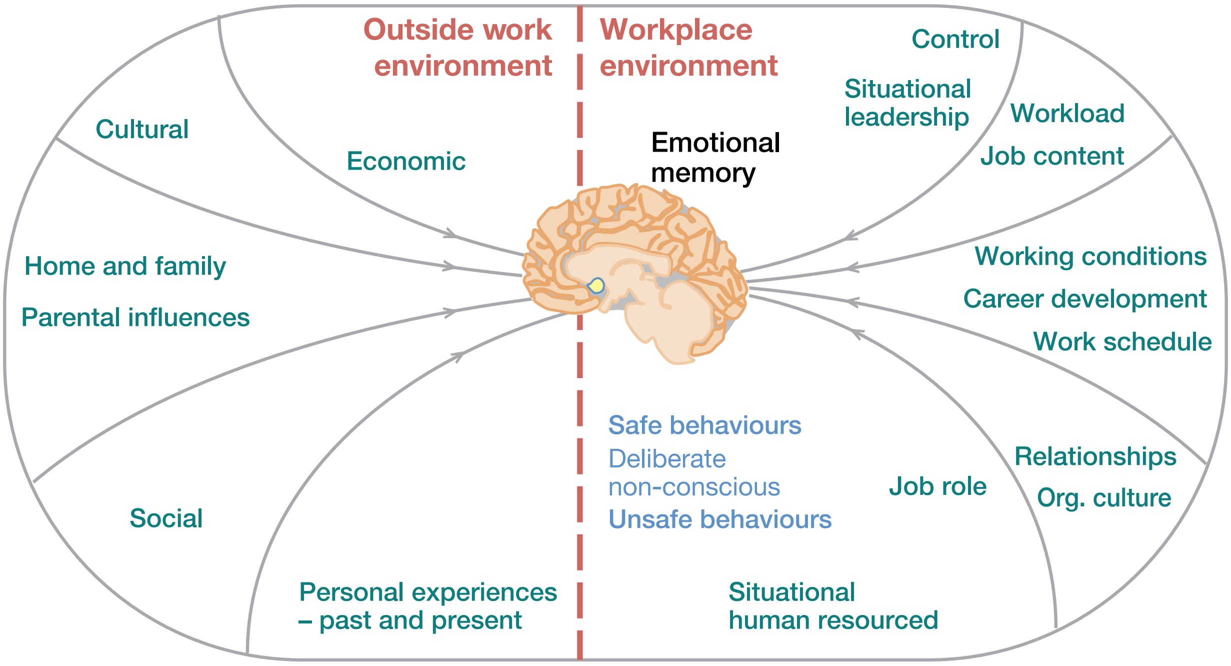

Figure 7: The Pathway model – the interrelation of social factors and workplace behaviour

The assumption of cause-effect underlies a lot of modern safety intervention strategies. In the case of psychosocial factors, determining the root cause can be a very difficult thing to achieve without significant input from psychologists and sociologists at an individual level. This work is not practicable with large groupings of the workforce. The nature of cause-effect may hold in retrospect, but its use as a predictive tool to protect workers in the future is limited.

Instead, a change of thinking is required. While some psychosocial influences can be isolated and treated in a classical sense, such as fatigue and stress, others are less obvious and therefore less obviously moderated. When considering interventions for a critical risk the question should be asked: 'Can psychosocial factors influence the way people will behave to such an extent that it overcomes the effectiveness of the intervention?' Second generation safety theorists focused on human error – 'to err is human'. Humans are naturally different. Their workplace behaviours are variable, leading to a summary more like – 'to vary is human'. Safety interventions in critical risk situations need to account for this variability.

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Land use options and economic returns for marginal hill country in Northland

Dean Satchell

Figure 1: Steep unproductive pastoral country in Northland

Abstract

This paper compares economic returns from existing pastoral production with plantation forestry on steep Northland hill country, to help inform decisions on land use change. The economic analysis specifically targets high erosion risk pastoral land and appraises two plantation forest options – radiata pine clearfell and permanent tōtara forest. Permanent (continuous cover) forestry offers improved environmental outcomes compared with clearfell forestry, by mitigating erosion and the sedimentation of water bodies. Because permanent forests are long-term investments, the analysis is over 150 years. Results compare relative profitability of existing pasture with new plantation forests and consider sensitivity to interest rate, carbon price, planting subsidies and a price on pastoral carbon emissions.

Introduction

Good land use decisions depend on being well informed and understanding the trade-offs between profitability and environmental sustainability. Importantly, soil erosion and the resulting sedimentation of water bodies negatively affect both the environment and the landowner's bottom line.

Sedimentation is the key water quality pollutant in Northland. Eroding steep land soils generate significant quantities of sediment that enter water bodies causing environmental degradation. For example, 70% of the sediment load entering water bodies comes from only 23% of the Kaipara Catchment with a slope of greater than 16° (Sorenson & Mitchell, 2018). This steeper land offers the lowest hanging fruit in terms of addressing sedimentation in Northland.

Once an erosion event occurs the productivity of the eroded land is permanently impaired, regardless of land use. Prevention of erosion retains farm soil capital and the land's productivity into the future. Forest cover mitigates erosion and retains soil capital. The question is, can environmental outcomes and economic returns both be improved by converting steep erodible farmland to plantation forestry?

Productivity of land in context

To achieve both the environmental and economic sustainability of farming systems, a site-specific mosaic of land uses may be required across the rural landscape in Northland. Forestry and grazing can complement each other at both the farm and landscape scale within a mosaic that ultimately has the potential to:

- Spread financial risk for the landowner by diversifying investment
- Reduce the environmental footprint of individual farms
- Improve the overall sustainability of pastoral farming in the region.

However, for landowners to be confident that land use change offers both financial and environmental benefits, careful analysis of returns is required for competing land uses according to slope and productivity.

Pastoral land use and stock carrying capacity

Factors that determine the stock carrying capacity of land include soil type, slope, aspect, climate, pasture quality and required fertiliser inputs. Slope is a key determinant for pastoral productivity, with Praat (2011) reporting that the stock carrying capacity in Northland reduces from 11 stock units/ha on moderate sloping land to six stock units/ha for steep land.

As slope increases, expenses (such as fertiliser, fencing, water reticulation and weed control) will eventually exceed the returns from grazing, which combined with higher levels of erosion, topsoil and nutrient loss results in the generation of more water-borne sediment. This loss of soil negates the effects of fertiliser applications to the point where the land should be retired from pastoral production or a change of land use considered.

Plantation forestry as an alternative land use

Trees are a more environmentally sustainable option than pasture on steeper slopes because they reduce erosion, retain the topsoil and preserve natural soil fertility over time, with little if any fertiliser inputs required (Satchell, 2018). However, clearfell harvesting will generate sediment from soil disturbance, soil compaction and canopy removal (slopewash). Sediment is also likely to be generated by soil slip events occurring during the 'window of vulnerability', estimated to be greatest between one and six years after clearfelling radiata pine (Phillips et al., 2012).

The tree species employed and the method for harvesting both influence the level of erosion and sedimentation. Faster-growing species tend to be harvested with a higher frequency and may therefore generate higher levels of sediment. In addition, clearfell harvesting produces significantly higher levels of erosion than continuous cover forest harvesting (Satchell, 2018).

Exotic timber species tend to grow much faster than native species. The economic case for selecting indigenous or exotic species will likely depend on the landowner's time horizon for a return on investment, the relative cost of establishing the forest and the expected returns from the timber. Payments for accrued forest carbon may improve the attractiveness of slower-growing species to the investor, especially if they value co-benefits such as biodiversity and control of sediment. Landowner preferences for amenity values may also influence species selection.

Plantation forests and carbon – two methods

Revenue is available to growers of new forest on pastoral land from the accumulation and sale of carbon units under the New Zealand Emissions Trading Scheme (NZ ETS). Two methods are used in this economic analysis for classifying such forests:

- Standard post-1989 forest for clearfell radiata pine (*Pinus radiata*) – the 'averaging' option
- Indigenous post-1989 forest (tōtara, *Podocarpus tōtara*) – the 'permanent forest' option.

Both accounting rules offer options to harvest without incurring carbon liabilities.

Standard post-1989 forest (averaging) under the ETS

Under the new ETS rules, growers of new clearfell forest on pastoral land will receive New Zealand Units (NZUs), up to an average level of carbon storage from growth and clearfell of their forest over time. Provided the forest is replanted and managed into the future on the same rotation, participants face no liabilities at harvest and earn no more NZUs for subsequent rotations. The forest can be harvested and replanted without the participant needing to buy NZUs.

Permanent forests under the ETS

Permanent forests (i.e. 'continuous cover forests') may not be clearfelled and must keep a minimum of 30% of the canopy (per hectare) for at least 50 years. Because permanent forests use carbon stock-change accounting, participants earn NZUs as trees grow but they also need to surrender NZUs upon harvesting or deforestation. As carbon is sequestered by the forest more units are earned and harvest liabilities increase, providing a strong financial incentive to maintain a higher canopy (tree crown) cover. By highlighting environmental co-benefits, NZUs identified and tagged as coming from a permanent forest could even command a price premium in the carbon market.

Economic analysis

This economic analysis compares returns from pastoral land on steep erodible slopes with plantation forestry. Net returns are estimated for erodible land under three land use scenarios:

- Pasture

- Radiata pine clearfell, including carbon revenue from averaging
- Tōtara permanent plantation forest, including carbon revenue from permanent forest accounting. The tōtara plantation option includes a nurse crop of mānuka (*Leptospermum scoparium*), which provides early income from honey production.

When comparing returns from the two afforestation options with pasture, the foregone benefit or opportunity cost of continuing with pastoral production provides the benchmark for financial comparison.

Because of the presumed long-term nature of tōtara production forestry, returns for each land use are compared over 150 years. Returns from the three land uses (pastoral production, radiata clearfell and permanent tōtara plantation) are estimated by compounding net annual returns forward with interest for 150 years, including approximately five 28-year radiata pine rotations with one year fallow between each rotation. That is, for comparative purposes all net returns for each land use are assumed to be saved and earn interest over time.

The central analysis uses a carbon price of $30/tonne ($CO_2$ equivalent) and a real interest rate of 3% p.a. A sensitivity analysis also provides returns for a range of carbon prices and interest rates, to show how these influence relative returns.

The model is intended to provide insight, not forecasts. Although the results in this paper represent the author's best projection of long-term returns from each land use, the user of these results must exercise care and judgement in their accuracy. Future returns will vary significantly from the results presented here because of the long timeframes involved. The purpose of this study is to put the competing land uses on an economic 'level playing field', to directly compare relative returns with all other factors being equal, while acknowledging the high level of uncertainty. It is acknowledged that:

- The fundamental assumption, that market changes would affect all land uses equally, is not tenable. This can be illustrated hypothetically: demand for meat products may decrease over time because of a global trend towards vegetarian diets, while timber as a carbon sequestering natural material might increase in price relative to meat, at the same time that demand increases and supply from natural forests decreases because of environmental concerns about endangered species habitats
- It cannot be expected that an interest rate or carbon price will remain stable over 150 years.

Assumptions made to provide an economic 'level playing field' between land uses are described in Satchell (2021, Appendix 1: General economic assumptions).

Carbon

To provide a level playing field between costs and revenues for farming vs forestry, biotic sources and sinks of carbon are included in the economic analysis as costs and revenues. Therefore, carbon emissions from livestock are assumed to be a cost of farming in the central analysis. The model has also been run with these costs excluded, to measure their effect. The level to which the New Zealand agricultural sector will be exposed to the costs this country faces for emissions is difficult to estimate because of the political nature of such decisions.

The Government has committed to providing 95% free allocation of emissions units if agricultural emissions were included in the ETS (MfE, 2019). This means the agriculture sector would for the short term only be exposed to 5% of the costs of their emissions. Free allocation (where the Government provides emissions units to emitters at no cost) is used to mitigate negative impacts on international competitiveness for the agricultural sector. However, because the cost of carbon emissions is picked up by the New Zealand taxpayer and land use change is influenced by costs, the current status of agriculture largely remaining free of emission liabilities cannot be assumed to be 'safe' into the future.

Pastoral farming

For this paper, net returns per hectare from pastoral farming were quantified as Earnings (Profit) Before Interest, Tax, Rent and manager wage (EBITRm), described in Satchell (2021, Appendix 2: Pastoral farm earnings). EBITRm is a metric used by Beef + Lamb NZ (2019) for measuring farm returns, defined as gross farm revenue less farm operating expenditure less depreciation. Land rental costs or mortgage interest is therefore not included.

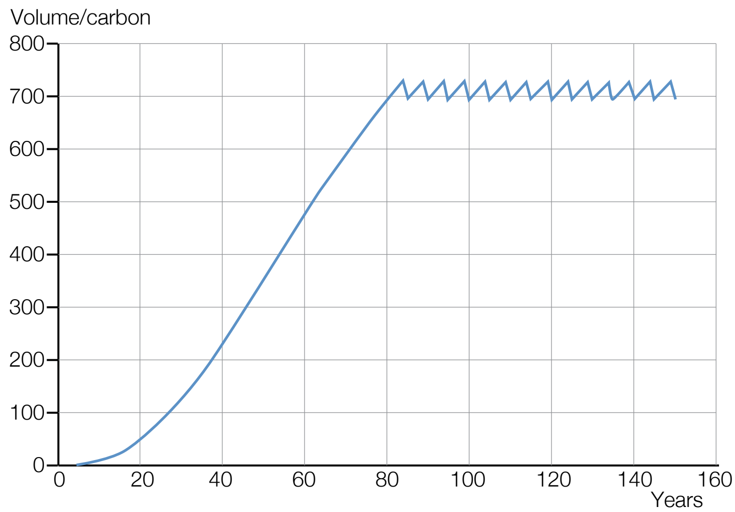

Figure 2: 150-year tōtara with sustainable cut five years from year 85

Radiata pine clearfell

Cost and income data for a radiata pine clearfell regime was produced using the ZBase model (Jenkins, 2017). Estimates were sourced on returns for radiata clearfell forestry for steep land with high erosion risk (hard access, high forest costs, low site yield) and distance to port of 100 km. These costs take into account estimates of tracking costs and harvesting difficulty (Satchell 2021, Appendix 5: Costs and returns for radiata pine clearfell).

Under the averaging accounting rules for clearfell harvesting:

> *' … the participant will account for the long-term changes in carbon in their forest. This means participants will earn NZUs up until their forest reaches its long-term average carbon storage (based on several cycles of growth and harvest). Participants will not usually need to pay any NZUs back to the Government when they harvest.'*
>
> MPI (2019)

The Ministry for Primary Industries (MPI) have not yet finalised what the average age is for a radiata forest in Northland harvested at 28 years old, but for this analysis it is assumed to be 17 years, which equates to 435 tonnes of carbon/ha based on the Auckland/Northland lookup tables (MPI, 2017).

Native forest (continuous cover/permanent forest)

Establishment cost estimates for a tōtara plantation with a mānuka nurse crop are provided in Satchell (2021, Appendix 4: Costs and returns for tōtara plantation). A model for carbon and accumulated volume as a continuous cover (permanent) forest is provided in Satchell (2021, Appendix 4: Costs and returns for tōtara plantation). It is assumed that harvesting will target larger diameter trees for a consistent log product over time. This model uses predicted growth for tōtara plantations provided by Horgan and Bergin (2017) rather than carbon accrual from the MPI lookup tables for indigenous forest. This is because the MPI lookup tables grossly underestimate accumulated volumes for plantation tōtara when compared with empirical models developed by Tāne's Tree Trust.

Tōtara trees are planted at 833 stems/ha (SPH) and it is assumed these will not require thinning or pruning. This is because mānuka trees are interplanted with the tōtara as a nurse crop at a rate of 1,666 SPH, following current best practice establishment methods for Northland. The side shading provided by the mānuka nurse crop is assumed to provide good form to the tōtara which would emerge as the canopy.

Honey production from the mānuka nurse crop is limited to the first 20 years, which is the age when the tōtara begin to out-compete the mānuka. It is assumed that nectar production from planted mānuka on hill country farmland is a bell curve with a normal distribution that peaks at year 10, with a standard deviation of 4 (Satchell 2021, Appendix 3: Mānuka nectar production).

Returns as stumpage for tōtara logs are conservatively estimated at $200 per log cubic metre (Dunningham et al, 2020).

Results and discussion

The focus of this paper is to produce returns for the two forestry land uses, relative to existing pastoral land use, in steep erodible Northland hill country. Since the landowner can choose to earn annual interest rather than invest in a forest, the comparison must take into account the returns from each land use over the long period of forest investment. Table 1 shows relative profitability under the central analysis of 3% p.a. real interest and $30 per NZU carbon price for a 150-year time period.

Radiata pine provides the highest profitability, with tōtara more profitable than pastoral grazing under this low interest rate scenario. Plantation forestry, as would be expected, shows increased profitability relative to pastoral production once the cost of carbon emissions is included as a cost in the pastoral grazing land use regime.

Forestry, being a long-term crop that can take decades to mature and produce returns for the grower with a high up-front investment, is highly sensitive to the time value of money (i.e. interest rate). Existing pasture, on the other hand, tends to produce returns annually while the historical costs incurred in breaking in the land, such as land clearance, fencing and capital fertiliser, become tied to land value rather than being a year one cost of production tied to this year's returns. Over time, regardless of land use, the initial costs of executing the land use change diminish into the past. To be consistent between land uses, the costs of permanent land use change should perhaps be written off from any future value the new land use (i.e. permanent forest) offers.

Table 1: Relative profitability of new forestry land uses compared with existing pasture (3% p.a. interest and $30/NZU carbon price)

	Radiata clearfell forest (excluding sale of carbon)	Radiata clearfell forest (including sale of carbon)	Tōtara permanent forest (Including sale of carbon)
Excluding cost of pastoral carbon emissions	141%	278%	141%
Including cost of pastoral carbon emissions	204%	403%	204%

If the landowner can avoid the initial cost of establishing the permanent tōtara plantation (e.g. by receiving a soil conservation planting grant), and can accrue carbon units for the growing permanent forest along with income from mānuka honey in the early years and timber as the tōtara forest matures, profitability relative to pastoral land use is significantly higher than pastoral land use alone (Table 2).

If the landowner incurs half the cost of establishing the tōtara plantation (e.g. from a soil conservation grant), and can accrue carbon units for the growing permanent forest along with income from mānuka honey in the early years and timber as the tōtara forest matures, profitability relative to pastoral land use remains higher than pastoral grazing for most interest rates and carbon prices (Table 3).

Sensitivity analysis – interest rate and carbon price

Table 4 shows how a range of interest rates and carbon prices influence relative profitability under the scenario where the landowner plants a bare pastoral site in trees, registers for the ETS, and sells accrued carbon and harvested logs.

Higher interest rates tend to reduce profitability of tōtara permanent forest because of the high upfront costs of establishing the forest and the long time period before receiving harvest revenues. If the landowner does not register for the ETS or is planting clearfell radiata pine on pastoral land that cannot accrue emissions units, the interest rate has a much higher effect on relative profitability (Table 5).

Table 2: New tōtara plantation permanent forest excluding establishment costs compared with existing pasture

Tōtara plantation permanent forest		Excluding cost of pastoral carbon emissions	Including cost of pastoral carbon emissions
$30 carbon price	3% p.a. interest	271%	393%
	7% p.a. interest	264%	376%
	10% p.a. interest	266%	374%
$50 carbon price	3% p.a. interest	323%	667%
	7% p.a. interest	294%	586%
	10% p.a. interest	286%	554%

Table 3: New tōtara plantation permanent forest excluding 50% of establishment costs compared with existing pasture

Tōtara plantation permanent forest		Excluding cost of pastoral carbon emissions	Including cost of pastoral carbon emissions
$30 carbon price	3% p.a. interest	206%	299%
	7% p.a. interest	116%	165%
	10% p.a. interest	57%	80%
$50 carbon price	3% p.a. interest	257%	532%
	7% p.a. interest	146%	291%
	10% p.a. interest	77%	149%

Table 4: Relative profitability of new plantation forest vs existing pasture

		Radiata clearfell forest		Tōtara permanent forest	
		Excluding cost of pastoral carbon emissions	Including cost of pastoral carbon emissions	Excluding cost of pastoral carbon emissions	Including cost of pastoral carbon emissions
$30 carbon price	3% p.a interest	278%	403%	141%	204%
	7% p.a. interest	242%	345%	Not profitable	Not profitable
	10% p.a. interest	202%	285%	Not profitable	Not profitable
$50 carbon price	3% p.a. interest	371%	767%	192%	397%
	7% p.a. interest	388%	772%	Not profitable	Not profitable
	10% p.a. interest	363%	703%	Not profitable	Not profitable

Table 5: New radiata clearfell forest profitability compared with existing pasture where the new forest is not entered into the ETS

Radiata pine clearfell land use with 100 km transport distance			
	Pastoral land not incurring cost of carbon emissions	Pastoral land use incurs cost of carbon emissions ($30 carbon price)	Pastoral land use incurs cost of carbon emissions ($50 carbon price)
3% interest rate	141%	204%	292%
7% interest rate	26%	37%	52%

Table 6: New radiata clearfell forest profitability compared with existing pasture where the new forest is entered into the ETS

Radiata pine clearfell land use with 200 km transport distance			
		Excluding cost of pastoral carbon emissions	Including cost of pastoral carbon emissions
$30 carbon price	3% p.a. interest	184%	266%
	7% p.a. interest	191%	272%
	10% p.a. interest	171%	242%
$50 carbon price	3% p.a. interest	276%	571%
	7% p.a. interest	337%	671%
	10% p.a. interest	332%	644%

Forestry produces higher returns if the establishment expenses are lower and the rotation length is shorter. On steeper hill country radiata pine tends to be less productive in terms of annualised volumes, and the costs of extraction and transport tend to be higher, especially when distance to market increases. By increasing the transport distance from 100 km to 200 km, stumpage at 28 years decreases from $18,178/ha to $9,499/ha. However, profitability is still very high relative to pastoral land use (Table 6).

The relative profitability is far more sensitive to carbon price than interest rate. Indeed, without the carbon revenue, steep hill country radiata clearfell forestry with a transport distance of 200 km produces positive returns only at the 3% p.a. interest rate.

However, it is important to understand that carbon units are effectively generated from cashing up part of the pastoral land's capital value (i.e. the land value reduces once carbon units are sold). Although the total asset value should increase for a permanent forest by converting land value to tree value, the asset value only produces returns if sold.

Of course, carbon values can change as a result of market forces (demand and supply), but once carbon units are received they cannot earn interest. Only once the units are sold can their value be realised and invested to earn interest, which then compounds. A decision to delay changing land use from pasture to forest is equivalent to the loss of benefit from planting the land in trees now and earning interest from cashing the carbon. This is an opportunity cost that landowners may not currently consider when making land use decisions.

Conclusions

Financial returns from converting pasture to forestry will likely exceed those from continuing to graze steep pastoral hill country in Northland. The results in this paper offer landowners some confidence that they can change land use from pasture to forestry on steep erodible hill country in accordance with environmental drivers without reducing the financial viability of their whole farm operation. Although permanent native forestry offers lower returns than clearfell radiata, clearfell forestry produces less environmental benefit, so choosing a forest type (permanent vs clearfell) is a trade-off between the environment and profit.

Carbon is an important component to include in land use decision-making. The opportunity to accrue and sell carbon units opens opportunities for landowners to plant trees on steeper slopes that would otherwise give poor returns. We are entering a brave new world with a market-based strategy for mitigating greenhouse gases, and where the toolbox should encourage a mosaic of land uses that achieve regional economic goals and environmental aspirations while also meeting landowner's needs.

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Volumetric yields in small-scale plantations of Guadalcanal Island

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Abstract

This paper aims to quantify the growth performance of four exotic timber species commonly planted in Guadalcanal Island, which is in line with a new strategy of the Solomon Islands Government to restructure and further develop the forestry sector. The inventories were carried out in three woodlots on Guadalcanal Island of 5.0, 11.25 and 11.5 years of age. A total of 726 trees were measured and the results of mean annual increments (MAIs) were statistically compared. Tree heights were estimated by trigonometry and their merchantable volumes by considering the main stem as a frustum of paraboloid. It was found that the tree dimensions and the MAIs for the tree species at the Tetere site in Guadalcanal Island were similar, with larger basal areas (BAs) being achieved by trees in the borders of the plantation due to less competition for light and soil nutrients. The performance of the first species *Eucalyptus deglupta* (eucalyptus) compared to the other species at two of the sites was exceptional, even in areas where the other species did not perform well. The lack of pruning and thinning slows down potential volume gains and lowers the quality of the main stem of the second species *Tectona grandis* (teak). The third species of *Acacia mangium* (acacia) trees were sensitive to diseases in the woodlots, but further results from other provinces are needed, including soil and canopy cover assessments. The fourth species *Swietenia macrophylla* (mahogany) grows well if placed in humid areas or areas without risk of drying and it does not need regular pruning. The potential gains that can be obtained by intercropping the species studied remain unexplored in the islands. However, local farmers are familiar with native fast-growing hardwoods such as *Flueggea sp.*, inter-planting them with teak for early returns. It also facilitates the thinning of the teak trees and is highly valued in the building of traditional houses. This paper aims to contribute to the optimisation of tree plantations by enhancing the prediction of their productivity and therefore their potential economic returns.

Introduction

The Solomon Islands (SI) is a double chain of islands located in the southwest Pacific between 155°30' and 170°30'W longitude and between 5°10' and 12°45'S latitude. Guadalcanal Island is of volcanic origin and the largest in SI with an area of 5,302 km^2. Its highest point at Kavo Range reaches 2,330 metres above sea level and its coasts are sometimes lined with mangroves and crossed by short, rapid streams coming down from the mountains. The temperatures are stable throughout the year (30–31°C) from November to April, with a slight drop from May to October. The rainfall ranges from 3,000 to 5,000 mm yr^{-1}, with a slight decrease from May to November. The soils are deep, intensely weathered and leached on the flatlands, and shallow with colluvial rock debris on steep slopes. In some areas they are rich alluvial soils and most are acid (pH 3–5) clays with low nutrient content.

Until 1997, the forestry sector in the SI accounted for 45–55% of foreign exchange earnings and 20–30% of government revenue. The volume of logs exported increased from 509,400 m^3 in 2001 to 3,402,339 m^3 in 2017, and within this time 9,839.59 ha of natural forests were cleared (MoFR, 2012). Therefore, the current government aims to restore sustainable levels of logging rates and one of the best ways to do this is by planning industrial timber plantations. Fisheries and agriculture are also key contributors to GDP, but subsistence agriculture is the dominant economic activity, with oil palm, copra, coconut and cocoa being the main agricultural exports.

Plantations from non-traditional (new) regions like Melanesia have been growing in size and economic importance and have therefore been playing an increasing role as a source of the world's industrial wood. However, planting native trees is still perceived as a risky activity due to limited knowledge about the performance of different species. Table 1 shows that the main species planted in the SI for commercial purposes are exotic.

The total forest planted area in 2005 was 28,000 ha, 7,600 ha less than in 2003, and distributed on Alu, Kolombangara, Viru, Gizo, Choiseul Bay, Moli, Allardyce and Santa Cruz Islands. The main species planted are *Gmelina arborea, Campnosperma brevipetiolatum, Eucalyptus deglupta, Terminalia calamansanai, T. brassiai, Acacia sp.* and *Swietenia macrophylla*. Replanting after harvest favours *G. arborea, E. deglupta, Tectona grandis* and *S. macrophylla* (Table 1), with a predicted mean annual growth of 5 m^3 ha^{-1} yr^{-1} and 30-year rotations (Pauku, 2009).

Table 1: Tree species commonly planted in the Solomon Islands. Source: MoFR (2012)

Industrial plantation	%	Village plantation	%
Eucalyptus deglupta	28	*Tectona grandis*	65
Gmelina arborea	19	*Swietenia macrophylla*	14
Campnosperma brevipitiolata	14	*Eucalyptus deglupta*	11
Swietenia macrophylla	14	*Gmelina arborea*	9
Terminalia spp	9	Others	1
Agathis macrophylla	7	Total	100
Tectona grandis	3		
Acacia sp	2		
Others	4		
Total	100		

Timber growth refers to the dimensional increase of one or more individuals in a forest stand over a given period of time, while yield refers to their dimensions at the end of a certain period of time. A growth equation may predict the growth of diameter, basal area (BA) or volume in units per annum on even-aged stands, as a function of age and other stand characteristics. A yield equation may predict the diameter, stand BAs or total volume production attained at a specified age (Vanclay, 1994). The significant differences in growth reported among individual trees affects the predictions of future timber yield, which helps to both evaluate the economic viability of forest management and derive practical recommendations as to how farmers should manage their trees to achieve stable timber outputs in the shortest time.

Several individual and stand characteristics can be estimated from tree bole diameter measurements. For example, the 64% of trees in the rainforests of Malaysia have diameter growth rates averaging 1 mm yr^{-1}, some reaching 15 mm yr^{-1}, over a 20 to 30-year period (Manokaran & Kochummen, 1994). Larger trees grow faster, probably because they receive more sunlight. However, when they reach very large sizes their height growth slows down and the diameter growth continues due to the exposition to strong winds and the development of wider crowns (King, 1996). Nevertheless, growth rates in natural forests are still lower than those reached in plantations by the same species, where diameter increments greater than 10 mm yr^{-1} are common, and some even greater than 20 mm yr^{-1} are found (Ng & Tang, 1974).

*Tectona grandi*s (teak), a native tree to Southeast Asia and India, is one of the most widely planted hardwoods in the world with 2.25 million ha in plantations globally (Ball et al. 1999). The volumetric mean annual increment (MAI) of this species ranges from 2.0 to over 15 m^3 ha^{-1} yr^{-1} by the middle of a 30 to 40-year rotation (White, 1991).

Swietenia macrophylla (mahogany) is a fast-growing, light-demanding species that appears late in the succession when there is an opening or canopy disturbance, and they thrive along riverbanks. In Belize they grow 0.6 to 0.80 cm yr^{-1}, depending on the site, and in logged areas growth decreases to 0.17 to 0.74 cm yr^{-1} (Bird, 1998). Its MAI for diameter exceeds 1 cm yr^{-1}, with slightly higher growth rates in trees of over 50 cm of diameter breast height (DBH). In Mexico the DBH of mahogany increases at around 0.73 cm yr^{-1} and reaches 55 cm in 75 years (Negreiros-Castillo & Mize, 2012). The inter-individual variation in growth rates is significant, usually from 0.16 to 0.38 cm yr^{-1} (Snook, 2000), with the fastest-growing individuals growing from 2.0 to 2.5 cm yr^{-1} (Shono & Snook 2006; Grogan et al., 2010). Mahogany seedlings reach 20 cm of DBH in 30 years and then the diameter increases 0.8 cm yr^{-1} (Snook, 2003).

Acacia mangium (acacia) is a secondary tree species in Indonesia and Papua New Guinea (Gunn & Midgley 1991) that is widely planted throughout Asia and the Pacific. It grows fast, has quality wood and is tolerant to a wide range of soils and environments. Its girth growth reaches 15 cm in three years, then it slows down after the fifth year and levels off at around 25 cm by the age of 8.0 years. The height growth follows a similar trend; in the first 2.0 to 3.0 years it grows up to 10 to 15 m, reaching 25 m by year five and levelling off afterwards (Krisnawati et al., 2011). Growth rates in the arid tropics vary from 2.0 mm yr^{-1} in Southern Turkana with a mean annual rainfall of 300 mm, to 14 mm yr^{-1} in Serengeti with an annual rainfall of 500 mm (Andersen & Krzywinski, 2007).

Eucalyptus deglupta (eucalyptus) are among the fastest-growing trees. The average of diameter and height increments of four eucalyptus species in 10-year-old plantations in New Zealand were 2.1 cm yr^{-1} and 1.9 m yr^{-1}, respectively (Miller et al., 2000). In Madang, Papua New Guinea, the dominant trees reached 38 m in height and 39 cm DBH in three years, corresponding to a volumetric MAI of 80 to 90 m^3 ha^{-1} yr^{-1} (Eldridge et al., 1993), while at two to four-year-old stands at Costa Rica it was only 2.0 to 39 m^3 ha^{-1} yr^{-1} (Sánchez, 1994).

The research questions in this paper are:

- Which of the tree species grows fastest?
- Is the tree location a significant factor for volumetric increase?
- How do these tree species perform in this SI province compared with similar plantations overseas?
- What are the annual increments of BA and volume per species per year?

Materials and methods

The inventories were based on three woodlots in Guadalcanal Island of 5.0 (Aruligo), 11.25 (Golf) and 11.5 years of age (Tetere) – see Figure 1. Not all the sites had the same number of species, but they were planted in pure blocks at an average spacing of 5.0 x 6.0 m. A total of 726 trees were measured and the results of mean annual volume increment were statistically compared. Depending on the ease of measurement the commercial heights were recorded at the Tetere and Golf sites, while total heights were recorded at the Aruligo site. Tree heights were estimated by trigonometry and volumes by considering the main stem as a frustum of paraboloid and a taper of 0.7.

A 100% inventory was performed at the Tetere and Golf sites, and a sampling at the Aruligo site along transects, until at least 50 trees were measured per species. All the trees were coded with white paint at 1.4 m above the ground. Tree heights were estimated by trigonometry with a Suunto clinometer and meter tape, the BA at breast height with metric tapes ($BA = \pi r^2$), and tree volumes were calculated as $V = BA \times height \times 0.7$. For comparison, the variables that were measured were standardised (i.e. commercial and/or total heights and diameters and breast height) then BAs and commercial volumes per species and per site were calculated, as well as their MAIs taking into account the means of all the trees measured (726) at the three sites.

The effects of border trees on the plantation means were considered negligible, because although they had more space available for development, soil humidity at the borders of the plantation are usually lower. Not all the species were found at each site (Figure 2). In most cases the commercial height was measured and for very young plantations the total height was measured.

The annual increments in diameter for the four species were compared with data from overseas, as this is the most frequent data available.

The x, y coordinates in metres of each tree at the Tetere site were measured along two transects of 350 m and two of 50 m, then recalculated in a single gridline plotted with Ilwis GIS, then converted to raster format in order to carry out points interpolation. Statistical tests for data analysis were performed with JASP, SISA and vassarstats open software. One-way ANOVA tests were performed to find significant differences in growth between species and among sites, with Tukey HSD when $K>2$ and the analysis of variance yielded a significant F-ratio. Volume tabulations and regressions were performed in Excel.

Results and discussion

Tetere site

This plantation is located on the northern plains of Guadalcanal within the boundaries of the current Correctional Camp on the island at 9°25’18.5’S 160°10’25.9’E coordinates and is 11.5 years old (Figure 3). The plantation was planted with the participation of inmates, locals and students, and partly funded by foreign economic assistance.

The three species at the Tetere site had a mean BA of 0.1 m^2, a mean volume of 0.3 m^3 per tree for the three species and commercial heights of 8.0 m (mahogany), 5.0 m (teak) and 6.0 m (acacia). The histograms for mahogany show a more normal distribution than for the other two species due to their higher number in the plantation (almost half of the total of trees). However, the merchantable heights of the acacia and teak trees are more uniform than those of mahogany.

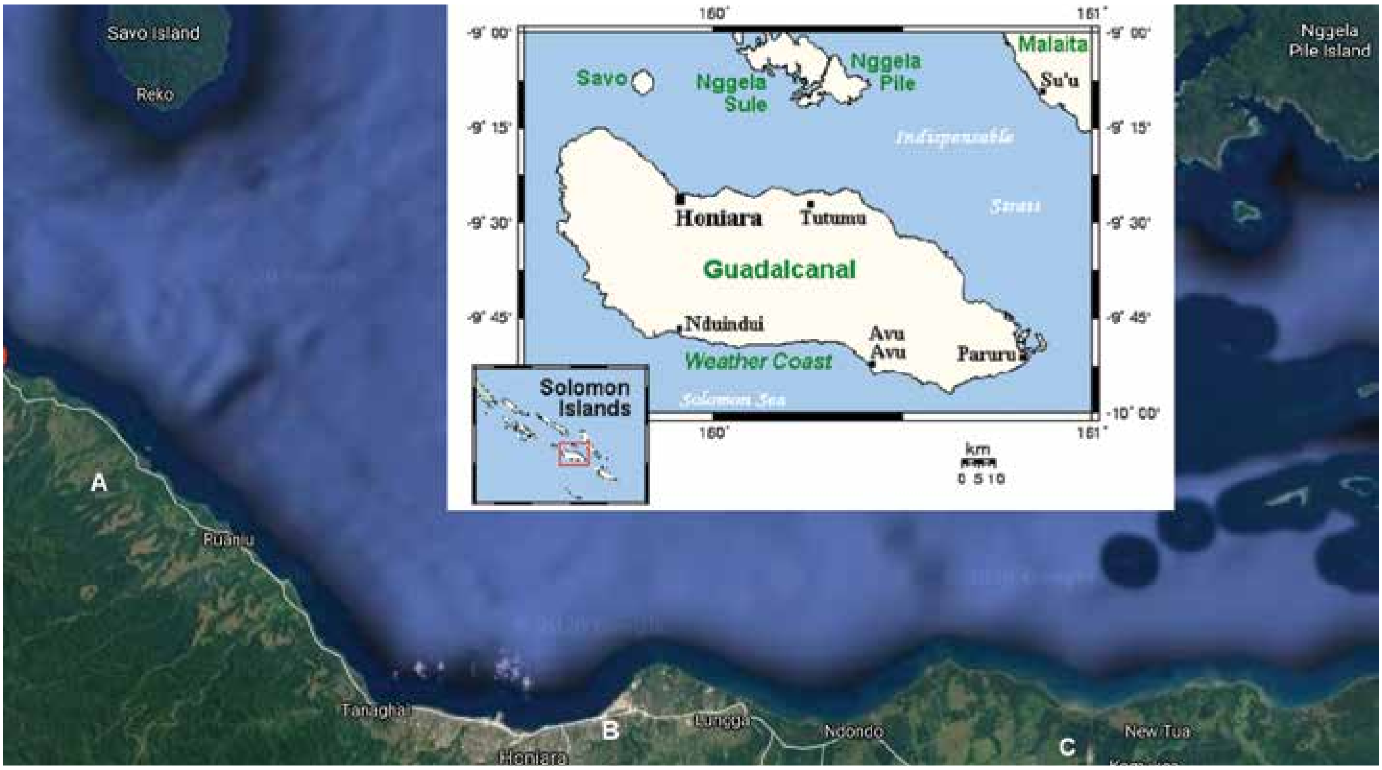

Figure 1: Location of study sites – Aruligo (A): 10 ha (sample of 165 trees), Golf (B) (126 trees in total) and Tetere (C): 1.2 ha (396 trees in total)

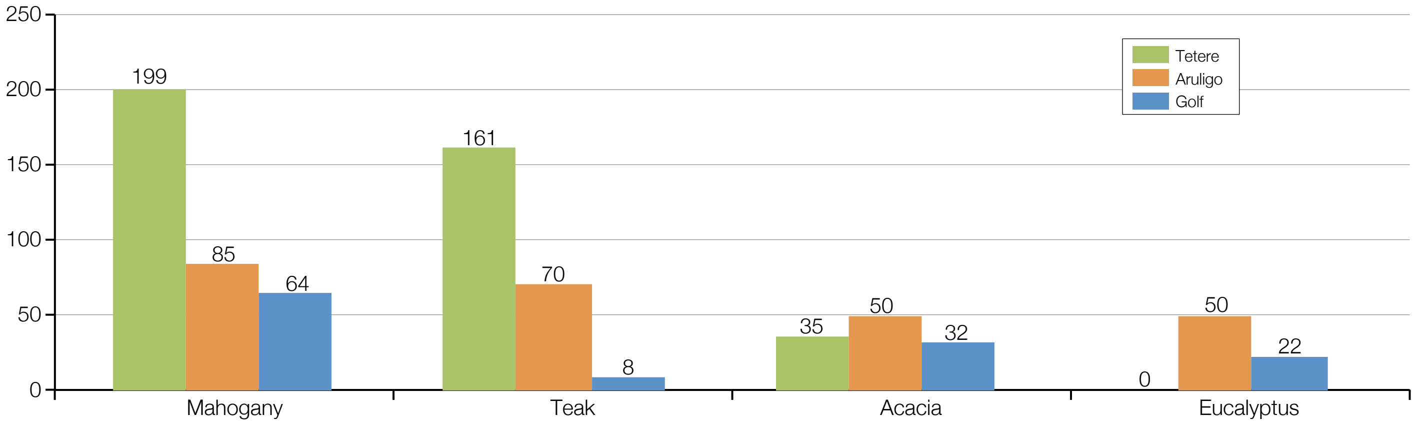

Figure 2: Total number of trees surveyed per species per site

Table 2: Trends between variables for the species planted at the Tetere site

	Linear regression	R-squared value
BA – Height Acacia	y = 2.6949x + 6.2081	R^2 = 0.0036
BA – Volume Acacia	y = 4.5108x + 0.0013	R^2 = 0.6866
BA – Height Teak	y = 28.235x + 8.937	R^2 = 0.0221
BA – Volume Teak	y = 8.5488x – 0.0414	R^2 = 0.4788
BA – Height Mahogany	y = 14.58x + 12.979	R^2 = 0.0022
BA – Volume Mahogany	y = 9.9472x – 0.0107	R^2 = 0.3233

Table 2 shows that the percentages of variation explained by the regression line between the BAs and the commercial volumes are much higher than those between the BAs and the commercial heights.

The regressions between BAs and heights were not as pronounced as for BAs with commercial volumes for the three species, with no significant differences ($P<0.01$) between the BAs, commercial heights and volumes. Tukey HSD comparisons between mean volumes (m^3), BAs ($m^2\ yr^{-1}$) and commercial heights ($m\ yr^{-1}$) at the Tetere site showed no significant differences between the three species ($P<0.001$).

Aruligo site

The plantation at this site located at the 9.3118°S, 159.7808°E coordinates was planned by the provincial government in order to support the relocation of displaced locals after major landslides and floods on the island during July 1965, February 1967 and April 1977. The plantation is 5.0 years old and the main planted species are teak, eucalyptus and mahogany. The BA MAI for eucalyptus was nearly three times as those for mahogany and twice as many as for teak. Mahogany trees did not perform well due to the low soil water retention capacity of the convex terrain.

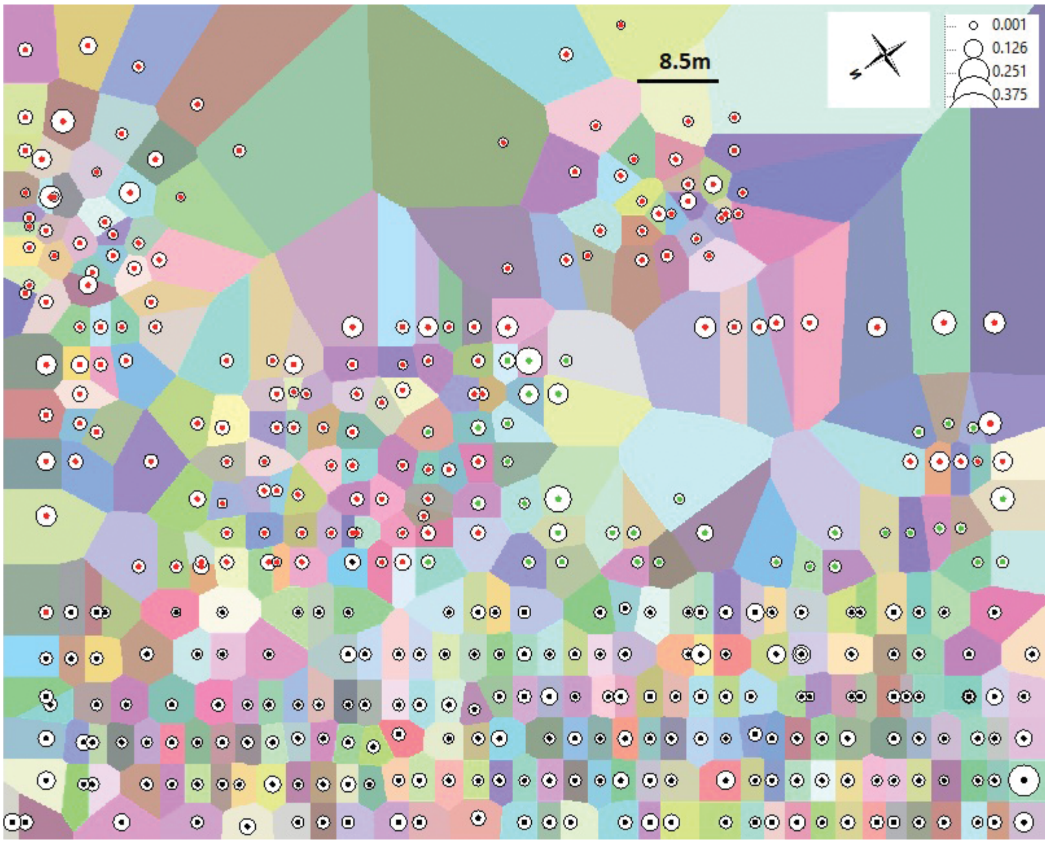

Figure 3: Map of trees location at the Tetere site with a total area of 125 x 100 m. Mahogany, teak and acacia trees are depicted by black, red and green points. Trees with larger diameter appear within larger circles. The background map is a Thiessen polygons map, which allocates space to the nearest point feature (tree stems) and every location is nearer to this point than to all the others (Boots, 1999). Trees with more available area for growth also have larger diameters at breast height. The regression curve between BAs and heights at the Tetere site does not fit as well as for BA with commercial volumes for the three species

Table 3: Trends between variables for the species planted at the Aruligo site

	Linear regression	R-squared value
BA – Height Eucalyptus	y = 48.168x + 11.549	0.0151
BA – Volume Eucalyptus	y = 13.256x – 0.0078	0.5979
BA – Height Teak	y = 40.791x + 10.934	0.0257
BA – Volume Teak	y = 11.694x – 0.0371	0.9113
BA – Height Mahogany	y = 53.995x + 6.5936	0.066
BA – Volume Mahogany	y = 7.025x – 0.0096	0.9022

Table 3 shows that the percentages of variation explained by the regression line between the BAs and the commercial volumes are much higher than those between the BAs and the commercial heights. Tukey HSD comparisons of MAI for total heights (m/yr) per species showed significant differences between teak and mahogany, and between mahogany and eucalyptus (P<0.001). Tukey HSD comparisons of MAI of BA (m² yr⁻¹) per species showed significant differences between the three species (P<0.001). All the species were planted at the same time. Commercial volumes at this site were not calculated for comparison as most of the mahogany trees were undersized.

Golf site

The Honiara Golf Club is located at 9°26'S 159°57'E coordinates and was built in 1958 to serve as the Henderson Airfield. A leaf hut that had been used as the Immigration and Customs Services building was rebuilt as the Golf Club house and the green areas were expanded. The plantation is 11.25 years old with an approximate area of 3200 m².

At this site eight teak trees and 32 eucalyptus trees had similar mean BA, but the mean total heights of teak trees were on average 5.0 m lower. Teak trees were planted in a single row at the border of the plantation, providing them with more space for growth. Eucalyptus yielded, on average, twice as much timber volume per tree than the other three species.

Table 4 shows that the percentages of variation explained by the regression line between the BAs and the commercial volumes are much higher than those between the BAs and the commercial heights.

MAIs of total heights (m yr⁻¹) per species were 3.6112 (acacia), 4.8234 (eucalyptus), 2.9732 (mahogany) and 4.0472 (teak) (Figure 4). MAIs of BAs (m² yr⁻¹) per species were 0.0156 (acacia), 0.0144 (eucalyptus), 0.0138 (mahogany) and 0.0194 (teak) for this site.

Acacia reached the highest BA MAI in all the sites (0.0111, with a standard deviation of 0.041), almost twice this value for the other tree species in all the sites.

At the Tetere site the commercial heights were recorded for all the species (the lack of thinning made it difficult to detect the top end of the trees), and at the Golf site both heights (commercial and total) were

Table 4: Trends between variables for the species planted at the Golf site

	Linear regression	R-squared value
BA – Height Acacia	y = 53.662x + 13.893	0.0595
BA – Volume Acacia	y = 8.3999x – 0.0292	0.792
BA – Height Eucalyptus	y = 67.52x + 19.251	0.2334
BA – Volume Eucalyptus	y = 8.3999x – 0.0292	0.7902
BA – Height Mahogany	y = 6.8728x + 14.394	0.0111
BA – Volume Mahogany	y = 4.7742x – 0.0414	0.3247
BA – Height Teak	y = 19.113x + 18.376	0.0308
BA – Volume Teak	y = 4.9608x – 0.0032	0.7418

recorded because of the good visibility. At the Aruligo site total heights were recorded for mahogany for being at the sapling stage. With the exception of acacia, the diameter increments for teak, mahogany and eucalyptus at the three sites were higher than those means overseas (Figures 5 and 6).

Eucalyptus yielded higher commercial volumes in the three sites with a standard deviation of 3.3196, followed by teak (2.0645), acacia (2.4425) and mahogany (2.684), this last with a poor performance at the Aruligo site.

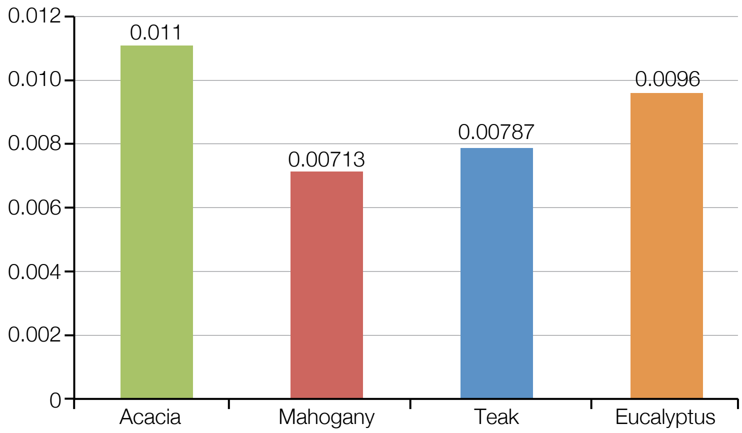

Figure 4: Overall MAI of BA (m² yr⁻¹) per species at the three sites

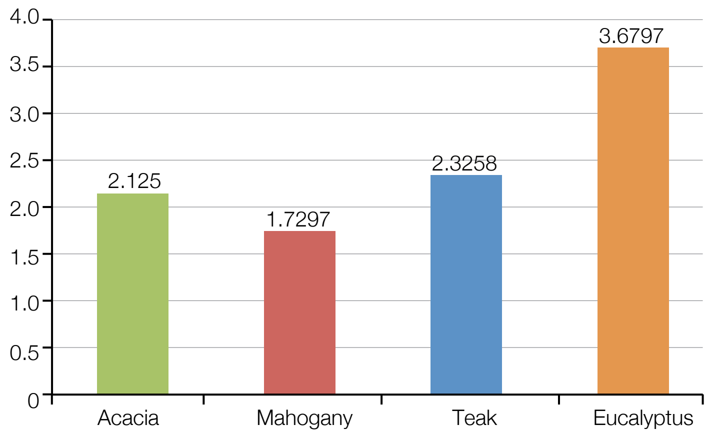

Figure 5: Overall MAI for commercial tree heights (m yr⁻¹) per species at the three sites

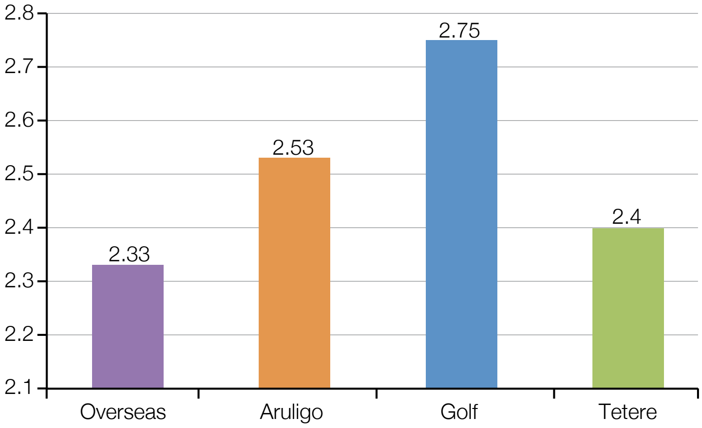

Figure 6: Comparison of diameter increments (cm yr^{-1}) of teak trees for all sites with overseas performance. Source of overseas data for 15-year-old trees: White (1991)

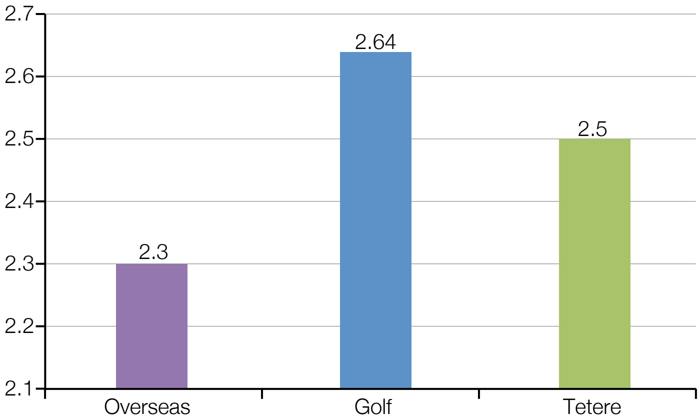

Figure 7: Comparison of diameter increments (cm yr^{-1}) of acacia trees for all sites with overseas performance. Source of overseas data for 12-year-old trees: Sein & Mitlöhner (2011)

Tectona grandis

The mean volume (0.415 m^3) for this species was lower than of acacia (0.423 m^3) and mahogany (0.483 m^3), but its MAI of BA was similar to those of acacia and higher than those of mahogany (0.0059 m^2 yr^{-1}). Its MAI of commercial height (0.62 m yr^{-1}) was similar to acacia (0.63 m yr^{-1}), but lower than for mahogany (0.81 m yr^{-1}), and at the Aruligo site it was higher than for mahogany. At the Golf site the same were higher than those from acacia and mahogany and its MAI of BAs (0.0194 m^2 yr^{-1}) higher than the other three species. The average diameter increment (2.4 to 2.75 cm yr^{-1}) of teak trees for all sites is higher than those overseas (Figure 6).

Acacia mangium

The MAI BA for this species at the Tetere site (0.0066 m^2 yr^{-1}) was similar to that of teak trees and higher than for mahogany (0.00585 m^2 yr^{-1}). Its MAI for commercial height is also similar to teak, but lower than for mahogany. At the Golf site it was lower than for teak, but higher than eucalyptus and mahogany. It grows better in drier areas (Golf) where the MAI of their total heights were higher than of mahogany. Its annual increment in diameter is higher than for overseas (Figure 7).

Swietenia macrophylla

The volumetric increment for this species performed best at the Tetere site compared to acacia and teak due to the good shape of its main stem, resulting in almost four times their growth at the Golf site. Results for mahogany at the Aruligo site were not optimum due to the drier soils in the hillsides, but it grows fast in the lowlands with regular water retention or alongside drains as at the Tetere site. At the Aruligo site the saplings were planted a few years ago. Its rate of diameter growth at the three sites is higher than for overseas (Figure 8).

Eucalyptus deglupta

The performance of this species is outstanding, even in land where other planted species ‘failed’. At the Aruligo site it reached the largest dimensions in both BA and heights, and at the Golf site eucalyptus showed the largest heights, but its MAI for BAs (0.0144 m^2 yr^{-1}) was lower than those for acacia (0.0156 m^2 yr^{-1}) and teak (0.0194 m^2 yr^{-1}). The diameter average increments at the Golf site (4.867 cm yr^{-1}) were almost double those from overseas (Figure 9).

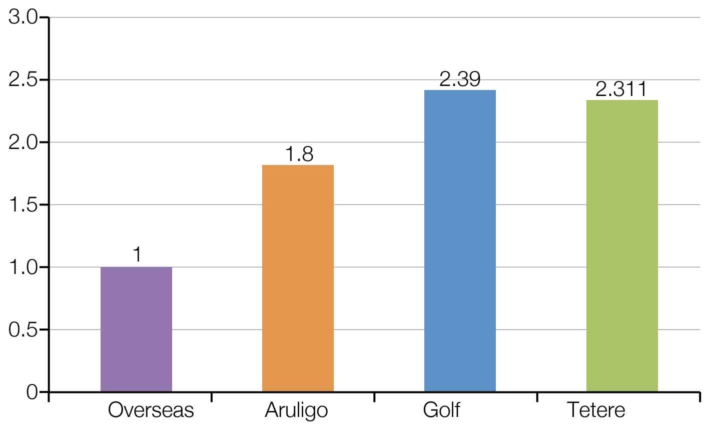

Figure 8: Comparison of diameter increments (cm yr^{-1}) of mahogany trees for all sites with overseas performance. Source of overseas data for 15 to 30-year-old trees: Snook (2000), Bird (1998), Grogan et al. (2005), Lamb (1996), Shono & Snook (2006)

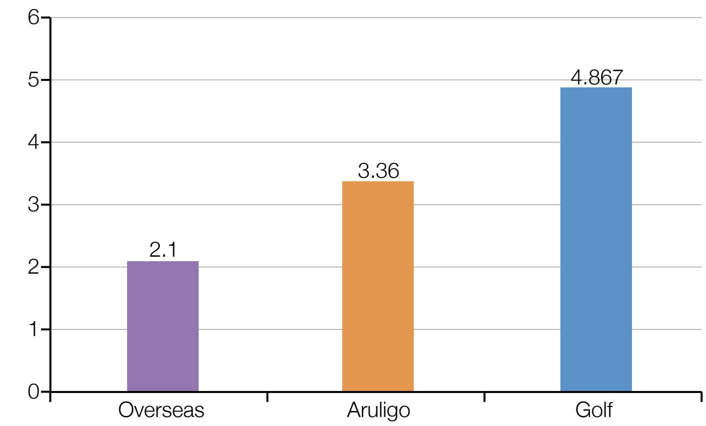

Figure 9: Comparison of diameter increments (cm yr^{-1}) of eucalyptus trees for all sites with overseas performance. Source of overseas data for nine-year-old trees: Eldridge et al. (1993), Ugalde (1980) and Sanchez (1994)

Figure 10: Eucalyptus trees at the Aruligo site

Figure 11: Teak trees at the Aruligo site

Figures 10 to 13 show photos of the four species – eucalyptus, teak, acacia and mahogany.

Conclusions

The tree dimensions and MAI values for the three species at the Tetere site were similar. Larger BAs were achieved by trees in the 'borders' due to less competition for nutrients and water and more illumination for photosynthesis. Diameter MAIs were higher for teak, eucalyptus and mahogany than for overseas. Acacia follows an alternative trend, because although they reach comparatively large dimensions in a short time they are susceptible to termites and fungus attack.

At this stage the results are promising, considering that there was no maintenance and fertilisation carried out at any of the sites, with the exception of Aruligo where seedlings were regularly watered in the first year. Regressions between BA, heights and volumes were included for future reference when yield tables are built for the evaluation of current increments, and for the calculation of required stocks, the sustained yields achievable by different coupes, the maximum possible BA capacity of an area, and the BA growth rates for periods long enough to rule out bias due to minor climatic irregularities.

It is recommended to set up trial plots of eucalyptus inter-planted with mahogany and/or teak. Mahogany is self-pruning, and as an under-crop for teak trees may facilitate heavy thinning of the latter without exposing the soil to desiccation and/or erosion. Inter-cropping with native hardwoods such as *Flueggea sp.*, which can be harvested after a few years, facilitates the thinning of the plantation and enables growers to have early returns. Otherwise, normal maintenance work such as pruning and thinning, especially on teak plantations, will increase the potential commercial value of the tree. Other options include: (1) the use of native rather than exotic species, (2) the use of mixed species rather than monocultures, (3) using the plantation to facilitate natural understorey regeneration, and (4) incorporating more structural and compositional diversity into plantations for wildlife habitat (Keenan et al., 1999). A similar survey in other SI provinces, together with soil and tree canopy assessments, will strengthen the conclusions.

Acknowledgements

The indispensable fund provided by the Research Office at Solomon Islands National University (SINU) is much appreciated, together with the participation in the field surveys of three lecturers – Mr Ramon Polycarpio, Miss Inesha Mazini and Mr Henry Kaomara – and a number of SINU students.

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Figure 12: Acacia trees at the Golf site

Figure 13: Mahogany trees at the Tetere site

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Farming – a forester's perspective

Jamie Falloon

Sometimes it pays to walk in another's shoes, is an adage that we should all stop and think about. Understanding different perspectives and considering others' views is something that is missing in the forestry carbon gold rush we are seeing playing out in rural New Zealand.

I grew up in a farming community in Bideford northeast of Masterton. My background is forestry, and after a few stop-start career plans and four years of fun at Otago I ended up working as an accountant. Quickly into this I realised this was a terrible career choice for me and I started a forestry degree in Canterbury.

My first job was working for Tasman forestry in Taupo in the woodlots team working for Mike Bartells. However, sometimes the call of the land beckons and my family and I left Auckland and moved back to the Wairarapa to live the farming dream at Bowlands. Sixteen years later I'm still here, so I suppose that's a win.

I've always had about seven neighbours, and now most them are forests. I'm right next door to Hadleigh Station, which was the poster farm of 50 Shades of Green. Disclaimer – I bought one of the houses and 95 ha of land from the forest company. So while I support their principles around rural communities, it would be hypocritical to be a strong supporter and I believe land and business owners should have the right to make decisions based on their positions and beliefs. I also think their message has become anti-forestry and slightly xenophobic.

Most of the land in Bideford was converted in the 1990s, with probably about seven or eight farms left. The forests are mainly investment forests of a range of sizes, which are now coming to the end of a 10-year logging cycle.

At the start of the logging there was a community meeting called, which involved mainly Forest Enterprises and their logging contractors, the Masterton District Council and local residents. This was a really valuable meeting because it allowed the community to understand what was happening, and it helped the loggers and truckies understand that there were people who were going to be massively impacted by the logging.

This also allowed the Council to plan the dust sealing around houses and buildings to lessen the impact of up to 100 logging truck loads a day. A bit more planning, like waiting for the road to dry a bit after heavy rain, would have made a huge difference to Council repairs and maintenance of the roads. However, we got through and the roads didn't become impassible.

Overall, we've got on pretty good, although everyone has a memory of a very close call. There are some rules though. Add another five minutes on the trip to town because passing a loaded logging truck is not for the faint-hearted. There are hardly any cyclists who use our road so that's a positive. The drivers have realised that a logging truck is not faster than a bolting calf and farmers appreciate the help from a truck horn when the dogs are getting tired. The main one though is don't get in the way of the speeding utes heading home about 4pm, so some work around this from the forest companies would be useful.

Anyway, back to the main story and the words of the first paragraph, which I think our relationship with logging and forestry in our community is trying to replicate. We are past the pissed off bit and well into the living with it stage. But this is not the case in many places and the large-scale planting for carbon is driving a bigger wedge between farmers and foresters.

This just plays into the anti-forestry farming divide. Messages are becoming very provocative and the recent debates between the forestry sector and 50 Shades are showing this. There isn't much listening going on, and hoping for a regulated solution from the Government is nuts. Asking for the Government to legislate/regulate land use and activities is a slippery slope towards a totally managed environment that tries to limit any possible environmental, social and community effects. The farming sector is guilty of this and they get the same message from me.

I firmly believe in the market being the solution, so at times I appear conflicted between the price of land and returns from farming versus forestry. But today's business environment has changed and there are other factors – environmental, social and community – that are becoming as important as just making money.

Sheep and beef farming is being squeezed. Losing neighbours to forests is sad as it takes a piece of the community out and we lose a some of our resilience. However, if you've slogged your guts out and get a good price then at least we need to be happy for the people who have made tough decisions.

My view is that both sides need to think smarter about how our industries should try to be closely aligned. My experience in water politics is that we are a long way apart and the drive to convert land into carbon forests is adding to this distance. Can it be bridged – well I'm not sure. Do the people buying the land come and get involved in the community? Do they ever make contact and get involved in the local horse sports or catchment groups or voluntary fire brigades? Or do you just plant it, lock the gates and move on to the next big deal?

I've seen forestry representatives highlighting all the environmental benefits and trying to discredit the farming industry. There are large areas of forest land on farms, but very few farmers are members of the Forest Owners Association. Why is this the case? Well it's probably because we are not well represented. How many forest companies are members of Federated Farmers? Until we recognise that hill country forestry and farming are complementary land use activities, rather than competitive, we will always have a point of tension.

If you dig below the surface, the two industries depend on each other for shipping of export and import products. One of the reasons we get good shipping is because the scale of the dairy and meat industries means New Zealand is well serviced by containerised shipping lines. If more farmers realised that the log boats coming here are full of fertiliser, or PKE, then they might understand the extra benefits of logs being shipped.

I think our industries are at a critical point and need to work closer together and not just pay lip service to this. I hope there are no discussions around trying to curry favour with the Government, especially now farmers have just rightly embarrassed them with the huge Groundswell protests.

I hate the slogan 'right tree in the right place'. I think it is so meaningless as most people believe it means natives. not pines. This is because there is an anti-pine tree rhetoric around this slogan. The right tree decision is actually based upon what the landowner wants rather than the Government or Councils imposing planting controls.

My model on my farm is 500 ha of forest on 1,300 ha of farm. Carbon credits and future log revenue will likely have a big impact on my farm's profitability and resilience. This model is one that should be progressed and used more around the country. This needs integrated land management planning, and identifying the good farm and forest land at both the farm and the catchment level. We still need to produce food and fibre, and both wool and wood, so rather than taking the easy option and buying the whole place bring different options to the table.

This will take a different mindset, and now it's time to bring the koha and the kai and get to know the community. Help is what we need to work together and understand the opportunity. This will take time and effort, but in the long run it will be a successful model for New Zealand's land use.

So foresters, go hug a farmer, and help them see the land use opportunities. Any farmers who read this will know the benefits, so I'm talking to the converted here, but there are still thousands who struggle to understand the ETS let alone the opportunities on their farms to have a piece of it.

Carbon is the gel to get this working. If this locks up huge areas of land it won't work. Foresters' social licence will be lost if it involves large-scale conversion to pines. Farmers have the land and carbon will provide new cashflow streams. The successful foresters will access this by working together, not just throwing cash at it and shutting the gate.

Appeal for Funds

Please help us to help NZ Forestry?

The NZIF Foundation was established in 2011 to support forestry education, research and training through the provision of grants, scholarships and prizes, promoting the acquisition, development and dissemination of forestry-related knowledge and information, and other activities.

The Foundation's capital has come from donations by the NZ Institute of Forestry and NZIF members. With this, the Board has been able to offer three student scholarships and a travel award each year. It has also offered prizes for student poster competitions at NZIF conferences.

To make a real difference to New Zealand forestry, including being able to offer more and bigger scholarships and grants, the Board needs to grow the Foundation's funds. Consequently it is appealing for donations, large and small, from individuals, companies and organisations.

The Board will consider donations tagged for a specific purpose that meets the charitable requirements of the trust deed. A recent example has seen funds raised to create an award in memory of Jon Dey who was known to many in New Zealand forestry. Donations for that award are still being sought.

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